Geologic Guide to the

GAS AND OIL FIELDS

of NORTHERN CALIFORNIA

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OF NORTHERN CALIFORNIA

OLIVER E. BOWEN JR., Editor
Geologist, California Division of Mines and Geology

Bulletin 181
CALIFORNIA DIVISION OF MINES AND GEOLOGY
FERRY BUILDING, SAN FRANCISCO, 1962

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BULLETIN 181
Price $8.00

prepared for the annual meeting of the
American Association of Petroleum Geogolists
and the
Society of Economic Paleontologists and Mineralogists
in conjunction with the
Pacific Sections of AAPG-SEPM-SEG
at
San Francisco, California
March 26-29, 1962

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LETTER OF TRANSMITTAL

To: Edmund G. Brown
Governor of the State of California

Dear Sir:

I have the honor to transmit herewith Bulletin 181, *Geologic guide to the gas and oil fields of northern California,* a symposium of more than thirty significant papers on the geology of gas and oil fields of the Sacramento Valley, northern San Joaquin Valley, and Santa Cruz basin, contributed largely by petroleum geologists. This bulletin is the result of cooperation between the State Division of Mines and Geology, the State Division of Oil and Gas, and the geological profession through the American Association of Petroleum Geologists and the Society of Economic Paleontologists and Mineralogists. Oliver E. Bowen Jr., Senior Mining Geologist of the California Division of Mines and Geology, compiled and edited the volume.

The Sacramento Valley, central theme of the bulletin, was established as a dry-gas-producing province in 1935 with the discovery of the Tracy field, and rapidly became a prolific gas-producing area. Rio Vista, on the Sacramento delta, is California's largest dry-gas field.

By the end of 1960, cumulative production from the Valley was 2,750,000,000 thousand cubic feet; in mid-1961, well-head price averaged 30 cents per Mcf. These figures show the Valley to be a major gas-producing province, of critical importance to the economy of northern California.

Bulletin 181 is a significant contribution to the geologic knowledge which is so basic to exploration for gas in this part of the state; for under one cover it contains much that has never been published before, as well as a summary of published, but scattered, data.

Respectfully submitted,
DeWitt Nelson, Director
Department of Conservation

January 11, 1962

PREFACE

In performance of its function as the State's public information bureau on geology, mineral resources, and mineral industries, the Division of Mines and Geology assists the petroleum industry, responsible for two-thirds of California's annual mineral production, in the general area of exploration. This it does by detailed geologic mapping of selected areas and by reconnaissance of large areas on the 1:250,000 scale, and by publication of several series of geologic reports and maps, many of which are useful to petroleum exploration. The Division's publications are: *Mineral Information Service*, a semi-popular monthly pamphlet; *Annual Report* of the State Geologist, Chief of the Division of Mines and Geology; the *Bulletin* series, on the geology and mineral resources of quadrangles, geologic guides to significant regions, or statewide commodity surveys; the *Special Report* series on shorter or more localized subjects; the new *County Report* series on the mines, mineral resources, and geology of counties; and the *State Geologic Map*, issued as colored, lithographed, 1:250,000-scale geologic map sheets, each 1 degree in latitude by 2 degrees in longitude.

In 1943 the Division's monumental Bulletin 118, *Geologic formations and economic development of the oil and gas fields of California*, was issued; it has since gone through numerous reprintings. The Division has long recognized the need for an up-to-date publication on the same subject, featuring particularly the Sacramento Valley province where some of the greatest activity in exploration for gas has taken place in the last few years. The Annual Convention of the American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists meeting jointly with the Pacific Sections of AAPG, SEPM, and the Society of Exploration Geophysicists in San Francisco in 1962 has given us the opportunity to produce the present volume as a cooperative project. The State Division of Oil and Gas is now completing a series of volumes on *California oil and gas fields—map and data sheets;* Part I—San Joaquin-Sacramento Valleys and northern coastal regions is now available. This includes a thumb-nail sketch of essential information on each field in the State placed on two facing pages. The left page usually consists of a geologic column, a structural contour map, and a geologic cross section; the right page consists of location, discovery data, data on production and producing zones, and selected references. Pages 356-493 from this volume, through the cooperation of E. H. Musser and E. R. Murray-Aaron, have been included here in order to present some data on all gas and oil fields in northern California between the covers of this one volume.

Part I of Bulletin 181, *Geologic guide to the gas and oil fields of northern California*, comprises five papers designed to give the reader, particularly if he is not familiar with northern California, some orientation with respect to petroleum and other mineral development, the geologic framework, the Late Mesozoic formations which include the oldest gas-producing horizons as well as the "basement" rocks, and the economics of development of the Sacramento Basin. Part II treats the regional geology—first surface, then the subsurface—of the Sacramento Valley, northern San Joaquin Valley, and the Santa Cruz Mountains. For each province there are papers on the general geology, followed by detail on selected gas and oil fields. Part III is the contribution of the State Division of Oil and Gas, comprising very short sketches of all gas and oil fields in northern California. Part IV consists of the field guides and road logs for five scheduled trips.

Bulletin 182, *Geologic guide to the Merced Canyon and Yosemite Valley, California*, is a companion volume, published for the AAPG-SEPM Convention, of less direct economic application than Bulletin 181, but of wide interest to all geologists, professional and amateur.

The Editor and the Division realize that this Bulletin violates some sound and accepted principles of editorial practice—a problem it has not been possible to solve satisfactorily. Names of subsurface zones and geologic units are those commonly used and well understood in each of the gas fields discussed, even though they are not always in conformity with the best recommendations of the American Commission on Stratigraphic Nomenclature. It was found impractical to re-draft all maps and charts to ensure uniform usage of geologic symbols, desirable as this might be. The Editor has made no attempt to reconcile differences of geological mapping and interpretation as expressed by different authors. This was not even considered desirable; differences in geologists' opinions have sometimes led to important discoveries. Finally, in the interest of economy, re-drafting of maps was avoided if they were already clear and legible.

Editor Oliver E. Bowen Jr., Field Trip Chairman Parke D. Snavely Jr., Chief of the Division of Mines and Geology Ian Campbell, and the General Chairman of the Convention are grateful to the large number of contributing authors, contributing agencies, working committees, and field trip leaders whose enthusiastic cooperation has made this *Guide to the gas and oil fields of northern California* a success. Also, special mention should be made of the Sacramento Petroleum Association, which, through the leadership of its president, Bruce D. Brooks, was responsible for securing the fine selection of papers that comprises the part dealing with the Sacramento basin.

GORDON B. OAKESHOTT, General Chairman,
AAPG-SEPM Convention, 1962, and
Deputy Chief, Division of Mines and Geology

San Francisco
July 1, 1961

Frontispiece. San Francisco and the Bay Bridge from Yerba Buena Island. Gabriel Moulin photo, courtesy of San Francisco Convention and Visitors Bureau.

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PLATES

HISTORY OF THE MINERAL INDUSTRY IN NORTHERN CALIFORNIA

By **WILLIAM B. CLARK**, Mining Geologist
California Division of Mines and Geology, Sacramento, California

Since the days of the gold rush the mineral industry has been closely associated with the history of northern and central California. The mineral industry in this region prior to Marshall's historical gold discovery at Sutter's Mill in 1848 was concerned mainly with the production of adobe brick (plus a few fired brick), the quarrying of stone, and the production of lime for mortar. With the establishment of permanent settlements soon after the beginning of the gold rush, there was a large increase in demand for construction materials. Numerous rock quarries were opened, brick plants were erected in the valley and foothill towns, and lime kilns were constructed in a great many places in northern California. Ruins of many of these old plants still remain.

Because of the greatly increased California demand for mercury for the winning of gold from ores and placers, a flourishing mercury-mining industry sprang up in the Coast Ranges, particularly in places such as New Almaden and New Idria.

The rich surface placers which yielded most of the flush production of the early part of the gold rush were exhausted in a few years, and hydraulic mines in the northern Sierra Nevada became the chief source of gold. Also, large amounts of mercury were mined in the Coast Ranges during the gold rush. During the Civil War years of the early 1860s, there was a copper "boom" in such places as Spenceville, Campo Seco, and Copperopolis in the foothill copper belt. In 1863, the famous granite quar-

Photo 1. The historic New Almaden quicksilver mine in 1876. From Thompson and West's *Atlas*.

HUTCHINGS' CALIFORNIA SCENES.—METHODS OF MINING.

SINKING A SHAFT

Is represented in the above engraving. These are sunk to ascertain if there is *pay dirt* upon the bed rock, or in any strata of gravel above it; or to find the basin or hollow in the rock upon a hill before commencing to tunnel. Sometimes all the pay dirt is thus hoisted by the windlass. These shafts are frequently very deep; one at Weaverville, Trinity Co., is 625 feet in depth.

CANALS.

The above is intended to represent a Canal, by means of which the water of a river or creek, after winding among the hills for many miles, supplies the mining districts with water. They are built at great cost, and are a great public convenience, for without them the mines would be comparatively useless. The time may come when the whole of the water from our mountain streams will be needed for mining and manufacturing purposes, and will be sold at a price within the reach of all.

The Hydraulic Telegraph.

The above represents the manner of constructing the "Hydraulic Telegraph," as it is named. A small flume is placed upon poles or high tressels, through which the water is conveyed from the canal or ditch to a barrel or square wooden funnel at the end, to which is attached the hose. These Telegraphs are generally from 80 to 130 feet above the pipe from which the water escapes, thus creating the required force for washing down banks of earth into the sluice.

SLUICING.

To the right a company of miners are "sluicing," those at the upper end are throwing in the pay dirt, and the man at the lower end is tending the sluice. Several lengths of sluice-boxes, or troughs with the ends out, supported by tressels, form the sluice; across the bottom, inside, are riffles or false bottoms, to save the gold, a stream of water being turned down, the gold is separated from the dirt, which is washed out

Hydraulic Washing.

The scene above represents a company of miners washing down the hill by the Hydraulic process. The water from above being confined in a strong hose, is played through a pipe upon the bank of sand and gravel, with great force and effect. By this process, great quantities of earth are washed down, and passing through a long sluice, the gold is there saved. Sometimes where the gold is very fine, the Guyaskutus is of great value to the miner, saving nearly enough to pay his weekly water bill.

The above is an illustration of a gold-saving machine, recently invented by Mr. Jas. Patterson of Placerville, by whom a similar one is patented, in which the finest particles of scale or flour gold are saved. The rocks are seen rolling over the end, while the dirt gold and water pass thro' a tom iron into the machine, where the gold is separated by means of quicksilver, and being washed over patent riffles.

TOMING.—The above represents three men working with a Tom; two are vigorously picking down and shoveling the dirt into the upper part of the Tom,—and the other is moving it about with a hoe or shovel, to wash it and throw out the larger rocks or riddlings. The gold, dirt and water passes thro' a seive or tom iron at the lower end into a riffle box underneath, where the gold is saved.

GROUND SLUICING.

This illustrates one of the many methods of ground sluicing. A trench is first dug down the hill side, into which a small stream of water is turned; miners then stand across or in the stream, and with their picks loosen the gravel and dirt, while the force of the water carries it into a sluice below. Sometimes a stream of water is made to run by the side of a bank, and by undermining or picking down the bank, it falls into the water, by which it is removed, and the pay dirt is afterwards carefully washed.

TURNING THE RIVER.

This view represents the building of a dam across the river, to turn it into a flume. From ten to twenty men form themselves into a joint stock company, for the purpose of draining and working the bed of the river. Sometimes several companies will unite, and by their enterprise build a flume several miles in length, into which the whole stream is turned. Wheels are placed in the flume to pump out the remaining water, or elevate rocks or dirt from below, after which the dirt is washed in a sluice, tom or cradle.

The "Sailors' Claim" on Feather River, cost over $200,000, and employed three hundred men daily.

NAMES OF MINING LOCALITIES

Salt Pork Ridge,
Potatoe Hill,
Mugawamp,
Blue Kanyon,
Devils' Basin,
Last Chance,
Red Caps' Bar,
Bunkumville,
Whiskey Slide,
One Horse Town,
Greenhorn Creek,
Humbug Gulch,
Sucker Flat,
Red dog Diggings
Snail Gulch,
Shirt Tail Bend,
Digger Creek,
Poppet Diggins,
Wolf Bar,
Hell's Delight,
Deadwood,
Buckeye Flat,
Oak Run,
Gass Hill,
Squaw Creek,
Peppermint Hill,
Brandy Creek,
Stud Horse Gulch
Rot Gut,
Dog Town,
Mad Ox Kanyon,
Yankee Jims,
Sailors Diggings,
Calf Bar,
Sam Town,
Rattlesnake Bar,
Stoney Gulch,
Hardscrabble,
Henpeck City,
Coffee Creek,
Poverty Bar,
Horse-shoe Bend,
Secret Ravine,
Jackass Gulch,
Don Pedro's Bar,
Morman Ravine,
Rough and Ready
Blanket Creek,
Angels' Camp,
Lovers' Hollow,
Mosquito Kanyon
Bottle Hill,
Pitchfork,
Pot Luck City,
Bloody Run,
Pepper Box,
Louse Village,
Hang Town,
Ground Hogs' Glory.
Ragged Breeches Bar
Rum Blossom Plain,
Grizzly Bear Ravine,
Egg-Nog Settlement,
Mad Mule Kanyon.

PANNING OUT.

The above represents the primitive method of mining. A pan filled with earth is set into the water, and by shaking it from side to side, the dirt is washed out, and the gold gradually sinking to the bottom of the pan, is there saved. This method is still used by every company to wash out the product of the days' labor; while the Chilian or Mexican uses the pan or bowl exclusively.

TUNNELING.

Tunnels are drifted into the hills, to save the labor of washing down the whole. The strata of gravel or pay dirt lying upon the bed rock is generally the richest, and is taken out as represented above. Sometimes tunnels are made through the solid rock, to drain the water off, and work the inside of the hill to advantage. The Table Mountain Tunnel near Jamestown is 916 ft through solid rock, upon which, 3,366 days labor have been expended.

ROCKING THE CRADLE.

The earth to be washed is carried in buckets to the cradle, and emptied into the seive or hopper, when water from a dipper is poured upon it, as the cradle is rocked from side to side, the earth and water falls through the seive upon an apron sloping towards the back of the cradle, and passing over the bottom, is washed out at the end,—while the gold remains on the apron, or at the end of the cradle. Chinamen are the principal operators now with this machine.

Entered according to Act of Congress, in the year 1855, by Jas M. Hutchings, in the Clerk's Office of the U. S. District Court for the Northern District of California. Published by J. M. Hutchings, San Francisco.

Photo 3 (above). Gold mining by means of "coyota diggings", in the Mother Lode. From J. Wesley Jones' *Pantascape of California* (early 1850s), courtesy of California Historical Society.

Photo 2 (opposite). Early day gold mining methods.

Photo 4 (below). Phenix dredging machine on the Yuba River. From J. Wesley Jones' *Pantascope of California*, courtesy of California Historical Society.

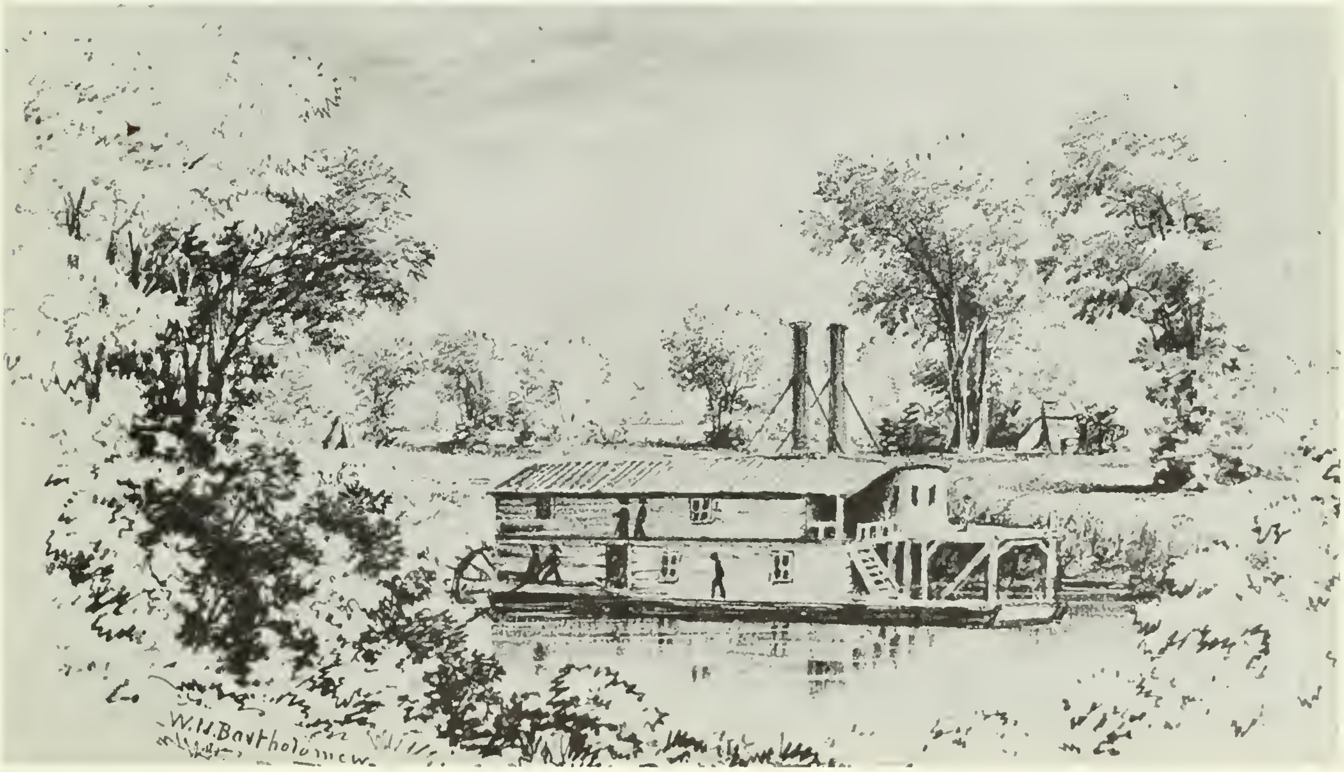

Photo 5. General view of the surface plant at the Empire Mines (lode gold), Grass Valley. Underground views (inset) show air drilling on the 2,200 level (below) and animal-drawn ore train (above). Unfavorable economic conditions during and after World War II put an end to large-scale mining at such mammoth gold producers.

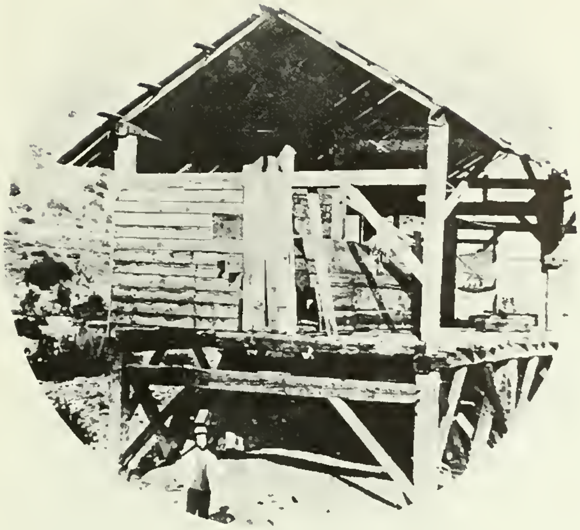

Photo 6. Sutter's Mill, site of gold discovery in 1848. This picture is supposed to have been made in 1853.

Photo 7. Basalt paving block quarry at Cordelia, Solano County, active in the early 1900s. Photo by W. L. Watts.

Photo 8. Dragline at American Lignite Products Company, Amador County. The lignite is not produced for fuel, but is used for the making of montan wax. Photo by Mort D. Turner.

ries at Rocklin were opened to provide stone for use in the construction of the Central Pacific Railroad. These quarries also provided material for the State Capitol Building. Northern California's fire-brick industry began in 1875 with the erection of the Gladding McBean plant at Lincoln. After the decline of hydraulic mining in the 1880s, large-scale underground lode gold mining became a major segment of the mineral industry, particularly in the Grass Valley, Sierra City, Jackson, Angels Camp, and Sonora areas. Gold dredging, introduced at Oroville in 1898, became highly important after 1900. Large quantities of copper were produced in Shasta County during the 1890s and early 1900s and in Plumas County in the 1920s. The extensive granite quarries at Raymond, Madera County, and the sandstone quarries at Sites, Colusa County, were the sources of stone used in the construction of many of the large buildings erected in San Francisco during the 1890s and early 1900s.

California's continued growth required greater and greater amounts of construction materials, and cement plants were erected at Napa and Fairfield in 1902-03. Later in 1926, the Calaveras Cement plants at San Andreas began operating. Sand and gravel began to be produced in large quantities, especially in the Sacramento and San Joaquin County areas. Several industrial lime plants were built in El Dorado and Tuolumne Counties.

Gold mining, which had declined during the flush years of World War I and the 1920s, became important again during the depression years of the 1930s. This was especially true after the rise in the price of gold in 1934, and by 1940, gold output was as high as it had been during the gold rush. Large underground mines at Grass Valley, Nevada City, Jackson, and Sutter Creek gave employment to several thousand men. Gold mining declined again during World War II, but appreciable amounts of copper, zinc, chrome, manganese, and mercury were mined then. However, in recent years metal mining—with the exception of mercury—has followed a diminishing trend because of unfavorable economic conditions.

The post-war boom in northern California has resulted in unprecedented demands on the nonmetallic mineral industry in this region. The demand for sand and gravel, stone, clay and clay products, and limestone and limestone products has resulted in increases in existing plants and the erection of many new ones. Calaveras Cement Company, for instance, has greatly increased the capacity of its main plant and established a new one at Redding. Owens-Illinois-Gladding McBean have erected a clay and silica plant near Ione, Johns-Manville an asbestos-pipe plant at Stockton, Basalt Rock an expanded-shale plant at Napa—all new mineral industries begun in this region in the past few years.

Photo 9. A Watkins photo of the Malakoff hydraulic mine as it appeared in the 1870s. This huge man-made placer-mining pit near Nevada City is today a miniature Bryce Canyon.

OIL SEEPS AND EARLY PETROLEUM DEVELOPMENT IN NORTHERN CALIFORNIA

By C. R. CARLSON
Union Oil Company of California, Bakersfield, California

More than 100 years ago, in 1854, a water-well drilled in Stockton, California, was producing enough gas to light the Court House Building. This early California gas production preceded by several years the successful oil well drilled by Colonel Drake in Pennsylvania.

A concerted search for oil began in California in 1861 and was localized along the coastal areas from Humboldt County southward. From 1862 to 1865 several unsuccessful shallow wells were drilled for oil, some in the vicinity of San Pablo and some adjacent to oil seeps in the vicinity of Bolinas Bay.

As the early prospectors continued their search for oil they found extensive gas and oil seeps in the hills and tributary valleys west of the main Sacramento Valley. These seeps were located in the Knoxville formation, the younger "Chico" beds of the Upper Cretateous, and even in the intrusive serpentines within the Knoxville formation near Franciscan contacts.

The most widely known oil and gas seeps occurred in the western portion of Colusa and Glenn Counties along a line extending from sec. 21, T. 14 N., R. 5 W. to sec. 35, T. 14 N., R. 5 W., near Wilbur Springs. Several operators drilled shallow unsuccessful wells near these seeps in 1865-66. Other unsuccessful wells were drilled in sec. 31, T. 15 N., R. 4 W., 2 miles south of Venado.

In the Sacramento Valley proper, a gas seep was discovered on the flank of Sutter (Marysville) Buttes, a volcanic intrusive plug. The seep was about 3 miles east of West Butte. In 1864 a mine shaft was sunk into the side of the hill in search of the source of the gas—which was thought to be oil or coal. This undertaking was stopped by an explosion which severely injured two of the miners.

About this time many water wells were furnishing gas to farm houses as far north as Tehama County and to several communities in the lower reaches of the Sacramento River valley.

By 1890, 15 wells had been completed by the Stockton Natural Gas Corporation and other operators such as Crown Mills, who were interested in fuel to run their engines. At that time, in Stockton, the gas was sold for $1.00 to $0.50 per Mcf, the price being affected by the volume purchased. It cost $2.50 to light a saloon for one week. The city's gas supply was continuously augmented by water wells, drilled to depths of 1000 to 2000 feet, that supplied both gas and water. The maximum yearly production was in 1910 when more than 300,000 Mcf of gas was produced.

In 1891 the Sacramento Natural Gas and Water Company was formed, and drilled a series of gas-water wells on the Haggin Ranch just outside the City of Sacramento.

In 1901 the Rochester Oil Company drilled an 1800-foot well near gas escaping from the surface in sec. 24, T. 5 N., R. W., Solano County. This well led to the drilling of several other wells which furnished gas to the towns of Suisun and Fairfield for a number of years.

The search for oil progressed southward, and centered south of San Francisco. Minor successes there spurred an occasional renewal of prospecting in the areas of known seeps along the west flanks of the Sacramento Valley and in adjacent lesser valleys. Gas in such remote areas

Photo 1. Bituminous sandstone exposed in a quarry on the I. W. Moore ranch on the west slope of Ben Lomond Mountain, Santa Cruz County. The rock was extensively mined for road-surfacing material prior to 1927. Photo by O. E. Bowen.

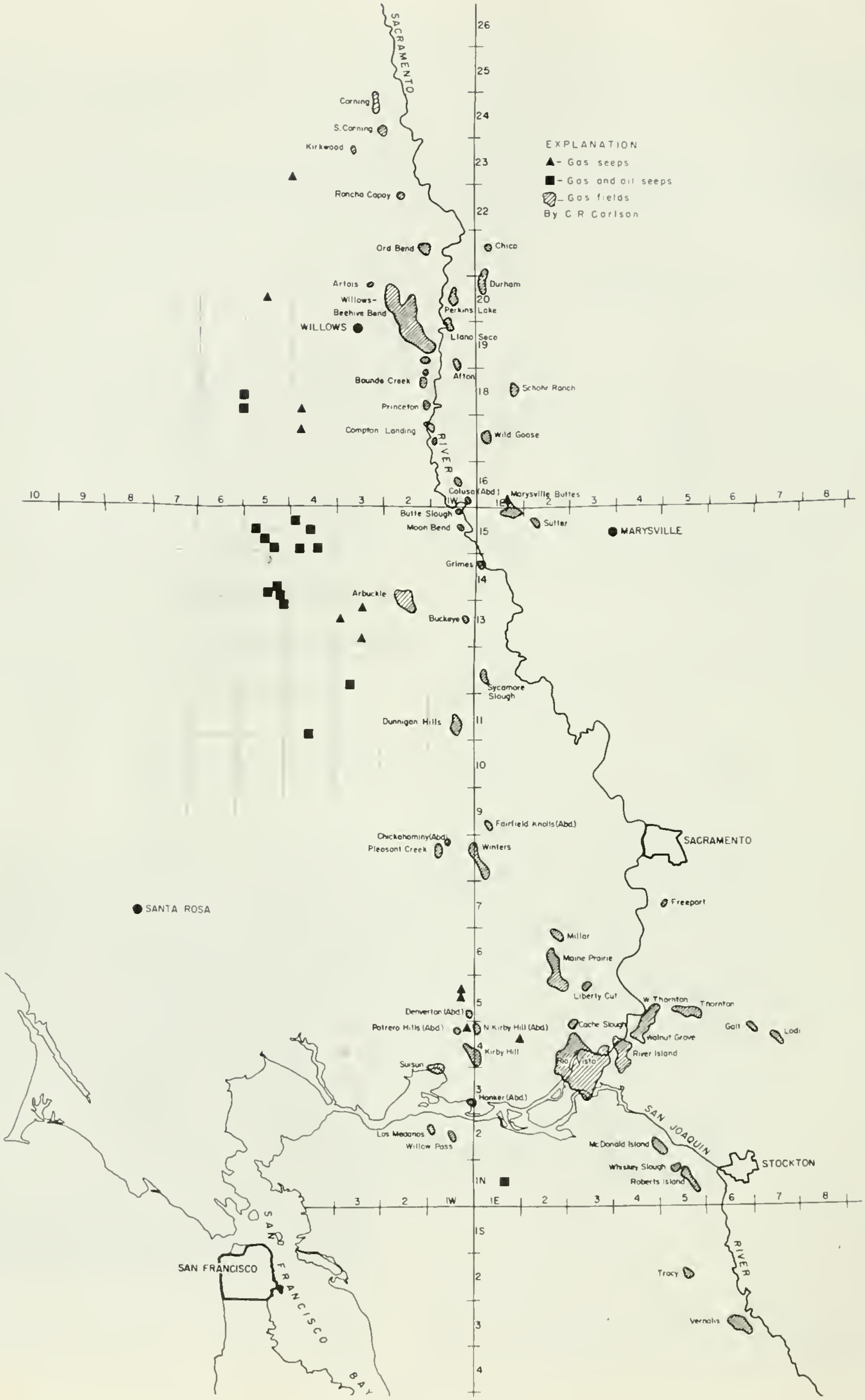
EXPLANATION
▲ - Gas seeps
■ - Gas and oil seeps
▨ - Gas fields
By C R Carlson
SACRAMENTO RIVER
SAN JOAQUIN RIVER
SAN FRANCISCO BAY
Corning
S. Corning
Kirkwood
Rancho Capay
Ord Bend
Chico
Artois
Durham
Willows-Beehive Bend
Perkins Lake
WILLOWS
Llano Seco
Bounde Creek
Afton
Schohr Ranch
Princeton
Compton Landing
Wild Goose
Colusa (Abd.)
Marysville Buttes
Butte Slough
Sutter
Moon Bend
MARYSVILLE
Grimes
Arbuckle
Buckeye
Sycamore Slough
Dunnigan Hills
Fairfield Knolls (Abd.)
Chickahominy (Abd.)
Pleasant Creek
Winters
SACRAMENTO
Freeport
SANTA ROSA
Millar
Maine Prairie
Liberty Cut
W. Thornton
Thornton
Denverton (Abd.)
Potrero Hills (Abd.)
N. Kirby Hill (Abd.)
Cache Slough
Galt
Lodi
Walnut Grove
Kirby Hill
River Island
Suisun
Rio Vista
Honker (Abd.)
Los Medanos
Willow Pass
McDonald Island
Whiskey Slough
Roberts Island
STOCKTON
SAN FRANCISCO
Tracy
Vernalis
10 9 8 7 6 5 4 3 2 1W 1E 2 3 4 5 6 7 8
26 25 24 23 22 20 19 18 16 15 14 13 11 10 9 7 6 5 4 3 2 1N
3 2 1W 1E 2 3 4 5 6 7 8
1S 2 3 4

Figure 1 (opposite). Map showing distribution of oil and gas seeps in northern California.

was probably considered only as a clue to the location of an oil pool.

Near Petaluma, prospecting began around 1900 and has continued in transitory cycles since that time. There has been some minor production of both oil and gas in the vicinity of Petaluma.

In 1921 the Blue Ridge Petroleum Company drilled a prospect well located by geologic mapping rather than on or near surface indications of petroleum. It was located on the anticline having surface expression in the Rumsey Hills of Colusa County, in sec. 34, T. 13 N., R. 3 W. This well encountered gas and oil from time to time, but salt water entering under high pressure caused abandonment of the hole. In 1923 the Mutual Oil Company drilled an unproductive well in sec. 31, T. 18 N., R. 4 W., Colusa County, on the Sites anticline in the vicinity of reported gas seeps. In 1930 the G. F. Getty Corporation attempted to drill a well on Rumsey Hills anticline but was forced to abandon it because of salt water under high pressure. This problem continues to plague drilling operations in the area. The reported "shows" in these wells have inspired other operators to drill here, but, discouraged by poor results, they have moved eastward in search of gas.

The valley proper was not prospected until after the introduction of the seismic method of geological prospecting. Even then much of the seismic effort was concentrated in localities that had some topographic expression.

The first successful well utilizing geophysical methods was drilled by The Buttes Oil Corporation 1933-34 in the Sutter Buttes adjacent to the old gas seeps discovered in 1864. Their well, the Sophie Davis #1 in sec. 36, T. 16 N., R. 1 E., was gauged at more than 3000 Mcf per day initial production. A small amount of condensate accompanied the gas.

This discovery led to the development of several fields in the Buttes.

At the time of this writing, an active drilling program is being carried on by several operators on the south

Table 1. Oil and gas seeps.

Location	Sec.	T.	R.	County	Date	Type of showing	Remarks
Wilbur Springs along line through secs. 21 and 35 (Rathbun)	21	14N	5W	Colusa	1865	Surface oil	Near Franciscan contact in Knoxville
	31	15N	4W	Colusa	1865-66	Surface oil	Along axis of north-trending anticline through town of Venado
Sand Creek	8	13N	3W	Colusa	1900	Surface oil	
	5	17N	4W	Colusa	1865	Surface gas	Peterson Ranch near Sites, and at Elgin mine near Sulfur Creek
Marysville Buttes				Sutter	1864	Surface gas	
Rumsey Hills	7	13N	3W	Sutter	Prior to 1900	Surface gas	Drilled 1900
Bear Creek		15N	5W	Sutter	1865	Oil	
Stockton				San Joaquin	1854-58	Gas-water wells	
City of Sacramento				Sacramento	1891	Gas-water wells	
	23	20N	5W	Glenn	Prior to 1902	Gas	Numerous gas "shows" from Chico sand along west side of valley
	31	18N	4W	Glenn	1865-66	Gas	Near town of Sites
		12N	3W	Yolo	Prior to 1900	Oil	Along fault on east side Capay Valley
	11, 14	5N	1W	Solano	Prior to 1921	Gas blow holes	1 mile southeast of Canon
Allen Ranch	2	4N	1W	Solano	1895	Surface gas	Natural gas escaped from 20 or more places
Berryessa Valley	25	9N	3W	Napa	Prior to 1921	Oil seeps	
	34	11N	4W	Napa	Prior to 1921	Oil seeps	
				Contra Costa	1864	Surface oil	Near Empire coal mine; well pumped 15 b/d green oil
Bennet Valley				Sonoma		Surface oil	7 miles north of Petaluma

flank of Sutter Buttes where numerous high-pressure gas sands have been discovered.

Immediately after the Buttes discovery, the Tracy gas field was discovered near the town of Tracy in T. 2 S., R. 5 E. In 1936 the Amerada Petroleum Corporation discovered Rio Vista gas field. Their discovery well, the Emigh #1, was drilled in sec. 35, T. 4 N., R. 2 E., Solano County. Initial production was 81,250 Mcf per day with some condensate. This field has been rated over 3 trillion Mcf recoverable, and is the largest dry-gas field in California. This discovery was followed immediately by the discovery of MacDonald Island gas field by Standard Oil Company of California. Stimulated by their success, these companies and other operators found a number of fields in a splurge of exploratory drilling that continued until World War II.

No large oil field has yet been discovered in or near the Sacramento Valley, though considerable money and effort have been spent looking for oil since the historical mines and shallow wells were sunk into the oil seeps in the hills on the west flank of the Sacramento Valley and in the adjacent valleys.

Minor commercial production resulted from the Petaluma discoveries. Some oil was sent to the San Francisco kerosene refineries from the wells along the coastal area and from some of the oil sands that crop out in the coastal area. However, the discoveries were insignificant —producing only enough oil to grease wagon wheels or for medicinal purposes—until 1960, when the Texas Company found oil in a sand zone that previously had yielded dry gas only. This well is in Winters gas field, in sec. 32, T. 8 N., R. 1 E.

At this time there is renewed exploration activity in the Sacramento Valley. There is a ready market paying a good price for gas. Pipeline coverage is more extensive and operators in outlying areas can find means to transport their gas to market. Land acquisition and drilling costs are not excessive and such conditions create a favorable economic climate for the small operator who is presently doing the majority of the drilling in the Sacramento and northern San Joaquin areas. This group represents the type of operator that gave birth to California's petroleum industry.

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Photo 2. A brea or oil seep in the Sargent oil field, Santa Clara County. Observer facing northwest. Photo by C. W. Jennings.

THE GEOLOGIC FRAMEWORK OF NORTHERN CALIFORNIA

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The Great Valley of California is a central alluvial plain about 50 miles wide by 400 miles long. The northern portion, that is, the Sacramento Valley, is separated geologically from the San Joaquin Valley on the south by a buried northeast-trending fault in the vicinity of Stockton. From this fault it extends 200 miles north-northwest, terminating in the Klamath Mountain foothills north of the city of Redding. The Sacramento Valley is relatively flat and is drained by the Sacramento River and its tributaries into San Francisco Bay. Approximately 15 miles south of Redding the Sacramento River crosses a 10- to 12-mile-wide belt of dissected upland. This belt results from arching of a gentle anticline which crosses the Valley, thus isolating the lowland at the north from the vast lowland south of Red Bluff. South of this anticline in latitude 40°, the river meanders broadly over a plain which is about 250 feet above sea level. The river passes through several flood basins along its course; the Butte basin north of the Marysville Buttes and, farther south, the Sutter, American, and Yolo basins. An intricate pattern of natural as well as man-made levees borders the Sacramento River and its tributaries in the delta country between Sacramento and Suisun Bay.

An anomalous feature, the Marysville (Sutter) Buttes, exists near the center of this broad and relatively flat valley. These "buttes" are the remains of a nearly circular Pliocene volcanic plug about 10 miles in diameter. Their summits rise 2,000 feet above the flat valley floor, and upturned Pliocene through Upper Cretaceous sediments ring the Buttes. Other significant topographic anomalies within the Valley are the Corning anticline, Dunnigan Hills nose, Potrero Hills and Montezuma Hills. These features will be enlarged upon in other portions of this guidebook.

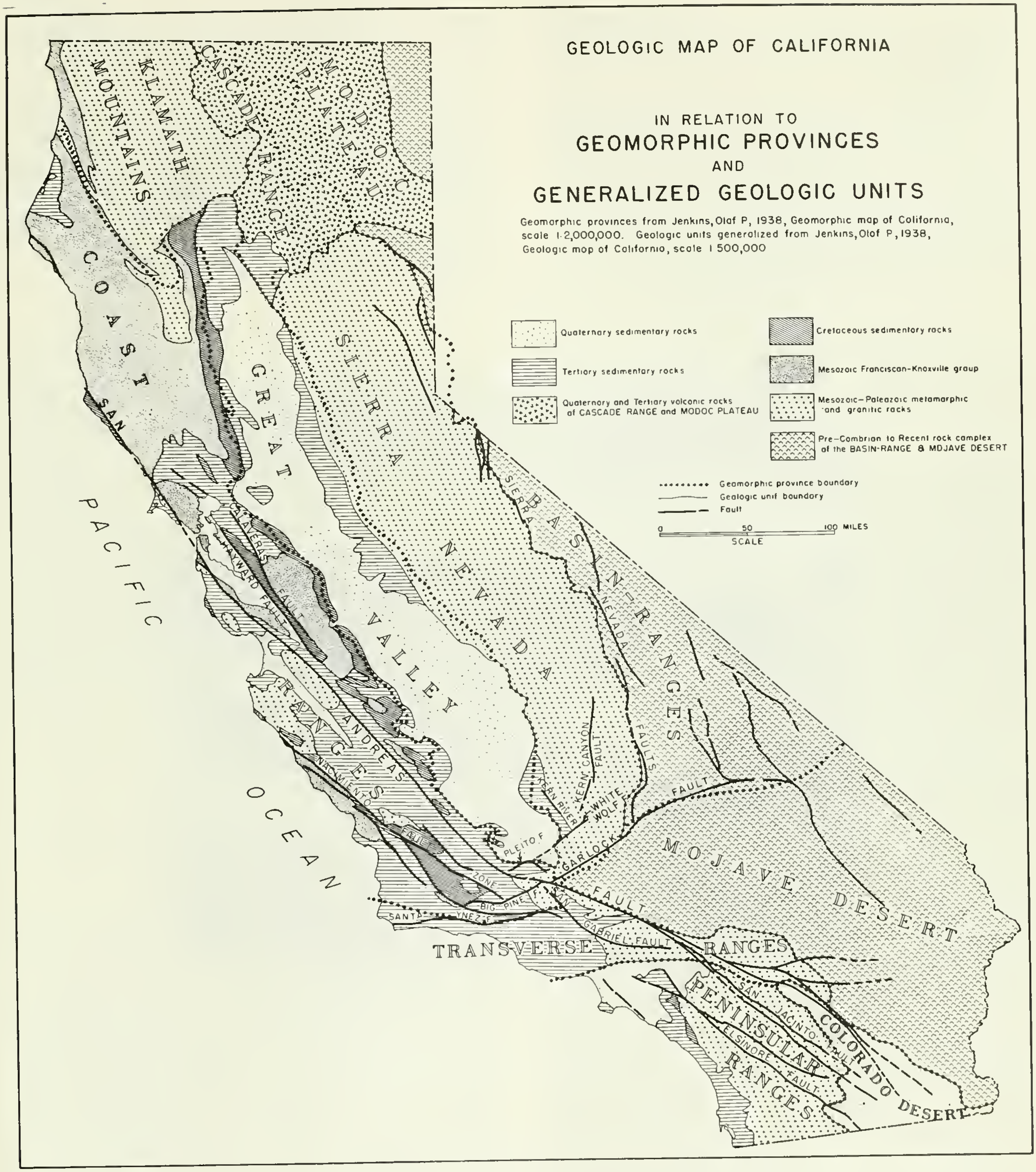
The Sacramento Valley is bounded on the east by the Sierra Nevada, the dominant mountain range in California. It is a westward-tilted fault block of great magnitude presenting a high multiple-scarp face on its east front, in contrast to the gentle western slope which disappears under the sediments of the Valley. The bedrock of the Sierra consists of Paleozoic and Mesozoic metasediments and volcanics intruded by a granitic batholith which forms the major portion of the range and isolates various roof pendants. Near the northern end of the range a fairly complete section of metasedimentary rocks is exposed. The northern end was subjected to less uplift and erosion than the southern end. Along the western slope of the range Tertiary sediments, volcanics, and isolated inliers of Upper Cretaceous sediments are found dipping gently westward beneath the Sacramento Valley. The north end of the Sierra Nevada terminates abruptly where the older rocks completely disappear beneath the Cenozoic volcanic cover of the Modoc Plateau and the Cascade Range.

The Cascade Range consists of a volcanic chain that extends into Oregon and Washington and is dominated, in northern California, by glacier-mantled Mount Shasta. Mount Lassen, the only active volcano in continental United States, lies within this province. Late Cenozoic volcanic rocks comprise the mass of the Cascades and in the southwestern portion these overlap the Eocene and Cretaceous sediments of the Sacramento Valley.

The Klamath Mountains lie to the west of the Cascade Range between the Coast Ranges of Oregon and those of California. This province is more closely akin to the Sierra Nevada than to the Cascade or Coast Ranges. The core of the Klamaths is composed of a complex of igneous and metasedimentary rocks ranging in age from Precambrian to Jurassic and intruded by Nevadan granitic rocks. Tertiary and Cretaceous sediments of the Valley are found overlying the range near the southern end. The Klamath Mountains are rugged, with elevations of over 8,000 feet above sea level. The drainage systems of the Trinity and Klamath Rivers are transverse and their very devious courses give little suggestion of order and pay small heed to geologic structure, as they empty into the Pacific Ocean near the northwest tip of California.

The Sacramento Valley is flanked on the west by the northern Coast Ranges which extend from the Klamath Mountains on the north to San Francisco Bay on the south. This province is characterized by longitudinal mountain ranges and intervening valleys trending approximately N. 30° W. Folding and faulting control the trend. The core is essentially the Upper Jurassic-Lower Cretaceous Franciscan formation, with younger rocks exposed in isolated down-faulted or down-folded blocks. The eastern border of this province is characterized by strike ridges and valleys of Cretaceous and uppermost Jurassic sediments which dip eastward under the alluvial

Photo 1. Mount Lassen from Manzanita Lake. Photo by Mary Hill.


GEOLOGIC MAP OF CALIFORNIA

IN RELATION TO
GEOMORPHIC PROVINCES
AND
GENERALIZED GEOLOGIC UNITS

Geomorphic provinces from Jenkins, Olaf P, 1938, Geomorphic map of California, scale 1:2,000,000. Geologic units generalized from Jenkins, Olaf P, 1938, Geologic map of California, scale 1:500,000

Figure 1.

sediments of the Sacramento Valley. A dendritic pattern of youthful streams drains the young Coast Ranges westward into the Pacific Ocean and eastward into the Sacramento Valley.

Three areas along the west slope of the Coast Ranges are of particular significance to the petroleum industry. The Eel River embayment, north of Cape Mendocino and in the vicinity of Eureka and Fortuna, is a Miocene-Pliocene embayment encompassing the sites of the Tompkins Hill and Table Bluff gas fields. The Mattole River country, immediately south of this embayment, was the site of some of the earliest prospecting for oil in California. The Point Arena area, about 125 miles north along the coast from San Francisco, is well known for the bituminous sandstone deposits in folded Miocene sediments.

The Sacramento Valley supports a rich agricultural economy including wheat, rice, barley, vegetable crops, various types of fruit, nut orchards, and stock raising. The summers are dry and hot, the winters, from November to March, rainy, foggy, and cool. Temperatures range from a maximum of 115°F. in the summer to a minimum of 30°F. during the winter. The annual rainfall averages approximately 25 inches within the Valley.

Photo 2. Fumaroles at Mount Lassen. Photo by Mary Hill.

THE LATE MESOZOIC OF CENTRAL CALIFORNIA C

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Plate 1, Correlation chart of Cretaceous formations in California, accompanies this paper.

Rocks of latest Jurassic and Cretaceous ages are more widespread in central California west of the summit of the Sierra Nevada than are those of any other comparable time interval. Nevertheless, until slightly over two decades ago, study of these rocks had progressed slowly (Popenoe, Imlay, and Murphy, 1960, pp. 1492-1502). At this time more intensive investigations began, and the store of available information about this sequence has increased tremendously. However, the problems and new data discovered during this period have destroyed many of the classic interpretations, and a drastic reorganization of data and conclusions is now in progress.

Two decades ago a common interpretation of the late Mesozoic geologic history of California would have presented a sequence of events about as follows:

Upper Cretaceous		Chico series
	unconformity	
Lower Cretaceous		Shasta series, including Horsetown above and Paskenta below
	unconformity	
Upper Jurassic		Knoxville formation Franciscan formation
	Nevadan Orogeny with large scale batholithic intrusions	
"Basement complex" including Mariposa formation of Upper Jurassic age in the Sierra Nevada.		

The simple version of events suggested above has now been greatly altered: the discovery of significant fossils of various ages in the Franciscan suggests that it is a eugeosynclinal assemblage of rocks (Irwin, 1957; Bailey, 1960) contemporaneous with a more normal sequence on the east; the "absolute ages" (Curtis, Evernden, and Lipson, 1958; Larson, et al., 1958) of many of the granitic rocks demonstrate that the emplacement of plutonic rocks on the West Coast was more widespread during the Late Cretaceous than during the Late Jurassic; and the suggestion of very large lateral movement along the San Andreas fault since the Cretaceous (Hill and Dibblee, 1953; Hill, 1954) as well as the recognition of the offshore Mendocino and Murray fracture zones as major structural features (Menard, 1955; 1960) extending at least up to the edge of the continent have greatly complicated interpretation of data.

Sedimentary and volcanic rocks of latest Jurassic and Cretaceous ages are found throughout a major portion of California (fig. 1) west of the Sierra Nevada between the Transverse Ranges on the south and the Klamath Mountains on the north. In the Coast Ranges from the west side of the Sacramento-San Joaquin Valley to the coast a major portion of the surface is covered by rocks of these ages, and in addition they are extensively developed in the subsurface of the Sacramento-San Joaquin Valley. Only in the Coast Ranges south of San Francisco, in a narrow belt immediately west of the San Andreas fault, is there a sizeable area where this complex is absent. Volumetrically these sedimentary and volcanic rocks are the most significant component of the "Superjacent series." Locally, as along the west side of the Sacramento-San Joaquin Valley and in the Diablo Range (Jenkins, 1943, fig. 3), they attain thicknesses ranging from 25,000 to 40,000 feet. Comparable accumulations may well be present in the northern Coast Ranges (Brice, 1953, fig. 2).

In large areas of the Coast Ranges immediately west of the San Andreas fault sedimentary and extrusive rocks of late Mesozoic age are absent, but granitic rocks are present. Until recently they were correlated with similar rocks in the Sierra Nevada and mostly considered to be of Late Jurassic age. However, application of the potassium-argon dating method to these rocks (Curtis, Evernden, and Lipson, 1958) has yielded "absolute" ages in the range from 81.6 to 91.6 millions of years. This age range seems to indicate that these intrusions were emplaced during the Cretaceous. Likewise, the plutonic rocks of the Sierra Nevada, long considered to be largely Jurassic or older, have recently been shown to include important Cretaceous elements (Curtis, Evernden, and Lipson, 1958; Larson, et al., 1958) as well as Jurassic. Curtis and his co-workers found that granitic rocks from the Yosemite area in the high Sierra Nevada had potas-

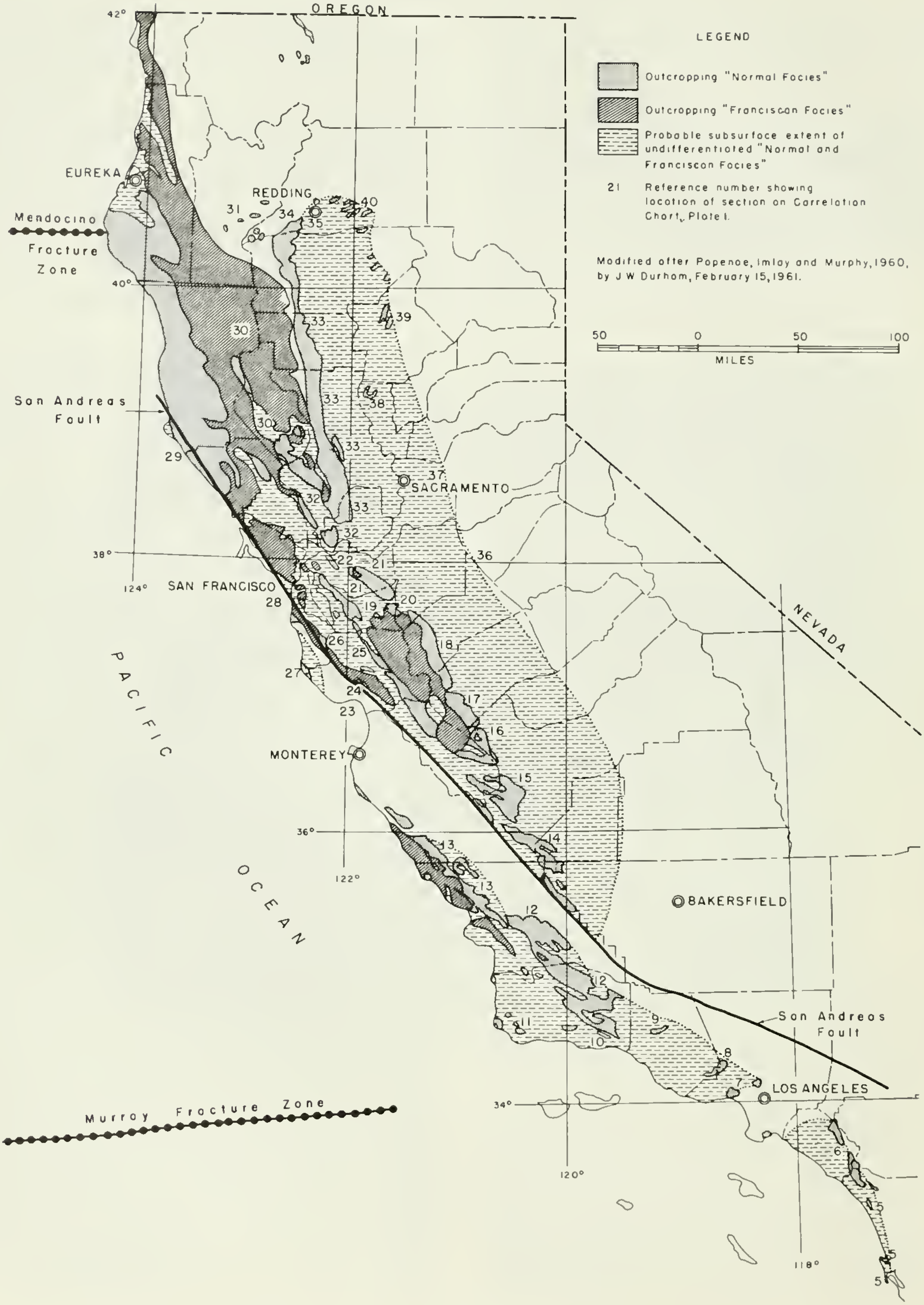

Figure 1. Areal distribution of Latest Jurassic and Cretaceous rocks of California. Modified after Popenoe, Imlay, and Murphy, 1960, fig. 2.

sium-argon ages ranging from 76.9 to 95.3 millions of years, while similar rocks from the northwestern foothills of the Sierra Nevada were from 130.6 to 142.9 million years old. The high Sierran intrusives would seem to have been intruded in the Late Cretaceous, whereas the foothill plutons must be no older than Late Jurassic, inasmuch as they intrude the fossiliferous Mariposa formation of middle Upper Jurassic (Oxfordian-Kimmeridgian) age. Larson et al., using the lead-alpha method found a nearly identical "absolute" age for a sample from one of the younger plutons sampled by Curtis, Evernden, and Lipson, but somewhat different ages for others.

The available data on "absolute" ages of the Sierra Nevada plutonic rocks seem to indicate that the western foothill belt is primarily of Late Jurassic age while the "high Sierra" granitics are of Late Cretaceous age. From the "absolute" ages given by Larson et al., it would appear that many, at least, of the "high Sierra" intrusives were approximately contemporaneous with those of the Baja California-Peninsular Ranges batholith, the Idaho batholith, and the Coast Ranges batholith of Washington, British Columbia, and Alaska. Thus it would seem that the major episode of batholithic intrusion in western North America was during the Late Cretaceous rather than during the latest Jurassic. The intrusive relationships of the Baja California-Peninsular Ranges batholith to rocks of Albian age and the unmetamorphosed Cretaceous rocks (locally as old as Turonian) that may rest upon an eroded surface cut into the granitics indicate that in southern California at least, granitic intrusion occurred during early Late Cretaceous (Cenomanian-early Turonian) time and was of relatively short duration. This short time interval is in accord with the estimate of Larson et al. (1958, p. 60) "of only a few million years . . ." for "the entire batholithic emplacement."

In recent years it has been suggested (Hill and Dibblee, 1953; Hill, 1954) that major right-lateral displacement, to a magnitude of 300 to 400 miles since the Jurassic, has occurred along the San Andreas fault and that the geologic history of California should be interpreted on the basis of such movement. Several authors (Curtis, Evernden, and Lipson, 1958, pp. 14-16; Hall, 1960) have presented evidence in support of this hypothesis. However, the distribution of the Late Mesozoic "normal" and "Franciscan facies" rocks on each side of the San Andreas fault (see fig. 1) does not support such major movement and no aspect of the Cretaceous faunas which would support the hypothesis of major displacement has yet been recognized. Major movement along the San Andreas fault zone of the magnitude indicated above appears improbable.

The Murray and Mendocino fracture zones of the eastern Pacific basin (Menard, 1955; 1960, pp. 1742-1745) need to be considered in evaluating the geologic history of California. Both of these zones extend at least to the edge of the continental shelf along the coast of California, with the Transverse Ranges of southern California appearing to include the inland continuation of the Murray zone, and the boundary between the northern Coast Ranges and the Klamath Mountains falling suggestively near the inland projection of the Mendocino zone. Unfortunately the importance of these great fractures has not yet been adequately explored, but it should be noted that the Transverse Ranges form a boundary between two regions with significantly different geologic histories during the Cretaceous and Cenozoic, thus suggesting that the inland extension of the Murray zone forms a major geological boundary. Recently Osterwald (1960, p. 233, fig. 1) has considered this inland continuation to form part of the "Texas geofracture" which extends eastward to the Gulf Coast. The relationship of this zone to the San Andreas fault zone has not yet been thoroughly explored, but Allen (1957) has shown that the San Andreas fault, as he maps it, "buts" into the Banning fault, a member of the Transverse Ranges or Murray zone system.

Within the great volume of rocks referable to the Late Jurassic and Cretaceous in central California, many types are present. The clastic sedimentary rocks consist largely of graywacke and shale with associated conglomerates. The sequence exposed along the west side of the Sacramento is composed almost exclusively of these types. Rocks of the suite usually referred to as Franciscan commonly include, in addition to the preceding, interbedded cherts and extrusive basic volcanics, often altered to greenstone, and have been intruded by large bodies of serpentine. Associated with these intrusions, but not restricted to areas where they have been recognized, may be areas of schistose rocks, including glaucophane schist. Limestone is notably absent from the sequence in most places, but the Calera and similar limestones, usually as small lenses, but occasionally, as at the type locality of the Calera, attaining thicknesses of over a hundred feet, have become notable because of the Upper Cretaceous pelagic foraminifers that they contain. Along the west side of the Sacramento Valley, as near Wilbur Springs, a few similar sized bodies of limestone of different lithology occur, but they are stratigraphically near the Jurassic-Cretaceous boundary and do not contain the same fossils as the Calera type limestones. A notable discovery of recent years is the finding of large transported blocks of quartz diorite at the base of the Turonian Venado sandstone on the west side of the Sacramento Valley (Brown, 1960). In the eastern part of the northern Coast Ranges, a considerable belt of rocks referred questionably to the Franciscan has been moderately metamorphosed, with large areas consisting mostly of low-to-moderate-grade slates and phyllites (Irwin, 1960, pp. 37-38).

Jenkins (1943, fig 1) listed 61 stratigraphic names of various ranks that had been used in the California Cretaceous. Since that date a number of significant contributions to the nomenclature of the Late Jurassic and Cretaceous have been made. Notable among these are the works of Goudkoff (1945), Murphy (1956), and Payne

(1951). Popenoe, Imlay, and Murphy (1960) have presented a long-awaited correlation chart for Cretaceous of the Pacific Coast. The part of this chart pertaining to central California is reproduced here (plate 1). Relying extensively upon the recently published studies of Matsumoto (1959a, 1959b, 1960), Imlay (1959, 1960), and Murphy (1956), they demonstrate that all the standard European stages of the Cretaceous except the Berriasian are represented in central California. Proof of the presence of the Berriasian is lacking. Loeblich (1958) concluded that Goudkoff's "A" zone (or Cheneyan) is to be correlated with the Danian of Europe and referred both to the Paleocene although this latter conclusion is the subject of considerable debate.

The most complete sections are present along the west side of the Sacramento Valley where beds ranging in age from Late Jurassic to lower Maestrichtian (except for the Berriasian) are present. Southward along the west side of the San Joaquin Valley the Upper Cretaceous is well represented, but the Lower Cretaceous seems to be largely absent as in several places rocks of Albian or slightly younger age rest on shales containing the Late Jurassic pelecypod *Buchia piochii* or the Valanginian *B. crassicollis*. Within the Coast Ranges fossils are much less abundant than in the Sacramento-San Joaquin Valley, but scattered occurrences have demonstrated that rocks of Tithonian, Valanginian, Albian, Cenomanian, Turonian, Campanian, and Maestrichtian ages are present. Fossils that unequivocally document the presence of the Hauterivian, Barremian, and Aptian are known only along the west side of the Sacramento Valley, but rocks of these ages must have once extended (and perhaps still extend) westward to the Pacific. Along the east side of the Sacramento-San Joaquin Valley the only Cretaceous rocks that are known to crop out are of Upper Cretaceous age (Popenoe, Imlay, and Murphy, 1960, pp. 1526-1527, notes 42-45). In most of the known outcrops only fossils of Campanian age have been found, but at Chico Creek the beds range in age from late Coniacian to Campanian. At the north end of the valley, near Redding, the sediments range in age from Turonian to Santonian.

The discovery (Nomland and Schenck, 1932) that the beds along the coast at Slates Hot Springs in Monterey County contained an unequivocal Late Cretaceous fossil (*Baculites*) and the consequent removal of these rocks from the Franciscan, although not recognized as such at the time, began the destruction of the traditional concept of the Franciscan as the lowermost member of the "Superjacent Series." Ironically this same locality was early cited (Fairbanks, 1895) as one where the Franciscan (termed Golden Gate series by Fairbanks) was fossiliferous and seemingly overlain by the Knoxville formation to which he assigned a Lower Cretaceous age. Fairbanks considered that the age of his Golden Gate series was either Jurassic or very Early Cretaceous, but subsequently C. H. Davis (1913), in part considering the same locality, assigned a Jurassic age.

Since 1940, a number of significant fossil discoveries have been made in rocks that have traditionally been referred to as part of the Franciscan. The Calera limestone member of the Cahill sandstone which was considered by Lawson (1914) to be the lowest formation of his Franciscan group, and similar limestones in the Coast Ranges, extending from near San Jose on the south to southern Oregon (Irwin, 1960, pp. 35-36), have been found to contain pelagic foraminifera indicating a Late Cretaceous age. According to a recent (1956) opinion of H. E. Thalmann (cited in Irwin, 1960, p. 36) these foraminifera indicate ages ranging from late Albian to Cenomanian for the various bodies of limestone. An ammonite (*Douvilleiceras*), found in Lawson's Marin sandstone member of the Franciscan group (Schlocker, et al., 1954) demonstrates that part of the type Franciscan is of Albian age. A cenomanian ammonite (*Mantelliceras*) has been found (Hertlein, 1956) in the same formation on the north side of San Francisco Bay. Durham and Jones (1959) have recorded fossils (*Inoceramus labiatus*, *I. schmidti*) indicative of Turonian and Campanian ages from beds that had been loosely referred to the Franciscan. Some of these data have been reviewed by Irwin (1957, 1960).

In contrast to the preceding records of fossils indicative of Cretaceous age in "Franciscan rocks" (including at least part of the type section), it should be noted that Late Jurassic fossils also are found, sometimes—as at Skaggs Springs, Sonoma County (Durham and Jones, 1959)—in close proximity to Late Cretaceous fossils, in rocks of this complex. *Buchia* [*Aucella*] *piochii* (Gabb), considered by Imlay (1959) to be characteristic of the Late Jurassic, is widely distributed in the Coast Ranges. Many of its occurrences have been discussed by Irwin (1957, 1960). It is found, especially along the west side of the Sacramento Valley and in the Berkeley Hills-Mount Diablo area, in rocks assigned to the Knoxville formation which Taliaferro (1941, pp. 125-127; 1943) considered to be an upper phase of the Franciscan. Along the west side of the Sacramento Valley the Knoxville formation, including its type area, is now (in contrast to earlier opinions) considered to be in fault contact with the Franciscan formation and associated basic igneous rocks (Irwin, 1960, pl. 1). In the Berkeley Hills (Lawson, 1914, p. 7), at Mount Diablo (type locality of *Buchia piochii*) and southward in the Diablo Range, rocks commonly referred to the Franciscan are either overlain by beds containing *Buchia piochii* or include these beds (Popenoe, Imlay, and Murphy, 1960, p. 1522, correlation chart; Anderson, 1933, pp. 1248, 1254-55; unpublished data). Likewise Easton and Imlay (1955) have reported *Buchia piochii* and other fossils indicating that both the "Franciscan and Knoxville formations" of the Branch Mountain quadrangle (San Luis Obispo County) in the southwestern Coast Ranges are of Late Jurassic age. *Buchia piochii* is also scattered throughout the western Coast Ranges (Fairbanks, 1895; Taliaferro, 1943; Irwin, 1957, 1960; Durham and Jones, 1959). It is clear from the fossil evidence that: (1) widely distributed rocks in the Coast Ranges which have been assigned to the Franciscan (formation or group) range in age from Late Jurassic to Late Cretaceous and are contemporaneous with "more normal" rocks along the west side of the Sacramento-San Joaquin Valley; (2) part, at least, of the type section of the Franciscan is of Albian and Cenomanian age; (3) throughout the region where there are rocks of "Franciscan facies," some of them are of Late Jurassic age. Resolution of the conflicts presented by recognition of the various ages of rocks included in the Franciscan in the past is still not clear. It would appear that "Franciscan", as it has been used in the past, implies an assemblage of rocks characteristic of a recurrent environment and not a single formation or group. As indicated by Bailey (1960) and Irwin (1960, p. 34) it is composed of a suite of rocks that are characteristic of a eugeosynclinal environment.

The known faunas of the Late Jurassic and Cretaceous of central California are almost entirely marine and consist mostly of molluscs and foraminifers. Locally fossils may be abundant, but except for a few areas the thick sequences of sediments of this interval are generally characterized by a lack of readily identifiable organisms. The scarcity of fossils may be in part due to the large volume of rapidly accumulating sediments having diluted or suppressed the biota. Many of the more significant fossils for correlation and their ranges are shown on the correlation chart (Pl. 1). The Tithonian and Valanginian are characterized by the presence of the pelecypod *Buchia* [*Aucella*], often to the exclusion of other organisms. The western American occurrences of this genus have recently been reviewed by Imlay (1959). This genus at times has had a "boreal" climatic significance attributed to it, but its common presence in dense populations with few or no other associated invertebrates suggests that it was controlled by some fac-

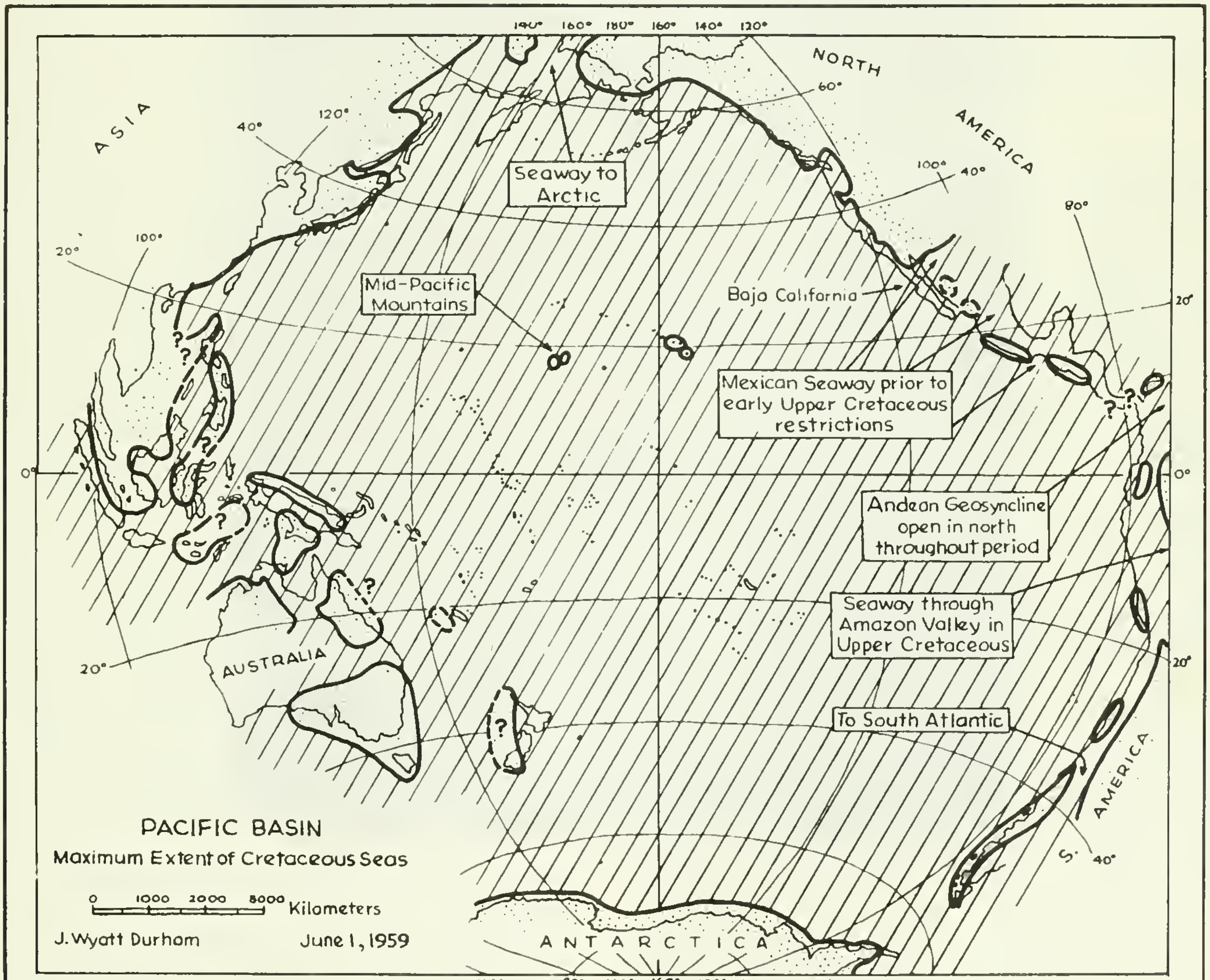

Figure 2. Map showing maximum extent of Cretaceous seas in the Pacific basin.

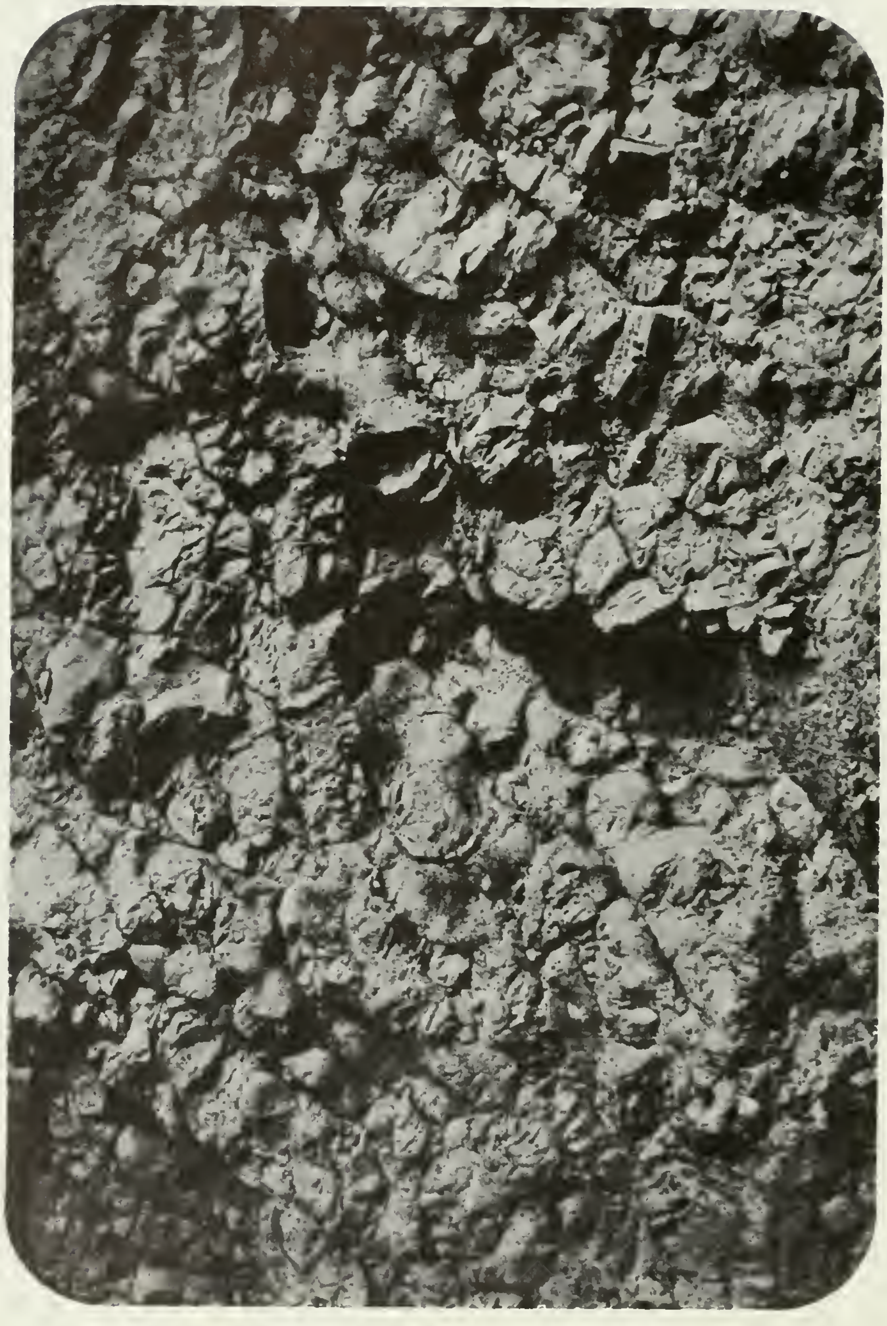

Photo 1. Pillow basalt in the Franciscan formation, exposed along Arroyo San Antonio, Marin County. Pillows are a foot or two in diameter. Photo by Olaf P. Jenkins.

tor of the environment other than climate. The fragments of cycad leaves rather commonly found in the same beds do not support any boreal climatic inferences. Occasionally ammonities are associated with *Buchia.* The Valanginian and Hauterivian ammonites of the Pacific Coast have recently been reviewed by Imlay (1960).

In central California only the cephalopod element of the molluscan faunas of the post-*Buchia* bearing beds has received much attention since the pioneering days of Gabb (1864; 1869). F. M. Anderson (1938; 1958) has recorded and described many species, mostly ammonites, from both the Lower and Upper Cretaceous of California. Tatsuro Matsumoto (1959a; 1959b; 1960) has presented an outstanding review of the Late Cretaceous ammonites from a world-wide perspective. Gastropods and pelecypods from the central California area, in general, have not been the subject of much study, although large and diverse faunas are known in the Upper Cretaceous of the Sacramento and San Joaquin Valleys. W. P. Popenoe and his colleagues are currently studying the faunas from the Redding and Chico Creek areas. In contrast to the situation in many other parts of the world, pachydont pelecypods are rare in most of the central California Cretaceous, probably because the environment was not suitable. The abundant *Coralliochama orcutti* White (unpublished data) in the Gualala group along the coast north of San Francisco are a marked exception to this generalization. Echinoids and corals are largely absent from the central California area, although they often are found in abundance in beds of similar age in Baja California. The distribution of foraminifers in the Late Jurassic and Cretaceous of central California is not well known although those of the Upper Cretaceous have been studied by a few investigators. The most significant contributions are those of Cushman and Todd (1948), Goudkoff (1945), and Küpper (1955; 1956).

Fossil vertebrates have rarely been found in the late Mesozoic of California, but a few fish and marine reptiles, as well as a duckbilled dinosaur, have been recorded (Camp, 1942; Hanna, 1946, p. 92; Welles, 1953; Anderson, 1958, p. 71).

Plant debris is common in the clastic sediments, but few floras have been described. Diller (1908) has presented floral lists from various localities of Late Jurassic and Early Cretaceous ages along the west side of the Sacramento Valley and in the northern Coast Ranges.

One of the oldest occurrences of fossil diatoms is in the Moreno formation of Maestrichtian age along the west side of the San Joaquin Valley. A flora of over 100 taxa has been recorded from this formation (Long, Fuge, and Smith, 1946).

Climatically, California was situated within the widespread tropical zone of the Late Mesozoic (Dorf, 1959; Durham, 1959; MacGinitie, 1958). The presence of pelecypods such as *Spondylus, Pinna, Crassatellites,* and *Cucullaea* as well as gastropods such as *Cypraea* and *Volutoderma* reflect the presence of warm tropical waters. Despite a generally unfavorable sedimentary environment the presence of occasional rudistid pelecypods (*Coralliochama, Durania*) and rare specimens of hermatypic corals (*Astrocoenia, Favites*) in central California supports the inferences regarding the climate.

The Pacific basin during the Cretaceous (fig. 2) had more numerous connections with the other oceans than at present. In consequence, faunal exchange was easy. Combined with the widespread tropical climates of the time this ease of migration resulted in the faunas of California being more cosmopolitan (Durham and Allison, 1960, pp. 66-68) than during the Cenozoic. Broad central American seaways permitted easy interchange of faunal elements with the Atlantic-Tethyan realm, and an Early Cretaceous seaway through northeastern Siberia gave communication with the Boreal realm. Among the Late Cretaceous ammonites of California, which were presumably mostly free-swimming, Matsumoto (1960, pp. 165-172) was able to list at least eight species and 23 genera that were cosmopolitan. Out of a total of 73 species which he recognized in California, he records 62 as also present in Japan. In other less mobile groups of organisms the specific similarity with other areas is less, but it is, nevertheless, marked (Durham and Allison, 1960, pp. 77-78, table 4).

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ECONOMICS OF SACRAMENTO VALLEY EXPLORATION AND DEVELOPMENT

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Introduction. The purpose of this paper is to analyze various factors effecting the profit from exploration for, and development of, natural-gas reserves in the Sacramento Valley of California. The Valley has been established as a dry-gas-producing province since 1935, when the Tracy gas field southwest of the city of Stockton was discovered; productive fields now exist within the area extending from the Vernalis gas field near Modesto on the south to the Corning gas field near the city of Corning on the north, a distance of 165 airline miles. Dry gas has been produced from rocks of Pliocene, Miocene, Eocene, Paleocene, and Upper Cretaceous ages. Cumulative production at the end of 1960 was about 2,750,000,000 Mcf.

Natural-gas consumption has been rapidly increasing in California, as elsewhere in the nation, and approximately 60 percent of the gas now consumed within the state comes from out-of-state sources. It may be demonstrated that about two-thirds of the delivered cost of out-of-state gas is accounted for by pipeline amortization, transmission, and profit charges. Thus, as the Sacramento Valley gas wells are in and adjacent to the marketing area, it is apparent that the Valley producer has a tremendous advantage over the producer of imported gas. This advantage is reflected in the well-head price of the gas, which currently averages 30 cents per Mcf for 1,000-BTU gas. In addition to this price advantage, the Valley producer enjoys generally favorable land-leasing costs, cheap drilling over most of the province, no proration by state authority, and no control over price by the Federal Power Commission. These incentives, coupled with a depressed crude market, have channeled the energies of the California operators toward the search for natural-gas reserves in the Valley, and the number of exploratory and development wells drilled per year has been increasing steadily. It is anticipated that this trend will continue as long as these incentives are maintained.

Geologic Conditions. The Valley area, consisting of some 11,600 square miles, contains a maximum composite stratigraphic thickness of clastic rocks of from 50,000 to 60,000 feet, of which more than 90 percent is of marine origin. The sediments range in age from Recent to Upper Jurassic, and practically every major sand unit younger than the Lower Cretaceous has produced oil or gas. Porosity usually ranges from 25 to 35 percent, and permeability is measured in darcies in some cases. Reservoir pressures are mostly hydrostatic, though there are important exceptions in the Upper Cretaceous "F" zone. Both water-drive and constant-volume reservoirs are in evidence. All three major types of traps (structural, stratigraphic, and combination structural-stratigraphic) are represented. Analyses of individual cases that are considered representative of the major reservoir conditions are presented below under the heading *Income*.

Land Costs. Exploratory acreage rentals range from \$1.00 per acre per year to \$10.00 per acre per year, the current average being about \$3.00 per acre per year. This average figure is derived from actual recent acquisition costs of one operator with some 90,000 acres—extending from Red Bluff on the north to Modesto on the south—under lease. In addition to the rentals, another \$1.00 per acre for landmen's salaries, title reports, recording fees, etc., may be added, making the current average total acquisition cost \$4.00 per acre. Landowners' royalties range from a low of 12.5 percent to a rare high of 25 percent, the current average being slightly over 14 percent. Competition for land is steadily increasing, producing a consequent rise in rental fees and acquisition and royalty rates. Because the rates vary with the level of activity in a given area of the Valley, and because there is so much land available, it is anticipated that land costs will not soon become onerous. Compared to land costs in the oil basins of California, the Valley costs are very reasonable, and are consistent with the profit to be realized from exploration and development.

Drilling Costs. Dry-hole drilling costs are generally low because of rapid penetration rates and minimum requirements for surface casing and mud. Figure 1 is a diagram relating the penetration rates in selected areas of the Valley to the dry-hole costs—which would include costs of site preparation and abandonment, contractors' charges for footage (including rig move, rig time, fuel,

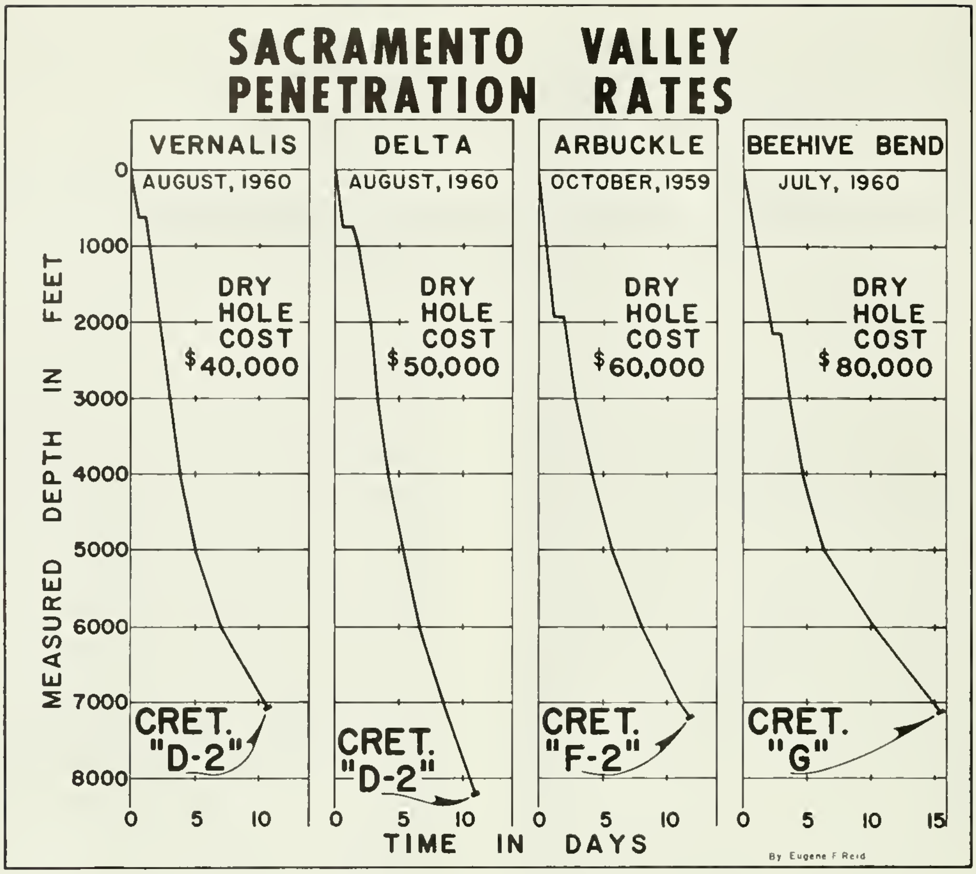

Figure 1. Chart showing penetration rates in the Sacramento Valley.

bits, etc.), surface casing and cementing, water, mud and mudding chemicals, and all evaluation tools such as induction-electric log, sonic log, microlog, dipmeter, and open-hole formation tester. Unusual circumstances which can balloon drilling costs are penetration of basalt remnants, loss of circulation in peat beds, and difficult surface locations such as those on swampy islands where pilings are required to support the drilling rig, or where extensive gravelling of roads and locations is made necessary by weather conditions. For drilling to the high-pressure Upper Cretaceous "F" and "G" zones, dry-hole costs increase rapidly because of the necessity of setting deep and heavy surface strings to prevent lost circulation in upper beds when carrying mud weights from 120 to 140 pounds per cubic foot. Dry-hole costs for a 9,000-foot hole to the lower "F" zone with bottom hole pressures above 6,000 psi may range upward from $125,000.

Completion Costs. Casing programs for completion have not been standardized to any degree, although 5½-inch casing is currently the most popular size for both single- and dual-zone completions. During 1960, 88 wells were completed in the Valley, 22 being dual-zone completions, and 5 being liner completions for gas-injection wells in a storage project. Of the total, almost 56 percent were completed through 5½-inch casing, and 24 percent were completed through 4½-inch casing. The trend toward the use of the smaller casing appears to be increasing.

Common practice for completion is to make water shut-off tests both above and below prospective zones, and to jet-perforate production holes. Either 2-inch or 2½-inch tubing is hung just above the perforated interval. Surface equipment consists of the christmas tree, heater, and scrubber.

Completion costs for a 5,000-foot well with the reservoir at hydrostatic pressure (gradient of 0.433 psi per foot) are estimated at about $25,000. For a 6,000-foot well with an overall gradient of 0.57 psi per foot, costs are estimated at $50,000. For a 7,500-foot well with an overall gradient of 0.68 psi per foot, costs may be as high as $75,000. Principal cause of the variation in cost would, of course, be the necessity of employing better-grade casings of greater weight when dealing with the higher pressures, and the allied increased cost of wellhead equipment, tubing, etc.

Production Costs, Mining Rights and Improvement Taxes. Production costs are particularly related to the number of wells that may be tended per man; naturally, the cost per well decreases as the man's salary and transportation charges are prorated over more units. For purposes of this paper, the cost per well per month is assumed to be $150.00 ($1800.00 per year). Where it is possible for a man to tend 15 or 20 wells, the cost may be reduced to less than $100.00 per month per well. Mining rights and improvement taxes are difficult to estimate because of the vagaries of assessment and tax rates. The current rates average less than 2 cents per Mcf, and this figure is used in the analysis below. Federal income taxes are excluded from the analysis.

Income. Based on current prices at the well head, 1000 BTU gas commands at least 30 cents per Mcf; lower quality gas is sold at a differential of 3 cents per Mcf for each 100 BTU below the standard 1000 BTU. Comparing the 30-cent price with that of prices throughout the nation, it is more than double, and in some cases triple, out-of-state well-head prices. The proximity to market of the Valley gas assures the continuance of such a price differential when the costs of transporting out-of-state gas over long distances are considered, and when it is realized that it is economically unfeasible to use out-of-state gas for "peaking" during periods of severe demand. Producer-purchaser contracts generally contain a minimum guarantee or "take or pay" clause specifying an amount of gas which will be paid for, whether taken or not. Such a clause gives the purchaser a degree of flexibility in drawing on the reserves subject to the contract, and at the same time allows the producer to estimate his minimum income.

Figures 2 and 3 are designed to illustrate the magnitude of recoverable reserves which may be expected from two types of Sacramento Valley gas fields. The generalized reservoir conditions have been derived from specific field data, and are considered typical of the average field conditions. Figure 2 shows the recoverable standard Mcf per acre foot for reservoirs at hydrostatic pressure with a water drive as the producing mechanism. Typical of such reservoirs would be the producing sands of Tertiary age in the Delta area such as at the Lodi, Galt, Thornton, River Island, and Rio Vista fields. One curve is shown for recovery of 50 percent of the total gas in place and the other curve is for recovery of 60 percent of the total gas in place. In general, these producing sands have high porosities, and permeabilities may be measured in darcies. Productive sand thicknesses rarely may be as much as 300 feet in an individual reservoir.

Figure 3 shows the recoverable standard Mcf per acre foot for constant volume reservoirs; one family of curves is plotted for a sand with a porosity of 30 percent and a water saturation of 35 percent, another for a sand with a porosity of 25 percent and a water saturation of 40 percent. Typical of these reservoirs are the sands of the Upper Cretaceous "F" zone, such as those productive at Arbuckle, Beehive Bend, and Grimes. Recovery factors ranging from 70 to 90 percent are generally applied to the original calculated reserves in place to reduce them to recoverable reserves; selection of the recovery factor must be based on experience derived from production of similar reservoirs. These curves particularly demonstrate the importance of a small increase in porosity and reduction in water saturation to ultimate recoverable reserves, especially in the higher pressure ranges.

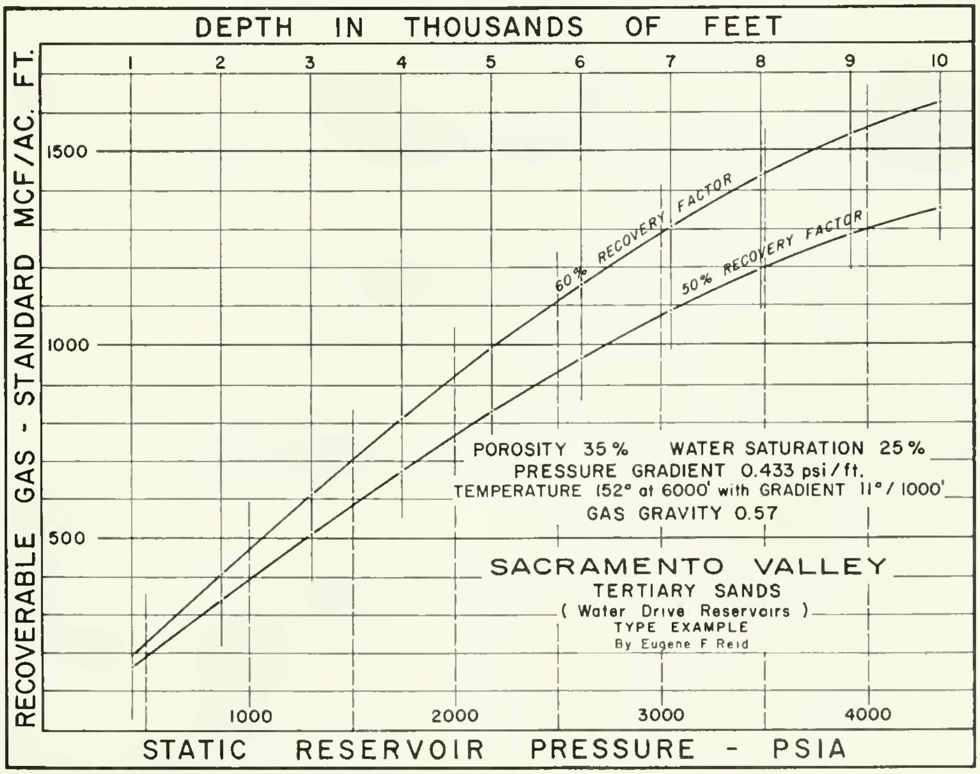

Figure 2. Chart showing static reservoir pressures in the Sacramento Valley Tertiary sands.

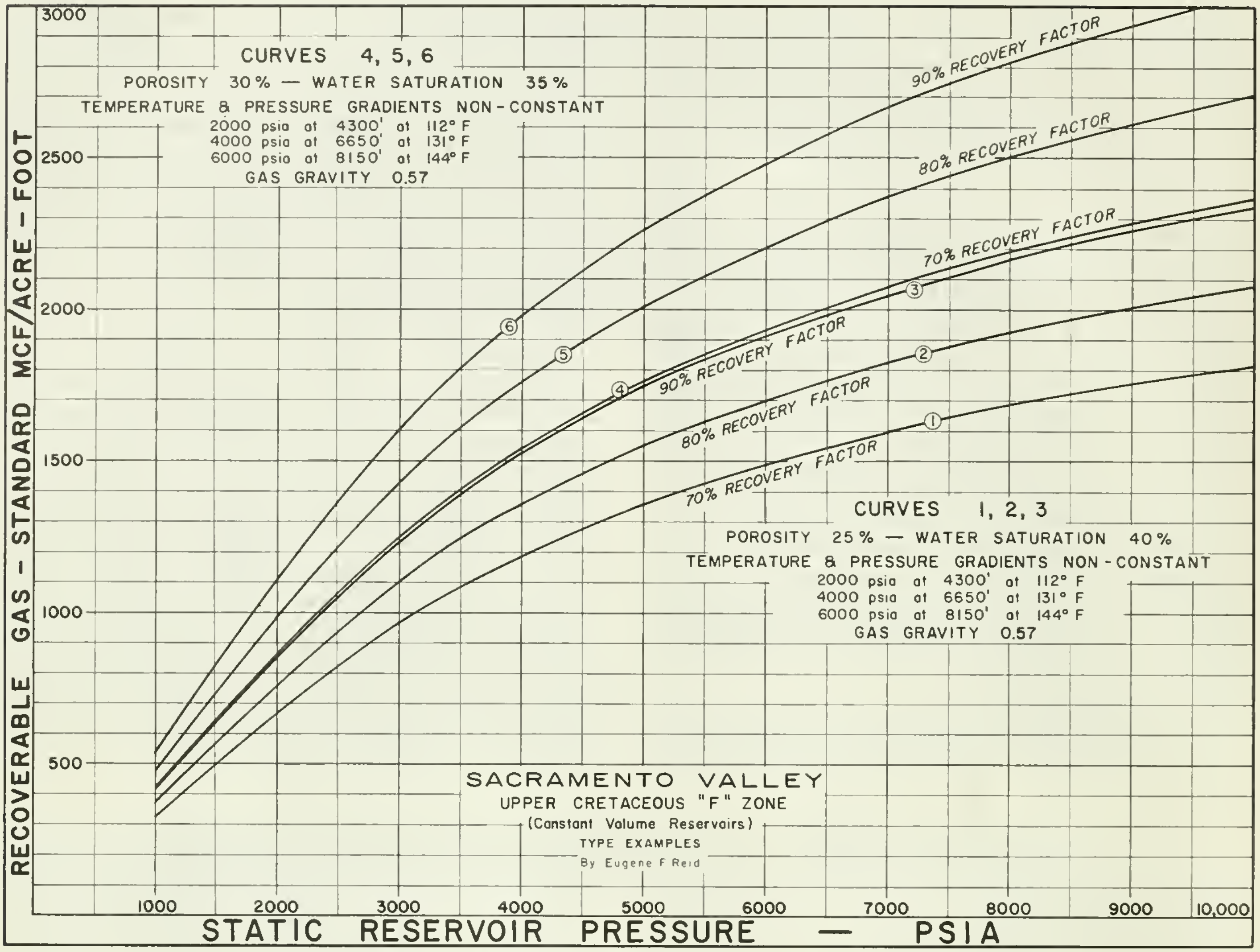

Figure 3. Upper Cretaceous F-zone constant-volume reservoirs in the Sacramento Valley.

Table 1. Recoverable reserves.

Examples	*X*	*Y*	*Z*
Geologic age of sand	Tertiary	Upper Cretaceous "F" zone	Upper Cretaceous "F" zone
Well depth (feet)	5000	6000	7500
Pressure gradient overall (psi/ft)	0.433	0.566	0.680
Reservoir mechanism	Water drive	Constant volume	Constant volume
Gas gravity	0.57	0.57	0.57
Porosity (percent)	35	25	25
Water saturation (percent)	25	40	40
Reservoir temperature (°R)	598	586	599
Reservoir pressure (psia)	2165	3400	5100
Compressibility factor—Z	0.875	0.882	1.002
Recovery factor (percent)	60	80	80
Standard temperature (°R)	520	520	520
Standard pressure (psia)	14.73	14.73	14.73
Reservoir volume conversion factor (ft^2/ac)	43.56	43.56	43.56
Recoverable reserves (Standard Mcf/acre-foot)	1000	1220	1570

Table 2. Value per well.

Examples (from table 1)		X	Y	Z
Drainage area	(acres)	160	160	160
Sand thickness	(feet)	40	30	30
Recoverable reserves:	(Mcf/ac.-ft.)	1000	1220	1570
(to closest 5000)	(Mcf)	6,400,000	5,855,000	7,725,000
Price at well head	($/Mcf)	0.30	0.30	0.30
Gross income	($)	1,920,000	1,755,000	2,320,000
Less: Royalty at 1/6	($)	320,000	295,000	390,000
Working interest income	($)	1,600,000	1,460,000	1,930,000
less costs				
Completed well	($)	55,000	110,000	200,000
Production costs & W.I. share M.R. & impr. taxes	($)	155,000	135,000	165,000
Provision for remedial work	($)	15,000	25,000	50,000
Total costs	($)	225,000	270,000	415,000
Undiscounted net income to producer (Before federal taxes)	($)	1,375,000	1,190,000	1,515,000

Table 1 presents data used in calculating recoverable reserves by the volumetric method. Example X is for a Tertiary water-drive reservoir at hydrostatic pressure, and examples Y and Z are for Upper Cretaceous "F"-zone constant-volume reservoirs with different pressure gradients. Calculation of the recoverable reserves in standard Mcf per acre foot may be made by substituting the appropriate factors in the following formula

$$R = A \times t \times \phi \times (1 - S_w) \times \frac{T_s}{T_r} \times \frac{P_r}{P_s} \times \frac{1}{Z} \times K \times F$$

where

R = Recoverable reserves in Standard Mcf/acre-foot
A = Drainage area in acres = 1 acre
t = Reservoir thickness in feet = 1 foot
ϕ = Effective porosity expressed in the decimal equivalent of percentage
S_w = Interstitial water saturation expressed in the decimal equivalent of percentage
T_s = Standard temperature expressed in degrees Rankin = 460° R
T_r = Reservoir temperature expressed in degrees Rankin
P_r = Static reservoir pressure expressed in pounds per square inch atmospheric
P_s = Standard pressure expressed in pounds per square inch atmospheric = 14.73 psia
Z = Compressibility factor
K = Mcf in one acre foot = 43.56 Mcf/acre foot
F = Recovery factor expressed in the decimal equivalent of the percentage of original standard gas in place that is recoverable before abandonment

In the examples cited, the greater depths, higher pressure gradients, and recovery factors in examples Y and Z (representative of the Upper Cretaceous "F" zone sands) account for significant increases in the recoverable reserves when compared to the shallower water-drive reservoir (representative of the Tertiary sands). However, as shown in table 2, a greater sand thickness in the Tertiary reservoirs may often more than offset the higher recoveries exhibited in the "F" zone reservoirs. In table 2, the gas has been assumed to have a heating value of 1000 BTU, a price at the well head of 30 cents per Mcf, and all dollar figures have been rounded off to the nearest $5,000.

It is readily apparent that the successful exploration for, and development of, natural-gas reserves can be very rewarding. Assuming a dry-hole cost for example X of $30,000, and land-acquisition, geological, geophysical, and overhead costs of $30,000 per exploratory test, approximately 23 tests to the same depths and reservoirs may be drilled from the undiscounted net income (before federal taxes) of a typical Tertiary well. For example Y, assuming a dry-hole cost of $60,000 and additional costs, as above, of $40,000, approximately 12 similar tests may be drilled from the undiscounted net income; and for example Z, with a dry-hole cost assumed at $125,000 and additional costs, as above, of $50,000, approximately 8½ similar tests could be drilled. This would make it appear that the reward-to-risk ratio is more favorable for the Tertiary reservoirs than the "F"-zone reservoirs, but the final reward is associated with the ultimate areal extent of the accumulation. The Tertiary reservoirs that remain undiscovered and available for exploitation appear to be limited to much smaller accumulations than those now developing in the "F" zone in the Colusa basin area. Further, it is possible that deeper "F"-zone drilling will establish greater productive sand thicknesses, which will make the recoverable reserves per well infinitely more attractive for exploration than at the present. It is quite apparent that any of the targets cited above is sufficienly attractive to encourage the expenditure of risk capital, particularly when it is recognized that the overall success ratio of exploratory wells in the Sacramento Valley has been better than one success in each seven exploratory wells drilled over a period of several years.

Summary. In summation, the reward-to-risk ratio resulting from favorable geological and marketing conditions, coupled with conservative land acquisition, drilling, and producing costs, favor the continued rapid exploration pace now being set in the Sacramento Valley.

PART II

REGIONAL GEOLOGY

CONTENTS

PLATES

GENERAL REFERENCES TO SACRAMENTO VALLEY AND VICINITY

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THE SACRAMENTO VALLEY—SURFACE GEOLOGY

CONTENTS

INTRODUCTION TO THE SURFACE GEOLOGY OF SACRAMENTO VALLEY, CALIFORNIA

By **ROBERT D. REEDY**
Gulf Oil Corporation of California

The ensuing discussions describing surface geology represent a combined effort on the part of geologists presently working in the Sacramento Valley. M. C. Lachenbruch, Don Rogers, and L. E. Garrison have given generously of their time and effort in order to provide a comprehensive report on rocks observed in their natural environment. Since the Sacramento Valley contains one of the most complete Mesozoic sections in North America, it affords a unique place for surface observation.

The Sacramento Valley is the northern part of the Great Valley of California, separated from the San Joaquin Valley on the south by a buried northeast-trending structural arch in the latitude of the city of Stockton (T. 1 N., R. 7 E.). The Valley is flanked on the west by the northern Coast Ranges, a rugged mountain chain with elevations surpassing 5000 feet above sea level. The Klamath Mountains rise abruptly to the north, whereas the Cascade Range forms the border of the northeast. The gently rising Sierra Nevada provide the eastern border for the Sacramento Valley. The valleyward peripheral edges of these orogenic systems provide an ideal laboratory for visual inspection and interpretation.

The recent economic importance of natural gas has encouraged both major and independent oil companies to embark on intensive drilling campaigns, and resulting data have strengthened correlations between subsurface and surface rock units. As gas seeps are found throughout the Sacramento Valley, and are particularly common on the west side, it is important that much be learned concerning their natural habitat. These seeps are in the Knoxville and all the Cretaceous formations, usually near faults and surface anticlines. A number of oil seeps have been reported throughout the Jurassic-Cretaceous section; however, none have been verified in Tertiary sediments.

The only prominent topographic break within the central part of the Valley is the Marysville Buttes, a Pliocene volcanic plug which rises abruptly 2000 feet above the relatively flat surrounding country. This unusual anomaly is further discussed in the succeeding pages.

Much of the information on surface geology contained in the three reports which follow has been made available through the courtesy of the respective managements of Gulf Oil Corporation of California, Standard Oil Company of California, and Humble Oil and Refining Company.

Photo 1. Aerial oblique view of the southern Sacramento basin during high water. The Yolo Bypass, a flood-control waterway, crosses the right middle ground. Mount Diablo is in the right background. Photo courtesy Cartwright Aerial Surveys, Inc., Sacramento.

GEOLOGY OF THE WEST SIDE OF THE SACRAMENTO VALLEY, CALIFORNIA

By M. C. LACHENBRUCH
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Plate 2, Geologic map of the Sacramento Valley, California, and Plate 3, Generalized cross-section along line A-A′ across Sacramento Valley; and east-west structural cross-section along line B-B′, Colusa County, California, accompany this paper.

This paper covers the geology of the western border of the Sacramento Valley from the approximate vicinity of Vacaville on the south to Redding on the north, a distance of about 150 miles. It is based on field work done by the writer in the area from April 1953 to April 1955 for Gulf Oil Corporation of California, and on numerous publications before and since that time. The writer especially wishes to recognize Mr. R. D. Reedy, Gulf Oil Corporation of California; Mr. Stuart Chuber, McElroy Ranch Company; Mr. Al Almgren, Union Oil Company; and Mr. John Silcox, Standard Oil Company; for their invaluable aid in providing ideas for and criticisms of this paper.

The rocks discussed are exposed in a band ranging in width from 6 to 18 miles between the alluviated flatlands of the Sacramento River basin on the east and the northern California Coast Ranges on the west. They are bounded on the north by the Klamath Mountains. Except for the southern end of the outcrop area, the exposed rocks are almost all sediments of Cretaceous or Upper Jurassic age. They have been tilted eastward into a fairly steeply dipping north-northwest-trending homocline broken by a few large folds and numerous faults.

Late Mesozoic sediments and ultramafic flows and intrusives of the "Franciscan" group make up the bulk of the northern Coast Ranges. These rocks are generally in fault contact with the sediments of the Sacramento Valley. The Klamath Mountains are composed of metamorphosed sedimentary and volcanic rocks ranging in age from Precambrian (?) to Jurassic and intruded by granitic plutonic rocks. The Klamath complex is overlain by the Lower and Upper Cretaceous beds of the Sacramento Valley in an onlap relationship.

STRATIGRAPHY

The west side of the Sacramento Valley contains one of the thickest and most nearly complete late Mesozoic sections in North America. The Upper Jurassic, Lower Cretaceous, and Upper Cretaceous sequences represent a long period of almost continuous deposition, with occasional episodes of non-deposition and local uplift. A maximum aggregate thickness of sediments in excess of 50,000 feet was deposited in a rapidly sinking trough or troughs extending from the approximate present site of the Sierra Nevada (or possibly farther east) into the Pacific Ocean, but varying in size, shape, and position with each period of deposition. That the axis of deposition has shifted eastward with time is suggested by the fact that the tremendous thickness of Jurassic, Lower Cretaceous, and older Upper Cretaceous sediments present in outcrop is missing to the east of a line near the center of the Sacramento Valley. Here late Upper Cretaceous beds rest directly on Sierran basement.

This entire sequence consists almost exclusively of shale, sandstone, and lenticular conglomerate, with a few mafic igneous flows and intrusives in the westermost edge of the valley outcrop area. The rhythmical interbedding of the shale and sandstone, the lenticular conglomerates, the high percentage of dirty micaceous matrix in the sandstone, and the numerous current structures and gravity slump deposits in various parts of the section all suggest rapid deposition in a marine environment in which submarine sliding and turbidity currents played an important role.

Considerable confusion exists in the classification of the Upper Jurassic and Cretaceous strata of the Sacramento Valley. This has resulted in part from ambiguous original definitions of the type localities and their geographic and stratigraphic limits, and in part from giving formational status to units with faunal or time boundaries.

Terms that have received general usage for the Sacramento Valley Mesozoic section are as follows: the Upper Jurassic strata have been designated as the Knoxville group; the Lower Cretaceous as the Shasta group, divided into the Horsetown (upper) and Paskenta (lower) formations; and the Upper Cretaceous as the Chico group. Recent papers on West Coast stratigraphy suggest that all of these terms, except possibly the Knoxville, should be abandoned. The term "Knoxville group"

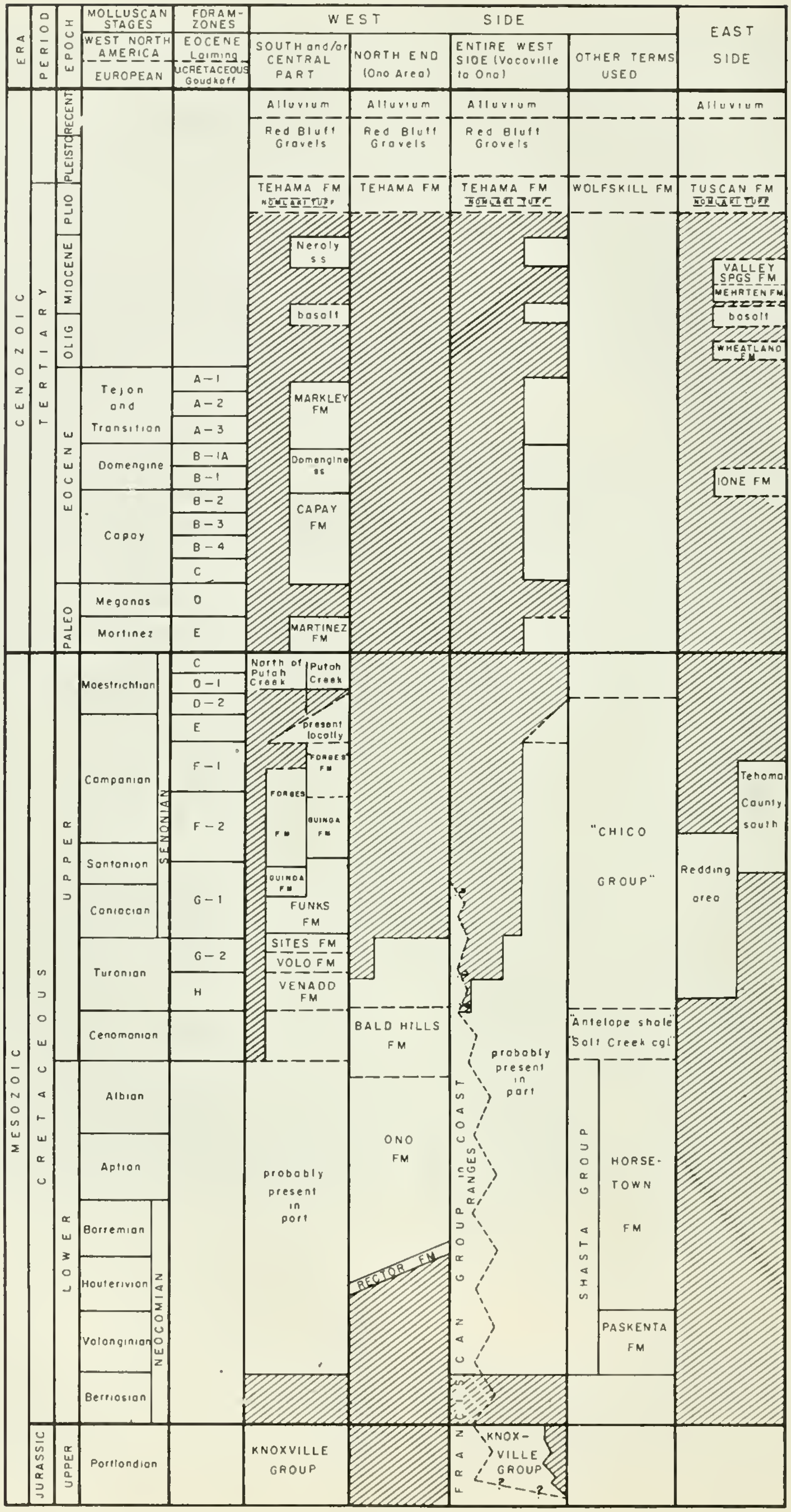


Figure 1. Stratigraphic chart showing sections cropping out in the Sacramento Valley.

has, as will be discussed later, some foundation as a rock-stratigraphic unit in that it is defined on a lithologic as well as a faunal basis. The Knoxville is the only term mentioned above that will be used in this report.

Detailed descriptions of Upper and Lower Cretaceous sections in parts of the west side of the Sacramento Valley have been made by Kirby (1943, pp. 279-305), Murphy (1956, pp. 2098-2119), and Murphy and Rodda (1960, pp. 835-858). Much more of such work is needed before a sound classification of the west side Mesozoic section can be made.

A generalized geologic map of the Sacramento Valley (compiled from several sources) is presented on plate 2. A stratigraphic chart (fig. 1) of the Sacramento Valley shows the inter-relationship of the Sacramento Valley rock units, and their relationship to the European and Pacific Coast molluscan stages. Figure 2 is a correlation diagram of west-side outcrop sections showing variation in thicknesses of the units from Ulatis Creek (T. 7 N., R. 2 W.) at the south end to Churn Creek (T. 32 N., R. 4, 5 W.) at the north end of the Valley. Plate 3 presents a generalized cross section A-A′ across the Sacramento Valley, and a typical structural cross section B-B′ through the west side Mesozoic outcrop. The locations of the cross sections are shown on the geologic map. (pl. 2).

Franciscan Group

Although the Franciscan group is confined mainly to the Coast Ranges, a brief description of this sequence of rocks is considered necessary because of its close association with the Mesozoic formations of the Sacramento Valley. The Franciscan group, named by Andrew C. Lawson (1895) for typical exposures on San Francisco peninsula, underlies a major portion of the Coast Ranges from Santa Barbara on the south into southwestern Oregon. It consists of a heterogeneous assemblage of marine clastics, basic volcanics, basic and ultrabasic intrusives (many metamorphosed) with smaller proportions of radiolarian chert and limestone. These are characteristic eugeosynclinal deposits and represent deposition in a tectonically active and rapidly subsiding trough. Glaucophane schists and other metamorphic rocks are found in the Franciscan in many areas, but slightly metamorphosed phyllites and semi-schists questionably assigned to the Franciscan group are the most common products of metamorphism in the ranges adjacent to the Sacramento Valley. Serpentine or serpentinized igneous rocks are almost universal at or near the contact between the Franciscan and the Knoxville group.

The age and correlation of the Franciscan group with other Mesozoic formations has long been an enigma to California geologists. This has largely been due to the scarcity of fossils and the complex structure of the Franciscan rocks. Increased interest in the geology of northern California in recent years has resulted in the discovery of many more fossil localities and a better understanding of the geology of the Franciscan group, although it still presents many problems.

Since the work of Taliaferro (1942 and 1943), the age of the Franciscan had generally been considered to be Upper Jurassic and its stratigraphic position below the Knoxville. Fossils found in various parts of the Franciscan in the last 10 to 15 years, however, have ranged in age from Upper Jurassic (Portlandian) to Upper Cretaceous (Cenomanian) or higher. On the San Francisco peninsula, the type locality of the Franciscan, a Lower Cretaceous (Albian) ammonite was found (Schlocker, et al., 1954). These fossil discoveries led W. P. Irwin (1957) to the conclusion that the Franciscan is actually a eugeosynclinal facies of the Upper Jurassic, Lower and early Upper Cretaceous formations of the Sacramento Valley, and accumulated contemporaneously with these formations in a more tectonically active part of the same (or of an adjacent) depositional basin. Complex faulting, probably the result of Plio-Pleistocene Coast Ranges diastrophism, has placed the eugeosynclinal facies of the Franciscan in juxtaposition to the foreland facies of the Sacramento Valley. Some field evidence suggests that earliest Franciscan deposition may have antedated earliest deposition of the Sacramento Valley strata.

Upper Jurassic

Knoxville Group

The term "Knoxville series" was applied by G. F. Becker in 1888 to the deposits that characterize the district about Knoxville, Napa County. Although the term was at times used to include Lower Cretaceous strata, F. M. Anderson (1933 and 1945) presented detailed lithologic and faunal descriptions of the Knoxville, particularly in Tehama County, and clearly distinguished it from the overlying Lower Cretaceous beds. The Knoxville group includes all the Upper Jurassic rocks exposed on the west side of the Sacramento Valley from eastern Napa County to near the Shasta-Tehama County line. A maximum of almost 18,000 feet of Knoxville sediments was measured by the writer along Elder Creek in Tehama County. To the north the formation is overlapped by Lower Cretaceous beds. In northern Yolo County to the south, the formation is only 2450 feet, the loss in section due, at least in part, to faulting.

The Knoxville is characterized by a predominance of clay shales with subordinate sandstone and conglomerate. The shale is generally interbedded with thin, hard, calcareous, sandstone beds and thin beds and lenses of calcilutite.

The sandstone of the Knoxville is graywacke (Pettijohn's definition), dark greenish gray to medium grayish brown in color, predominantly fine grained, well indurated. It contains a high percentage of interstitial material. It is generally found as thin ½-inch to 1-foot interbeds in the shale; however, massive sandy zones several hundred feet thick locally form ridges continuing for several miles. These massive beds are often medium to coarse grained, but have low permeability. Slump structures, load casts, current bedding, and other sedimentary structures suggesting turbidity-current deposition are present locally within the Knoxville.

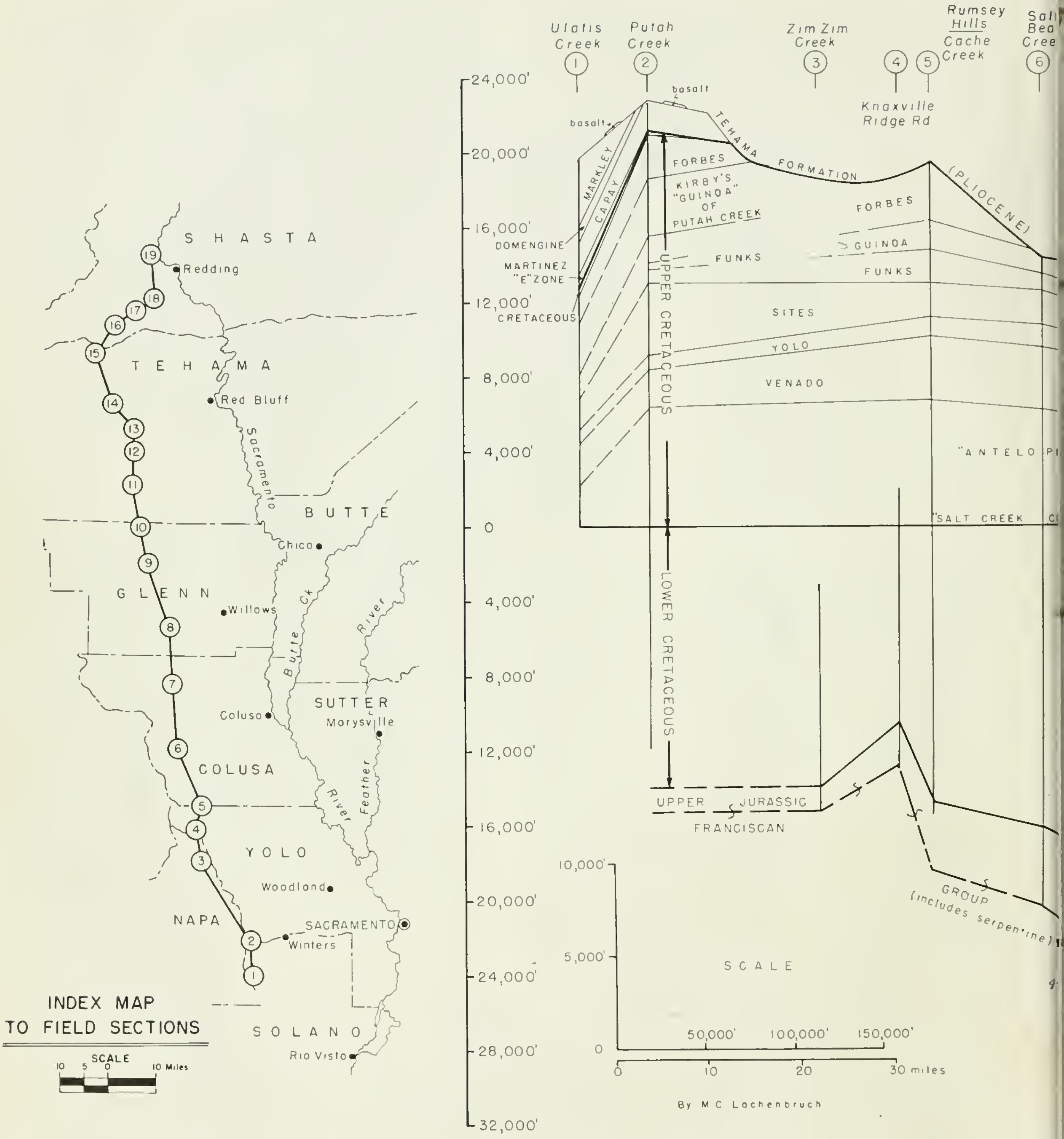
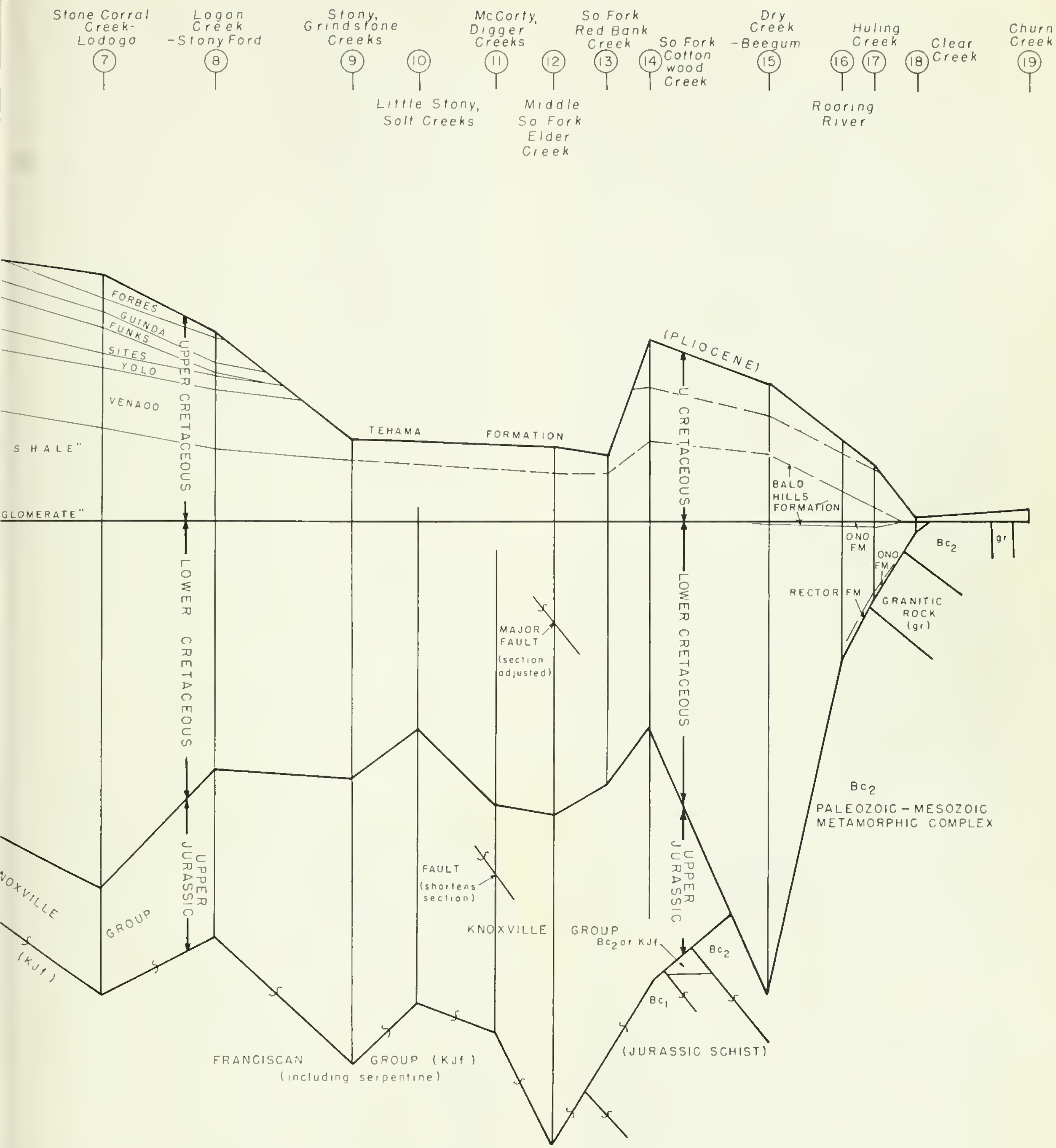


Figure 2. Correlation diagram of sections exposed at the surface in the Sacramento Valley.


Stone Corral Creek-Lodoga
7
Logan Creek -Stony Ford
8
Stony, Grindstone Creeks
9
10
Little Stony, Salt Creeks
McCarty, Digger Creeks
11
12
Middle So Fork Elder Creek
So Fork Red Bank Creek
13
14
So Fork Cotton wood Creek
Dry Creek -Beegum
15
16
Roaring River
Huling Creek
17
18
Clear Creek
Churn Creek
19
FORBES
GUINDA
FUNKS
SITES
YOLO
VENADO
S HALE"
GLOMERATE"
UPPER CRETACEOUS
LOWER CRETACEOUS
UPPER JURASSIC
TEHAMA FORMATION
(PLIOCENE)
U CRETACEOUS
LOWER CRETACEOUS
UPPER JURASSIC
BALD HILLS FORMATION
ONO FM
ONO FM
RECTOR FM
GRANITIC ROCK (gr)
Bc2
gr
MAJOR FAULT (section adjusted)
Bc2
PALEOZOIC – MESOZOIC METAMORPHIC COMPLEX
NOXVILLE
GROUP
(KJf)
FAULT (shortens section)
KNOXVILLE GROUP
Bc2 or KJf
Bc2
Bc1
(JURASSIC SCHIST)
FRANCISCAN GROUP (KJf)
(including serpentine)

Basic intrusives and serpentine are found locally within the Knoxville group mainly in the southern part of the outcrop area.

The Franciscan and Knoxville groups are in fault contact almost the entire length of the Sacramento Valley. In northern Tehama and Shasta Counties, however, the Knoxville (?) rests unconformably upon metamorphosed Paleozoic and Mesozoic rocks of the Klamath Mountains complex. At one locality, in T. 27 N., R.8 W., Tehama County, the strata unconformably underlying the Knoxville (?) may possibly be Franciscan.

Franciscan-like debris consisting of basalt, red and green chert, and serpentine, in some of the basal and lower Knoxville conglomerates in different parts of the outcrop area, suggest that part of the Franciscan formation may predate the Knoxville and may have been locally exposed to erosion prior to and during early Knoxville deposition. However, one formation of the Klamath Mountains complex resembles lithologically the Franciscan—and many of the pebbles mentioned above could be derived therefrom. The slightly metamorphosed character of some of the Franciscan beds immediately west of the Knoxville outcrops also suggest that this part of the Franciscan is younger, but two Lower Cretaceous fossil localities in this belt of rocks tend to support an older age.

In northern Tehama County, the entire section of Knoxville is believed by the writer to be progressively overlapped by the base of the Lower Cretaceous sequence so that south of the Shasta-Tehama County line Lower Cretaceous conglomerates are resting on rocks of the Klamath Mountain complex. However, north of the Elder Creek fault zone (T. 25, 26 N., R. 6W.), a major structural feature in the west side outcrop, contact relations are very uncertain and the thickness and northern extent of the Knoxville are open to question.

The most common megafossil in the Knoxville is the small pelecypod *Buchia (ex-Aucella) piochii* (Gabb). This fossil is considered to belong to the Portlandian stage of the Upper Jurassic.

Oil has been encountered in seeps and in several wells drilled in the Knoxville formation near Wilbur Springs (T. 14 N., R. 5 W.), Colusa County, and in the Cappell-Putah Creek area (T. 8 N., R. 3 W.), Napa County. Some of these wells produced small quantities (1 to 5 barrels per day) of green to amber oil of reported 27° to 29° API gravity.

Lower Cretaceous

No formal name will be used in this paper for the entire Lower Cretaceous sequence of the Sacramento Valley because of the confusion in nomenclature.

Murphy's detailed lithogic and faunal descriptions of the Ono and Rector formations at the north end of the Sacramento Valley, encompassing the Hauterivian (?) through Albian stages of the Lower Cretaceous, are the only unequivocal descriptions of Lower Cretaceous formations in the valley. These terms are local, however, and were not intended to include Lower Cretaceous beds of different lithology and fauna farther south on the west side.

Lower Cretaceous rocks crop out continuously along the west side of the Sacramento Valley from the town of Fairfield (T. 5 N., R. 2 W.), Solano County, on the south, to Ono (T. 30 N., R. 7 W.), Shasta County, on the north, with scattered outliers to the north and west in the Klamath Mountains. Strata of this age have an average thickness of about 13,000 feet in the Valley and reach a maximum of well over 20,000 feet near the Shasta-Tehama County line.

The lithology of the Lower Cretaceous strata closely resembles that of underlying Knoxville. In general the Lower Cretaceous sediments are not quite as well indurated, and the sandstones are slightly more permeable than those of the Knoxville. Silty and clayey shale with frequent thin to massive sandstone interbeds make up the bulk of the Lower Cretaceous sequence. Calcilutite beds and lenses are commonly associated with the clay shale. Lenticular conglomerate is prominent locally in this section, particularly in the northern part of the valley. This conglomerate differs markedly from that of the Knoxville both in content and size of the pebbles. Pebble types include grantic intrusives, chert, Knoxville sandstone and calcilutite, varied silicified porphyries and volcanics and some mafic igneous rocks characteristic of the Franciscan. The common presence of granitic types, which are extremely rare in Knoxville conglomerate, suggests that the earliest granitic intrusives of the Nevadan orogeny first became exposed to extensive erosion at the end of the Jurassic period. It also suggests (but does not prove) a source area to the north or east where granitic rocks are now exposed.

A conglomerate unit is found at the base of the Lower Cretaceous sequence in several parts of the outcrop area. In Yolo and Napa Counties, this conglomerate contains large granodiorite boulders.

Serpentine breccia is well developed in the lower part of the Lower Cretaceous in the vicinity of Wilbur Springs. On State Highway 20, 2 miles south of Wilbur Springs, 5000 feet of breccia is exposed at the base of the sequence. It is found on both flanks of the Wilbur Spring anticline, which has an intrusive serpentine core. The serpentine breccia is composed of rounded pebbles to blocks 6 feet in diameter of dark-green serpentine in a matrix of finely divided serpentine. Superficially it closely resembles badly sheared bodies of intrusive serpentine. Its detrital nature is proven, however, by occasional pebbles to boulders of sedimentary rock and interbeds of dark-gray shale, which become more and more numerous both along strike and up section, finally predomininating over the breccia. Similar but smaller serpentine breccia bodies are found 1000 feet above the base of the Lower Cretaceous section east of Knoxville in Yolo and Napa Counties (T. 12 N., R. 5 W.).

At the north end of the Sacramento Valley, Lower Cretaceous strata overlap those of the Knoxville and also the metamorphic rocks of the Klamath Mountain complex. This overlap becomes progressive so that younger and younger Lower Cretaceous beds rest on basement to the north and east toward Ono and Igo in southern Shasta County.

There is disagreement as to the point at which the Knoxville formation is overlapped. The writer bases the Cretaceous age of the lowermost strata in northern Tehama and Shasta Counties in part on a fragment of an ammonite found with Professor H. E. Wheeler of the University of Washington in the conglomerate at the base of the sedimentary section along Beegum Creek in sec. 22, T. 29 N., R. 9 W. This fossil was found to be of probable Cretaceous age.

Throughout much of the Sacramento Valley no lithologic or angular discordance can be found between strata of the Knoxville and Lower Cretaceous. However, evidence for local disturbances at the end of Knoxville time and a possible disconformity at the base of the Cretaceous is given by the serpentine breccia in the basal beds at Wilbur Springs; by the discontinuous conglomerate at the base of the sequence which often contains material from the underlying Knoxville; by the presence of distorted beds in the Knoxville, but not in the Lower Cretaceous in certain areas; by overlap of the Knoxville by the Lower Cretaceous at the north end of the Valley; and by the apparent lack of fauna of the Berriasian (lowermost Lower Cretaceous) stage.

No fauna of the Berriasian stage have been recognized in northern California (Popenoe, et al., 1960, p. 1504). There is some disagreement as to whether all of the European stages of the Lower Cretaceous except the Berriasian are represented on the west side of the Sacramento Valley (see stratigraphic chart, fig.1). The basal beds in the south and central parts of the valley contain *Buchia (ex-Aucella) crassicollis* Keyserling which has been referred to the Valanginian stage. Popenoe, et all., (1960, p. 1490), on the basis of a prolific ammonite and pelecypod fauna, conclude that Murphy's Ono and Rector formations embrace the Hauterivian to Albian stages. They also believe that some of F. M. Anderson's collections in Shasta and Tehama Counties belongs in this time interval. Others (Wheeler, written communication, 1-12-61) doubt that all of these stages are present.

Dark orange-brown oil of 12° API gravity was collected by the writer from seeps in sandstone and serpentine breccia in the lower part of the section on a tributary to Bear Creek southeast of Wilbur Springs (T. 14 N., R. 5 W.). Oil of 18.5° gravity was said to have been found in the breccia in the Abbot quicksilver mine in the same area. Other seeps in the Lower Cretaceous have been reported but not confirmed.

Upper Cretaceous

Nomenclature of the California Mesozoic is probably nowhere more confused than in the Upper Cretaceous of the Sacramento Valley. Most of the confusion has arisen over the use of the term "Chico." As originally proposed by Gabb (1869, pp. XIII, XIV, 29) the Chico group included " . . . those beds of which Chico Creek, Pence's Ranch and Tuscan Springs are typical localities." These beds are all on the east side of the Sacramento Valley and represent only a small portion of the upper part of the Upper Cretaceous section exposed on the west side. The term has been applied by various authors at one time or another to practically all of the Upper Cretaceous rocks of California. Recent publications on California geology have wisely discontinued use of the term for west-side Upper Cretaceous strata.

As previously mentioned, only two detailed lithologic and faunal descriptions of the Upper Cretaceous on the west side of the Sacramento Valley have been published. Kirby (1943, pp. 279-305) divided the upper part of the Upper Cretaceous from Putah Creek, Yolo County, to Logan Creek, Glenn County, into six formations—from top to bottom the Forbes, Guinda, Funks, Sites, Yolo, and Venado. He believed the Venado to be the basal unit of the Upper Cretaceous.

Murphy and Rodda (1960, pp. 835-858) described a conglomerate, sandstone, and mudstone unit at the northwest end of the Sacramento Valley to which they applied the name "Bald Hills formation." This formation includes the lower part of the Upper Cretaceous and the uppermost Lower Cretaceous.

Taliaferro (Jennings, et al., 1954) applied the term "Antelope shale" to the Upper Cretaceous unit below the Venado formation in the southern part of the outcrop area. This term, however, was preoccupied by a subsurface Miocene unit in Kern County.

Because of a distinct lithologic break in the lower and upper strata of the Upper Cretaceous in the west-side outcrop area, these two sequences will be described separately.

Lower Upper Cretaceous

Beds on the west side of the valley that represent the lower part of the Upper Cretaceous can be mapped as a lithologic and faunal unit—with some interruptions in Glenn and Colusa Counties—and with less certainty in Tehama and Shasta Counties. South of Colusa County no lithologic distinction from the underlying Lower Cretaceous strata is apparent. This unit is thickest in Yolo County and southern Colusa County where about 6500 feet are exposed. It thins northward to about 3000 to 4000 feet in Glenn County, to about 1000 feet near Ono, Shasta County, and is completely overlapped by younger Cretaceous strata farther to the northeast.

The sediments of the lower part of the Upper Cretaceous are, in general, lighologically more like the Lower Cretaceous than the overlying Upper Cretaceous beds; but in southern Tehama County they more closely resemble the upper beds. Shale is predominant south of Colusa County, but sandstone and conglomerate become important components to the north. The sandstone of this sequence, in general, has relatively low permeability.

A persistent conglomerate marks the base of this unit for more than 20 miles, with but few interruptions, in Colusa County. This horizon, locally called the "Salt Creek conglomerate" (Jennings, et al., 1954) varies from one to as many as four individual conglomerate beds and is composed largely of material derived from the underlying Lower Cretaceous beds. Similar but discontinuous conglomerate zones are found at approximately the same stratigraphic horizon to the north end of the valley.

Murphy and Rodda (1960, p. 838), in describing the Bald Hills formation at the north end of the valley, state that the " . . . lowest unit of the formation on the North Fork of Cottonwood Creek and on Huling Creek is a very fossiliferous cobble conglomerate . . .", containing ". . . clasts. . . largely of limestone derived from the underlying formation or from deposits accumulating contemporaneously in other areas." Although this conglomerate is actually at the top of the Lower Cretaceous, it seems likely that it is a lithogenetic equivalent of the Salt Creek conglomerate.

The contact between the strata representing the early part of the Upper Cretaceous and those of the Lower Cretaceous appears gradational in some parts of the Sacramento Valley, particulary south of Colusa County. Evidence for active uplift and erosion of the Lower Cretaceous beds (at least in local source areas) prior to deposition of the overlying beds is seen in the reworked Lower Cretaceous clasts in the conglomerates at the base of this unit.

It appears from present knowledge that this disturbance did not take place at exactly the same time throughout the Valley but was initiated at the north end of the Valley in upper Albian time, and did not affect the strata in Colusa County until the beginning of Cenomanian time. This conclusion is based on the work of Murphy and Rodda (1960, p. 839) who found upper Albian and older fossils reworked in the basal Bald Hills conglomerate, previously mentioned, which is also of upper Albian age. The base of the Salt Creek conglomerate in Colusa County has been tentatively placed at the base of the Cenomanian stage of the Upper Cretaceous, (Jennings, et al., 1954, and Popenoe, et al., 1960, p. 1490). Further detailed studies may alter this conclusion.

The upper limit of this sequence, including Taliaferro's Antelope shale and Salt Creek conglomerate in Glenn and Colusa Counties, has been placed at the top of the Cenomanian stage, whereas Murphy and Rodda (1960, p. 838) state that "the Bald Hills formation ranges in age from upper Albian through Cenomanian and possibly into lower Turonian."

Small quantities of very light amber oil have been produced from beds in the lower part of the Upper Cretaceous on Salt Creek and Freshwater Creek (T. 15 N., R. 4 W.). These wells have been long since abandoned. Intermittent oil seeps are found in salt- or brackish-water springs just north of Highway 20 in this area.

Other petroleum from rocks of this age has been reported in Tehama and Napa Counties.

Natural gas seeps from sediments of this age were found along Antelope Creek (T. 16, 17 N., R. 4 W.) just south of Sites anticline, and also associated with the oil seeps on Salt Creek mentioned above. Near Fluornoy (T. 24 N., R. 5 W.), gas in water wells, possibly coming from the lower Upper Cretaceous or younger strata, is used by several inhabitants for heating.

Upper Part of Upper Cretaceous

Kirby's formations, the Venado, Yolo, Sites, Funks, Guinda, and Forbes, were deposited during the Turonian, Coniacian, Santonian, and Campanian stages of Europe (see stratigraphic chart, fig. 1).

Strata representing all of these stages, as well as younger Maestrichtian strata, are also present in some parts of the subsurface section of the Sacramento Valley. Equivalents of the Venado and probably the Yolo and Sites formations are overlapped by the younger formations against basement rock of the Sierra Nevada east of a line near the center of the Valley. No rocks older than the Venado have been penetrated by the drill in the alluviated portion of the Valley east of the outcrop area. Except at the extreme southern end of the Valley, no beds younger than the Forbes are present in the west-side outcrop.

Beds representing portions of this part of the Upper Cretaceous are exposed along the entire west side of the Sacramento Valley except in southern Tehama County where they are locally covered by the Pliocene Tehama formation. The thickest outcrop section of these strata is nearly 15,000 feet along Putah Creek (T. 8 N., R. 2 W.) on the Solano-Yolo County line, where all of Kirby's formations are exposed. To the north the younger beds become overlapped by the Tehama formation.

Goudkoff (1945, p. 962) subdivided the six formations described by Kirby on the basis of Foraminifera into zones F through H from the top down (see fig. 1). These zones, with some modification, provided the basis for subsequent sub-surface correlations.

Alternating sandstone, siltstone, and shale comprise the bulk of Kirby's six formations, fine clastics predominating slightly over the coarse fraction. Conglomerate beds are found less frequently than in the underlying sequences, and most of them are in the Venado formation.

Natural-gas seeps are common in or near outcrops of late Upper Cretaceous rocks on the west side of the Sacramento Valley. Some of the localities where they have been found are in T. 5 N., R. 1 W. north of Fairfield, Solano County; at Rumsey Hills (T. 11 N., R. 3 W.), Yolo County; north and south of Salt Creek (T. 14, 15 N., R. 4 W.), Colusa County; and at Orland Buttes (T. 22, 23 N., R. 4 W.).

Venado Formation. The Venado formation is predominantly a sandstone unit forming prominent strike-ridges which Kirby mapped from Putah Creek (T. 8 N., R. 2 W.) to Logan Creek (T. 19 N., R. 4 W.). It can be traced southward at least to Ulatis Creek (T. 7 N., R. 2 W.) with some degree of certainty. Beds of the same age (Goudkoff's H zone) are exposed intermittently to the north end of the Valley.

The Venado formation is more than 3000 feet thick in southern Glenn and Colusa Counties but thins to less than 2000 feet on Putah Creek (T. 8 N., R. 20 W.), southern Yolo County. Here it consists of hard, massive beds of fine-grained sandstone, interbedded with varying amounts of shale, and occasional conglomerate beds at the base. The matrix is relatively tough, and calcareous cement is common. It is generally not very permeable in outcrop.

Brown (1959) found ". . . lenticular bodies of submarine slump deposits as much as one mile long and 100 feet thick . . . at or near the base of the Venado . . ." along the west side of the Sacramento Valley in the Lodoga quadrangle (T. 17 N., R. 4 W.). These ". . . slump lenses are characterized by rotated blocks of relatively undeformed rock, by massive, unsorted pebbly mudstone containing segments of resistant beds, by exotic blocks of quartz diorite, and by reworked fossils"—many of Albian age.

Brown believes that the ". . . slumping may have begun in an area where late Albian sedimentary rock rested upon a quartz diorite basement". He feels that the ". . . size and extent of the deposits suggest tectonic movement".

The above observations provide evidence for at least a local disturbance in the source area, which would appear to be in the Nevadan basement rocks to the east, just prior to deposition of the Venado. Local pre-Venado uplift and erosion is also suggested east and west of Redding at the north end of the valley where beds believed to be of equivalent age overlap older Cretaceous beds onto the Klamath Basement. In parts of Tehama County, however, it is difficult to distinguish any break in sedimentation at this horizon.

Yolo Formation. The Yolo formation, representing the lower part of Goudkoff's G-2 zone is quite shaly throughout its entire outcrop area. It ranges in thickness from about 500 feet to 1200 feet in Glenn and Colusa Counties. Beds of equivalent age may be present in some of the west-side outcrop section in Tehama and Shasta Counties.

Sites Formation. The Sites formation shows extreme variation in thickness. It thins from almost 4000 feet on Putah Creek, Yolo County, to about 120 feet on Logan Creek, Glenn County. Sites sandstone is fine-grained, rather dirty, thick-bedded, and concretionary. Some softer, more permeable sandstone is found between the hard, impervious concretionary beds.

Faunally, the Sites sandstone embraces the upper part of Goudkoff's G-2 zone. Similar microfauna are found in shale with minor sandstone interbeds at the top of the Cretaceous section on Dry Creek (T. 28 N., R. 6 W.) northern Tehama County, and time-rock equivalents are probably present along other creeks in this part of the valley.

Funks Formation. The Funks formation, assigned to the lower part of Goudkoff's G-1 zone, is about 600 feet thick on Logan Creek (T. 19 N., R. 4 W.) and thickens slightly to the south. Although primarily a shale unit, the Funks formation contains some sandstone interbeds in the southern outcrop area. On Putah Creek, a 350-foot sandstone unit with "cannonball" calcareous concretions is present about 600 feet above the base of the Funks formation as mapped by Kirby, which here is more than 2500 feet thick. Due to a miscorrelation carried over from Rumsey Hills, only that part below the sandstone unit is equivalent to the Funks formation to the north.

Guinda Formation. The Guinda formation of Kirby's section from the type locality at Rumsey Hills (T. 12 N., R. 3 W.) northward consists of massive sandstone beds with numerous characteristic large calcareous concretions interbedded with various amounts of shale. The sandstone is soft to hard depending upon the percentage of calcareous cement. The more massive beds are medium grained, fairly friable, and despite considerable kaolinitic matrix, have fair to, locally, fairly good permeability. The thinner beds are fine-grained, harder, and less permeable. The Guinda ranges in thickness from 600 feet to about 1500 feet in the sections north of Rumsey Hills.

The Guinda formation as here described comprises the upper part of Goudkoff's G-1 zone. At Putah Creek, however, the term "Guinda" was used for 3000 feet of sandstone and shale with an F-2 fauna, and correlations from Rumsey Hills to Putah Creek were in error. The G-1 zonation is used in subsurface correlations.

Forbes Formation. At the type locality at Rumsey Hills Kirby assigned 3000 feet of strata which contain an F-2 microfauna to the Forbes formation. These strata are equivalent in age to the "Guinda" formation on Putah Creek, whereas Kirby's Forbes formation on Putah Creek belongs to Goudkoff's F-1 zone.

The dominant lithology of the Forbes formation is shale with fairly thin, fine-grained sandstone interbeds. Some moderately thick sandstone beds are also present, as on Putah Creek. The sandstone, though usually hard and calcareous, commonly is moderately soft, friable, and fairly permeable.

Most of the gas produced in the more recently discovered fields on the west side of the Valley comes from lenticular sands of F-1 and F-2 age, equivalent in part to the Forbes formation of the type locality or the Guinda formation of Putah Creek, and to the Forbes formation of Putah Creek.

The Forbes formation of Kirby from Putah Creek north is the youngest Cretaceous formation definitely recognized in outcrop on the west side of the Sacramento Valley. Younger Cretaceous beds crop out in certain surface sections from Putah Creek south, in Solano County, but these have not been described in the literature.

Tertiary and Quaternary

Early Tertiary sediments are exposed only in Yolo and Solano Counties at the south end of the west side of Sacramento Valley. To the north the only post-Cretaceous rocks found in outcrop belong to the Pliocene Tehama formation, the Pleistocene Red Bluff formation, or a Tertiary basalt of either Eocene or Miocene age.

Paleocene

Martinez Formation. The Paleocene epoch is represented in the area under discussion by scattered outcrops of the marine Martinez formation, stretching from Potrero Hills (T. 4 N., R. 1 W.), to Pleasants Valley (T. 7 N., R. 2 W.) in Solano County. The Martinez formation, named for exposures southwest of Martinez, Contra Costa County, provides some of the reservoirs for gas in fields in the southern part of the Sacramento Valley. Lithologically it is predominantly a massive, well-sorted, quartzose sandstone with interbedded shale and local conglomerate lenses. Much of the detritus of the Martinez was derived from Cretaceous formations. It resembles some of the Upper Cretaceous strata except that it is better sorted, less silty, and exhibits few, if any, current structures.

A shale unit at the base of the Martinez is difficult to distinguish from the underlying Cretaceous shale except by Foraminifera. This shale is completely overlapped by basal grit beds of the Eocene Capay shale west of Pleasants Creek (sec. 9, T. 7 N., R. 2 W.). The northernmost Martinez sandstone beds are overlapped south of Ulatis Creek on the west side of Vaca Valley (sec. 1, T. 6 N., R. 2 W.).

Eocene

Capay Formation. The Capay formation crops out on the west side of the Sacramento Valley in Capay Valley, Yolo County—its type locality (secs. 10, 11, T. 12 N., R. 3 W.) in Solano County at Potrero Hills (T. 4 N., R. 1 W.), and along a strip from Vacaville (T. 6 N., R. 1 W.) to Putah Creek (T. 8 N., R. 2 W.). The Capay formation is lower Eocene in age and represents Laiming's foraminiferal zones B-2, B-3, B-4, and C.

At its type locality the Capay formation consists of more than 1,000 feet of massive, brownish-gray, medium-grained feldspathic sandstone, with numerous lenses of conglomerate and interbedded silty shale. It is predominantly silty shale in the Vaca Valley exposures (T. 7 N., R. 2 W.), as it is in practically all wells penetrating it in the Sacramento Valley.

An important unconformity separates the Capay formation from underlying formations in the subsurface penetrations as well as in outcrop on the west side of the Valley. The base of the Capay, here represented by a glauconite grit, rests on several hundred feet of Paleocene sandstone and shale in Vaca Valley (T. 7 N., R. 2 W.), but truncates successively older beds northward, so that along Putah Creek (T. 8 N., R. 2 W.) it rests on Upper Cretaceous strata. Gas is trapped in Upper Cretaceous sand beneath this unconformity at Dunnigan Hills (T. 11 N., R. 1 W.).

Domengine Sandstone. The marine Domengine sandstone of middle Eocene age unconformably overlies the Capay shale at the south end of the Sacramento Valley. The limited exposures that crop out in Vaca Valley (T. 7 N., R. 2 W.) consists of 200 feet to 800 feet of brownish-to-white, quartzose, medium-grained sandstone and a basal galuconitic grit. The Domengine is also exposed at Potrero Hills (T. 4 N., R. 1 W.) and in the low hills to the north in T. 5 and 6 N., R. 1 W. It is the most important gas-producer in the southern part of the Sacramento Valley.

Markley Formation. The upper Eocene marine Markley formation overlies the Domengine sandstone and is exposed south of Putah Creek (T. 8 N., R. 2 W.) and east of Vaca Valley, as well as south to the vicinity of Vacaville (T. 5 N., R. 1 W.). The Markley formation consists predominantly of 3,700 feet of massive brownish-gray feldspathic sandstone containing characteristic large muscovite flakes and subordinate interbeds of sandy shale to clay shale. The Markley is recognized in well sections in the southern Sacramento Valley. The Nortonville shale, which contains some important gas sands in the subsurface penetrations, underlies the Markley formation at Mount Diablo (T. 1 N., R. 1, 2 E.), but is not present in the Vaca Valley outcrops.

Tertiary Basalt

A dense black hemicrystalline augite basalt flow 50 feet to 250 feet thick overlies the Upper Cretaceous and Eocene Capay shale in scattered outcrops on the west side of the Sacramento Valley. This basalt forms Orland Buttes (T. 22 N., R. 4 W.) at the north end of Glenn County, and crops out in several small exposures near the east edge of southern Glenn County, north of Putah Creek (T. 8 N., R. 2 W.) and east of Vaca Valley at Putnam Peak (T. 7 N., R. 2 W.), Solano County. A similar basalt forms Table Mountain (T. 20 N., R. 4 E.) north of Oroville on the east side of the Valley. Scattered wells in the north and central portions of the Sacramento Valley have penetrated a basalt of similar character in approximately the same stratigraphic position. At Putnam Peak the basalt overlies the upper Eocene Markley sandstone and underlies the upper Miocene Neroly sandstone. Therefore, the age of the basalt in this area must lie between upper Eocene and upper Miocene.

Miocene

Neroly Sandstone. A 300-foot-thick band of bluish-gray, tuffaceous sandstone and shale overlies the Markley formation in the Vacaville Hills, T. 6 and 7 N., R. 1 W., between Vacaville and Putah Creek. Fossils indicate that this formation, the Neroly sandstone, is upper Miocene in age.

Pliocene

Tehama Formation. The Tehama formation of upper Pliocene age unconformably overlies all older formations on the west side of the Sacramento Valley in almost continuous outcrops from Putah Creek (T. 8 N., R. 2 W.) to north of Redding (T. 32 N., R. 4 W.). South of Putah Creek the Wolfskill formation is the probable equivalent of the Tehama formation. The Tehama formation, ranging up to 2,000 feet in thickness, consists of fluviatile clayey silt, sand and gravel, greenish to yellow-brown in color. In the north central portion of the Valley, the Tehama formation interfingers to the east with the Tus-

Photo 1. Pliocene Nomlaki tuff unconformably overlying Upper Cretaceous strata on Elder Creek, T. 25 N., R. 6 W., M.D., Tehama County.

can formation, which is made up largely of volcanic material.

Most of the detritus of the Tehama formation was derived from pre-Cretaceous rocks, indicating that the area underlain by Cretaceous strata was of relatively low relief during Tehama deposition (Russell and Anderson, 1939, p. 242). Commercial accumulations of gas, probably originating in the underlying Cretaceous beds, are found in Tehama sediments in the Corning gas field (T. 24 N., R. 3 W.).

Very near the base of the Tehama formation is a distinctive vitric tuff bed called the Nomlaki tuff, for its type locality near Nome Lacke monument in sec. 12, T. 24 N., R. 6 W., Tehama County.

The Nomlaki tuff can be traced from T. 20 N., R. 4 W., east of the town of Fruto, Glenn County, to the North Fork of Cottonwood Creek (T. 30 N., R. 6 W.), Shasta County, a distance of more than 50 miles. A somewhat similar tuff bed is found at the base of the Tehama formation 70 miles to the south on Putah Creek (T. 8 N., R. 2 W.). The Nomlaki tuff is white to pink in color and consists of pumice fragments in a matrix of finely divided tuff and tuffaceous siltstone. It ranges in thickness from about 10 feet to 80 feet.

Pleistocene

Red Bluff Gravels. The Red Bluff gravels, a Pleistocene alluvial deposit consisting primarily of coarse pebble to boulder gravels with minor amounts of clayey sand, unconformably overlies the Tehama formation. It is typically exposed west of the town of Red Bluff (T. 27 N., R. 4 W.) where it can be distinguished from the Tehama by its coarseness and usual brick-red color. The average thickness of the Red Bluff gravels is about 50 feet.

Recent

Alluvium. The Sacramento Valley is now receiving alluvial deposits from the Sacramento River and its tributaries from the town of Red Bluff south. These deposits are similar to those laid down in Tehama time, but are not as coarse as the gravels of the Red Bluff formation. The present configuration of the Sacramento Valley probably closely approximates that of Tehama time except that the Mesozoic strata were then topographically lower and the Tehama alluvial basin extended farther north and west (Russell and Anderson, 1939, p. 242).

STRUCTURE

The present configuration of the Cretaceous-uppermost Jurassic basin in the Sacramento Valley is that of an asymmetric synclinorium whose faulted west flank is much steeper than its east flank. The axis of this structural basin, trending N. 10° W. to N. 15° W., is well west of the center of the valley for the older sediments, but it migrates eastward for the later strata of the Upper Cretaceous. The essentially homoclinal west flank (west side outcrop) dips 30° to 70° E. except at the extreme north end where attitudes are shallower. This homocline is broken by moderate to large folds trending northwest to north, and by numerous faults of various trends. The azimuth of most of the major faults falls in the northwest quadrant.

The east flank of the synclinorium (see pp. 67-68) is a fairly uniform homocline with a shallow (5° to 15°) west to southwest dip, unbroken (so far as has been determined) by major folds except northeast of Red Bluff, Tehama County, but cut by many northwest- to north-northwest-trending faults.

Faults

Several types of faults can be observed cutting the strata on the west border of the Sacramento Valley. A reverse fault apparently separates the Franciscan rocks from the Knoxville for almost the entire length of the outcrop area. The serpentine band that generally lies between these two rock units probably was originally intruded along the fault. The serpentine may then have provided a lubricant for later (and possibly much greater) movement along the fault zone (possibly during the Pleistocene Coast Ranges diastrophism.

Normal and lateral faults are common on the west side. The majority of these faults trend northwest to north-northwest. However, many have an east-northeast strike. Although displacement across most of the faults is small, a significant number have lateral separations measurable in miles. A typical example of the latter type is the Elder Creek (or Lowry) fault trending N. 50° W. to N. 70° W., which passes near the town of Lowry (T. 25 N., R. 6 W.) on Elder Creek, Tehama County. This fault, which has a left-lateral separation of more than 2 miles, cuts Knoxville, Lower Cretaceous and probably Upper Cretaceous beds. Associated with the fault is a contorted zone of 500 feet to 3000 feet wide in which the beds are intensely twisted and broken. This may be a part of a major fault system which continues for many miles to the northwest in the Coast Ranges.

The most intense faulting observed in the west side exposures of the Sacramento Valley is in central Tehama County. It might be significant that this area is roughly on trend with the Gorda escarpment off the coast of northern California south of Cape Mendocino.

Folds

Sites Anticline. The major anticlinal flexure on the west side of the Sacramento Valley is the Sites anticline, a north-trending, sharp fold which can be traced continuously in Cretaceous beds for about 20 miles through T. 17-20 N., R. 4 W., in northern Colusa and Glenn Counties, and—with interruptions—for perhaps another 25 miles to the north. Basal Upper Cretaceous and some Lower Cretaceous sediments are the oldest beds exposed along the axis of this structure.

Both flanks of the Sites anticline are quite steep, with dips of 50° to 90° at the crest. The east flank is the steeper of the two. Faulting is indicated at several localities along the crest and it seems quite likely that a crestal fault—a steep reverse fault dipping to the west—is present along the entire length of the structure. The syncline to the west is broad and shallow.

The Sites anticline may represent a large-relief fold caused by excessive shortening of the upper beds during a period of synclinal folding of the Sacramento basin by east-west compressive forces.

Rumsey Hills Anticline. Rumsey Hills, a topographic feature in T. 11 and 12 N., R. 2 and 3 W., Yolo County, are bounded on the west by Capay Valley and on the east by the Sacramento Valley. The Hills are an asymmetric anticlinal flexure 22 miles long with an axial strike of N. 25° W. As mapped by Kirby (Jenkins, 1943, p. 602) an eastward-hading reverse fault follows the crest of the structure for 15 miles between the towns of Capay (T. 10 N., R. 2 W.) and Rumsey (T. 12 N., R. 3 W.). Gently east-dipping Upper Cretaceous beds have been thrust west along this fault-plane, which dips about 45°, over steep Upper Cretaceous and Pliocene Tehama sediments. A 400-foot escarpment just west of the anticlinal crest marks the surface trace of the fault and represents the approximate displacement.

Photo 2. Oil seeps in Lower Cretaceous sandstone east of Wilbur Springs, T. 14 N., R. 15 E., M.D., Colusa County. Dark stains on sandstone are oil seeps. Thick oil scum covers water in the foreground.

Wilbur Springs Anticline. The Wilbur Springs anticline (T. 13 and 14 N., R. 5 W.) in southwest Colusa County is a southeast-plunging anticlinal nose involving Franciscan, Knoxville, and Lower Cretaceous rocks. Franciscan sedimentary and igenous rocks are found in the core of the anticline, surrounded by a thick serpentine sill. Movement along a west-hading reverse fault at the eastern edge of this sill has brought the sill very close to the basal Lower Cretaceous beds southeast of Wilbur Springs. Either the serpentine south of Wilbur Springs was originally intruded high in the Knoxville or else it has been faulted up to its present position in diapir fashion during the folding of the anticline.

GEOLOGIC HISTORY

Paleontological correlations along the west side of the Sacramento Valley suggest that this area is unique in the recorded geologic history of the Cordilleran region in that an almost complete sequence of Mesozoic rocks spanning the European stages from Portlandian (Upper Jurassic) to Campanian (Upper Cretaceous), except for the Berriasian stage (Lower Cretaceous), appear to be at least in part represented.

In most other areas of Mesozoic disposition along the Pacific Coast and Alaska, paleontological evidence suggests that there were periods of transgression (late Jurassic to early Lower Cretaceous, late Lower Cretaceous to early Upper Cretaceous, and late Upper Cretaceous) with intervening periods of regression, uplift, and erosion. The Sacramento Valley appears primarily to have remained structurally negative throughout most of this part of the Mesozoic era.

Local disturbances, which did not necessarily coincide with the periods of regression mentioned above, did affect the sedimentation in the Sacramento Valley. The most notable of these were between the Upper Jurassic and Lower Cretaceous, near the end of the Lower Cretaceous (upper Albian) and at the end of deposition of Cenomanian stage Upper Cretaceous rocks.

After the metamorphism of all rocks of Upper Jurassic (Kimmeridgian) age or older, during the early stages of the Nevadan orogeny, transgressive Upper Jurassic (Portlandian) seas began to inundate northern California, as well as southwestern Oregon and other areas of the Pacific Coast. Rocks of the Franciscan group were deposited in the western part of this area, which was a tectonically active eugeosyncline involved in considerable volcanism. After an unknown length of time, strata of the Knoxville group began accumulating contemporaneously to the east in a somewhat more stable environment.

Just before the start of the Knoxville deposition, granitic rocks probably were formed in the area now occupied by the southern Klamath Mountains and foothills of the Sierra Nevada. At the end of the Jurassic period these rocks were first exposed to extensive erosion during an episode of uplift that affected at least part of the present Klamath Mountains area and possibly parts of the present Sierra Nevada.

The ensuing Lower Cretaceous seas covered an area similar to but probably greater than those of the late Upper Jurassic, and the environments of disposition were similar. Parts of the southeastern Klamath Mountains were probably not completely submerged, however, until middle Cretaceous time, inasmuch as strata of middle Cretaceous age are now found overlying granitic basement in this part of California. It is also possible that a period of submergence followed by another episode of uplift and erosion can explain the present relationship of these rocks.

Local uplift and erosion in the source areas of the Sacramento Valley sediments took place toward the end of Albian time, as evidenced by the reworked Lower Cretaceous clasts in the conglomerate of the Bald Hills formation and in the Upper Cretaceous Salt Creek conglomerate. After accumulation of a few thousand feet of sediment in latest Albian and Cenomanian time, under similar conditions to those of the Lower Cretaceous, tectonism again affected northern California. The slump deposits described by Brown (1960) near the base of the Upper Cretaceous Venado formation, which includes large blocks of quartz diorite and reworked fossils of Albian age, suggest that the Sierran basement rocks to the east, upon which Lower Cretaceous strata had been deposited, were at this time uplifted and subjected to erosion. This is also indicated by the fact that no above-basement wells east of the outcrop in the Sacramento Valley have penetrated beds older than the Venado formation. How far east early Upper Cretaceous and Lower Cretaceous strata were deposited and how many of these strata were removed during this tectonism is unknown.

An important change in the tectonic environment of the Mesozoic geosyncline began to take place as the strata of the Venado-to-Forbes formations were being deposited in the Sacramento Valley. The volcanic eugeosynclinal deposits (Franciscan group), which had been accumulating to the west, gave way to a shelf-type facies similar to that being laid down in the Sacramento Valley. The late Upper Cretaceous seas apparently transgressed slowly eastward in the Sacramento Valley, as successively younger beds are found overlying basement eastward from near the center of the valley.

Granitic intrusions continued into Upper Cretaceous time in the present high Sierra Nevada and Klamath Mountains. Absolute age determinations suggest that the intrusion of a considerable portion of this granite may have been initiated during the period of tectonic activity immediately preceding deposition of the Venado formation.

The relatively mild uplift which closed the Cretaceous period was more pronounced at the north end of the Sacramento Valley than to the south. A shallow Paleocene sea covered the southern part of the valley, but if it extended north of Marysville Buttes, all traces of it were removed by pre-Eocene erosion.

A mountain-building episode in early Eocene time raised most of northern California above sea level. Many structures in Sacramento Valley Cretaceous strata were initiated at this time. The middle Eocene Capay sea transgressed the upturned edges of the Paleocene and Cretaceous strata. The extent of the Capay sea is uncertain, but the waters probably did not reach far into the low hills which at this time surrounded the Sacramento Valley. The coarse conglomerate in Capay Valley suggests proximity to a western Capay shoreline.

Disturbances also preceded deposition of the middle Eocene Domengine sandstone and the upper Eocene Markley formation. At some period before upper Miocene time, a fluid basalt flow was extruded, probably in the volcanic area of the southern Cascade Mountains, or possibly from several vents now covered; this extended south into the Sacramento Valley.

Except for a local shallow sea existing during Oligocene time, the Sacramento Valley probably remained above sea level for the remainder of the Tertiary and Quaternary periods. Volcanic material accumulated during the Miocene near the Sierran foothills, but no further record of sedimentation is preserved in western Sacramento Valley until late Pliocene time, when fluviatile deposits, together with some volcanic debris, were carried into the Valley by streams and floods. Major diastrophic movements in late Pliocene and middle Pleistocene time caused uplift in the Coast Ranges, Sierra Nevada, and Klamath Mountains, approximately delineating the present geomorphic provinces of northern California. Great displacement along faults, already developed or newly initiated in the Coast Ranges and western Sacramento Valley, probably occurred at this time.

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SURFACE GEOLOGY OF THE EAST SIDE OF THE SACRAMENTO VALLEY, CALIFORNIA

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The sedimentary basin of the Sacramento Valley is outlined on the north and east side by a series of discontinuous outcrops. These outcrops form an arc across the northern end of the valley and extend down its east side; they range in age from Quaternary terrace deposits of Pleistocene age to the igneous and metamorphic rocks that make up the Sierra Nevada basement complex of Mesozoic and Paleozoic age. At the north end of the valley the sediments in contact with the Klamath basement complex are the Tuscan and Tehama formations. Some Upper Cretaceous rocks are present, which correlate with F′-1, F-2, G-1, G-2, and H foraminiferal zones as described by Goudkoff (1945). A publication by T. Matsumoto (January 1960) contains the following statement:

. . . "Upper Cretaceous beds are known in the stream valleys north, northeast and east of Redding, Shasta County, forming several discontinuous outcrops. Their geologic structure is gentle and the fossils are well preserved. The whole area is conveniently called the Redding area, which represents the northeastern side of the Sacramento Valley. . . . This area has been precisely investigated by W. P. Popenoe since 1936, who published concisely the stratigraphy in 1943. . . . The subdivisions of Popenoe (1943) are called Members I to VI. There are several, isolated, narrow outcrops of the Upper Cretaceous on the east side of the Sacramento Valley from which ammonites have been obtained. The best known is Chico Creek, Butte County. A few narrow exposures also occur in adjacent Little Chico and Butte Creeks, and near Pentz, about 10 miles north-northwest of Oroville. To the south near Sacramento another old and poorly investigated locality is recorded at Folsom in Placer County."

Portions of these Upper Cretaceous beds correspond in age to the producing formations in Beehive Bend, Arbuckle, Grimes, Buckeye, and other gas fields in the central Sacramento Valley.

Southward along the east side of the valley these same sediments are in contact with Pliocene volcanic rocks (basalt), thought to be associated with the Mt. Shasta flows. These flows extend as far south as Sterling City (T. 24 N., R. 4 E.). From this point, sediments ranging in age from Pleistocene (Red Bluff gravels) to Eocene are in contact with the basement complex. This relationship continues along the east side of the basin and on into the San Joaquin Valley. One of the few units that outcrop along the east side that has been described is the Ione formation. Allen, in a University of California publication in 1928, gave this formation extensive treatment. Parts of his published manuscript read as follows:

"The Ione formation lies along the foothills of the Sierra Nevada where the rolling topography of the Bedrock series changes to the level plain of the Great Valley. It consists of quartz sands and gravels, clays and seams of lignite. . . . Several writers have correlated the Ione formation with the auriferous gravels of the Sierra Nevada. . . . The term Ione, as a formational name, was first used by Lindgren in the text of the Sacramento Folio submitted in 1892. Part of his published statement is as follows:

". . . The white clays of the Ione formation are frequently well suited to the manufacture of pottery. This industry is at present extensively carried on near Lincoln, where local conditions permit the clays to be quarried with little expense."

One surface feature that is very apparent on topographic maps and aerial photographs is a surface flexure that has been given the local name "Tuscan monocline". This feature trends southeast, roughly parallel to the edge of the Cascade and Sierra foothills, for 35 to 40 miles. It begins about 7 miles east of Red Bluff and extends to a point about 6 miles northeast of Chico. The average dip of the surface east of this line of flexure is 2° to 3°. West of this line the dip changes and averages from 5° to 9°, continuing at this rate until the surface beds disappear beneath the valley alluvium.

Gas seeps have been observed in two areas approximately 6 miles east of Red Bluff, California. These areas are known locally as Tuscan Springs and Salt Creek. The seeps are in exposures of Upper Cretaceous shale; hot sulphur water also issues from the Tuscan Springs seep.

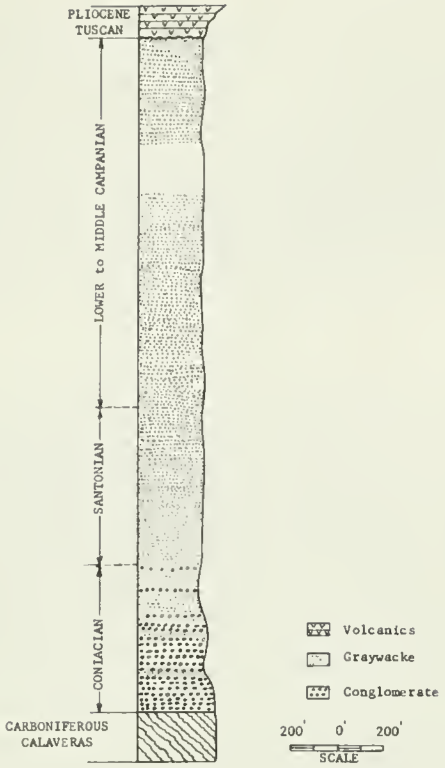

Figure 1. Columnar section of the type Chico formation, Big Chico Creek, Butte County. Compiled by T. Matsumoto from data provided by W. P. Popenoe, L. E. Saul, S. Chuber, and T. Matsumoto.

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Photo 1. Tuscan Springs as they appeared in 1955. The springs emit gas as well as water.

THE MARYSVILLE (SUTTER) BUTTES, SUTTER COUNTY, CALIFORNIA

By LOWELL E. GARRISON
Gulf Oil Corporation, Socromento

Plate 4, Generolized geologic mop of Marysville Buttes, accomponies this poper.

The Marysville Buttes (locally called Sutter Buttes) together form an isolated topographic prominence 10 miles in diameter, located 10 miles north of Marysville, Sutter County. Their 2000-foot elevation contrasts dramatically with the surrounding featureless valley.

The Buttes were formed in Pliocene time by piercement intrusions of rhyolite porphyry, followed by andesite porphyry, in several volcanic episodes. These episodes were accompanied by folding, warping, and faulting of the pre-existing early Pliocene, Eocene, and Upper Cretaceous sediments.

The Buttes are roughly circular, and their geology is reflected in the topography. The central core of andesite porphyry and vent tuff is surrounded by a radial belt of low, rampart-like hills made up of the sediments; these disturbed sediments in turn are girdled by a shallow sloping ring of andesite tuff and breccia, which merges into the valley alluvium. Intrusions of rhyolite porphyry are scattered through the sedimentary ring and the central core.

Late Cenozoic. "Sutter beds" is the local name given to the Pliocene Tehama formation, which regionally truncates Eocene and Upper Cretaceous formations in turn throughout the Sacramento Valley. The Sutter beds are continental fine-grained sediments, tuff, sand, silt, and gravel of Mio-Pliocene to Plio-Pleistocene age some 1800 feet thick in outcrop, at Marysville Buttes. A prominent basal conglomerate is present.

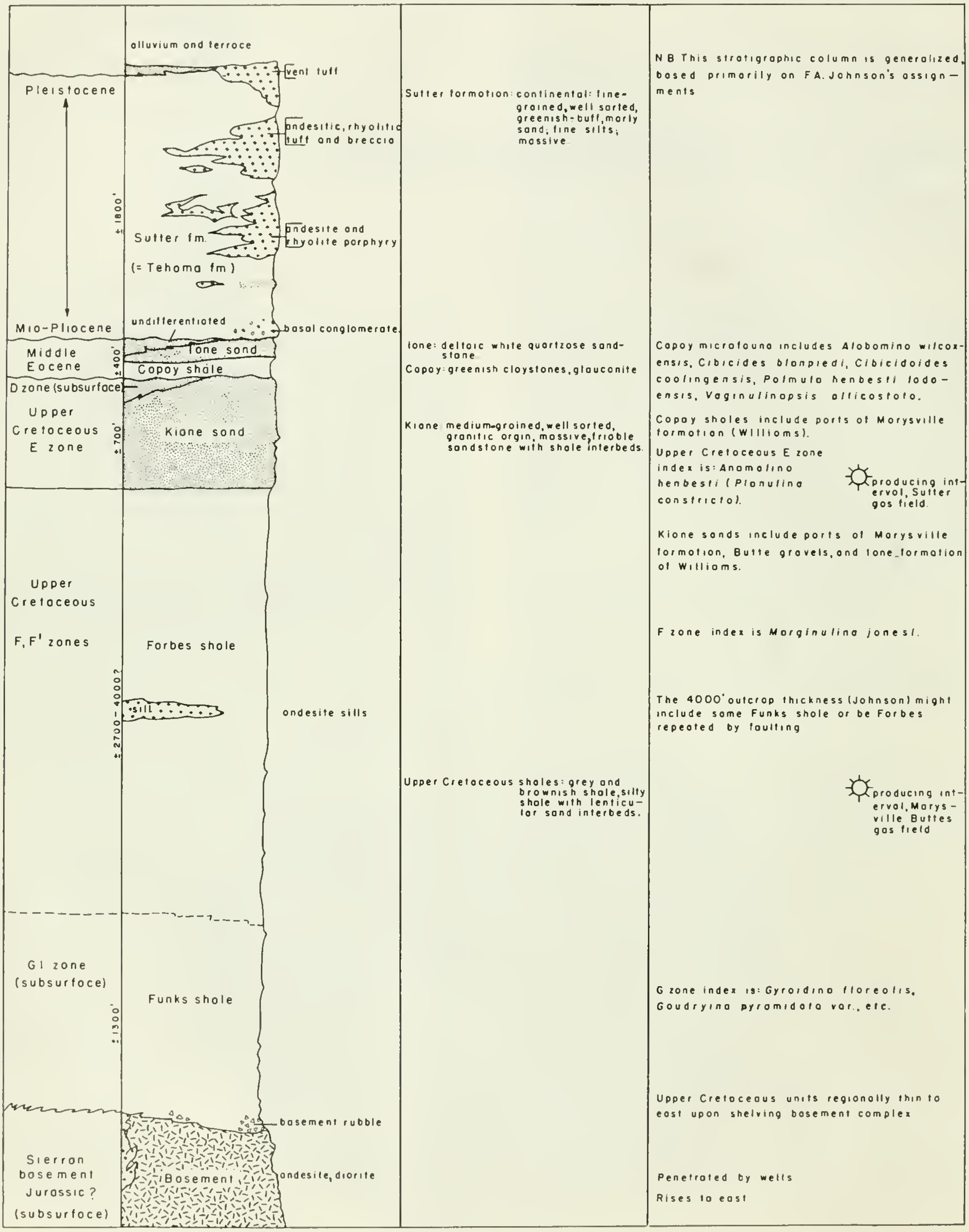
Eocene. Unconformably underlying the Sutter beds, approximately 400 feet of Eocene marine sediments are exposed. Williams (1929) included the Butte gravel, Ione sand, and Marysville formation (in descending order) in the Eocene, a maximum of 1200 feet. Later paleontological work has shown that some of these units, or portions of them, belong in the Upper Cretaceous. In outcrop, the thickness of the emended Eocene at the Buttes is 400 feet maximum; it comprises about 150 feet of Ione sand, and some 250 feet of Capay shale.

The Ione sand is a white, quartzose, friable sandstone, probably of deltaic origin and of Eocene age. The Capay shale is marine middle Eocene greenish-gray claystone and shale, glauconitic and fossiliferous. Foraminifera place this unit roughly in Laiming's (1940) Eocene B-4 and C zones, and in Mallory's (1959) Penutian stage. Israelsky (1940) presents comparisons of this Capay microfauna with those of the Gulf Coast Claiborne, Wilcox, and Midway formations (lower and middle Eocene).

Upper Cretaceous. Unconformably underlying the Capay is Upper Cretaceous Kione sand, lithologically similar to the Eocene Ione. Williams (1929) apparently did not differentiate the two, but later paleontological and subsurface work has shown them to be noncontemporaneous. The name Kione is a connection of "K" (for Cretaceous) and "Ione", as the Cretaceous Ione was designated after its age was established; some geologists believe Kione to be Paleocene in age. Below the Kione is Upper Cretaceous Forbes shale. According to Johnson (1943, p. 614), a 2750-foot to 4350-foot sequence is the most complete section of Forbes exposed in the Buttes. Kione sands are contemporaneous with the E or E′ zone of Goudkoff (1945), the Forbes shale with the F or F′ zone. These age units have equivalents in the Upper Cretaceous Taylor group of the Gulf Coast.

The Igneous Sequence. In Pliocene time, after deposition of at least 1500 feet of Sutter formation (Johnson, 1943, p. 611), a series of volcanic episodes—the intrusion of rhyolite porphyry volcanic necks followed by the intrusion of an andesite porphyry plug—resulted in formation of the Marysville Buttes. The order of intrusion—rhyolite porphyry followed by andesite porphyry or vice-versa—is in dispute. Williams (1929) thought the andesite was first, but later work has suggested that the rhyolite preceded the andesite. These volcanic rocks were intruded into the Upper Cretaceous and Eocene sediments, and into the lower part of the Sutter beds. The placing of the andesitic core was (Williams, 1929, p. 139, 140)

> "probably a slow, aggressive process, . . . [into] the more or less flat-lying sediments laid down in the persistent Sacramento Valley. This sedimentary roof, by reason of its lower specific gravity, may well have been arched upward by the invading andesite owing to the continued accession of fresh magma coming from below under pressure. Whatever the *modus operandi*, the sedi-



Sutter formation: continental: fine-grained, well sorted, greenish-buff, marly sand; fine silts; massive.

Ione: deltaic white quartzose sandstone.

Capay: greenish claystones, glauconite.

Kione: medium-grained, well sorted, granitic origin, massive, friable sandstone with shale interbeds.

Upper Cretaceous shales: grey and brownish shale, silty shale with lenticular sand interbeds.

N B This stratigraphic column is generalized, based primarily on F. A. Johnson's assignments

Capay microfauna includes *Alabamina wilcoxensis*, *Cibicides blanpiedi*, *Cibicidoides coolingensis*, *Pulmula henbesti lodoensis*, *Vaginulinopsis alticostata*.

Capay shales include parts of Marysville formation (Williams).

Upper Cretaceous E zone index is: *Anomalina henbesti* (*Planulina constricta*).

☼ producing interval, Sutter gas field.

Kione sands include parts of Marysville formation, Butte gravels, and Ione formation of Williams.

F zone index is *Marginulina jonesi*.

The 4000' outcrop thickness (Johnson) might include some Funks shale or be Forbes repeated by faulting

☼ producing interval, Marysville Buttes gas field

G zone index is: *Gyroidina floreolis*, *Gaudryina pyramidata* var., etc.

Upper Cretaceous units regionally thin to east upon shelving basement complex

Penetrated by wells

Rises to east

Figure 1. Stratigraphic column in the vicinity of Marysville Buttes, Sutter County.

> ments continued to yield to the intrusion by folding until such time as the strain was more readily relieved by fracture. In this way, the sedimentary cover was broken by a series of faults, disposed in general, both radially and concentrically with respect to the laccolithic margins (map). The radial blocks or sectors thus produced were then tilted outwards at different angles. Reference to the map and sections will show that the sedimentary block immediately south of South Butte was tilted almost to verticality, whereas the remaining blocks were tilted outwards at angles of from 10° to 40°, the blocks on the northern flank of the laccolith having the smallest outward dip."

Johnson (1934, p. 611) has a somewhat different interpretation in that he believes "that this plug must have either reached the then surface or even been pushed, at some points, as spire-like prominences above it". The present form of the Marysville Buttes, at any rate, has resulted from erosional stripping of the arched sedimentary roof, or its pierced remnant. The intrusion of the central andesitic plug, 4 miles in diameter, must have proceeded slowly, "aggressively" as Williams and Johnson describe, and not catastrophically, so that erosion must have proceeded with the uplift.

The sediments around the andesite core consequently became warped, folded, and faulted.

The final igneous episode was an explosive phase—the formation of a volcano within the andesite plug—the ejecta of which mantled the slopes with andesitic tuff and breccia. The crater of this ancient extinct volcano is 1 mile in diameter. It lies in the center of the andesite porphyry core and is filled with vent tuff. Fragments of andesite erupted from this central vent range from boulders 30 feet in diameter to fine-grained tuff, the character of the ejecta being due to the differing strengths of volcanic explosions. During quiescent periods between explosions, streams were cutting channels on the flanks of the cone. The coarse and fine ejecta probably were placed around the periphery by mud flows (Williams, 1929; Johnson, 1943). Three types of pyroclastic rocks are distinguishable (Williams, 1929, p. 182-183):

> "1. coarse ejecta, a chaotic assemblage of blocks in a finer matrix which may or may not have been removed by erosion,
> 2. fine tuffs and lapilli tuffs, generaly stratified,
> 3. bedded volcanic sands and gravels.
>
> "These three formations are irregularly interbedded and in many places pass gradually into one another. It is probable that the coarse ejecta represent the products of eruptions of Pelean type, and that the bedded tuffs are due chiefly to explosions of Vulcanian type. The sands and gravels are doubtless the result of the washing and redeposition of these ejecta, partly during the actual eruptions and partly during the intervals of quiescence."

Contemporaneous with the andesite were eruptions of rhyolitic ejecta, which may have been initiated earlier than the andesitic phase. The infilled crater as now seen is the final explosive phase.

Erosion of the Buttes. Erosion proceeded with and was subsequent to the volcanic episodes. The geologic units at the Marysville Buttes are geomorphologic units as well, due to differential weathering. These units are disposed from periphery to center, into: (1) the outer belt of low-lying slopes of gently dipping, soft volcanic ejecta; this outer belt surrounds (2) the higher bluffs and hills composed of more resistant discontinuous patches of disturbed sediments, upturned about the intruding volcanic core; at the center (3) is the andesitic core, with the ancient, infilled, vent. This core is sculptured and cast into craggy prominences, 2000 feet high.

The Marysville Buttes Gas Field. Gas seeps in the sedimentary rocks of the Marysville Buttes were noted prior to the 1870s. Dexter Cook, in 1864, searching for coal in clinkered rocks (in this case, Upper Cretaceus baked shales near the andesite core), started a shaft in which he encountered a pocket of gas which exploded, "discouraging future operations" (Hunter, 1955). Later, geologists became aware that "this structure presented a gas and oil problem that appeared to have some similarities to the salt domes of the Gulf of Mexico coastal plain and to the volcanic plugs of Mexico" (Stalder, 1943, p. 378). The first attempt to drill for gas and oil was the Buttes Gas and Oil Co. (formerly Buttes Oilfields Inc.) "Buttes" 1, in Sec. 35, T. 16 N., R. 1 E. This well, drilled to 2727 feet, bottoming in andesite, and completed February 9, 1933 for 3425 Mcf/d, was the discovery well for the Marysville Buttes field. According to Stalder (1943, p. 378) this well was drilled to test the theory that accumulation could be found in "baked and cracked shales adjacent to the igneous core or beneath any sills projecting from under it." The latter condition was, indeed, the trap encountered. Gas from the discovery well was used to supply power for subsequent drilling. The first commercial well was "Buttes" 4, completed August 9, 1937, for 18,800 Mcf/d, 1 inch bean, 620/1780 pounds, SIP 3125 pounds, from the interval 5725 feet to TD 5855 feet. The producing horizons are lenticular discontinuous sands in the Forbes shale. The producing structure is a regionally south-dipping flexure against the andesite porphyry core.

In 1953, new production was discovered in Kione sands by the Richfield Oil Corporation. "Sutter Community A" 1 in sec. 8, T. 15 N., R. 2 E., on a small closure. This Kione pool is called the Sutter gas field to differentiate it from the Forbes shale production in the original Marysville Buttes gas field.

Analyses of the gas produced at Marysville Buttes indicates BTU range from ±900 to over 1000; methane range from 83 to 99+ percent. A minor amount of condensate is produced with the gas.

To date (February 1, 1961) 13 wells have been drilled at Marysville, of which 11 are producers, and 5 producers at Sutter. Production of the Marysville Buttes field for the month of March 1960 was 221,747 Mcf, an average of 7153 Mcf/d.

The formational units present in outcrop at Marysville Buttes are present below the surface at the gas fields, though down-dip thickening takes place.

Stalder (1943, p. 381) puts into capsule form the salient facts regarding accumulation at Marysville Buttes:

> "Structurally, the Sutter Buttes are so high with relation to the surrounding Sacramento Valley, and the feeding area to them for

oil and gas is so large from beneath that valley, that they constitute an ideal locality to test to great depths for other gas and possibly oil horizons. It is the central core of these buttes that forms the barrier against which such gas and oil will accumulate."

Acknowledgments. Thanks are extended to the Gulf Oil Corporation of California for permission to publish this paper; and to Buttes Gas and Oil Company, for permission to use certain data on the geologic map.

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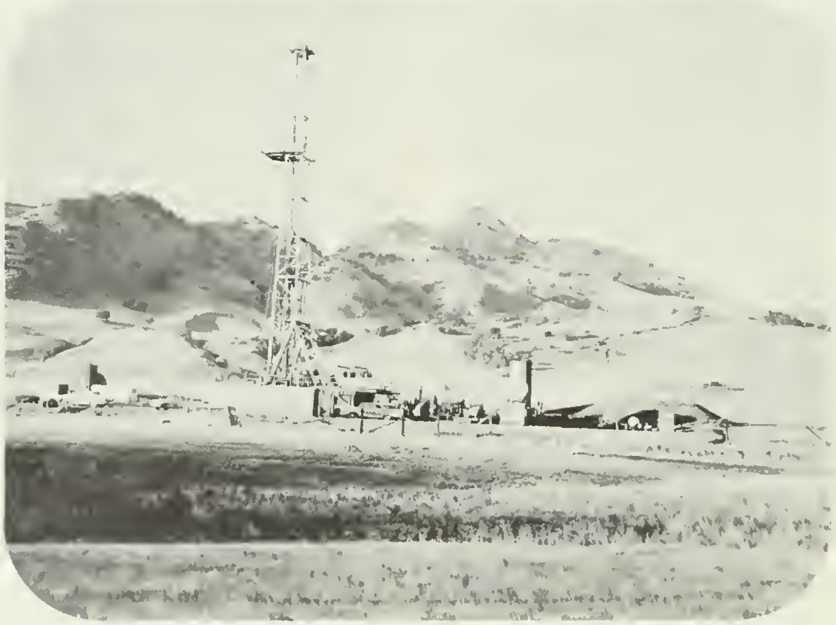

Photo 1. Natural gas well being drilled by Santa Fe Company in section 34, T. 16 N., R. 1 E., along South Pass Road of Marysville (Sutter) Buttes. Photo by Edmund W. Kiessling.

THE SACRAMENTO VALLEY—SUBSURFACE GEOLOGY

CONTENTS

Index Map 1 (opposite). Index map to Part 2, *Subsurface Geology* section, showing: Location of sections on plate 5, and figures 2, 3, 4, 5, and 7, which accompany *The challenge of the Sacramento Valley, California*, by Anatole Safonov; The areas covered by Contributions 1-8 in the article *Typical gas fields of the Sacramento Valley, California*, by Members of the Sacramento Petroleum Association; Location of the section on plate 10, which accompanies *Geology of the Arbuckle-Grimes vicinity, California*, by José Corvalán and John W. Harbaugh; And the various gas fields located in and bordering the Sacramento and northern San Joaquin Valleys.


AAPG Section number 13 (plate 5)
Sofonov fig 3
RED BLUFF
SACRAMENTO
Contribution 1
Corning
S Corning
Kirkwood
Rancho Capay
APPG Section number 13
(plate 5)
Ord Bend
Chico
Artois
Willows-Beehive Bend
Durham
Contribution 2
Perkins Lake
WILLOWS
Llano Seco
Contribution 3
Afton
Bounde Creek
Schohr Ranch
Princeton
Contribution 4
Compton Landing
Wild Goose
Colusa (Abd)
Marysville Buttes
Butte Slough
Moon Bend
Sutter
MARYSVILLE
Corvalen-Harbaugh, Plate 10
Grimes
Sofonov fig 4
Arbuckle
Buckeye
Contribution 5
Sycamore Slough
RIVER
Contribution 6
Dunnigan Hills
Sofonov fig 2
Fairfield Knolls (Abd)
Chickahominy (Abd)
Pleasant Creek
Winters
SACRAMENTO
Freeport
SANTA ROSA
Millar
Sofonov fig 5
Maine Prairie
Liberty Cut
Contribution 7
W Thornton
Thornton
Denverton (Abd)
N Kirby Hill (Abd)
Potrero Hills (Abd)
Cache Slough
Walnut Grove
Galt
Lodi
Kirby Hill
Suisun
Rio Vista
River Island
Contribution 8
AAPG Section number 13
Sofonov fig 7 (see plate 5)
Honker (Abd)
Los Medanos
Willow Pass
McDonald Island
Whiskey Slough
Roberts Island
STOCKTON
SAN JOAQUIN RIVER
SAN FRANCISCO
SAN FRANCISCO BAY
Tracy
Vernalis
1N
1S
1W
1E

Frontispiece. West side of the Sacramento Valley, view north. Putnam Peak is in the right foreground, the north end of Pleasant's Valley in the foreground. Steep hills at left in photo are Cretaceous outcraps. Sacramento Valley is in the upper right background. Photo courtesy Cartwright Aerial Surveys, Inc., Sacramento.

THE CHALLENGE OF THE SACRAMENTO VALLEY, CALIFORNIA

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Plate 5, Correlation section longitudinally north-south through Sacramento Valley from Red Bluff to Rio Vista [A.A.P.G. correlation section 13] accompanies this report.

The Sacramento Valley, because of its geologic history, may be called a geologist's paradise. Within its comparatively small area, a geologist encounters just about everything he has ever studied in school and in the field; also some of the things he has not. For the same reason, the Sacramento Valley is a place on the far side of paradise, for those who are charged with making a drilling location. Even in an offset hole, the objective sands are likely to be missing where they are supposed to be "for sure"; on the other hand, production is often found in new and unexpected intervals. The brief analysis presented in this paper, confined as it is to Upper Cretaceous and younger formations penetrated by drilling, purports to give an insight into the subsurface geology of the Valley to those unfamiliar with it; to clarify some obscure points for those who have worked on it but for a short time; and to provoke a volley of objections from the old timers.

The main factors affecting the geology of the Sacramento Valley are: southerly tilt of the Valley; progressive uplift of the west side and the Diablo uplift in the south; oscillatory and differential movements within the valley.

These primary factors gave rise to a number of secondary ones, more important from the practical point of view, because they were immediately responsible for the nature and distribution of gas-carrier sands. These secondary factors are: a multiple source of sediments; bottom currents and density currents; subaerial erosion; deltas.

All by itself is the factor of volcanism, which is of a local significance, being confined to the northern part of the Valley (basalt flows) and especially to the Marysville Buttes area. This last factor is discussed in more detail in another paper.

These factors bring about the main feature of the Valley, which affects its exploration: the inconsistency of its sedimentary facies, locally extreme, which leads to the above-mentioned erratic and apparently haphazard distribution of sands.

The total effect of the tectonic and sedimentary factors has been a continual sanding up of the Sacramento Valley sedimentary basin, first by almost completely isolating it from the western sea, then by filling it with progressively more continental deposits.

PRIMARY FACTORS

For convenience, we shall take up the analysis of each of the above-named factors.

The Southerly Tilt of the Valley. The southerly tilt of the valley is well illustrated in the latest A.A.P.G. longitudinal cross-section, No. 13 (see pl. 5), although the latter meanders, for technical reasons, from the east to the west side and does not reflect the standard section along the axis of the valley. The cross-section shows a steady northerly rise of all formations. The magnitude of this movement can be judged from the fact that the Guinda sand, reached at about 13,000 feet in the General Petroleum, Glide No. 1 (sec. 10, T. 7 N., R. 3 E.), lies at about 6,000 feet at the north end of the Beehive Bend field, some 80 to 85 miles to the northwest, and at just below 1,000 feet in sec. 24, T. 29 N., R. 3 W. The Winters sand, which is just above 11,000 feet in the Rio Vista field, west of the Midland fault, has its time equivalent at about 3,000 feet, in the south part of T. 15 N., R. 1 E. A well drilled on the eastern tip of Van Sickle Island, just west of the deepest part of the Sacramento Valley basin, did not reach the Nortonville at 7,000 feet. In the north, about Township 15, this formation is truncated by continental deposits.

By virtue of this tilt, the southern part of the valley—the Rio Vista basin—is the deepest, and contains what may be called its standard section.

In this connection, it is pertinent to mention the similarity between the Sacramento and the San Joaquin Valleys. In the latter, the southerly tilt continues, bringing the Eocene to below 20,000 feet, in the southern part, with a thick marine Tertiary section between it and the

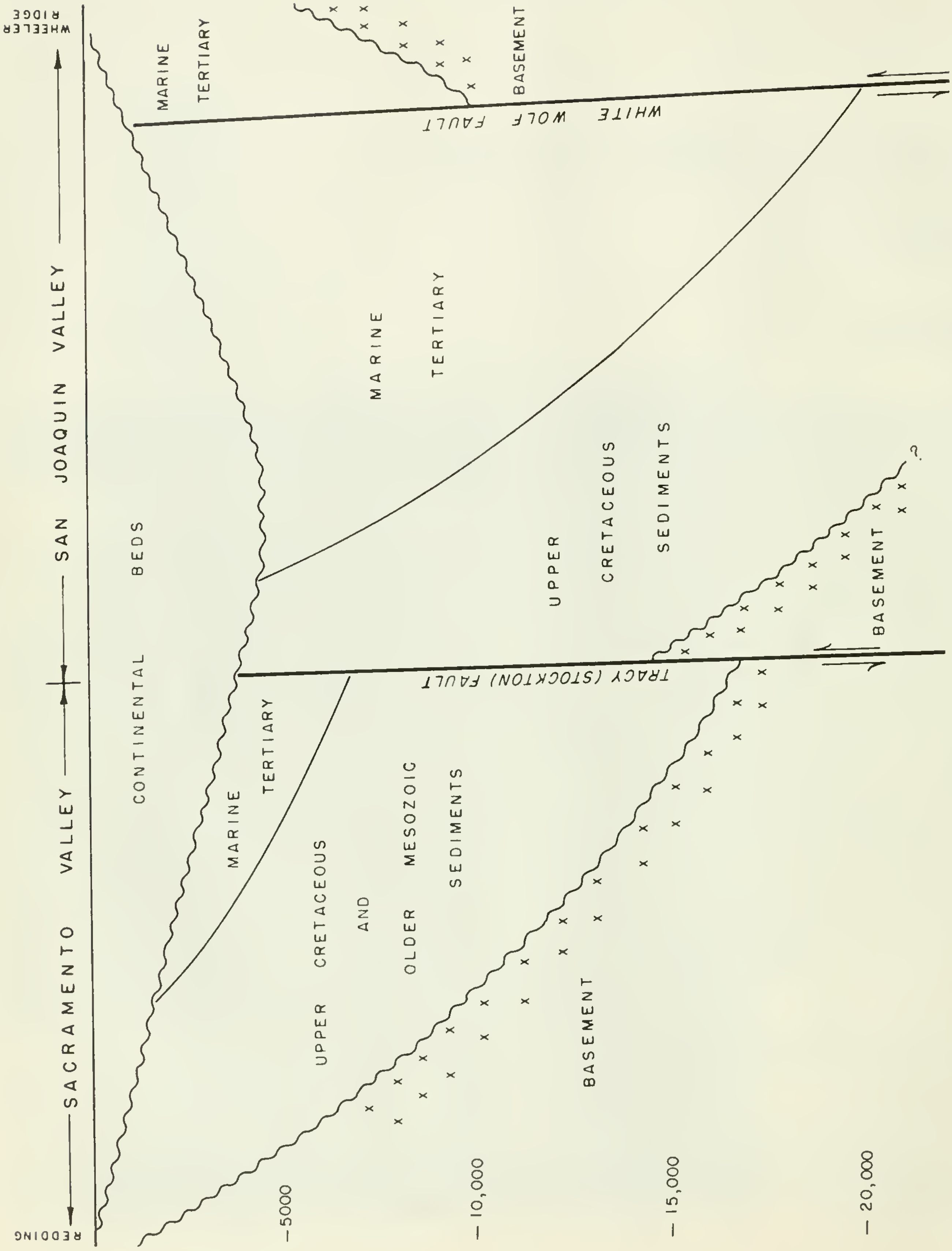


Figure 1. Tectonic diagram of the Great Valley of California, Redding to Wheeler Ridge. Courtesy Sacramento Petroleum Association.

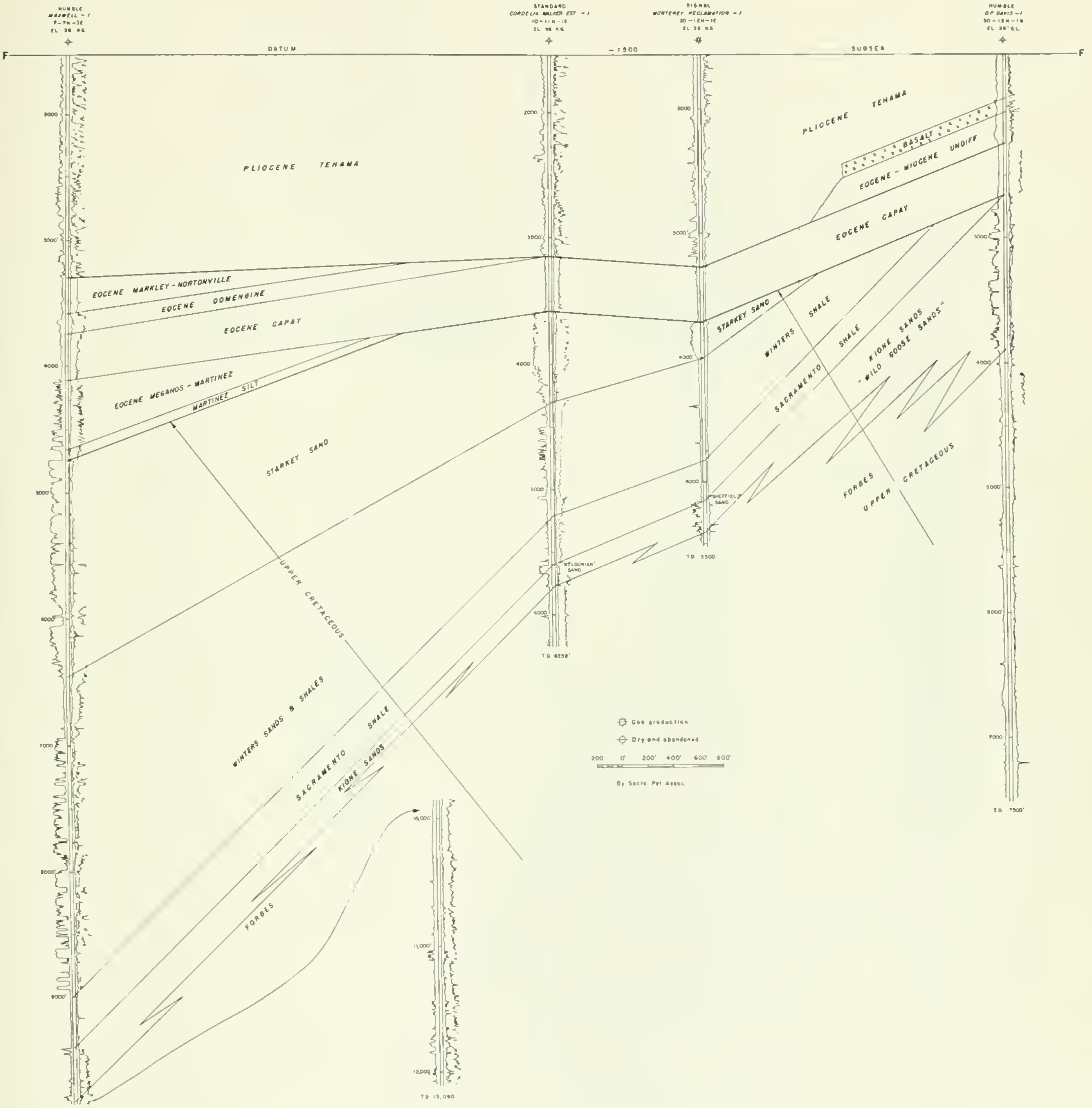


Figure 2. South to north section across Sacramento Valley along line F-F, showing correlations of various formations with Kione sand. For location of section, see Index map 1.

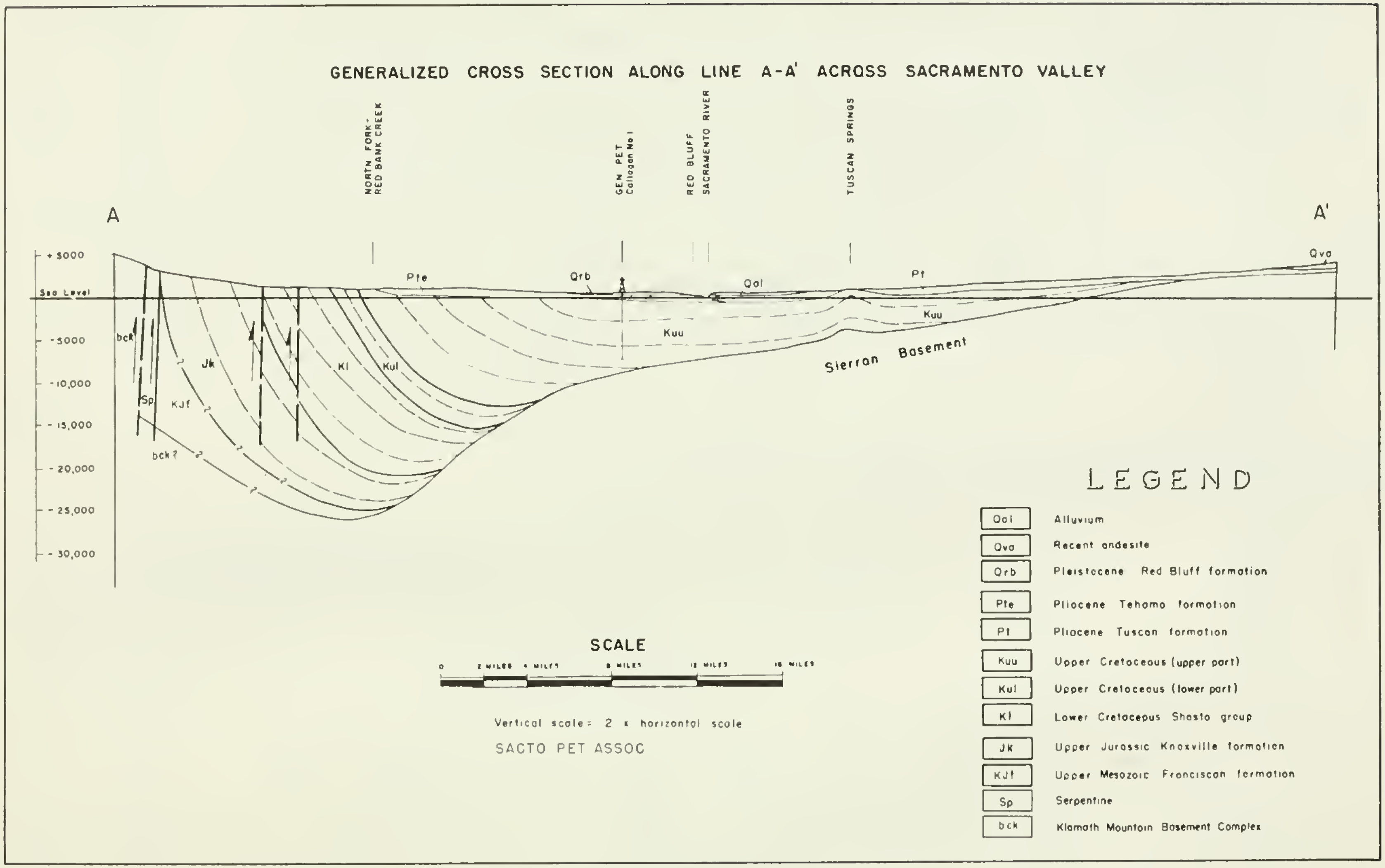


Figure 3. Generalized section across the northern Sacramento Valley through Red Bluff. For location of section, see Index map 1.

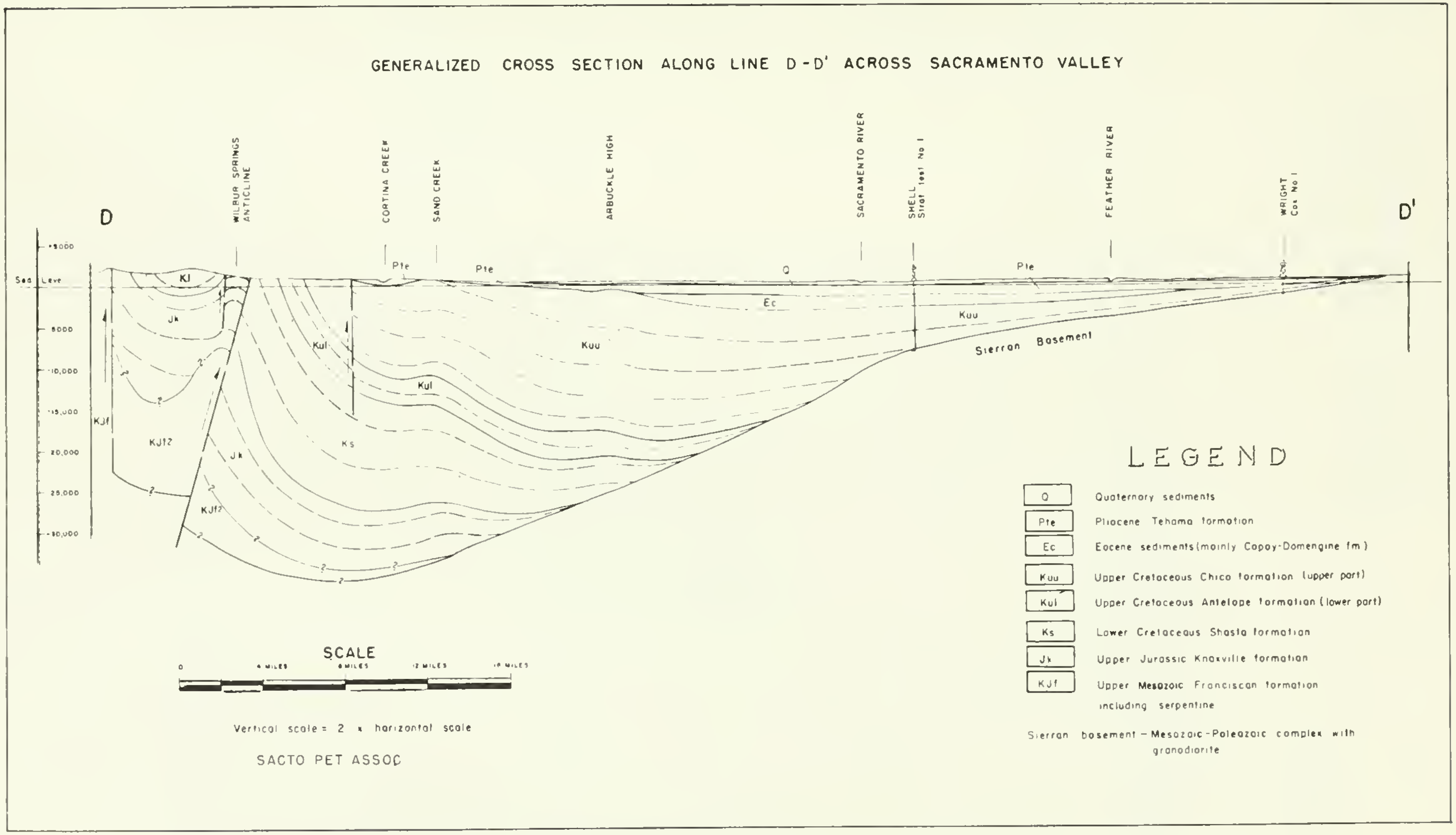


Figure 4. Generalized section across the northern Sacramento Valley through Arbuckle gas field. For location of section, see Index map 1.

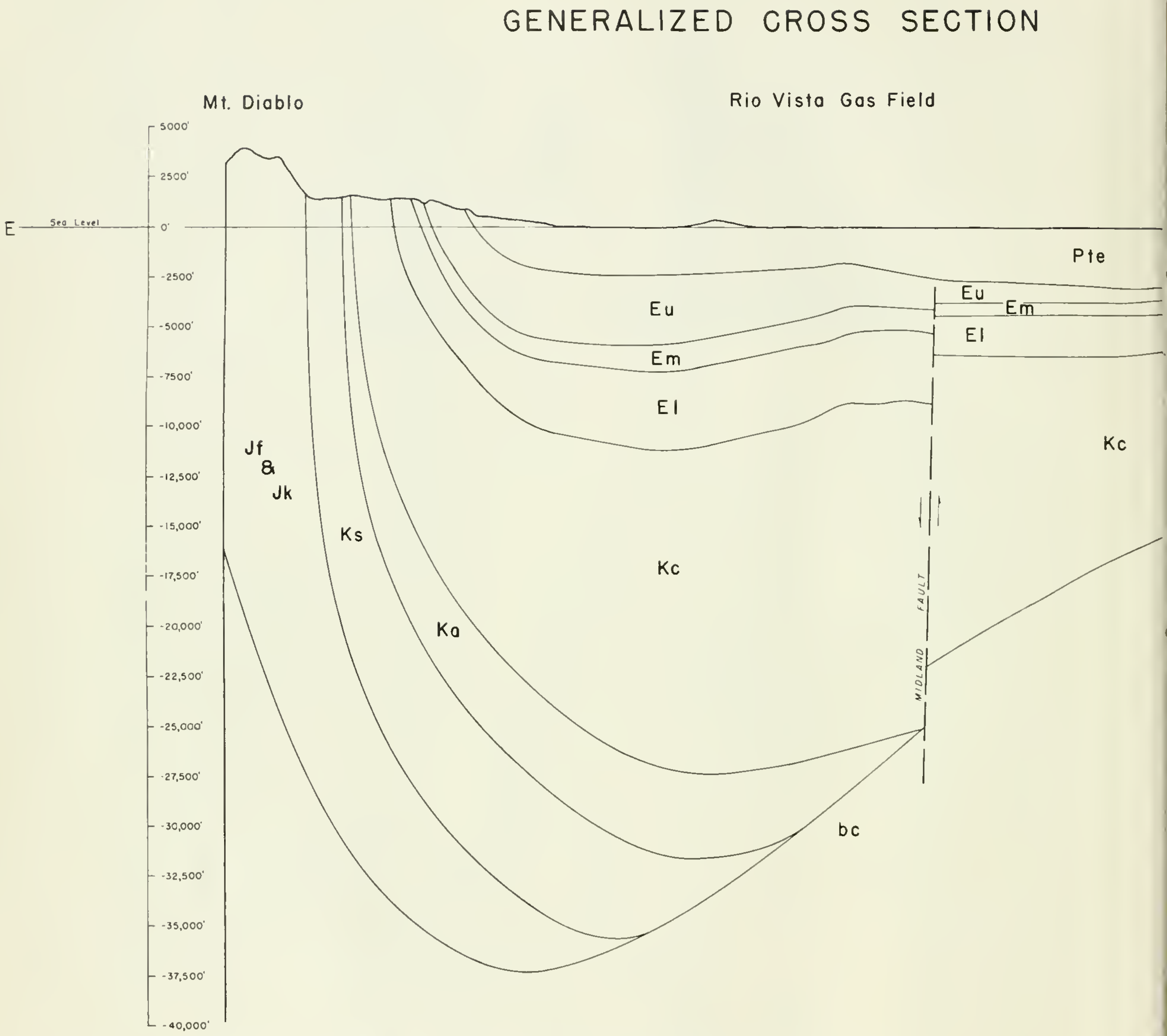
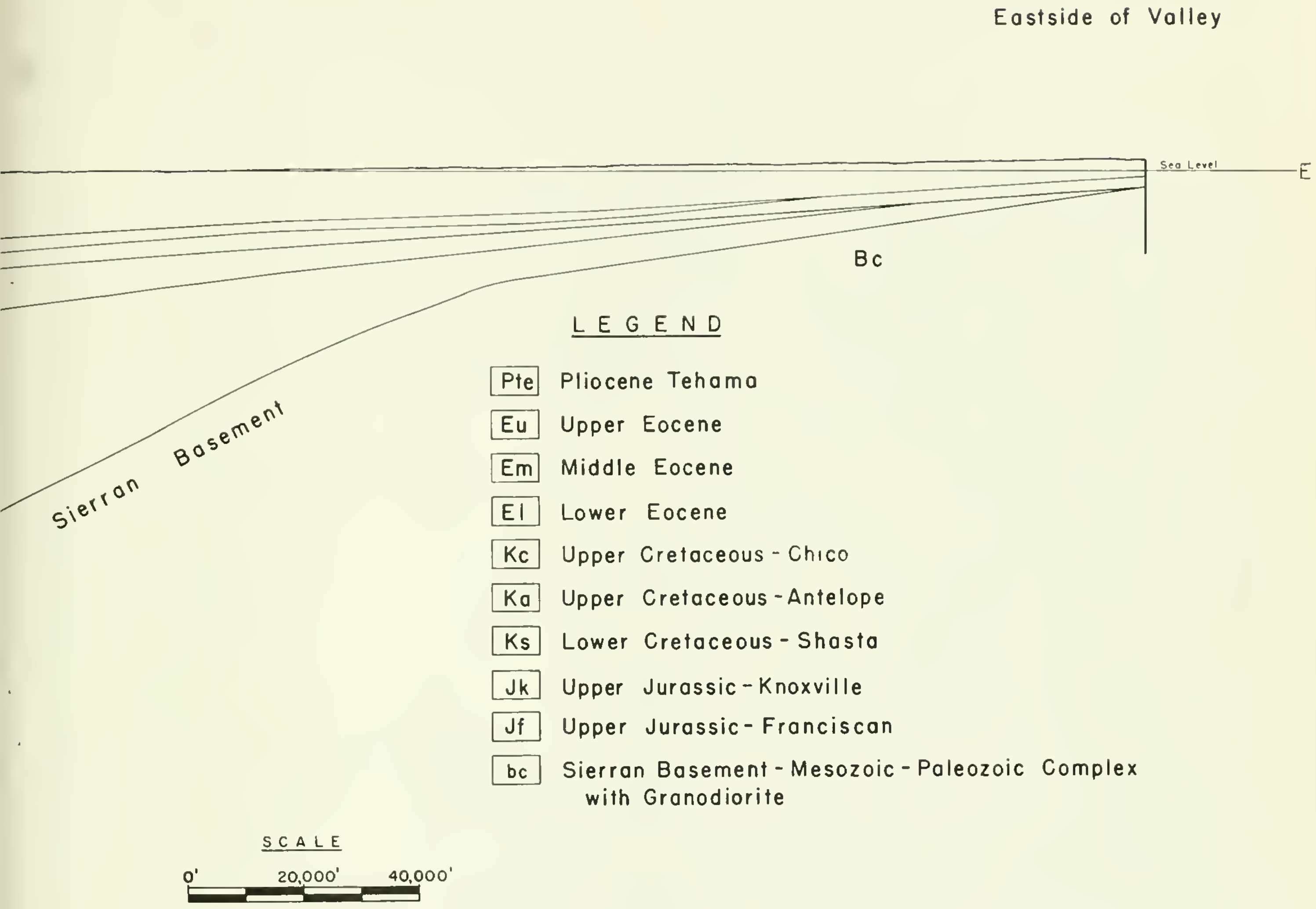


Figure 5. Generalized section across southern Sacramento Valley, Mt. Diablo to Auburn. For location of section, see Index map 1.

ACROSS SACRAMENTO VALLEY



By SACTO PET ASSOC


RED BLUFF
SACRAMENTO
Corning
S Corning
Kirkwood
Rancho Capay
Ord Bend
Artois
Willows-Beehive Bend
WILLOWS
Bounde Creek
Princeton
Compton Landing
MARYSVILLE BUTTES
Arbuckle
RIVER
TYPE CAPAY
Gas fields
CONTOUR INTERVAL 500'
By Karl Arleth, Jr, Ohio Oil Comp
SANTA ROSA
CAPAY OUTCROP
CAPAY SHALE missing due to Tmk GORGE Erosion
SACRAMENTO
Denverton (Abd.)
Potrero Hills (Abd.)
Kirby Hill
Suisun
Honker
Los Medanos
Willow Pass
SAN
JOAQUIN
STOCKTON
MT DIABLO
CAPAY OUTCROP
Tracy
RIVER
Vernalis
SAN FRANCISCO
SAN FRANCISCO BAY
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75
?

continental beds. In the north of the Sacramento Valley, the continental Tehama formation (Pliocene?) rests on the Cretaceous Forbes sand; there is but a local development of post-Eocene marine sediments, in the south (Valley Springs, Miocene). In the northern part of the San Joaquin Valley, the continental sediments rest on the so-called Cretaceous bridge, south of the Stockton (also known as Tracy and French Camp) fault zone. Thus, the two valleys appear to represent a single tectonic unit—the Great Valley of California—broken in two by a major fault (fig. 1).

Like most tectonic movements, this southward tilting of the valley was continual rather than continuous. In other words, it occurred in spurts between periods of relative quiescence. An intensification of this movement, the one which is well reflected in plate 5, took place at the close of the Cretaceous and at its transition to the Tertiary, where it culminated in the Capay sea transgression—the last of the major sea invasions of the valley. Plate 5 and fig. 2 show the northerly shortening and convergence of the Winters-Starkey sand, and the progressive truncation of the overlying Meganos sand followed by the truncation of the remaining Winters sand.

Another intensification of this southerly tilt occurred toward the close of the Eocene. It is reflected in a thick Markley interval, in the south, as against no known marine Markley in the north.

A practical effect of this movement is a greater volume of potentially productive rocks in the south. Another factor, perhaps somewhat offsetting the first one, is the probable general tendency for up-the-valley migration of gas.

The West Side Uplift. This phase of the Sacramento valley tectonics also was in progress toward the end of the Cretaceous, as witness the numerous unconformities in that section, and evidence of a westerly source of some sediments. In this connection, it should be stated that most Upper Cretaceous sands did not come from very far away. They were washed out from local uplifts and redeposited in the same sedimentary basin, often very close to their source.

Toward Capay time, the northern and middle parts of the valley were fully isolated from the sea, as witness the shallow-water facies in the north and west and a progressive truncation of the Winters sand, going west, in the Winters-Pleasant Creek-Dunnigan Hills area. By that time, one of the main features of the Sacramento Valley became apparent—its asymmetry, with its axis hugging the west side. The axis runs immediately west and parallel to the Sacramento River, along the latter's course north of Colusa. In the south, the deepest part of the valley is about at the junction of the Sacramento and San Joaquin Rivers.

Another and economically more important feature of the valley also became apparent by Capay time: the difference between its west and east sides. On the west side, there is a fairly sharp angular unconformity, with pre-Capay dips steeper than the post-Capay. The change in dip with age is more gradual on the east side (figs 3, 4, 5).

In the Diablo uplift, the conditions are essentially those of a homocline dipping north and northeast, away from Mount Diablo.

Oscillatory and Differential Movements. As a rule, the standard section of the valley is an alternation of sand and shale intervals, the Cretaceous sands carrying limy streaks in the deeper part of the valley and west of the axis. The spindle-shaped pattern of sand bodies on electric logs in deeper parts of the valley, where the section is more representative, reflects an alternation of emergence-submergence sedimentary cycles. In the vicinity of contemporaneous structures, and everywhere on the east side, this pattern is broken by numerous hiatuses and by the general easterly convergence. The lower shales, such as the Dobbins (between the Guinda and Forbes sands), and the Sacramento (between the Forbes and Winters sands) are traceable practically throughout the Valley; the upper ones, such as the unnamed shale between the Winters and Starkey sands (D_2) and the Martinez shale break, grade into sand to the north. All of the Eocene shales "sand up", thin down, or are truncated in the same direction, as well.

In the Colusa area, the continuity of the southerly tilt of the valley appears to be complicated by a local downwarping which has resulted in what may be called the Colusa sub-basin. It is marked by a very poor to nearly non-existent Forbes sand and by a baffling relationship of the Kione (Wild Goose) sand interval with the contemporaneous sediments of the Rio Vista basin, which will be considered below. Structurally, it is camouflaged by a post-Capay development of the Colusa anticline—one of the major structures of the valley; by the volcanic plug of the Marysville Buttes, in the east; and by a high trend in the west, between the sub-basin and the southern end of the Princeton Gorge.

Another local subsidence—the Chico sub-basin—is suggested east of Orland.

The Capay shale occupies a position of its own, marking, as it does, the last major sea transgression. Being widespread and conspicuous on electric logs, it is a good marker. Its base provides the only datum for a general map of the valley (fig. 6). It reflects the post-Capay movement of the Valley, the southerly tilt, and the trough effect.

Going north from the deepest part of the Rio Vista basin, the Capay lies on progressively older formations,

Figure 6 (opposite). Structural contour map drawn on the base of the middle Eocene Capay formation.

from Meganos to Kione. It also gets thinner in the same direction, especially in the Colusa sub-basin, toward the northern end of which it is replaced by the Princeton Gorge and shallow facies. The so-called type Capay section on the west side belongs to this special facies rather than to the true Capay shale of the basin.

A line across the Valley in the vicinity of the northern line of T. 12 N. appears to be a pivotal one, with the rate of tilt increasing south of it. This line may be regarded as the northern rim of the Rio Vista basin.

Differential movements on the east side tended to break it up into areas of differential deposition, making correlation even more difficult. The Natomas shelf, north of the Freeport high, roughly in the Sacramento-Feather River area, is such an area, in which erratic sands are developed in the converging Forbes-Winters-Kione interval, and are not definitely correlative with either. Eocene movements south of there resulted in an inlet between the Freeport nose and the high Thornton-Lodi trend, and in a southeasterly extension of the Rio Vista basin, south of Lodi.

Capay time witnessed the last major sea invasion of the Sacramento Valley. From then on, the "sanding up", initiated with the appearance of a western land or a chain of islands, and intensified beginning with the deposition of the Kione and Winters sands, became the predominant process. The last two sea invasions—the Nortonville and the Markley—were never as widespread. The extent of Oligocene-Miocene marine sediments is very small, confined only to the south.

The distribution of major stratigraphic units is illustrated on figures 11 and 12.

SECONDARY FACTORS

We shall now turn to the secondary factors of the Sacramento Valley sedimentation.

Bottom currents undoubtedly were a major factor of deposition. The usual causes of such currents were modified in the nascent Sacramento Valley, toward the close of the Cretaceous, by its geographic position, with land emerging in the west and with streams flowing from the mainland in the east.

Judging from incomplete data on the Forbes sand, it came from several sources, in different parts of the valley, and was distributed by currents in a pattern which begins to emerge as new data come in. In the Beehive Bend area, it appears to have come from the north, grading into shale, which becomes limy, to the west. The Forbes sand also "shales out" into the Colusa sub-basin. The lower sand of this group is regionally better developed than the upper. In the Arbuckle area, the source of the sand appears to be in the west.

The generally better development of lower Forbes sand at the expense of shale appears to hold true for the Rio Vista basin, as well. The main source of the Rio Vista basin Forbes sand was in the east, but some of the sand came from the west. The same is true of the Kirby Hills area.

The distribution of the next higher sand, usually called the Winters (Maxwell), is very interesting. As already mentioned, north of Winters it merges with the higher Starkey sand (fig. 2) and is progressively truncated by the Capay; the remaining lower portion turns to shale to the north and east, and is completely absent in the northeastern quarter of T. 12 N., R. 1 W. Going west of Winters to the Pleasant Creek field, the lower part of the Winters sand also is seen to "shale out" before it is truncated by the Capay formation. Going south and east, the Winters sand spreads throughout most of the Rio Vista basin in a delta-like formation, turning to shale to the south and west, and wedging out up dip on the east side, with the middle part persisting the farthest. The production from the one-well Freeport field and the deeper production in the Walnut Grove area are accounted for by these phenomena superimposed on a broad arch.

Thus the main source of the Winters sand appears to have been somewhere west and north of Dunnigan Hills. Chances are that this sand is eroded older sand, reworked and redeposited. In the Natomas shelf area, and locally south of there on the east side, as well as in the south, there appear to have been other sources of contemporaneous sands, not genetically related to the Winters.

The correlation of the Winters-Kione sands, from the Rio Vista basin to the Colusa basin, presents formidable difficulties, and was at one time—and occasionally still is—a subject of controversy. It is generally agreed that the Kione sand is correlative with the so-called Sheffield sand of the Shell, Strat. Test No. 1 (sec. 31, T. 14 N., R. 2 E.), as shown on the A.A.P.G. cross-section (see plate 5). The latter sand, in turn, is approximately correlative with the "Weldonian" sand on the west side (see fig. 2) What is left of the lower Winters sand turns to shale and wedges out in the vicinity of the Rio Vista-Colusa basins hinge line. On the other hand, the top of the Kione (Wild Goose) sand, toward the west, is modified by the above-mentioned subsidence of the Colusa basin, to form the so-called Kione-Wild Goose interval. Going farther west, into the basin, the Kione sand becomes more broken, tending to turn to shale. Considering the regional tectonic and sedimentary setup, it must be assumed that the Winters-Starkey section has been truncated and "shaled out" at the south rim of the Colusa basin. North of there it is replaced by delta-like Kione-Wild Goose sand which has come from the east and north. Since the Kione is correlative with the Sheffield-Weldonian sand, and since the latter is definitely in the F zone of Goudkoff, the Kione also should be in the F zone.

A problem is introduced, however, by the fact that Foraminifera of the D-2 zone were found in the Cretaceous shale immediately above the Kione sand, below the Capay unconformity, indicating that this sand belongs in the E zone. This correlation is substantiated by the fact that going north and west toward the Beehive Bend field, the sand is correlative with those including the Hill-Elvidge sand, which definitely carries E zone Foraminifera.

At this point, it is pertinent to digress somewhat on the subject of paleontology as applied to the Sacramento Valley. This simple fact often seems to be overlooked: the Foraminifera were not just scattered throughout the rocks, either to help or to confuse paleontologists. Neither were there periodical rainfalls of different foraminiferal assemblages over the Valley, to mark the corresponding horizons. The "bugs" were living organisms, at home under the conditions of their time and environment—especially the environment—and utterly ignorant of their posthumous importance. They stayed on as long as the staying was good. When the conditions changed too radically, they either died or retreated to a more suitable abode. With the numerous and rapid facies changes going on in the Sacamento Valley, some specific environments might and did persist longer, in some areas, and the microfauna persisted with them. Such a situation is common throughout the sedimentary basins of the world. In the Sacramento Valley, more than in most places, the Foraminifera may have been confused as to their proper zones and horizons. In the middle of a basin, or in some marine embayment, they persisted higher in the section than in less favorable adjacent areas of the same age. Thus in Humble's Maxwell No. 1 well in sec. 7, T. 7 N., R. 3 E., F-zone Foraminifera (without *Marginulina jonesi*) were found halfway up in the Winters sand. In the Natomas shelf area, a detailed paleontological differentiation is just about impossible; in any event, it is inconsistent with the electric-log correlation. In the Arbuckle area, the G-zone assemblage appears to persist higher in the section than in the Beehive Bend area.

Generally speaking, foraminiferal assemblages are depressed in the section going from south to north and from west to east, from deeper marine to shallow marine —to continental conditions. With this in mind, and considering that the Winters and the Kione sands have been deposited in different subdivisions of the Sacramento Valley basin, and came from different sources, the incongruity of their E-log and paleo-correlations is only apparent. Paleontology notwithstanding, the "Kione-Wild Goose" sands are correlative with paleontologically older upper Forbes sand (fig. 2).

As mentioned before, the Kione sand becomes more broken, going west. Its complete "shaling out" was prevented by the narrowness of the basin, and by a development of equivalent—or nearly equivalent—sands coming from the west side. The E-zone sands in the vicinity of Willows, with the producing Hill-Elvidge sand among them, become less broken to the west and north. Their upper boundary with Eocene (Capay) sand is often indistinguishable on an E-log. The exact relationship between the eastern and western components of this horizon may never be determined because of the Princeton Gorge which has washed out their lateral contact.

During Kione-Forbes time a radical difference in the northern and southern halves of the Valley developed. In the north, the Capay almost everywhere rests on the Cretaceous Kione equivalent, though "sub-Capay" sands were deposited locally because of differential subsidence. In the south, the Capay lies on the truncated and thickening Starkey-Winters sands, and then on the Martinez-Meganos formations, farther south.

The Starkey sand is probably the last Cretaceous formation to be deposited. It grades into shale from east to west. The Martinez shale break closes to the north, because of the tilt of the Valley. Except for its top—the H. and T. Sand—the Starkey sand is strangely unproductive—so far—despite its position between two productive sand intervals.

The Meganos sand is one of the most productive in the Valley. Its most important body is in a belt from Rio Vista to Thornton and beyond that, getting progressively thinner, in that direction. West of the Midland fault, the Meganos sand is more broken and the entire section is thicker—an evidence of compensatory deposition on the downthrown side of an active fault. It appears to be missing on the west side—by "shaling out," truncation, or both—except for the Kirby Hills area where the Wagenet sand is supposed to be its equivalent. South of the Rio Vista-Walnut Grove area, there is a sand-free gap, down to the "Zuckerman" sand (fig. 7). South of that sand-free gap, the Meganos section is again developed, with the MacDonald sand on top. There is another relatively sand-free gap east of Maine Prairie, capped by the Millar-Midland sand—which also spreads over the Meganos sand east of the Midland fault. The sand-free gap in the south continues toward Walnut Grove as a Capay "channel", skirting the south and east sides of the River Island field area. The sand-free interval never descends below the Zuckerman sand. Going north, it becomes shallower and narrower. It is of interest that in the northern gap, the Zuckerman sand equivalent also is intact (fig. 7). It is also significant that the shales in both gaps are no younger than the sands enclosing them. It is therefore the contention of this author that these gaps are not channels carved out of the body of Meganos sand by Capay density currents, streams, etc. They rather are the standard section of the contemporaneous Rio Vista basin into which a delta protruded from the vicinity of Courtland, as outlined on the map (fig. 7). Another delta, originating in the south, was responsible for the MacDonald-Whisky Slough fields. The southern gap, being in the basin, remained free of sand. The northern gap, much narrower because of the sedimentation strike along the east side, was never completely free of sand. In addition it was capped by a blanket of reworked Meganos sand shifted over the truncated Meganos body and known locally as the Midland, Millar, and Capital sands.

To be sure, such a delta—as is the case of the present Mississippi delta—would be complicated by additional and true channels, either filled or not filled by the Midland sand. It is also possible that some currents may have been helpful in keeping the southern gap open. It is remarkable that they were uniformly careful not to abrade the Zuckerman sand!

At Walnut Grove, the western wall of this "channel" provides an excellent closure for Meganos production.

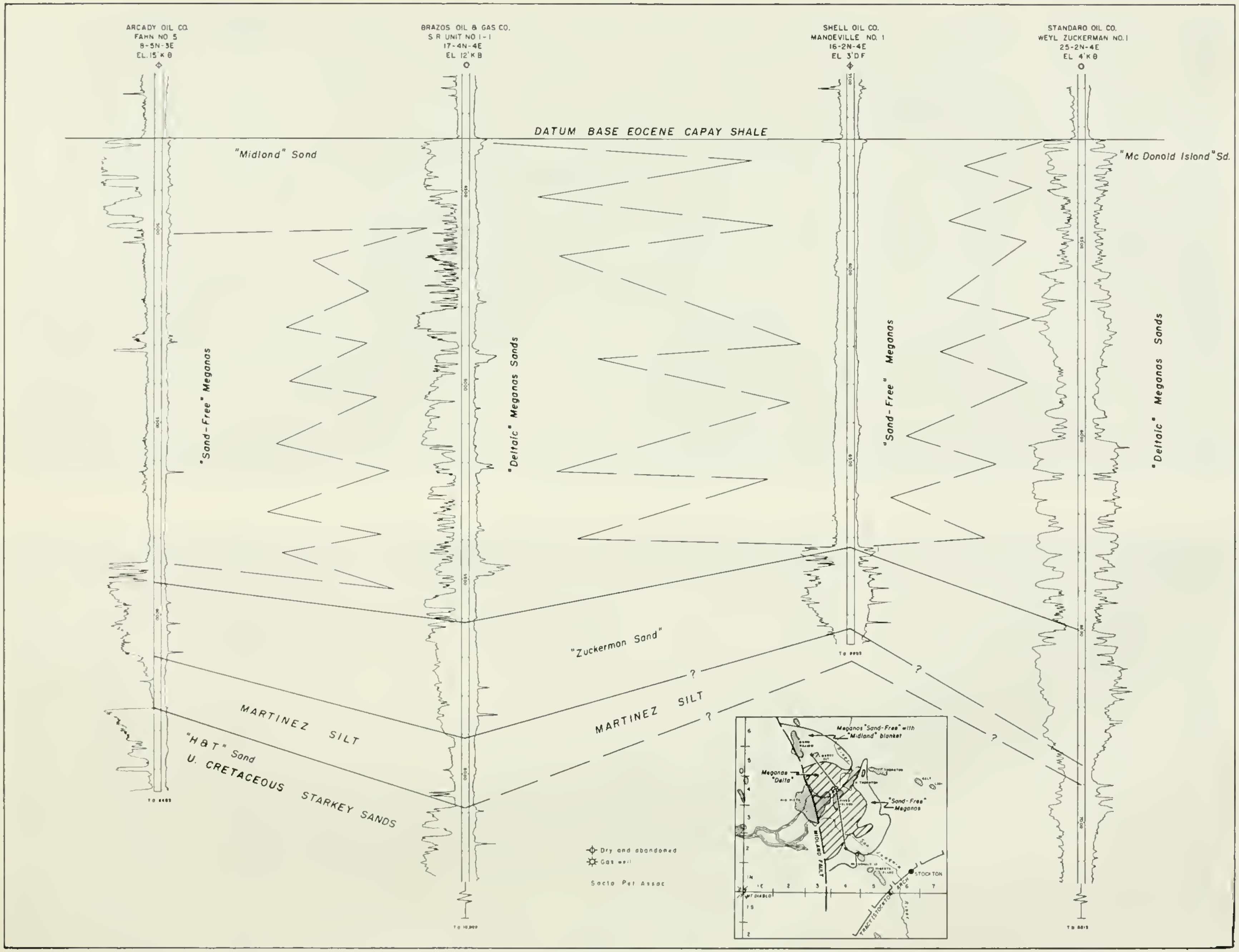


Figure 7. Cross section illustrating the structure of the Meganos delta in the vicinity of River Island. For location of section, see Index map 1.

A deltaic origin of the Meganos sand is also suggested by its semi-continental nature, with abundance of plant remains and with a few thin streaks of lignite. Incidentally, it is very probable that most, if not all, of the Meganos gas originated right there. The Wagenet sand of the west side does not have the continental features of the east-side Meganos sand. Obviously, it has come from a local source in the west.

Everywhere on the east side, and along the middle and northern stretches of the west side, the Capay becomes sandy to gravelly, indicating the proximity of the shore. In the northwest, beyond the wedging out of its marine facies, it is represented by facies of the Princeton Gorge (fig. 10). Unlike the southern "channels", the Princeton Gorge is definitely an erosional feature. It trends from south to north, just west of the Sacramento River, a few miles north of Colusa, and on to the Beehive Bend field, into which it cuts. North of Beehive Bend it widens, the main trend being to the northeast, by way of the Perkins Lake field. A southwesterly branch of the Gorge passes in the vicinity of Maxwell. The Princeton Gorge probably represents a canyon of what may have been the ancestral Sacramento River. Its origin possibly was helped by a north-trending fault zone, evidence of which is present immediately west of the Comptons landing field. East of there, the true marine Capay of the Valley is seen wedging out against the high trend along the river, as mentioned before. It is this author's theory that the mouth of the Gorge lies immediately northwest of Colusa, where the Gorge joins the main Capay basin. In plan, the Gorge area is funnel-shaped, very much like that of the younger Sacramento Canyon (Markley Gorge) in the south. Locally (Perkins Lake) the basal sand of this Gorge, in contact with the Cretaceous, is productive.

A system of more or less erratic Capay sands is developed over the Meganos delta in the Isleton-River Island area. It has produced a considerable amount of gas, for its size. It undoubtedly was dropped by currents slowed down by shallow places.

Developed in the same area is a system of true, although shallow, channels of the so-called River Island sand—a transition from Capay to Domengine. In these channels, Capay shale and fine- to medium-grained, pepper-salt sands are scoured out and replaced by well-rounded, coarse, channel sand. An isopach map of the interval from the base of this sand to the top of the Midland is given in figure 8. The shortest remaining intervals represent the deepest scouring, and the deepest part of the channel. The resulting dendritic pattern is spread over the delta and is obviously reflected to the north by the Rio Vista structure. The small and erratic production from these sands, unexplainable by structure alone, becomes very rational if the channel pattern is superimposed on a structural map. The production comes from the channels with faults immediately east and updip.

After Capay time, the sanding up of the Sacramento Valley proceeded, interrupted only by the more restricted Nortonville-Markley sea transgression. The Domengine sand coming mostly from the east and partly from the south and southwest, spread over practically the entire valley, thinning and "shaling out" only in the vicinity of Winters. Like the Meganos, it becomes more continental in character toward the east, where it carries numerous plant remains. Far on the east side and in the south, it forms a single body with the Nortonville sand. The Nortonville shale gap appears and grows wider, westward, with productive sand streaks similar to those in the Capay developed in the River Island-Isleton-Rio Vista area. The shale gap widens because of currents from the southeast which apparently slowed down over shallow places and deposited more of their load. In the Rio Vista basin, the Nortonville-Markley contact becomes practically indiscernible on the electric log.

The Markley itself, approaching a continental phase in the east, thickens rapidly and becomes marine, going west, in the Rio Vista basin. Its thickness in the deepest part of this basin points to the magnitude of the differential movement of that time.

A body of Markley shale and sand is present in and east of the Liberty Farms area in the so-called Markley Gorge (fig. 10) which might more appropriately be called the Sacramento Canyon. This is another true erosional feature, somewhat like the older Princeton Gorge. It is funnel-shaped and opens to northeast, with the Markley resting progressively on older Paleocene-Cretaceous horizons, from west to east. On either side of it, there is the standard Rio Vista basin section, expressed in the familiar E-log pattern of sand and shale. Going into the channel from either side, the Markley is seen to cut off progressively deeper horizons, beginning with the Nortonville. The axis of the channel hugs its southeastern side. A profile of the channel, drawn to scale both vertically and horizontally, some distance away from the Midland fault zone, looks like that of a valley having side slopes of about 1:5. The axial part appears to be deepened, with steeper walls. The maximum depth of the channel is about 1200 feet. Regionally, it is located on the northwestern wing of the southwest-trending, broad Freeport nose. It is undoubtedly the canyon of another stage of an ancestral Sacramento River, whose location and course was determined by the Freeport nose and by the fault system on it. After its subsidence, the canyon may have been further scoured by density currents.

This feature transversely cuts the northwest-trending Liberty Farms anticline, eroding some of its would-be productive beds at the top of the structure. In the Liberty Cut, the channel fill provides a closure for upper Domengine production.

There is still another and much smaller Markley channel in the Walnut Grove area, superimposed directly above the Capay gap. It does not cut deeper than the Domengine sand. It may be a branch of the Sacramento Canyon; on the other hand, there is evidence of its trend to the south, toward the main Rio Vista basin.

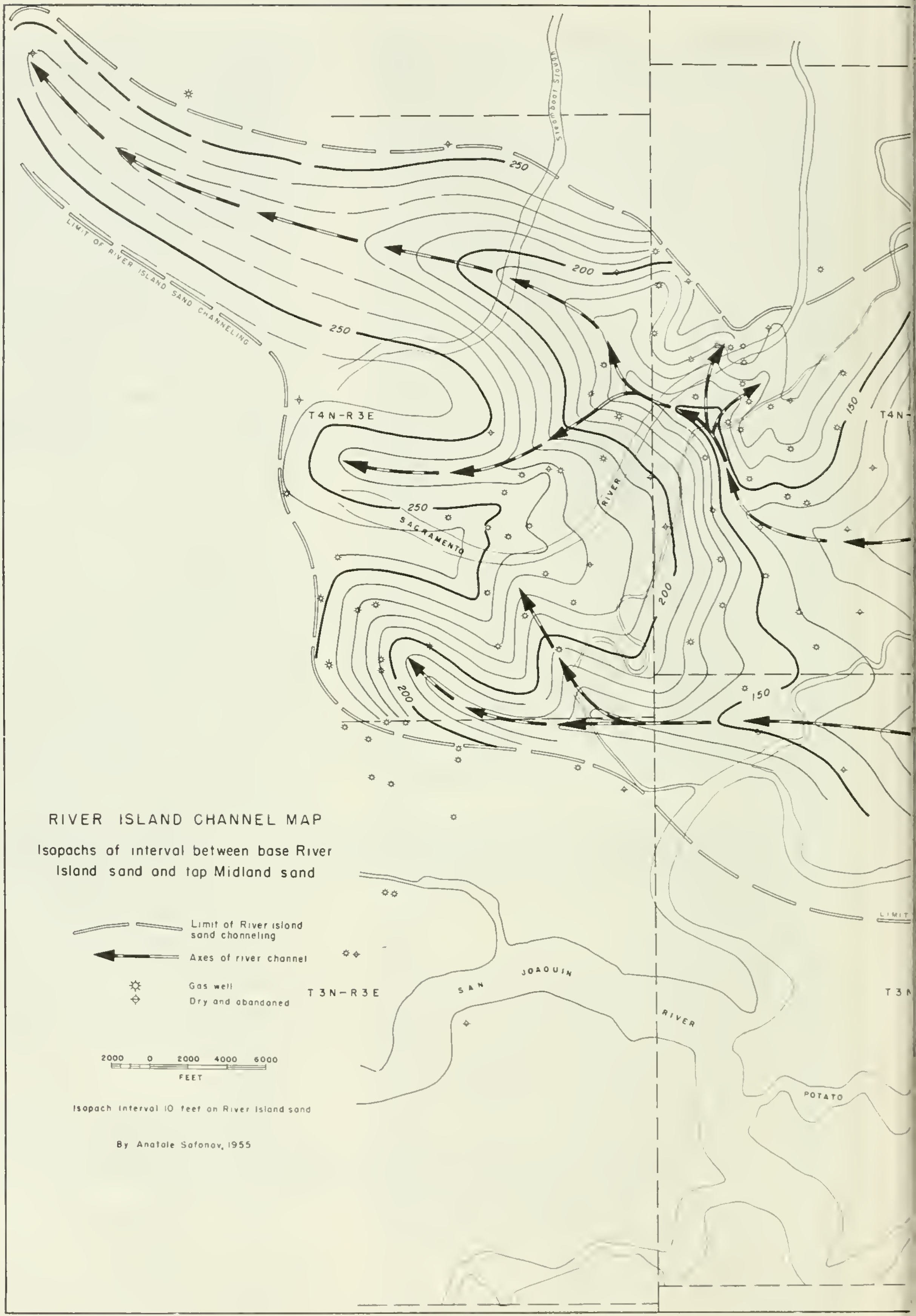
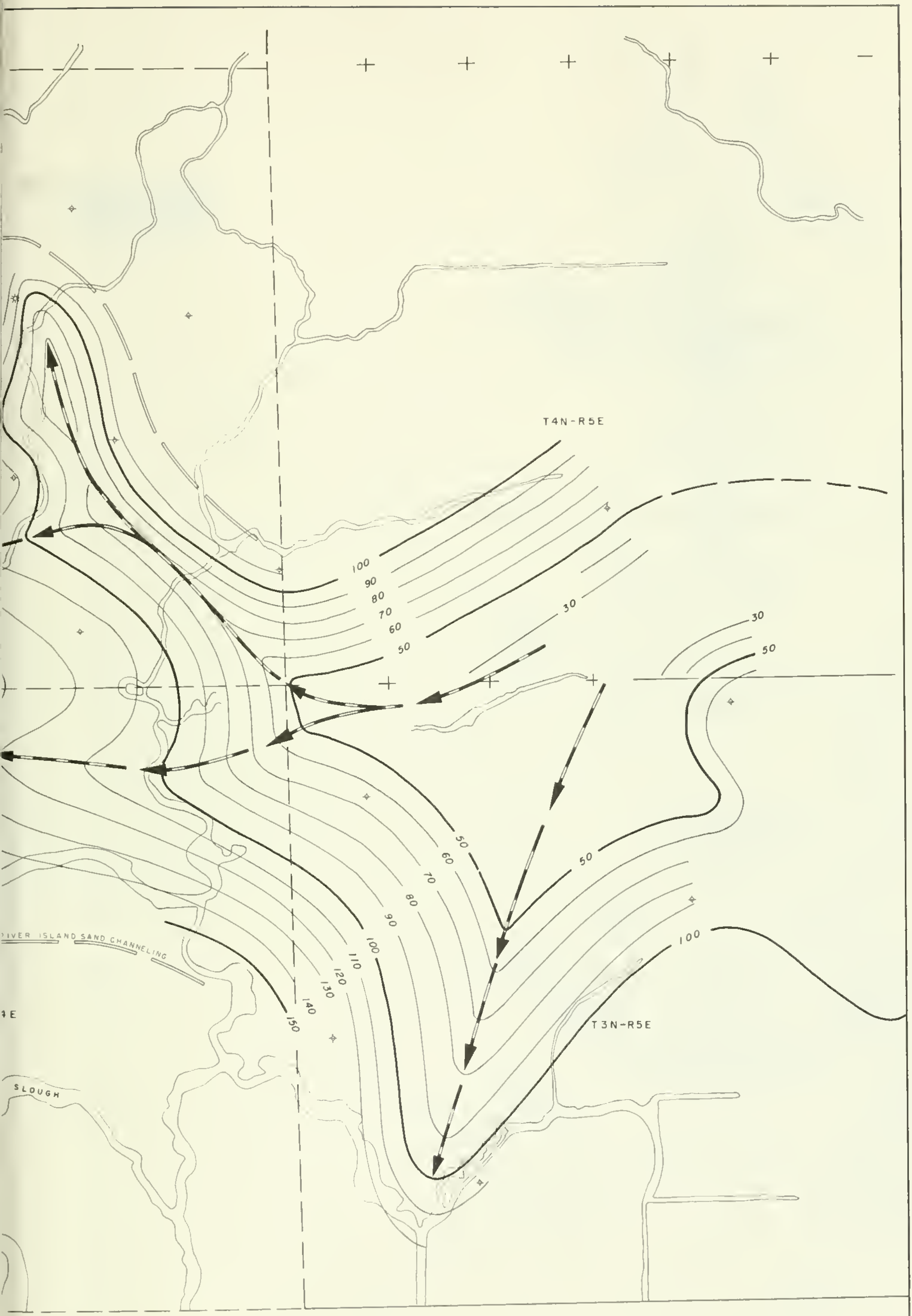


Figure 8. Subsurface channeling in the vicinity of River Island. Isopach map showing the interval between the base of the River Island sand and the top of the Midland sand.


T4N-R5E
100
90
80
70
60
50
30
30
50
50
60
70
80
90
100
110
120
130
140
150
50
100
T3N-R5E
IVER ISLAND SAND CHANNELING
SLOUGH

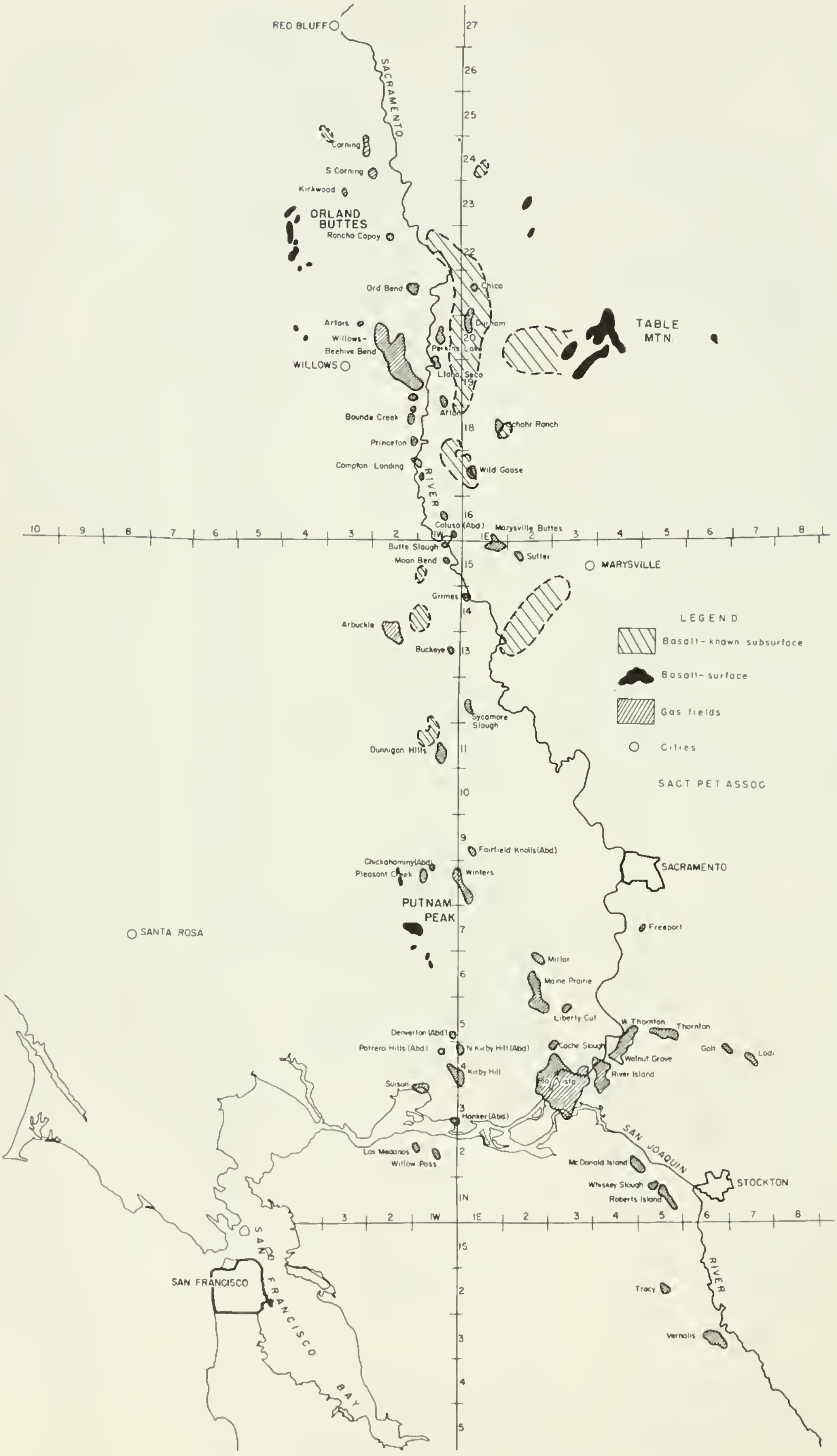
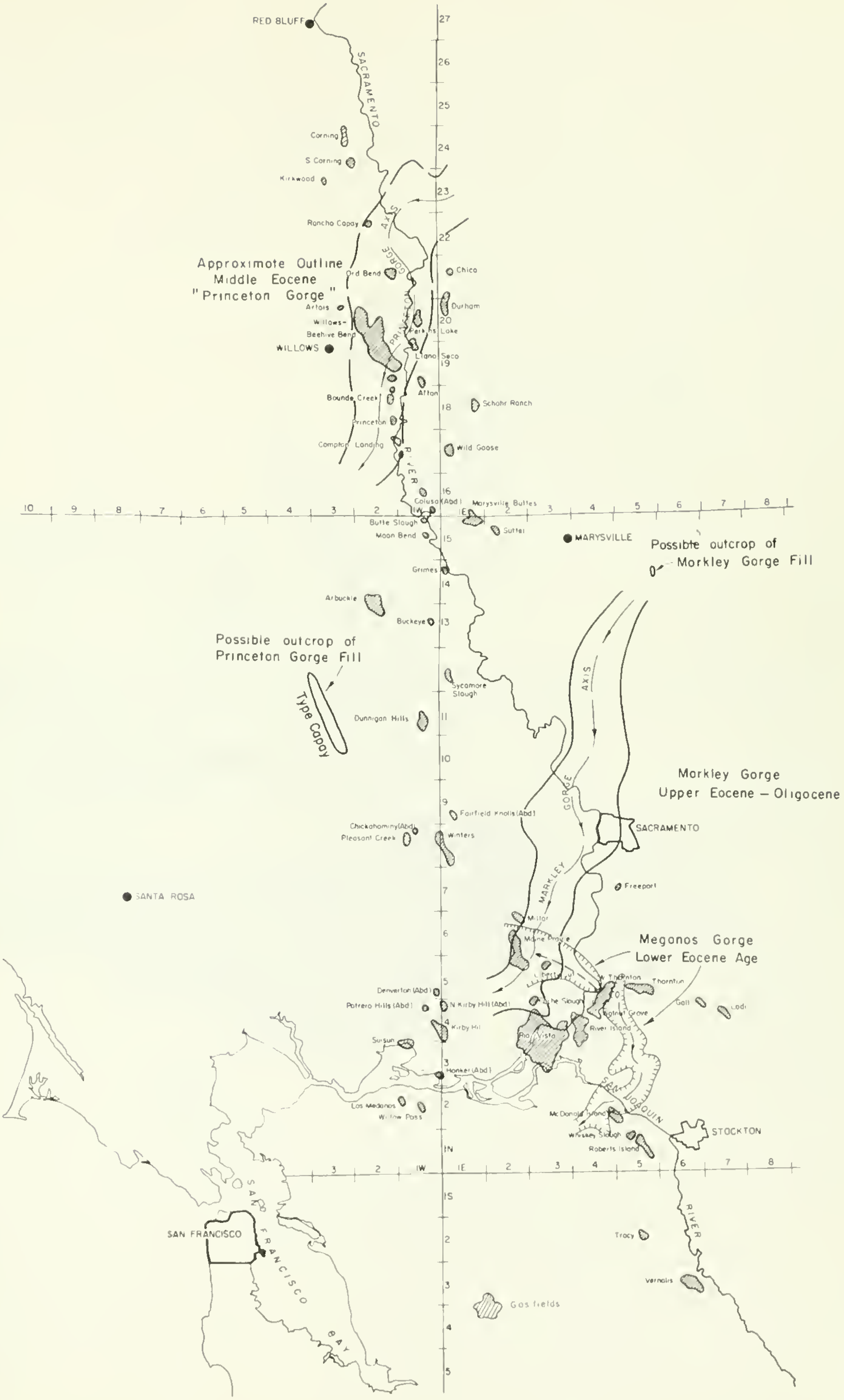
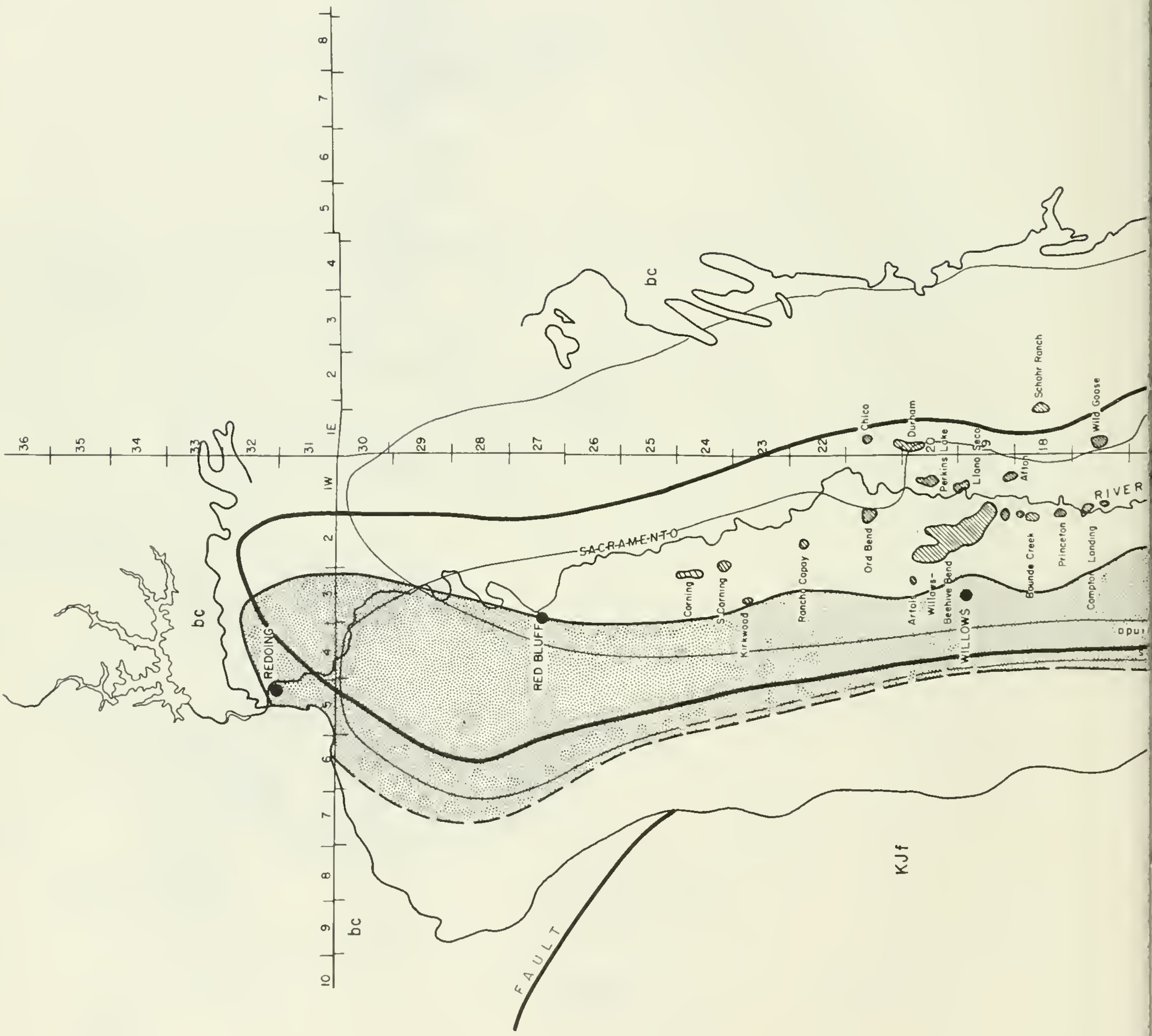


Figure 9. Surface and subsurface distribution of Tertiary basalt in the Sacramento Valley.

Figure 10. Map showing the position of the Eocene gorges in the Sacramento Valley.




REDDING
RED BLUFF
WILLOWS
SACRAMENTO
RIVER
bc
bc
bc
KJf
FAULT
Corning
S. Corning
Kirkwood
Rancho Capay
Ord Bend
Chico
Durham
Perkins Lake
Llano Seco
Afton
Schohr Ranch
Wild Goose
Artois
Willows-Beehive Bend
Bounde Creek
Princeton
Compton Landing
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
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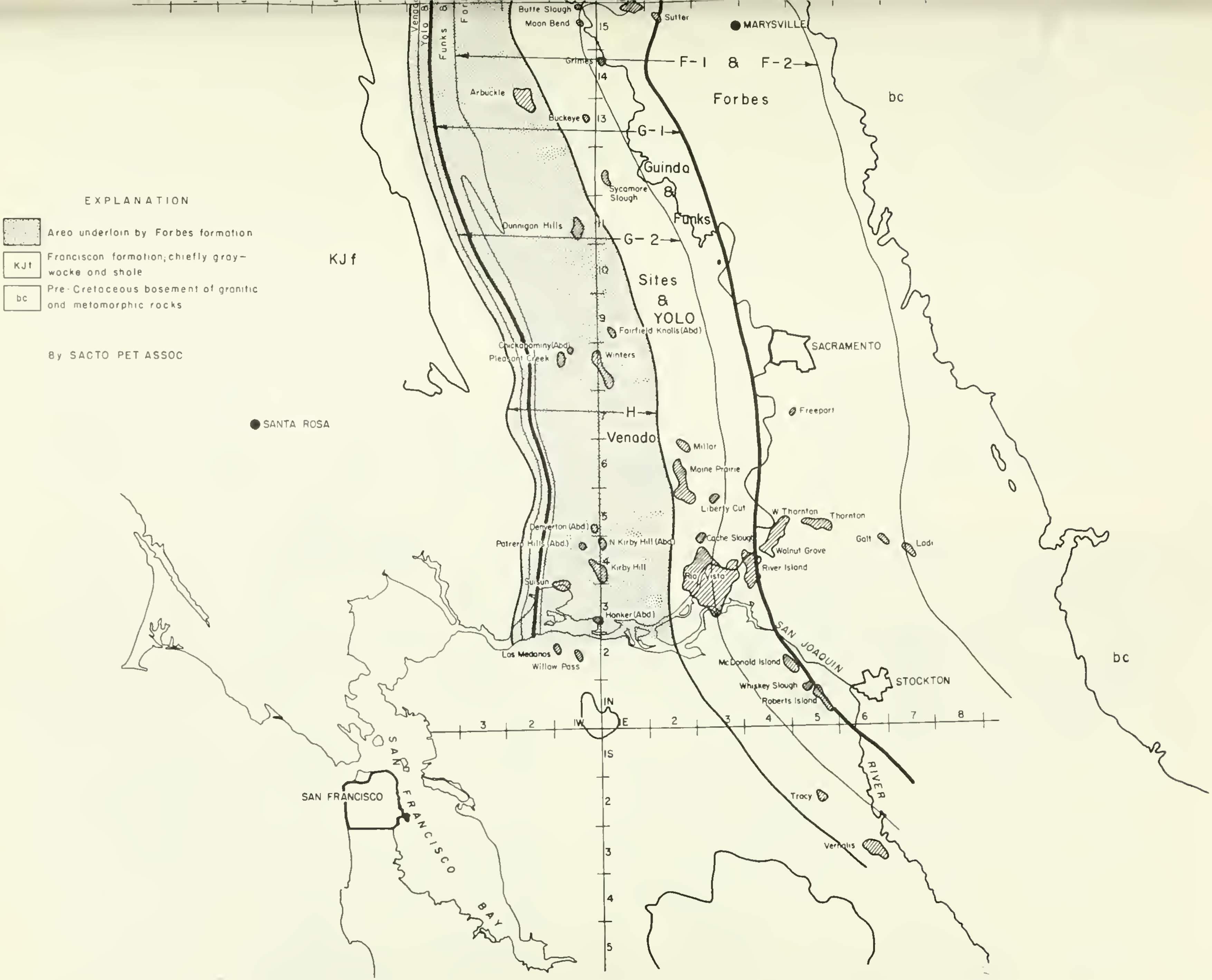


Figure 11. Paleographic map showing distribution of the Upper Cretaceous Venado through Forbes formations in the Sacramento Valley.

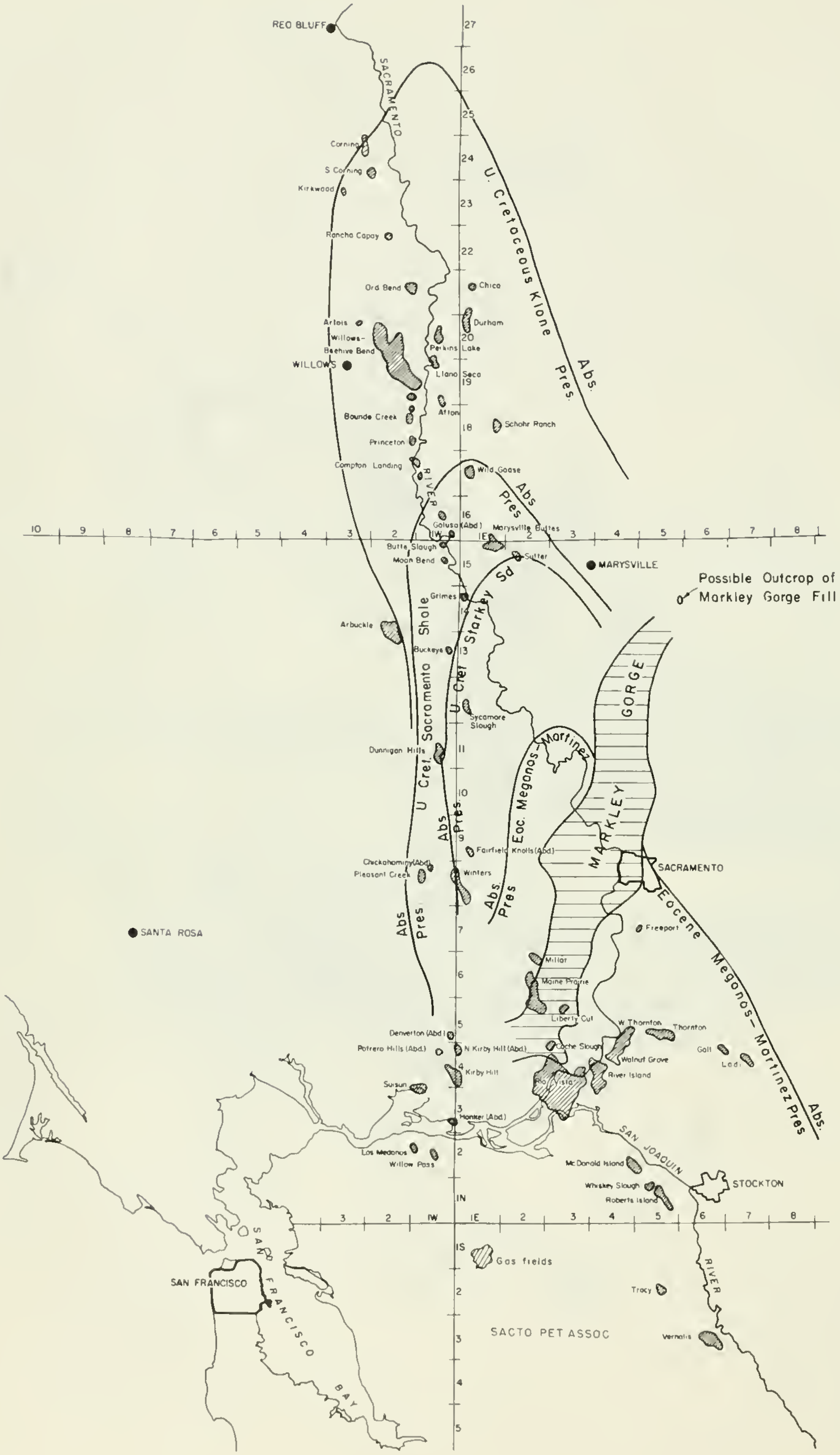


Figure 12. Map showing distribution of the lower Eocene Martinez and Upper Cretaceous Kione formations in the Sacramento Valley.

At the close of the Eocene, the "sanding-up" of the Sacramento Valley was practically complete, with marine Oligo-Miocene lingering only in the southern part of it (Valley Springs). It is possible that an Oligocene and later channel persisted in the Sacramento Canyon. Such an assumption would bring solace to those geologists who argue for a younger-than-Markley age of that feature.

Igneous activity is expressed in the Sacramento Valley, besides the Marysville Buttes, in diabase dikes cutting the G-sands in that vicinity; in volcanic ash, especially noticeable in the Nortonville of the Delta area; and in islands of a basalt flow, scattered throughout the northern part of the Valley, especially toward its east side (fig. 9). The basalt attains a thickness of 150 feet. It has nuisance value only. It interferes with shooting and makes drilling more expensive. The Nortonville bentonitic shale, although easy to drill, may cause trouble if drilled without regard to water loss: it swells, and may bridge the hole for the E-log run. Some bentonitic streaks are present in the Cretaceous shales, as well.

SUMMARY

It should be clear from this brief review that the tectonics of the Sacramento Valley, as reflected in sedimentation alone, is quite a problem. Taken in conjunction with its structural expression—in major and minor faults, high rrends, and local structures—it makes the geologist's problem difficult.

The Sacramento Valley, being part of the extremely mobile circumpacific belt, shares in its mobility, with differential movements taking place either prior, during, or after the deposition of any given sand body. In the two first instances the deposition of the sand is affected by the structure. The distribution of gas is affected by any combination of these.

When the Upper Cretaceous sea invaded what is now the Sacramento Valley, it apparently transgressed a Jurassic surface of schist and igneous rocks on its east side, although comparatively few wells reached the basement. This sedimentation was of flysch type, with alternating sandstone, claystone and silt, and with increasing thin limy streaks to the west. The three major factors—the southerly tilt of the valley, the rise of the west side, and oscillatory and differential movements—brought about a discrete although complicated process of "sanding up." It started in earnest with the deltaic deposition of the Kione and correlative sands, in the north, and of the Winters sand in the south. By that time, the Valley was differentiated into three sub-basins: the Rio Vista, the Colusa, and the Chico. The two northern sub-basins soon became a cul de sac, the dead end of the Valley, while the Rio Vista basin persisted into post-Eocene times.

Because of the islands in the west, eventually merging into land, and because of the influx of fresh water from the continent to the east, most sediments of the Sacramento Valley proper were laid down under conditions not truly marine. Perhaps this is the reason for the absence of oil in the valley, except for seeps on the west side and the solitary occurrence in the Winters area. There may be more of such oil near the west side and especially toward the south. The probability of oil on the east side is rather slight. The oxidation-reduction conditions there were more favorable to the generation of gas; and the early uplift of the west side created dips that would have prevented an easterly migration of any oil that might have been formed there.

The time element has gained a general recognition among geologists. Geology has become four-dimentional. This fourth dimension is by no means of purely academic interest in petroleum geology. If a structure is formed after the hydrocarbons or their carrier waters have passed by its site, such a structure will be one of those "geological successes." This is of particular moment in the Sacramento Valley, because of its high mobility. Each new movement, either regional or differential, disturbed the hydrodynamic equilibrium of the valley. It also may have broken up old traps and creared new ones.

A decrease or an increase in the formation pressure, as a result of vertical movements, would correspondingly liberate some solution gas or send some more gas into solution, thus modifying the nature of its migration and capture. A continuous influx of gas-saturated water from depressed to uplifted areas would contribute to the growth of open gas pools. The confined gas pools would keep their original pressure—"abnormal" under the new conditions. These new traps are extremely hard to find because of the complexity of the factors controlling them.

For instance, there does not seem to be any good reason why the Colusa structure—one of the best in the Valley—does not produce from the Wild Goose sand, except for the fact that its top touches the continental Tehama sand. Thus an escape for the gas may have been provided. On the other hand, there does nor seem to be any special reason why the Tehama continental beds should produce in the Corning dome except for the fact that the gas has migrated into it from the underlying Cretaceous sands. The above-mentioned River Island channel-sand production, however small, is very significant because it graphically illustrates the peculiar aspect of the Sacramento Valley geology: its facies-to-structure relationship. What is true for the River Island sand is true for the Valley as a whole—except that we know more about the River Island area.

It is a basic premise of petroleum geology that oil and gas occur in anomalies—structural, sedimentary, or both. In order to recognize an anomaly, one has to know what the normal situation is. In the Sacramento Valley, a "normal" situation is hard to come by, because of the many factors disturbing it. By the same token, there is an abundance of "abnormal" situations—and with them the opportunity for the accumulation of gas, and perchance of oil.

TYPICAL GAS FIELDS OF THE SACRAMENTO VALLEY, CALIFORNIA

By MEMBERS OF THE SACRAMENTO PETROLEUM ASSOCIATION

Plate 6, Penetration chart of oil and gas fields of the Sacramento Basin, accompanies this report.

Plate 7, Cross section A-A′, Dunnigan Hills gas field, Plate 8, Cross section B-B′, Dunnigan Hills gas field, and Plate 9, Cross section C-C′, Dunnigan Hills gas field, accompany Contribution 6 of this report.

The following paper, *Typical gas fields of the Sacramento Valley, California,* consists of eight Contributions by members of the Sacramento Petroleum Association—Contribution 1, *The Corning and South Corning gas fields, California,* by the Sacramento Petroleum Association; Contribution 2, *Perkins Lake gas field, California,* by Tod P. Harding; Contribution 3, *Willows-Beehive Bend gas field, California,* by James H. Alkire; Contribution 4, *Wild Goose gas field, California,* by Arthur S. Hawley; Contribution 5, *The Arbuckle gas field, California,* by Richard H. Vaughan; Contribution 6, *Dunnigan Hills gas field, California,* by Rafael Rofé; Contribution 7, *Maine Prairie gas field, California,* by the Sacramento Petroleum Association; and Contribution 8, *Thornton and Walnut Grove gas fields, California,* by J. H. Silcox.

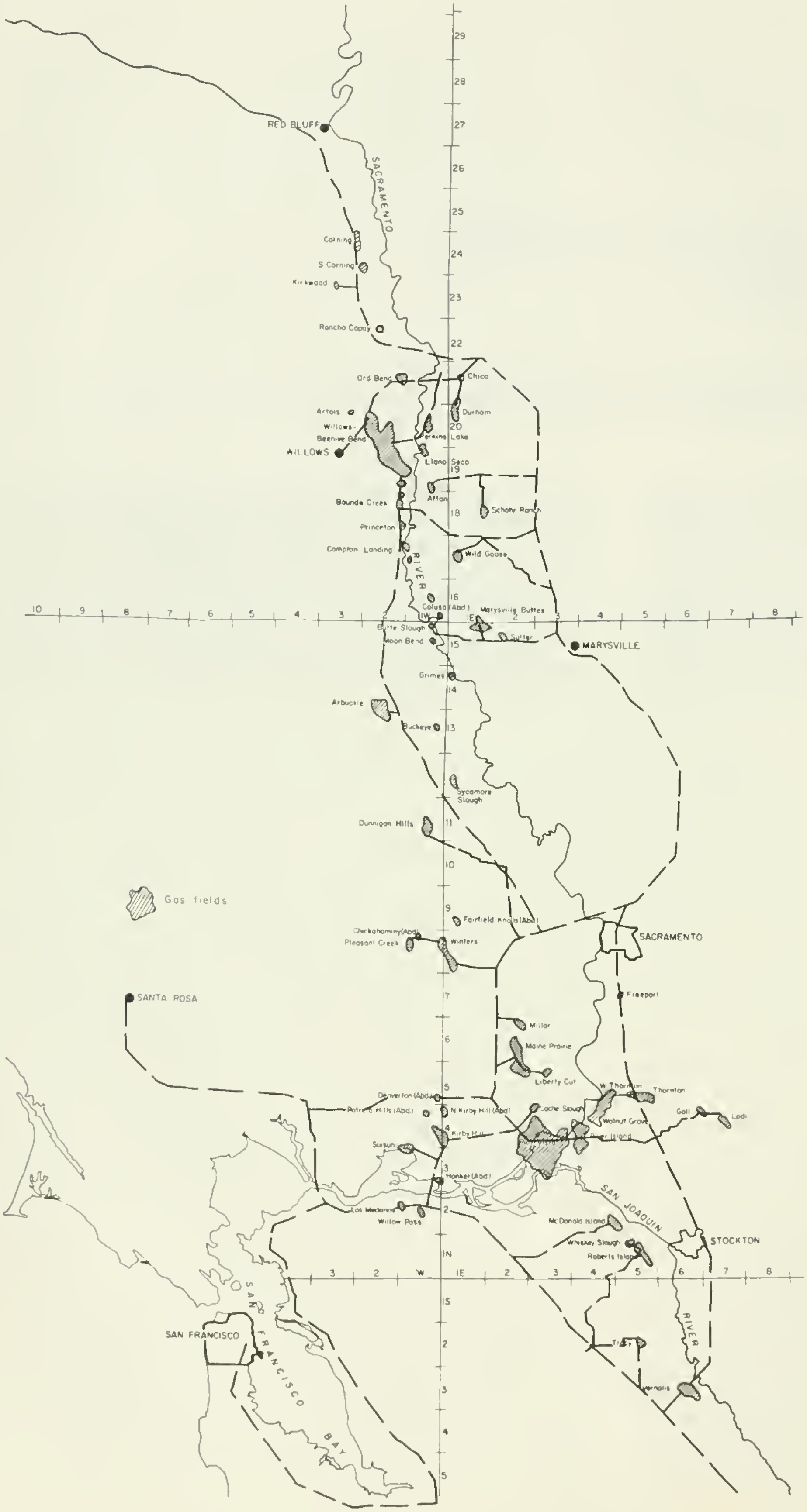


Figure 1. Gas pipelines in the Sacramento Valley.

Contribution 1

The Corning and South Corning Gas Fields, California

By Sacramento Petroleum Association

The Corning anticline is one of the major structural features of the Sacramento Valley. It is located in Tehama County, in the north-central portion of the Valley immediately east of the city of Corning, about 4 miles west of the Sacramento River.

Physiography. The anticlinal structure was recognized early in the exploration history of the Sacramento Valley because its trend is marked by topographically high areas. The Corning Hills comprise two groups, one situated immediately northeast of Corning, the other centering approximately 3½ miles to the southeast of the city. The maximum elevation of the hills is slightly more than 300 feet, and they rise about 50 feet above the surrounding alluvial plain.

Additional physiographic and geologic evidence for the structure includes dip slope reversals, oversteepened stream gradients, and the fact that Pleistocene Red Bluff gravel comprises the flanks and lower elevations of the structure, whereas the crest exposes the underlying Pliocene Tehama formation.

Exploration and Development. Probably because of its physiographic prominence, the Corning structure was chosen for one of the first deep tests in the Sacramento Valley, the Northern Counties Petroleum Company's Ewers-Mooney No. 1 well, in sec. 25, T. 24 N., R. 3 W. This well was spudded on August 7, 1934, and abandoned on August 6, 1936, at a total depth of 8253 feet. The 228 cores taken represent one of the most completely cored Cretaceous sections in the Sacramento Valley.

In 1944, the Superior Oil Company drilled the Saldubehere No. 1 well in sec. 12, T. 24 N., R. 3 W., a 9225-foot test on the Corning North Dome. After several unsuccessful tests in the Cretaceous portion of the hole, the well was completed on October 22, 1944, as a dual gas-producer in the nonmarine Pliocene Tehama formation, flowing a combined 17,676 Mcf/D through a 1-inch bean with 380/485 psi (pounds per square inch) flow pressure and 660/545 psi shut-in pressure. Perforations were in the intervals 1200-1300 feet and 1387-1504 feet, with a production packer at 1366 feet. The completion of this well marked the northernmost production in the Sacramento Valley—a distinction which the Corning gas field still holds. To the present time 14 producers and 4 dry holes have been drilled in the North Dome area. All production is from four separate sands in the basal Tehama formation.

On February 1, 1951, the Buttes Oilfields, Inc. (now the Buttes Oil and Gas Company) completed Saldubehere 1A in sec. 25, T. 24 N., R. 3 W. as the discovery well of the South Corning gas field. Initial production was 10,000 Mcf/D through a 1-inch bean in the Tehama interval 1560-1590 feet. Closed-in pressure was 660/660 psi. Tehama production at the South Dome at the present stage of development appears more restricted, both vertically and areally, than at North Dome. There are two producing Tehama sands in the South Dome—the discovery sand in Saldubehere 1A which is believed to be the equivalent of the Third gas zone of the North Dome, and a thin, unnamed shallow zone believed to be stratigraphically higher than the highest producing horizon at North Dome.

In 1959, Buttes Oilfields, Inc. completed its Saldubehere A-5 in sec. 36, T. 24 N., R. 3 W. as a deeper-pool discovery in the South Corning gas field. Production is from the Upper Cretaceous Kione sand about 500 feet below the base of the Tehama. Perforations in the interval 2340-2354 feet yielded initial rates to 16,970 Mcf/D through a 1-inch bean with 638 psi flow pressure and 945 psi shut-in pressure. This marked the first Upper Cretaceous production on the Corning trend. The extent of this pool is not yet determined. To date four wells have produced gas in the South Corning field.

Structure and Stratigraphy. The diagrammatic cross section at the side of the accompanying figure 2 illustrates the stratigraphy of the Corning anticline area and shows the relative position of the various producing sands in the two oil fields.

The subsurface structure of the Corning area is also illustrated in figure 2. Contours are drawn on top of the Third gas zone as illustrated on the typical electric log adjacent to the contour map. The North Dome appears to have a maximum of 400 feet of closure within the Tehama, half of which is productive closure. By contrast, the Tehama structure of the South Dome area is more gentle, with a maximum of about 50 feet of actual and productive closure. The presence of the cross fault at the north end of the field is assumed on the basis of the exceptionally low wells on the north. Its alignment is uncertain. Cretaceous structure is unknown because of the lack of adequate well penetration.

The cross section clearly illustrates the progressive overlap of Cretaceous beds in a northerly direction by the basal Pliocene unconformity. This may account for the unusual presence of natural gas in the nonmarine rocks of the Tehama formation. The gas could have originated in the underlying Cretaceous beds and migrated upward into the highly porous basal sand and conglomerate of the Tehama formation.

Production. The Corning and South Corning gas fields first started producing gas in July 1954. Cumulative production of the two fields to January 1, 1960, was 6,128,264,000 cubic feet.

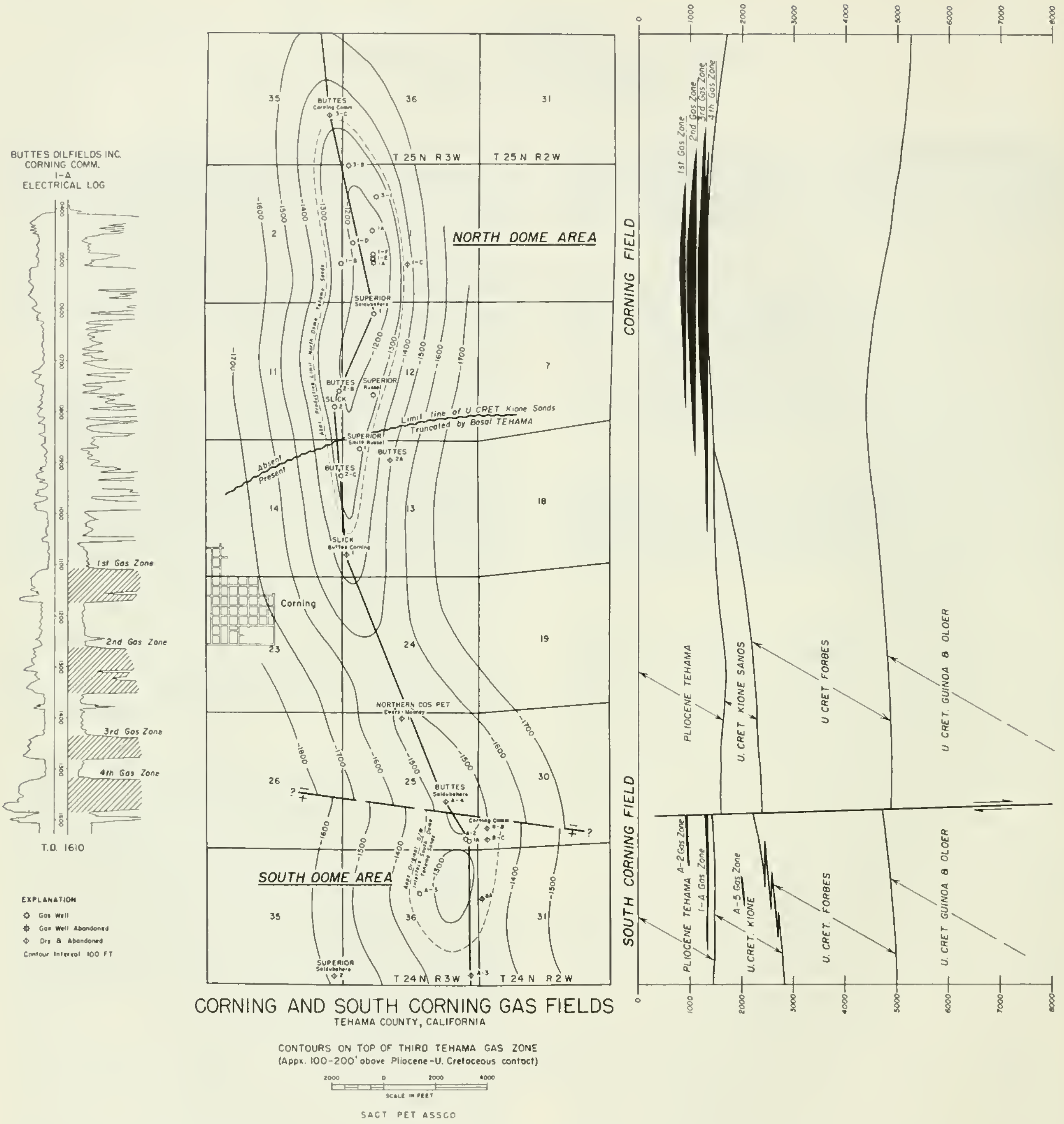


Figure 2. Structural contour map of the Corning-South Corning gas fields, Tehama County, drawn on top of the third Tehama gas zone.

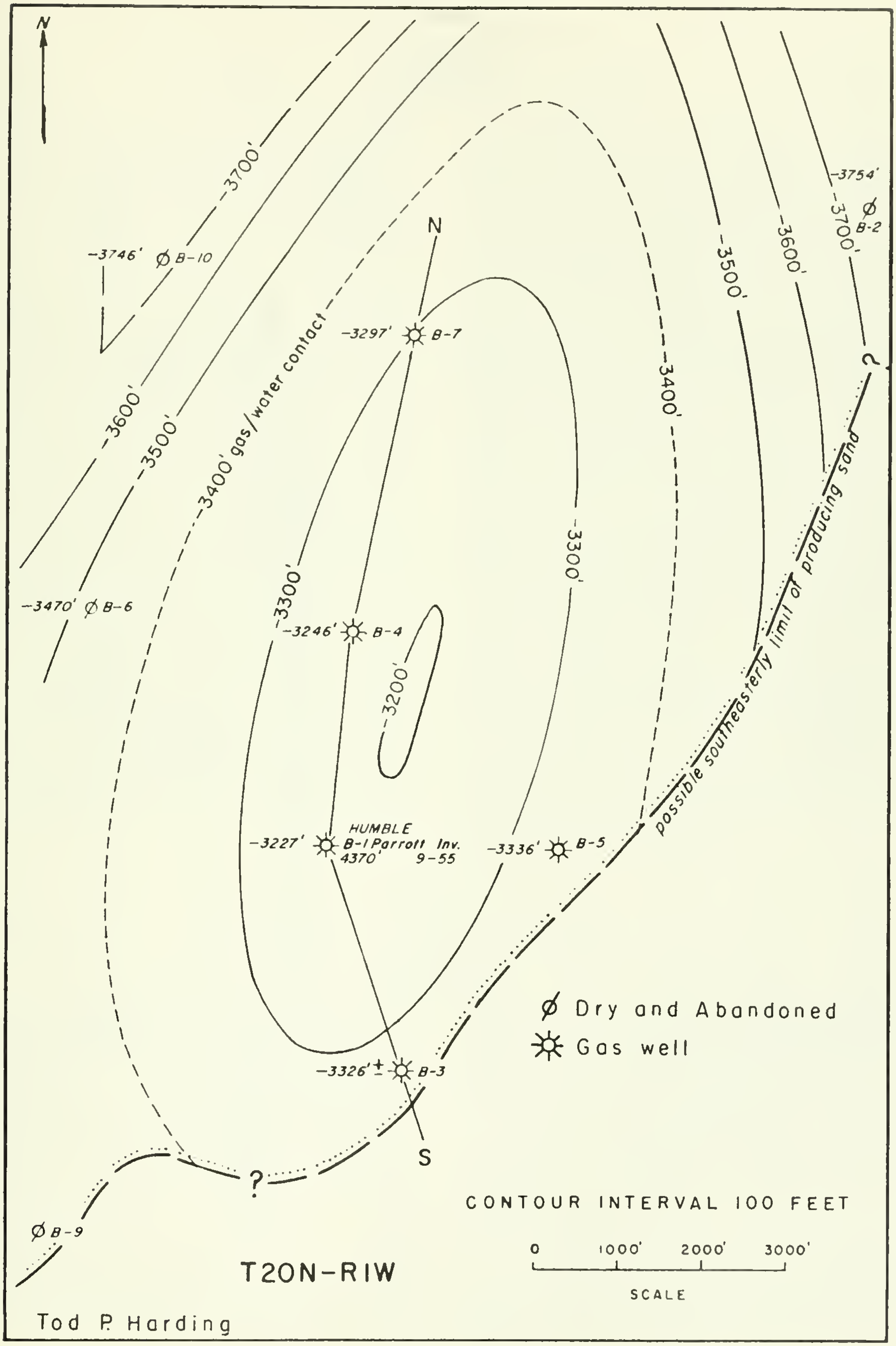


Figure 3. Structural contour map of the Perkins Lake gas field, Butte County.

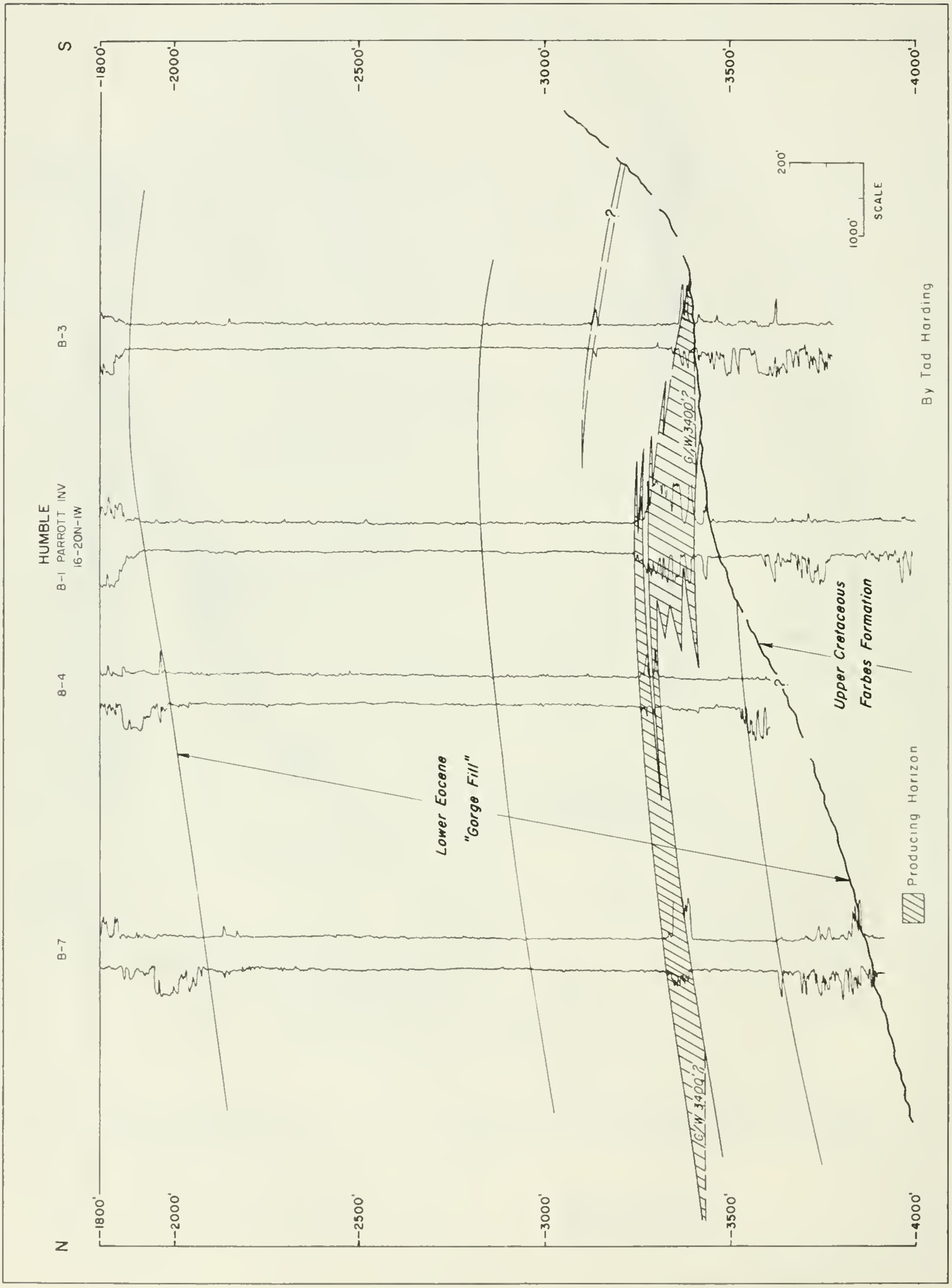


Figure 4. North-south cross section through Perkins Lake gas field.

Contribution 2

Perkins Lake Gas Field, California

By Tod P. Harding
Humble Oil and Refining Company, Los Angeles, California

The Perkins Lake gas field is located in the northern portion of the Sacramento Valley in Butte County, 75 miles northwest of the city of Sacramento. The field was discovered by the Humble Oil and Refining Company in September of 1955 after a seismic survey had indicated the presence of an anticlinal structure in the area. The discovery well, the Humble Parrott Investment Company No. B-1, located in projected sec. 16, T. 20 N., R. 1 W., was completed for 4,060 Mcf per day of 940 BTU dry gas through a ⅜-inch choke. Production came from perforations opposite the interval 3,365-3,390 feet.

The Perkins Lake gas accumulation is a result of stratigraphic variations within the lower Eocene and localized entrapment on an anticlinal fold. The structure is an elongated, generally north plunging, anticline with approximately 200 feet of closure (fig. 3). Part of the closure may be provided by a transgressive southward overlap of the producing sands along a regional unconformity. The productive area covers approximately 1,350 acres. There are five producing wells and four dry holes, one of which was a test to 6500 feet.

The main producing zone is composed of lenticular marine sands and conglomerates interbedded with thin discontinuous shale beds, and is lower Eocene in age. Thickness of the zone ranges from 25 to 175 feet and rapid lateral variations in lithology are common. An 8-foot sand lens is present and productive 160 to 220 feet above the main zone in two wells in the southeast portion of the field. The main producing zone is overlain by 1220 to 1570 feet of lower Eocene shale which, except for this one sand lens, is notable for its lack of interbedded silt or sand. Underlying the producing horizon are the interbedded sands and shales of the Upper Cretaceous Forbes formation. The contact at the base of the Eocene is a pronounced angular unconformity which dips to the north and cuts out progressively older Upper Cretaceous beds in that direction. As the contact drops in the section, lower Eocene sands and shales lap off the unconformity. At the northernmost producing well there is 450 feet of lower Eocene below the producing horizon while at the southernmost well these beds have been transgressively overlapped, and the producing horizon, here only 25 feet thick, rests directly on the Upper Cretaceous (fig. 4).

Well control south of the Perkins Lake gas field indicates that the unconformity at the base of the Eocene rises 1000 feet vertically in this direction in a distance of only 1 mile. As the contact rises, the lower Eocene beds above continue to "lap out" while progressively younger Upper Cretaceous beds appear below. Additional control indicates that the contact rises abruptly again north of the Perkins Lake field where the 1275 feet of Upper Cretaceous beds, truncated to the south, reappear. Regionally, this erosional feature has the appearance of a buried valley, submarine canyon, or gorge. The Perkins Lake production is derived from a basal member of the gorge fill, the producing horizon most likely being a local bar deposited on a terrace or structural nose on the side of the gorge. The gas accumulation has in part been caused by this initial trap.

At the end of 1959 cumulative production was 6,754,706 Mcf; expected ultimate recovery is approximately 42 billion cubic feet of dry gas.

Contribution 3

Willows-Beehive Bend Gas Field, California

By James H. Alkire
Mobil Oil Company

History and Production Data. The Willows-Beehive Bend gas field contains the largest natural gas reserves of any California field producing from sediments of Cretaceous age. It is centrally located in the Sacramento Valley, 70 miles north of Sacramento. Ohio Oil Company discovered the field in 1937 by drilling the Willard No. 1 (sec. 18, T. 20 N., R. 2 W.) on the crest of a seismically defined anticline. The Willard No. 1 blew out of control, and the Willard No. 1-A, a relief well, was the first producer. Only minor reserves were developed as a result of this new field discovery.

In 1953, additional shallow gas reserves were located by the Estes No. 1 well in sec. 18, T. 19 N., R. 1 W., the discovery well in the Beehive Bend area. Sunray Mid-Continent Oil Company drilled the Estes No. 1 on acreage farmed out by the Ohio Oil Company. A deeper pool discovery, the Richard S. Rheem, Zumwalt No. 1-63 (sec. 2, T. 19 N., R. 2 W.), led to a period of deeper drilling responsible for boosting the reserves to the present volume in the Willows-Beehive Bend trend.

The California Division of Oil and Gas estimates that as of January 1, 1960, the field reserves are 215,308,243 Mcf of gas. A maximum of 7,100 productive acres were defined by the completion of 86 producers out of 153 new and redrilled wells, for a 56 percent success ratio.

The annual and cumulative gas production data published by the California Natural Gas Association for the Willows gas field and Beehive Bend gas field are combined in the tabulation on page 109.

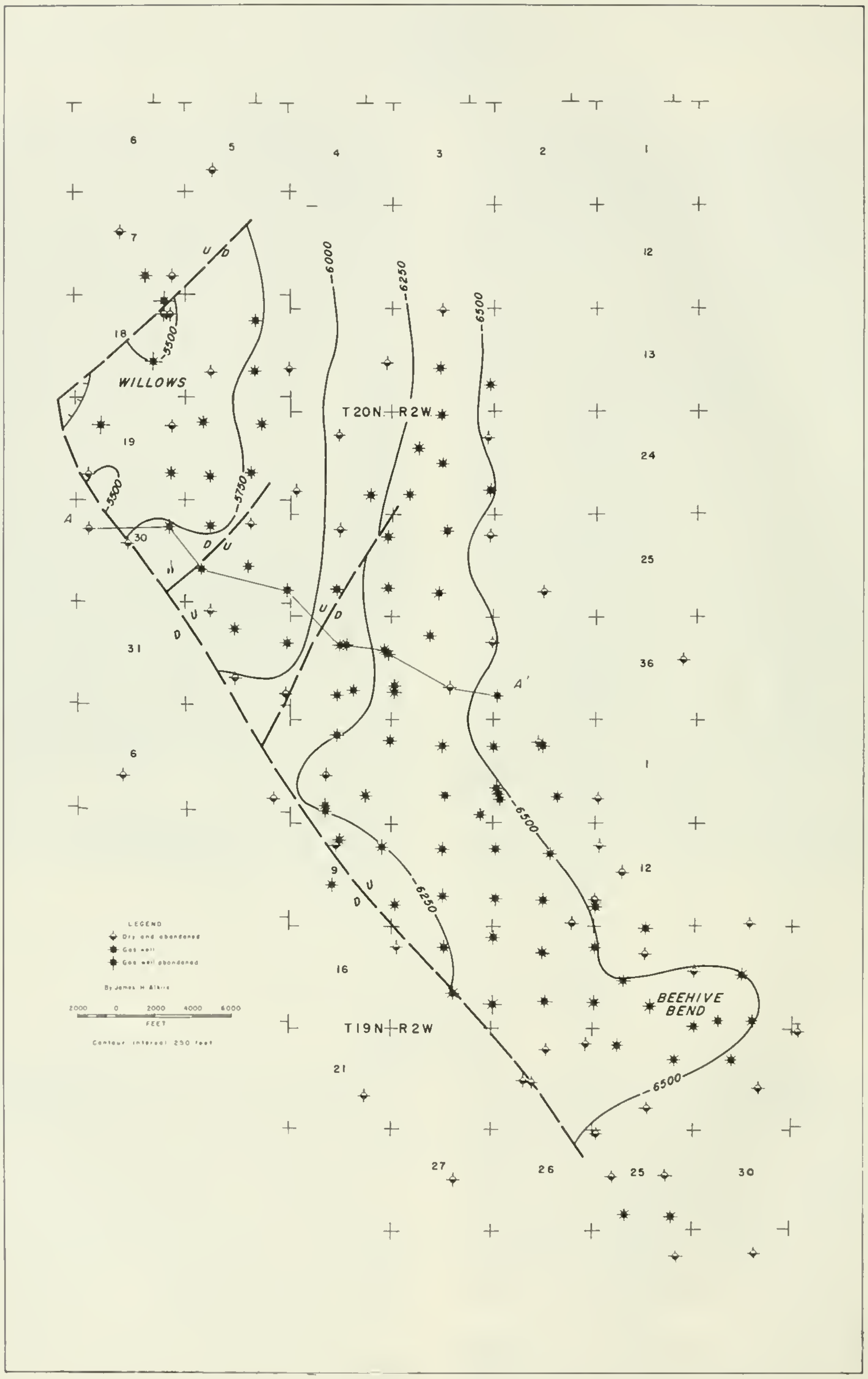


Figure 5. Structural contour map of the Willows-Beehive Bend gas field, Glenn County. For structure section A-A', see figure 6.

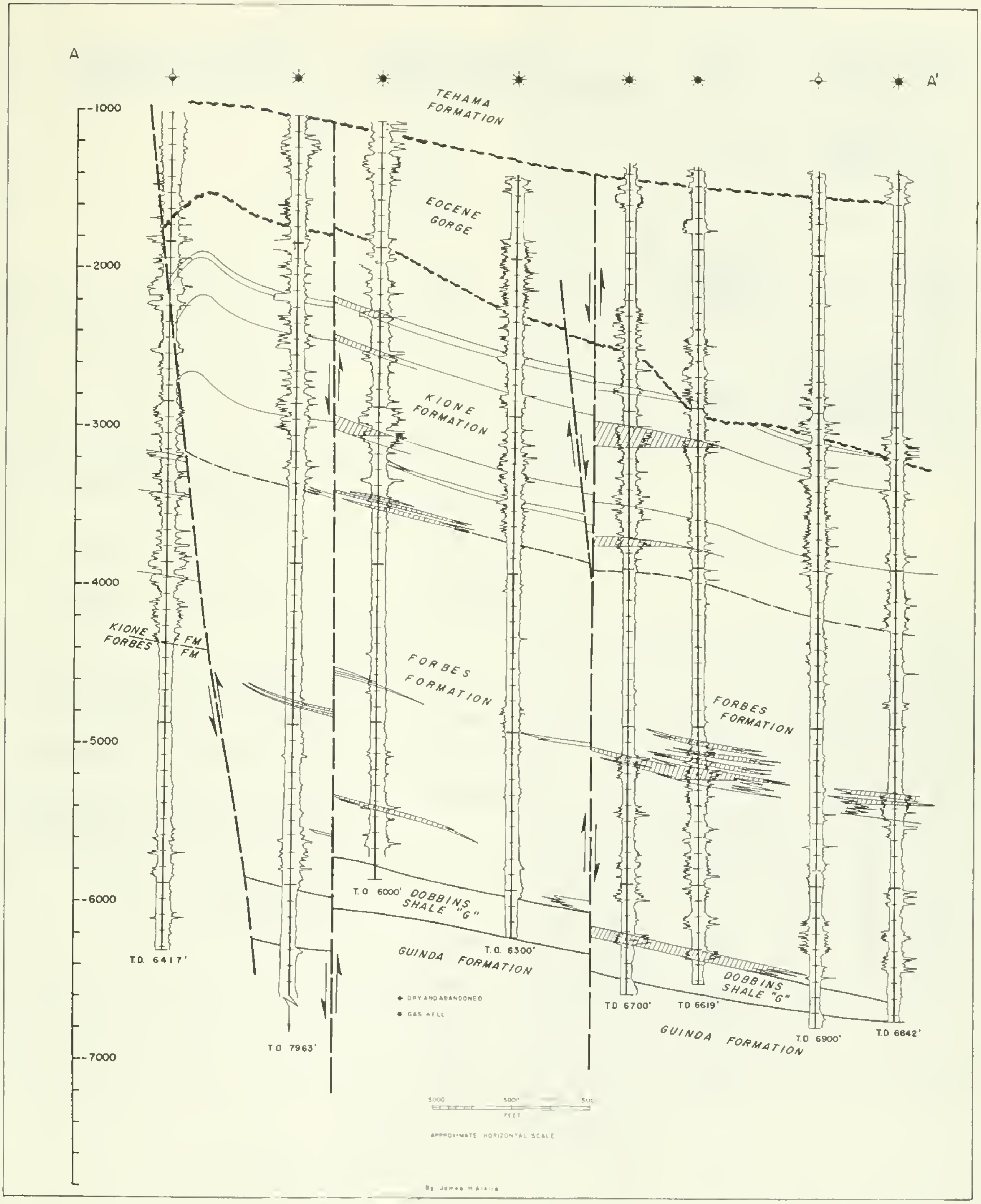


Figure 6. Cross section through the Beehive Bend gas field along line A-A'. For orientation of line section, see figure 5.

TIME UNITS	TIME-ROCK UNITS		ROCK UNITS	THICKNESS	RELATIVE POSITION OF PRODUCING SANDS	TYPICAL WELLS CONTAINING PRODUCING INTERVALS.
EPOCHS	Paleontological Zonation		Formations			
PLIOCENE & YOUNGER	None		Tehama fm. & younger continental deposits	1300'±	None	
EOCENE	Laiming's foram. zones	B-2 to B-4	Eocene "gorge"	1000'±	None	
UPPER CRETACEOUS	Goudkoff's foraminiferal zones	E	Kione	1500'±	Afton Lower Wild Goose	Mobil Whyler-Capital Unit #1 (24-19N-2W)
					Estes	Sunray Estes #1 (19-19N-1W)
					Willard	Ohio Willard #1-A (18-20N-2W)
		F-1 & F-2	Forbes	2700'±	Friesen	Sunray Friesen #1 (19-19N-1W)
					Zumwalt	Rheem Zumwalt #1-63 (2-19N-2W)
					Capital	Mobil Capital #17-2 (17-20N-2W)
					Sprague-Lewis	Mobil Sprague-Lewis #2 (33-20N-2W)
		G-1	Dobbins Sh. (G shale)	300'±		Mobil Miner Jones #5 (24-20N-2W)
			Guinda	800'±		Mobil Wolcott-Capital #1 (13-19N-2W)
			Funks	500'±	None	
		G-2	Sites	1300'±	None	
			Yolo	120'±	None	
		H	Venado	1150'±	None	

BASEMENT COMPLEX

Figure 7. Generalized columnar section in the Willows-Beehive Bend gas field.

Production data, Willows-Beehive Bend.

Year	Annual production (Mcf)	Cumulative production (Mcf)
Prior to 1952		25,384
1952	61,556	86,940
1953	95,285	182,225
1954	97,001	279,226
1955	878,890	1,158,116
1956	5,370,364	6,528,480
1957	17,079,971	23,608,451
1958	20,247,549	43,856,000
1959	29,393,587	73,249,587

The dry gas has a heating value ranging from 978 to 1008 gross BTU per cubic foot. Its average volume composition is 96.5 percent methane, 3 percent nitrogen, 0.4 percent ethane, and 0.1 percent other gases. All gas delivered and all future production is contracted for by the Pacific Gas and Electric Company.

Structure and Stratigraphy. Regionally, the Willows-Beehive Bend anticline is situated near the center of the present-day Sacramento Valley syncline. All commercially productive wells are on the east or upthrust side of a major northwest-trending fault which bisects the anticline. The southeast-plunging anticline contains many small gas pools which collectively constitute a major gas field.

Sand lenticularity and minor transverse faults control the gas entrapment. The Kione formation contains fairly continuous sand and its gas reserves are located in faulted structural traps. Near the base of the Kione, the sand becomes lenticular and the contact with the Forbes formation is gradational. Gas zones in the basal Kione formation and throughout the Forbes formation are trapped primarily by sand lenticularity.

Producing beds are generally fine-grained, dirty quartz sandstone with air permeability ranging from 20 to 1,500 millidarcies, and with porosity of 25 to 36 percent. The maximum net thickness of an individual producing sand is 120 feet.

Only two wells have been completed below the Forbes formation—one in a sand lens of the Dobbins (G zone) shale and the other in the Guinda formation. The sands below the Forbes formation have little permeability and provide faint hope for commercial production from deeper zones.

Contribution 4

Wild Goose Gas Field, California

By Arthur S. Hawley, Consultant

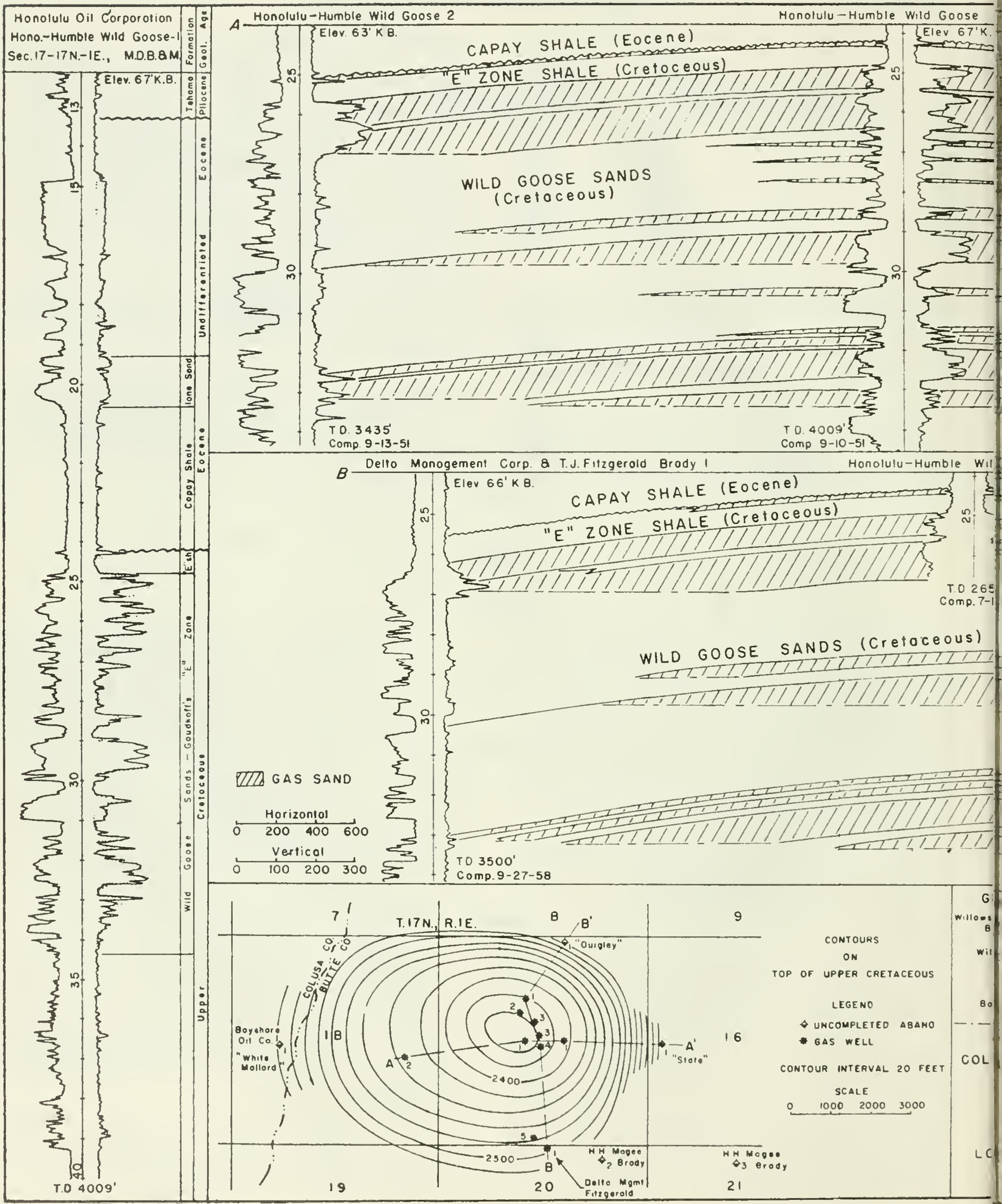
The Wild Goose gas field is located in Butte County in secs. 17 and 18, T. 17 N., R. 1 E., 7 miles northwest of the Marysville Buttes, a topographically prominent volcanic plug in the center of the Sacramento Valley. The field was discovered August 9, 1951 by the completion of the Honolulu Oil Corporation's Honolulu-Humble Wild Goose No. 1 in section 17. This well had an initial production test of 4020 Mcf per day through a 24/64-inch bean, tubing pressure of 1,370 psi, from the Wild Goose sand series of Upper Cretaceous age.

Interest in this area was first stimulated by the observance of a residual gravity maximum located about 3 miles northwest of the present field. In 1950, Humble Oil and Refining Company and Honolulu Oil Corporation conducted a joint reflection seismograph survey of the general area which eventually indicated the existence of the Wild Goose structure, an elongate dome. It is possibly a secondary structure related to the Marysville Buttes intrusion. This theory has never been disproved, for the deepest well in the field, Honolulu-Humble Wild Goose No. 1, was drilled to a total depth of 4010 feet, several thousand feet short of the basement complex. Presumably the entire F- and G-zone section (after Goudkoff) of Upper Cretaceous formations remains unexplored. The discovery well was drilled within the highest closing contour on the elongate dome, and it and subsequent wells were completed from several zones within the Wild Goose sand series lying below the unconformable contact with the Eocene Capay shale.

The Wild Goose sand series, generally accepted as Upper Cretaceous in age, although Foraminifera are rare and arenaceous, is approximately 925 feet thick. The net sand thickness is about 625 feet and the net thickness of gas-bearing sands about 425 feet. The productive closure is slightly less than 200 feet. This field differs from other gas fields in northern California in that it has an unusual thickness of producing sands (fig. 8, cross sections A-A′ and B-B′). These sands are light- to medium-gray, fine- to medium-grained, ranging from clean to silty, with good permeability and porosity. The presence of carbonaceous plant remains and ash fragments coupled with the lateral variability of the sands to siltstones suggests that the productive zone is an estuarine rather than a true marine deposit.

Remnants of a Tertiary basalt flow were encountered in two wells at or near the base of Pliocene; the Honolulu-Humble Wild Goose No. 2 in section 18 and the Honolulu-Humble Hangtown No. 2 in the northwest quarter of section 17. The presence of basalt was indicated by a magnetic low near the Honolulu-Humble Wild Goose No. 2. However, it was not anticipated but did appear on a magnetic high at the Honolulu-Humble Hangtown No. 2 location.

The Honolulu Oil Corporation, acting as operator, completed eight productive wells during the years 1951-53. The Delta Management Corporation and Thomas J. Fitzgerald, Operator, completed their Brady No. 1 well in September 1958. In 1959 Honolulu completed the


Honolulu Oil Corporation
Hono.-Humble Wild Goose-1
Sec.17-17N.-1E., M.D.B.&M.
Formation
Geol. Age
Elev. 67'K.B.
Tehama
Pliocene
Undifferentiated
Eocene
Ione Sand
Capay Shale
Eocene
"E" sh
Wild Goose Sands – Goudkoff's "E" Zone
Upper Cretaceous
13
15
20
25
30
35
40
T.D 4009'
A
Honolulu-Humble Wild Goose 2
Elev. 63' K.B.
Honolulu–Humble Wild Goose
Elev. 67'K.
CAPAY SHALE (Eocene)
"E" ZONE SHALE (Cretaceous)
WILD GOOSE SANDS
(Cretaceous)
25
30
T.D. 3435'
Comp. 9-13-51
T.D. 4009'
Comp. 9-10-51
B
Delta Management Corp. & T.J. Fitzgerald Brody 1
Honolulu–Humble Wil
Elev 66' K.B.
CAPAY SHALE (Eocene)
"E" ZONE SHALE (Cretaceous)
WILD GOOSE SANDS (Cretaceous)
T.D 265
Comp. 7-1
T.D 3500'
Comp. 9-27-58
▨ GAS SAND
Horizontal
0 200 400 600
Vertical
0 100 200 300
7
T.17N., R.1E.
B
B'
9
"Quigley"
COLUSA CO.
BUTTE CO.
Boyshore Oil Co.
"White Mallard"
18
16
A
A'
2
"State"
2400
2500
5
H H Magee 2 Brody
H H Magee 3 Brody
Delta Mgmt Fitzgerald
19
20
21
CONTOURS
ON
TOP OF UPPER CRETACEOUS
LEGEND
◇ UNCOMPLETED ABAND
● GAS WELL
CONTOUR INTERVAL 20 FEET
SCALE
0 1000 2000 3000
Willows
Wil
Bo
COL
LC

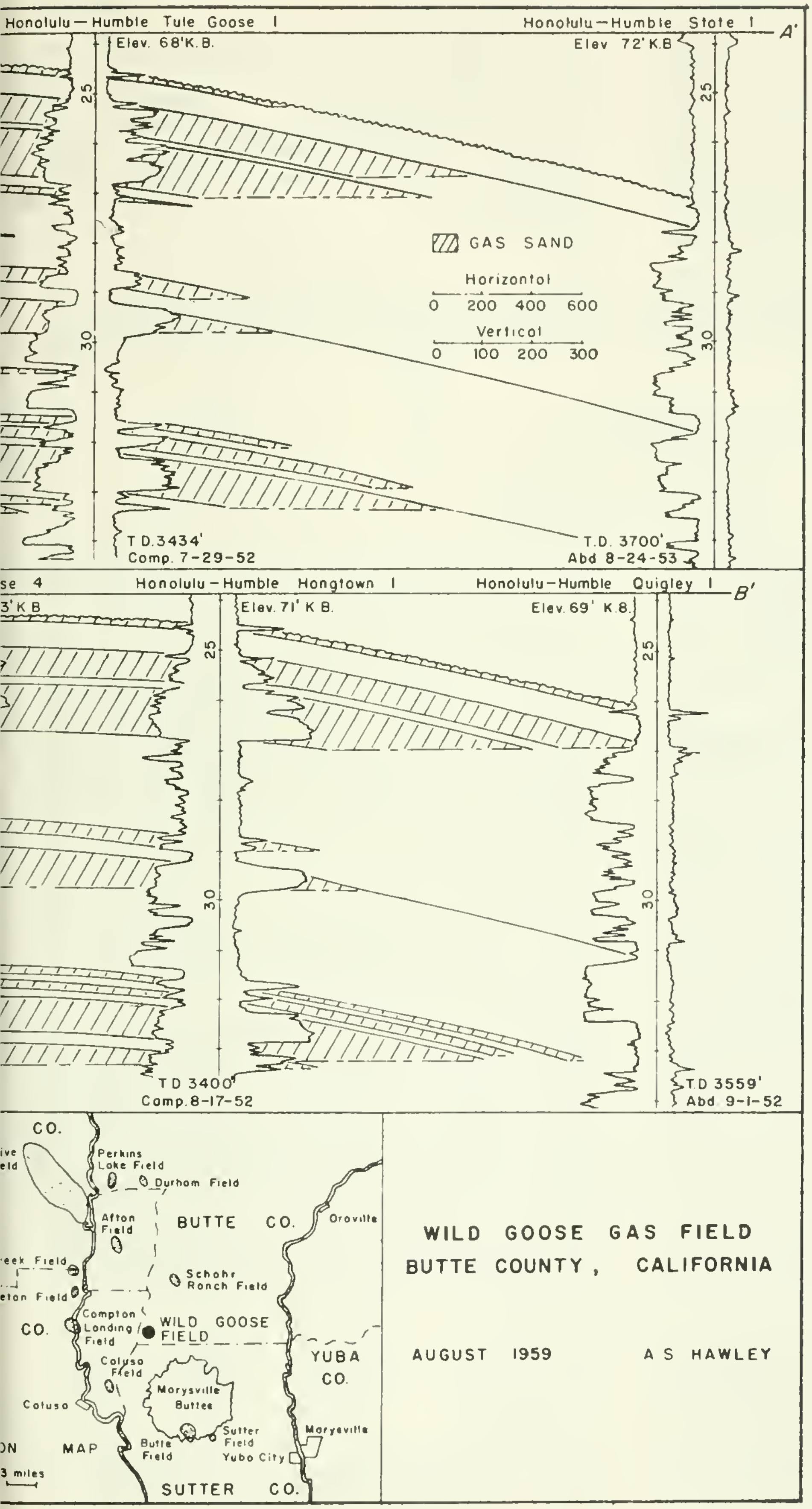


Figure 8. Wild Goose gas field, Butte County, California, including: index map, electric log, sections A-A' and B-B', and map showing contours on top of Upper Cretaceous.

Honolulu-Humble Wild Goose No. 5 as a northerly offset to the Delta Management well. Average drilling time from spudding-in to completion was 12 days. Approximately 800 feet of surface casing was used to afford an anchor for blow-out prevention equipment. Usually 5½- or 7-inch casing was run for the water string and cemented through the producing interval. After water shut-off tests were made above the producing zones, the casing was perforated.

The operator has been regulating the productive rates of the wells completed in the various zones with plans to deplete the lowermost zones first. Relatively high reservoir pressures are expected to be maintained during depletion because of an active water drive. The calorific value of the gas ranges from 799 to 814 BTU per cubic foot and the specific gravity from 0.64 to 0.646. The total recoverable gas estimated for all zones is 87,750,000 Mcf; annual production averages 4,750,000 Mcf; cumulative production was 28,415,700 Mcf to December 31, 1958. Gas reserves as of January 1, 1959 are estimated at 59,334,300 Mcf.

References

Hunter, G. W., 1955, Wild Goose gas field: California Division of Oil and Gas, Summary of Operations, vol. 41, no. 1, pp. 5-8.

Matjasic, W. L., 1954, Case history of Wild Goose gas field, Butte County, California: Geophysics, vol. 19, no. 3, pp. 509-516.

Contribution 5

The Arbuckle Gas Field, California

By Richard H. Vaughan, Chief Geologist
Occidental Petroleum Corporation

Location. The Arbuckle gas field is located in Colusa County, California, some 50 miles northwest of Sacramento. The field is adjacent of the foothills of the northern Coast Ranges along the western edge of the Sacramento Valley, and envelops portions of Arbuckle, a small agricultural community in an area planted to grain and orchards.

Discovery. The Arbuckle gas field was not officially discovered until 1957, although one of several shallow wells which were drilled on the structure 7 years earlier is located within the present field limits.

The first well to explore the Upper Cretaceous F zone was the Arbuckle Unit A-1 drilled by the Western Gulf Oil Company in 1955. This well, although abandoned, located F zone sand and encouraging gas "shows". The Alexander No. 1 well, drilled by the same operator in 1956, while not completed because of mechanical difficulties, was probably capable of commercial production. Perseverance rewarded the Western Gulf Oil Company, and the Arbuckle gas field was officially discovered when their Arbuckle Unit C-1 well (sec. 3, T. 13 N., R. 2 W.) was completed, flowing, in February 1957. Production was from 64 feet of perforations in the intervals 5581-5608 feet and 5873-5910 feet at an initial rate of 7,780,000 cubic feet per day through the tubing on a ½-inch bean with a well-head flowing pressure of 1245 psi.

Development. A one-well-to-160-acres spacing pattern was established and the development of the field proceeded on an orderly basis as the Western Gulf Oil Company successfully completed a total of 12 gas wells through July of 1958.

No further development took place until October 1959 when the Occidental Petroleum Corporation successfully completed as a dual-zone producer their Arbuckle Unit W-1 well, a new fault-block discovery with a combined-zone initial rate of over 13,000,000 cubic feet per day on ½-inch beans. Occidental Petroleum Corporation has subsequently completed eight additional gas wells with initial rates ranging from 1,500,000 to in excess of 20,000,000 cubic feet per day, and Western Gulf has added four new gas wells to its total.

The productive limits of the field have not yet been completely defined. For this reason detailed maps of the field cannot be released at this time and only a generalized structure-contour map (fig. 9), accompanies this paper. Development is actively progressing—one to three drilling rigs have been continuously busy in the field since September 1959. As of July 1960 both operators have successfully completed a combined total of 25 gas wells, proving up a productive area of approximately 4,000 acres.

Character, Pressures, Reserves of Gas. The dry gas from the various producing sands at Arbuckle is quite uniform in character, having an average specific gravity of 0.57, an average heating value of 998 BTU, and an average CH_4 content of 97.9 percent.

More than 130 drill-stem tests, casing tests, and static bottom surveys have been run in which bottom hole formation pressures have been recorded. These pressures have ranged from 1100 psi in the Tehama formation at a depth of 2540 feet to 6145 psi at a depth of 7145 feet within Cretaceous rocks. The pressure gradients have ranged from hydrostatic gradient (0.44 psi/ft.) in the Pliocene beds to gradients in excess of 0.85 psi/ft. in zones below 7000 feet. Within the producing interval a "stairstepping" increase, not only of pressures but also pressure gradients has been noted, a generalized summary of which follows:

Zone	*Depth (ft.)*	*Pressure (psi)*	*Gradient*
Unit C sands	5500	2800	0.51
Byers sands	5800	3100	0.535
Wiggin sands	6000	3300	0.55
Unit E sands	6300	3600	0.57
Mathews sands	6700	4000	0.595

It is apparent that within this interval itself a near pound-per-foot or geostatic gradient exists. These reser-

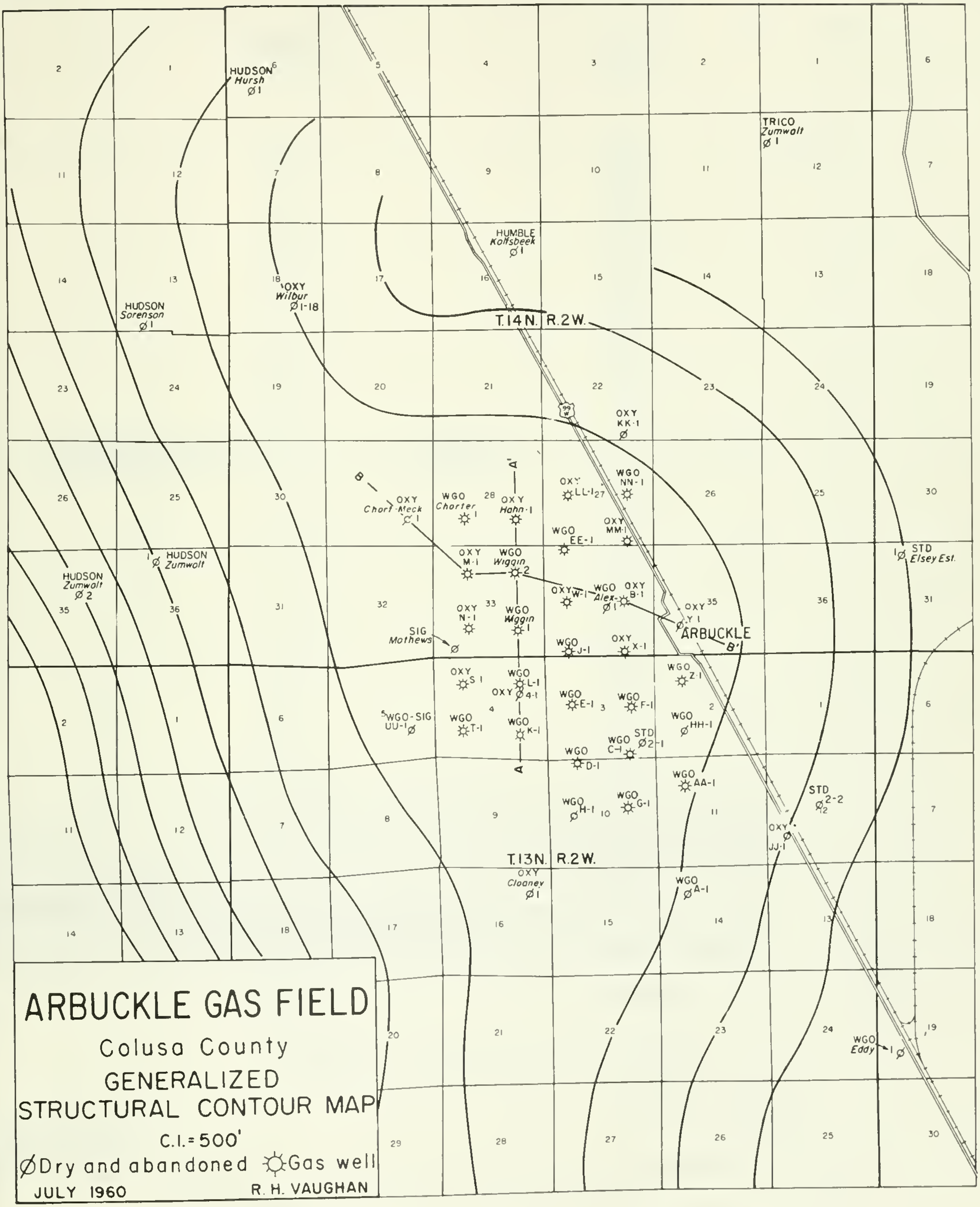


Figure 9. Generalized structural contour map of Arbuckle gas field. Electric logs on section lines A-A' and B-B' are figures 10 and 11.

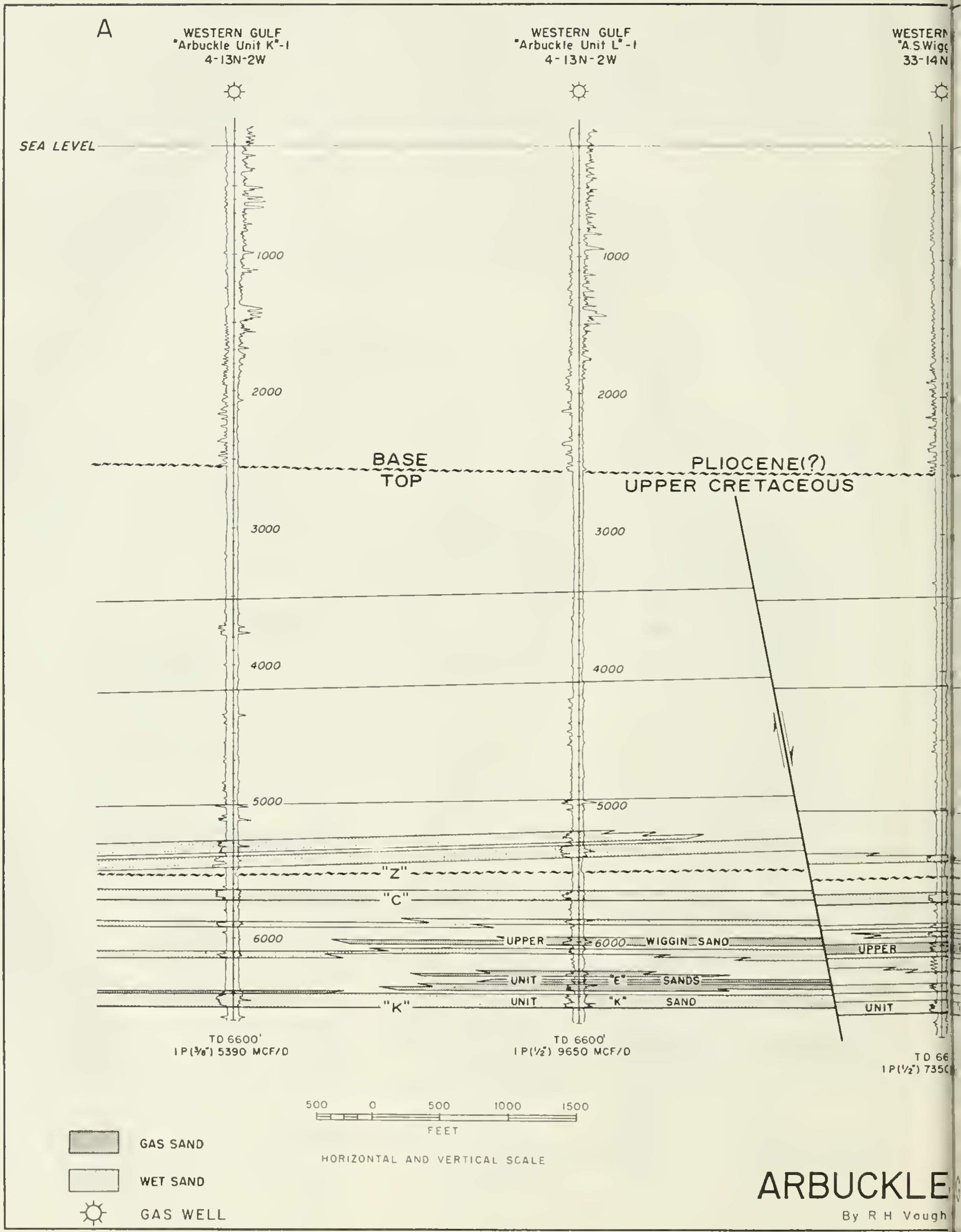
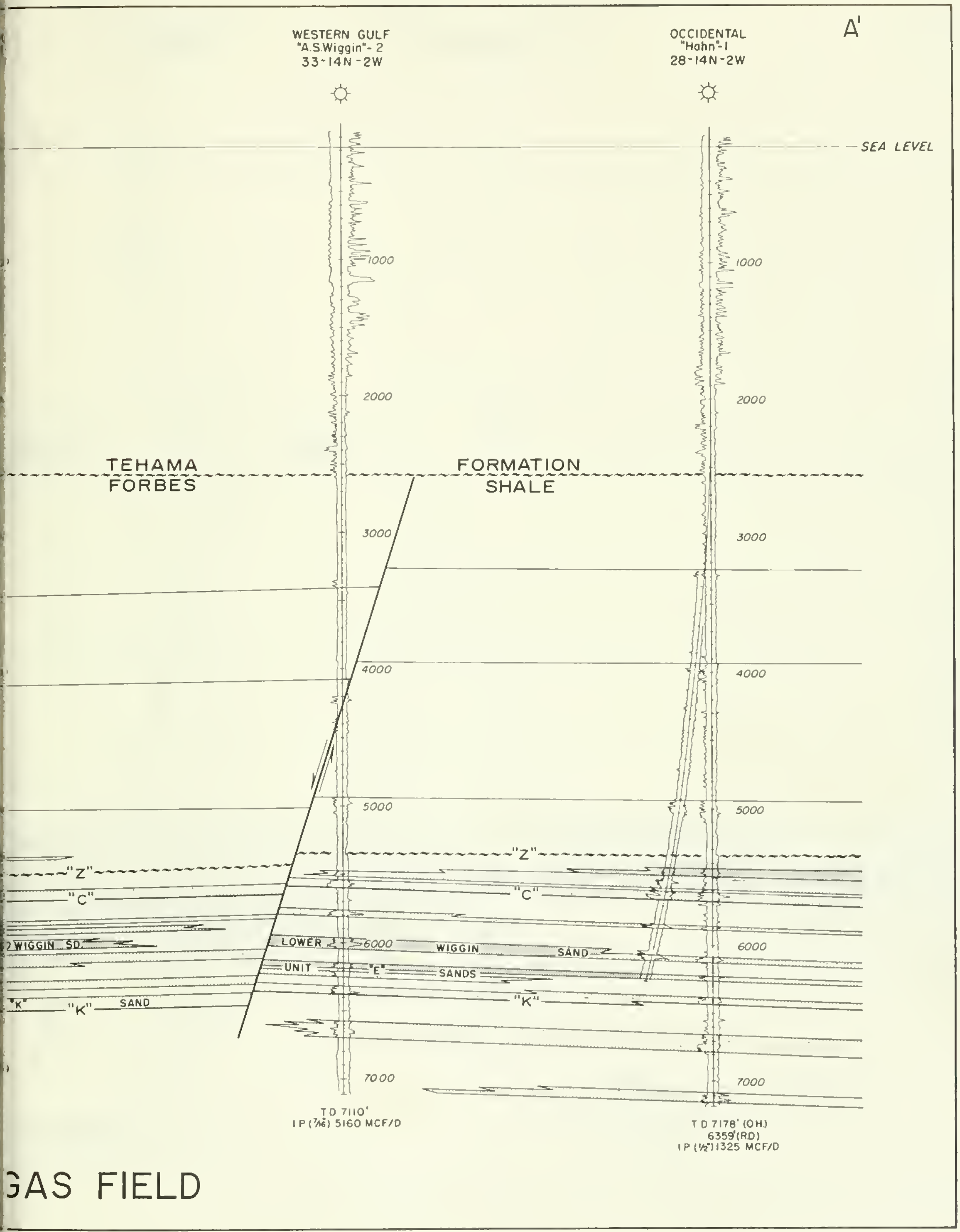


Figure 10. Cross section A-A' (south to north) through Arbuckle gas field. For location of section, see figure 9.


A'
WESTERN GULF
"A.S.Wiggin"-2
33-14N-2W
OCCIDENTAL
"Hahn"-1
28-14N-2W
SEA LEVEL
1000
2000
3000
4000
5000
6000
7000
1000
2000
3000
4000
5000
6000
7000
TEHAMA
FORMATION
FORBES
SHALE
"Z"
"Z"
"C"
"C"
WIGGIN SD.
LOWER
WIGGIN
SAND
UNIT
"E"
SANDS
"K"
"K"
SAND
"K"
T D 7110'
I P (7/16") 5160 MCF/D
T D 7178' (OH)
6359'(RD)
I P (1/2") 1325 MCF/D
GAS FIELD

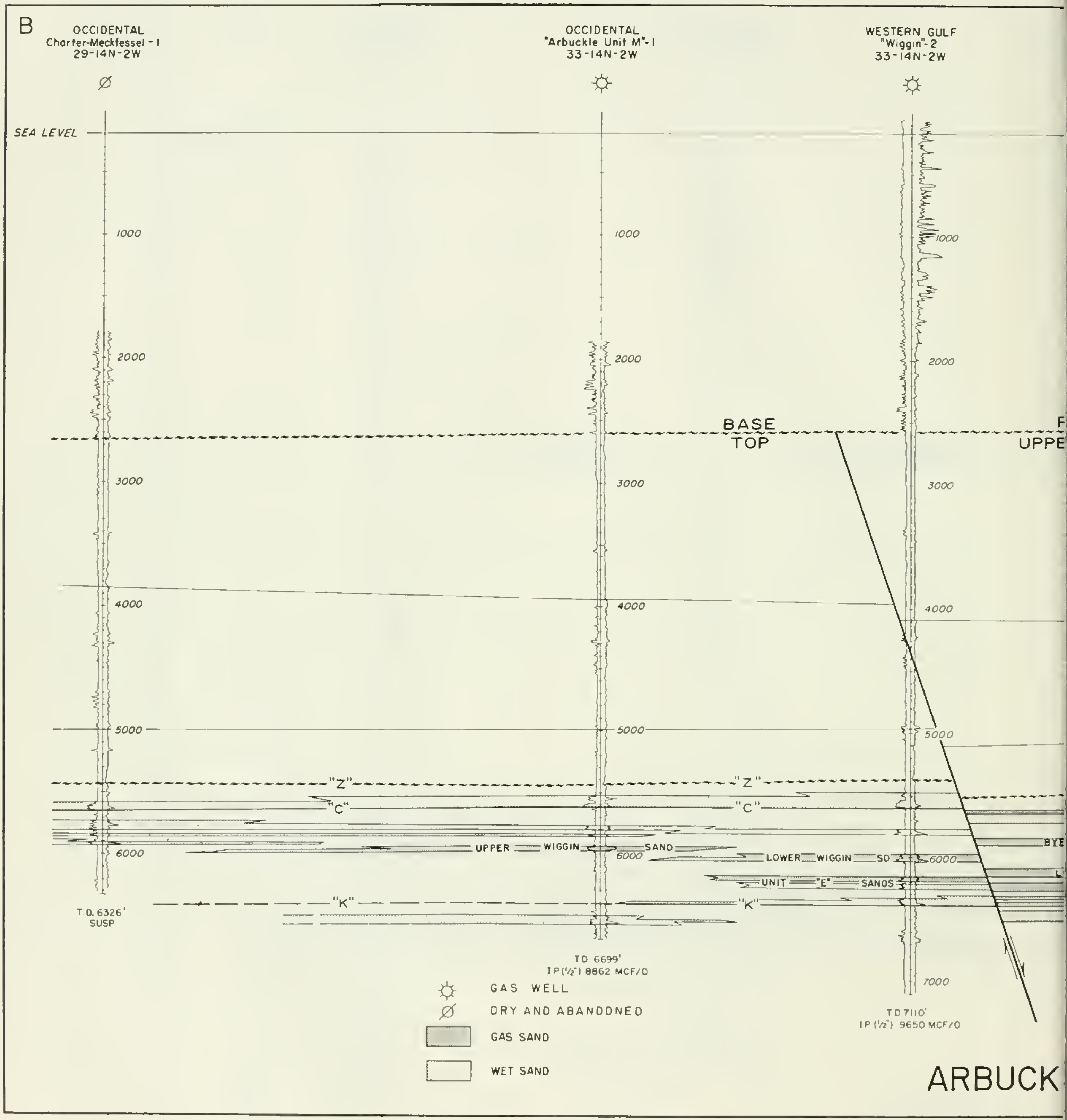
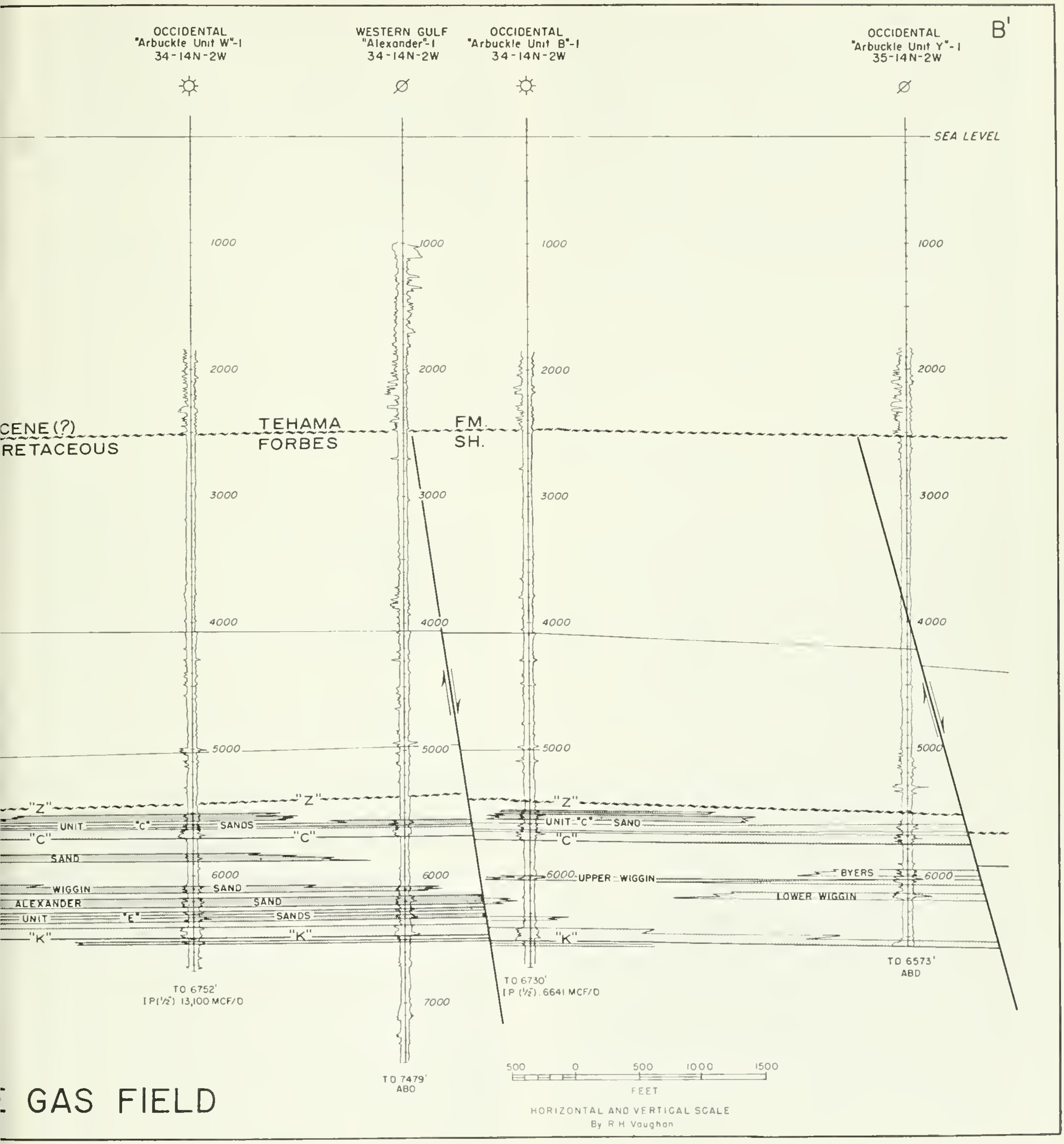


Figure 11. Cross section B-B' (northwest to southeast) through Arbuckle gas field. For location of section, see figure 9.


B'
OCCIDENTAL
"Arbuckle Unit W"-1
34-14N-2W
WESTERN GULF
"Alexander"-1
34-14N-2W
OCCIDENTAL
"Arbuckle Unit B"-1
34-14N-2W
OCCIDENTAL
"Arbuckle Unit Y"-1
35-14N-2W
SEA LEVEL
1000
2000
3000
4000
5000
6000
7000
CENE(?)
RETACEOUS
TEHAMA FM.
FORBES SH.
"Z"
UNIT "C" SANDS
"C"
SAND
UNIT "C" SAND
UPPER WIGGIN
BYERS
LOWER WIGGIN
WIGGIN SAND
ALEXANDER SAND
UNIT "E" SANDS
"K"
TD 6752'
IP(½") 13,100 MCF/D
TD 7479'
ABD
TD 6730'
IP (½") 6641 MCF/D
TD 6573'
ABD
500 0 500 1000 1500
FEET
HORIZONTAL AND VERTICAL SCALE
By R H Vaughan
E GAS FIELD

voirs are obviously not in hydrostatic adjustment, as is to be expected in such a series of discontinuous lenticular sands. Although other explanations exist it is believed that the Arbuckle sands are a possible example of fossil-pressure-type reservoirs. Since the field is not located in a structural province in which tectonic forces can be called upon to explain the abnormally high pressures, these can best be accounted for as result of compaction due to the once great thickness of overburden of uppermost Cretaceous, Paleocene, and Eocene beds subsequently eroded prior to the deposition of the nonmarine Pliocene beds.

Recoverable reserves have been estimated to be in excess of 100 billion cubic feet. The field was not connected into Pacific Gas and Electric Company's 18-inch Westside Pipeline until March 1958. Production for the first 12 months after connection totalled 5¼ billion cubic feet. Subsequently 14 additional gas wells have been completed and have increased the field's deliverability by over 100 percent.

Structure. The Arbuckle gas field is an excellent example of a combination structural-stratigraphic trap in which the gas accumulation is contained in a series of lenticular Upper Cretaceous sand bodies that cross a gently folded and rather complexly faulted terrace.

Structurally the Arbuckle gas field is situated upon a local structural terrace superposed upon the now east-dipping regional homocline, the outcrops of which define the western edge of both the Sacramento Valley geomorphic province and the present Sacramento Valley structural basin. The Arbuckle terrace has a maximum width of more than 2 miles. The axial plane of the flexure is inclined. The eastern edge of the terrage is offset nearly a mile between the depths of 3000 feet and 12,000 feet.

The Arbuckle structure has been defined seismically and the discovery of the gas field is attributed largely to this.tool. Though subdued, the flexure displays a degree of surface expression, with the northern and eastern edges of the terrace being suggested by topographic mapping.

A nearly conjugate system of predominantly normal faults is developed upon the terrace; these faults have offset producing horizons, 50 to 200 feet vertically. Some of the faults display apparent rotational movement. These faults, in combination with the lenticularity of the sands, provide the traps necessary for the present accumulation of gas. Although some of the large faults may have some history of earlier movement, the primary entrapment of gas upon the Arbuckle flexure was probaly effected by the lenticularity of the sands. Many of the faults that are present barriers to migration have offset gas-water interfaces within a single sand and have displaced the younger Cretaceous beds, thus suggesting relatively late movement.

A marked change in structural attitude occurs across the large faults which define the eastern edge of the terrace. On lower horizons the essentially flat strata of the terrace abut beds dipping 15° to 20° E.

Stratigraphy. The youngest beds beneath the surface veneer at Arbuckle are those of the nonmarine Tehama formation, of probable Pliocene age. The base of this sequence of soft sand, gravel, and silty clay is an angular unconformity which reflects the pre-Tehama topography. The Arbuckle flexure was in existence at that time with a surrounding Cretaceous strike oriented north-northeast in contrast to the north-northwest strike of today. The basal Tehama unconformity is encountered at depths ranging from 2200 feet to 2600 feet.

Directly beneath the Tehama formation is a truncated section of gray marine, clay-shale varying to sandy, silty mudstone of Late Cretaceous age and within the faunal E zone as defined by Dr. Paul P. Goudkoff. Some wells along the eastern periphery of the field have penetrated up to several hundred feet of E-zone Kione sand beneath the unconformity. Two miles east of Arbuckle the Standard Oil Company Elsey Estate No. 1 encountered the truncated western edge of the marine Eocene Capay formation, which in itself has truncated the Kione sand in a westerly direction. The base of faunal E zone and the top of the underlying faunal F′-1 zone is usually picked at a depth of about 2850 feet in the field wells. There is no noticeable lithologic variation across the faunal change. However, within the F′-1 zone, in addition to the stratigraphic thinning of certain intervals, several minor unconformities have been observed which probably have no regional connotations but which do record local events.

The base of the faunal F′-1 zone and the top of the underlying F-2 zone is found at an average depth of 5400 feet in the field wells. This faunal change is found in the proximity of the angular unconformity referred to as the "Z" marker; however, it has been picked both above and below the unconformity based on ditch sample determinations. A marked contrast in velocity characteristics has been observed across the unconformity with the older beds having a faster interval transit of some 10 to 15 microseconds per foot.

The "Z" marker unconformity has angularly truncated the underlying strata across the Arbuckle flexure and has resulted in the thinning of the older interval in a westerly direction which is antithetic to the regional depositional thinning of these beds.

With the exception of the Unit D sand, which may well represent a more recent secondary migration, the producing sands of the Arbuckle gas field are of Late Cretaceous F-2 zone age. (The field nomenclature for the various gas sands is shown on the accompanying cross-sections, figs. 10 and 11.) These sands are lenticular in nature and appear to be elongate though locally meandering bodies which are generally parallel to the regional strike. They are thought to be offshore or basinal sand bodies of current derivation. The sands are predominately non-additive; that is, they appear to be facies counterparts of the contiguous shales and do not differentially thicken the section. In contrast, some of the sand buildups above the Z marker do differentially thicken the section and possibly represent offshore bars. The producing sands are generally fine to very fine grained, consolidated-but-friable quartz sands, with porosities ranging from 20 to 30 percent.

Studies indicate that the Arbuckle flexure had a degree of structural expression by the beginning of F-2-zone time. It is hypothicated that this fact in part precipitated the sedimentary environment favorable for the deposition of the F-2 zone Arbuckle sands. The Arbuckle gas field, I believe, is a fine example of the delicate interplay of related structural and stratigraphic phenomena and timing necessary for the accumulation of hydrocarbons.

To date the faunal G zone of Goudkoff has been penetrated in only one well in the Arbuckle gas field, that being the recently completed 12,007-foot-deep test Occidental Petroleum Corporation's Arbuckle Section Four Unit No. 1 which encountered the G-1 shale at a depth of 8235 feet. This test demonstrated favorable reservoir characteristics, as well as the presence of G-1 and G-2 zone sands; furthermore, the pressures encountered approached the geostatic gradient.

Considering the many thousands of feet of pre-F zone source rock, the lack of extreme structural complexity, and the abnormal pressures, it is inevitable that, when these lower Upper Cretaceous sands are found in areas with favorable geologic history, they will provide the Sacramento Valley with tomorrow's discoveries of major proportions.

Contribution 6

Dunnigan Hills Gas Field, California

By Rafael Rofé

Creole Petroleum Corporation

Plate 7, *Cross section A-A′, Dunnigan Hills gas field,* Plate 8, *Cross section B-B′, Dunnigan Hills gas field,* and Plate 9, *Cross section C-C′, Dunnigan Hills gas field, accompany this paper.*

The Dunnigan Hills gas field is situated 30 miles northwest of Sacramento, in central Yolo County, California. One of several gas fields of major importance in northern California, it is situated in a region of smooth, rolling hills, with elevations from 118 to 305 feet above sea level. The field is about 4 miles long in a north-south direction and 2 miles wide in an east-west direction, or approximately 8 square miles in area.

To obtain the information in this paper, conventional electric logs from 26 wells in the field were used, in addition to micrologs, induction logs, gamma ray logs, dipmeters, and velocity logs from some wells. Many descriptions of rotary cores were provided the writer, plus pertinent information related to drilling practices. Electrical log definitions are such within the field that they permit detailed correlations. Characteristics of the various curves and lithology are jointly used in the determination of formational tops and other boundaries. Figure 12 shows the location of the various wells and cross sections.

History. The Dunnigan Hills gas field was discovered by the Texas Company in 1946, who drilled Dunnigan Unit One-1 (Well 7 of this report) on a structural high which was revealed by a reflection seismograph survey. The well encountered a gas-bearing sand immediately below the Eocene-Cretaceous unconformity at 2,414 feet, which indicated a potential production rate of 6,500 Mcf of gas per day. The sand was named the Hermle zone. As drilling progressed, several thin stringers of sand, the Dubois zone, were encountered approximately 100 feet below the base of the Hermle. Production tests indicated their potential at 2,600 Mcf per day. After successful completion, the well was shut in due to the lack of pipe-

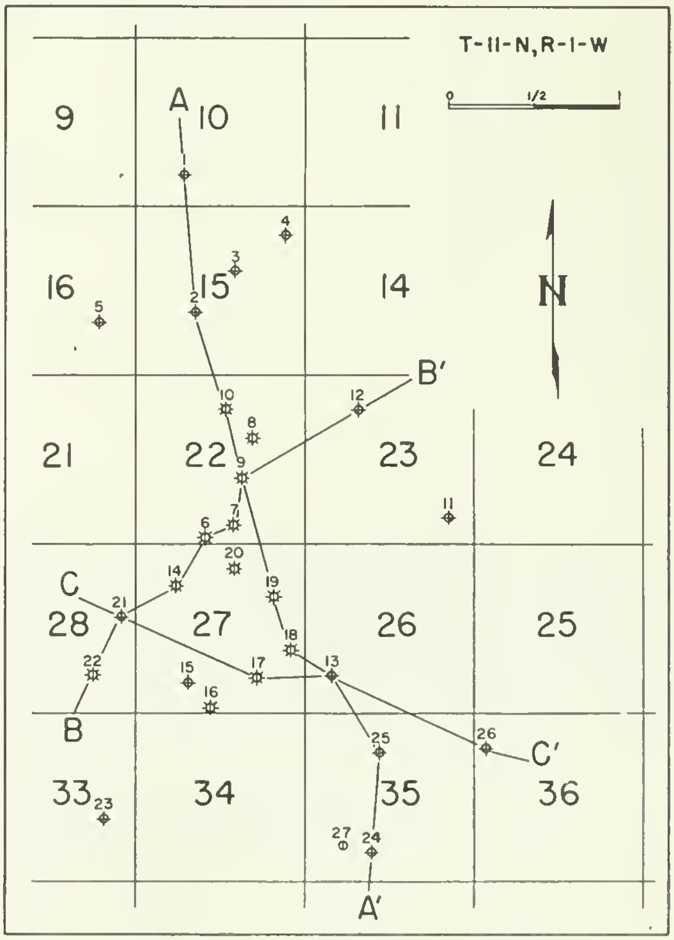


Figure 12. Index map showing location of wells and cross sections.

Table I

DRILLING HISTORY OF THE DUNNIGAN HILLS GAS FIELD

Well	Name	Operator	Date Spudded	Producing Sand	Initial Rate Mcf per day	Choke inch	Remarks
7	Dunnigan Unit One-1	The Texas Co.	Jan. 7, 1946	Hermle Dubois	6,500 2,600		
2	Laugenour - 1	Standard Oil Co.	Mar. 3, 1946				abandoned
22	Dubois - 1	Natural Gas Corp.	April 7, 1946	Dubois	1,227	1/4	
13	Dunnigan Unit One-2	The Texas Co.	May 8, 1947				abandoned
17	Dunnigan Unit One-3	The Texas Co.	Aug. 27, 1947	One-3	5,000	28/64	
19	Dunnigan Unit One-4	The Texas Co.	Sept. 15, 1947	Dubois	3,204	3/8	
25	Dunnigan Unit One-5	The Texas Co.	Nov. 20, 1947				abandoned
6	Hermle - 1	Standard Oil Co.	Jul. 18, 1948	Hermle	3,451	3/8	
15	Bemmerly Unit-1	Standard Oil Co.	May 11, 1950				abandoned
18	Dunnigan Unit One-6	The Texas Co.	Aug. 24, 1950	One-3	1,500	1/4	
9	Dunnigan Unit One-7	The Texas Co.	Sept. 4, 1950	Hermle	1,000	1/4	
16	Bemmerly Unit-2	Standard Oil Co.	Nov. 29, 1950	Dubois	1,165	1/4	
8	Dunnigan Unit One-8	The Texas Co.	Sept. 17, 1951	Hermle	2,557	3/8	
20	Dunnigan Unit One-9	The Texas Co.	Sept. 26, 1951	Hermle	36,000	24/64	
14	Donahve - 1	Superior Oil	Jan. 13, 1948	Hermle	1,500	16/14	
12	Bemmerly - 1	Stanebury Inc.	May 29, 1951				abandoned
10	Bemmerly Unit-3	Standard Oil Co.	Oct. 29, 1951	Dubois	2,500	3/8	
3	Cobb - 1	Mohawk Petrol. Co.	Jul. 29, 1952				abandoned
4	Mohawk Cobb - 1	W.W. Holmes	Sept. 4, 1953				abandoned
24	Mast - 1	C.K.M. Oil Co.	Jul. 15, 1954				abandoned
1	Mohawk-Bemmerly - 1	W.W. Holmes	Jul. 20, 1954				abandoned
26	L.M. Bemmerly A-1	Western Gulf Oil	Oct. 5, 1954				abandoned
21	Hermle - 1	Marshall Co.	Oct. 15, 1954				abandoned
5	Laugenour ET AL-1	Mohawk Petrol. Co.	Mar. 13, 1955				abandoned
11	L.M. Bemmerly - 1	The Texas Co.	Nov. 27, 1956				abandoned
23	Roca Schaupp 75-33	Artnell Co.	May 27, 1958				abandoned

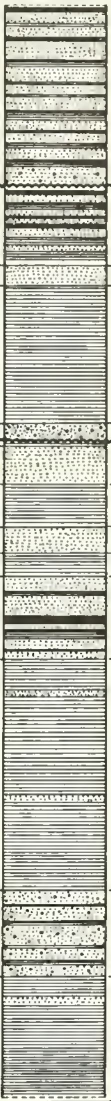
line facilities. In May 1947, the Texas Company drilled Dunnigan Unit One-2 (Well 13 of this report) to a depth of 4,000 feet. A previously unknown sandy zone was discovered approximately 120 feet above the top of the Hermle zone. This was named the One-3 zone. Table 1 gives a chronological history of the drilling in the field during the following years.

Structure. The gas trap is an elongated anticlinal nose. Its major axis trends in a northwest direction and plunges to the southeast. This major feature is clearly indicated by the structure on the top of the Cretaceous unconformity (fig. 18).

The north-south cross section A-A′ (pl. 7) indicates the general plunge of the formations to the south, but mostly reveals a smooth arching along the axis of the anticline, with its culmination under Well 9 and Well 10. This arching, visible along the Eocene unconformity, is better developed along the Cretaceous unconformity, and probably is a result of compressional movements in late Eocene time. The Dubois zone which wedges out to the north, illustrates a secondary trap subsequently formed during the above-mentioned arching. The Eocene-Cretaceous unconformity removed the One-3 zone to the north, and partially eroded the Hermle zone. A northeast-trending fault is shown cutting the Cretaceous section between Well 18 and Well 19. Referring to figures 14, 15, and 16 which show the tops of the Cretaceous sands, it can be seen that a fault extends in a northeast direction just south of Well 11. The throw to the south

Table 2

GENERALIZED COLUMNAR SECTION IN THE DUNNIGAN HILLS GAS FIELD

GEOLOGIC AGE	FORMATIONS AND ZONES	GRAPHIC SECTION	THICKNESS	LITHOLOGIC DESCRIPTION	ORIGINAL REFERENCE
PLIOCENE	TEHAMA		1862' to 2015'	Yellow brown to dark olive green claystone with subordinate amounts of fine to coarse sands.	Russell (1927, pp. 11-21)
				UNCONFORMITY	
MIDDLE EOCENE	NORTONVILLE		92' to 235'	Blue and brown, firm, mottled, micaceous sandy claystones interbedded with grayish green, gritty sands	None
	DOMENGINE		19' to 62'	Dark gray to greenish gray, fine grained, well sorted silty sands.	Anderson, (1905, p. 167)
	CAPAY		480' to 558'	Medium gray to dark green, massive, micaceous, glauconitic, pyritic claystones.	Crook & Kirby (1935, pp. 334-335)
	CAPAY GRIT			Dark gray, medium grained, poorly sorted, massive gritstone.	
				UNCONFORMITY	
UPPER CRETACEOUS	CHICO — ONE-3		0' to 104'	Light gray, fine grained, massive, well sorted, clean sand.	Gobb (1869)
	HERMLE		0' to 102'	Light gray, fine grained, massive, well sorted, silty, biotitic sand.	
	DUBOIS		0' to 267'	Light gray, fine to medium grained, poorly sorted, massive, silty, micaceous sand with subordinate amounts of claystone.	
				Medium dull gray, firm, massive, silty, muscovitic, fossiliferous claystone grading locally into siltstone.	
	WELDONIAN SAND		300' Est.	Light gray, fine to medium grained, poorly sorted, silty sand. Wet.	

is estimated at 130 to 150 feet, if a dip-gradient of 200 feet per mile is taken as an average. No visible displacement is suggested where the Eocene Capay formation was evenly laid over the surface of the unconformity. The Nortonville formation, as shown in plate 7, has a greater preserved thickness to the south than it does to the north. The difference in thickness of the formation, which amounts to 200 feet between Well 1 and Well 24, is an estimate of the late Eocene upwarping.

Cross section B-B′ (pl. 8), which is approximately perpendicular to the axis of the anticlinal nose, reveals the strong curvature of the nose and the uniform distribution of the Capay formation over Cretaceous strata. Furthermore, it suggests for the first time the good development of the Cretaceous sands to the east. Deep post-Cretaceous erosion removed completely the One-3 zone, and left only a thin section of the Hermle zone on the culmination of the structure. The Dubois zone which thins progressively to the southwest and wedges out is found again at the western edge of the field at Well 22, where it is truncated by the Cretaceous unconformity. This wedging indicates that arching during late Eocene time rejuvenated an existing positive area in Dubois time between Well 22 and Well 7. The approximate limit of the Dubois zone (fig. 16) outlines this Cretaceous positive area. There is a strong suggestion that at deeper horizons other sand bodies may be wedging out around this positive area to create potential stratigraphic traps.

Cross section C-C′ (pl. 9), trending west-northwest in the southern portion of the field, clearly illustrates the

Table 3

TOPS OF FORMATIONS IN THE DUNNIGAN HILLS GAS FIELD

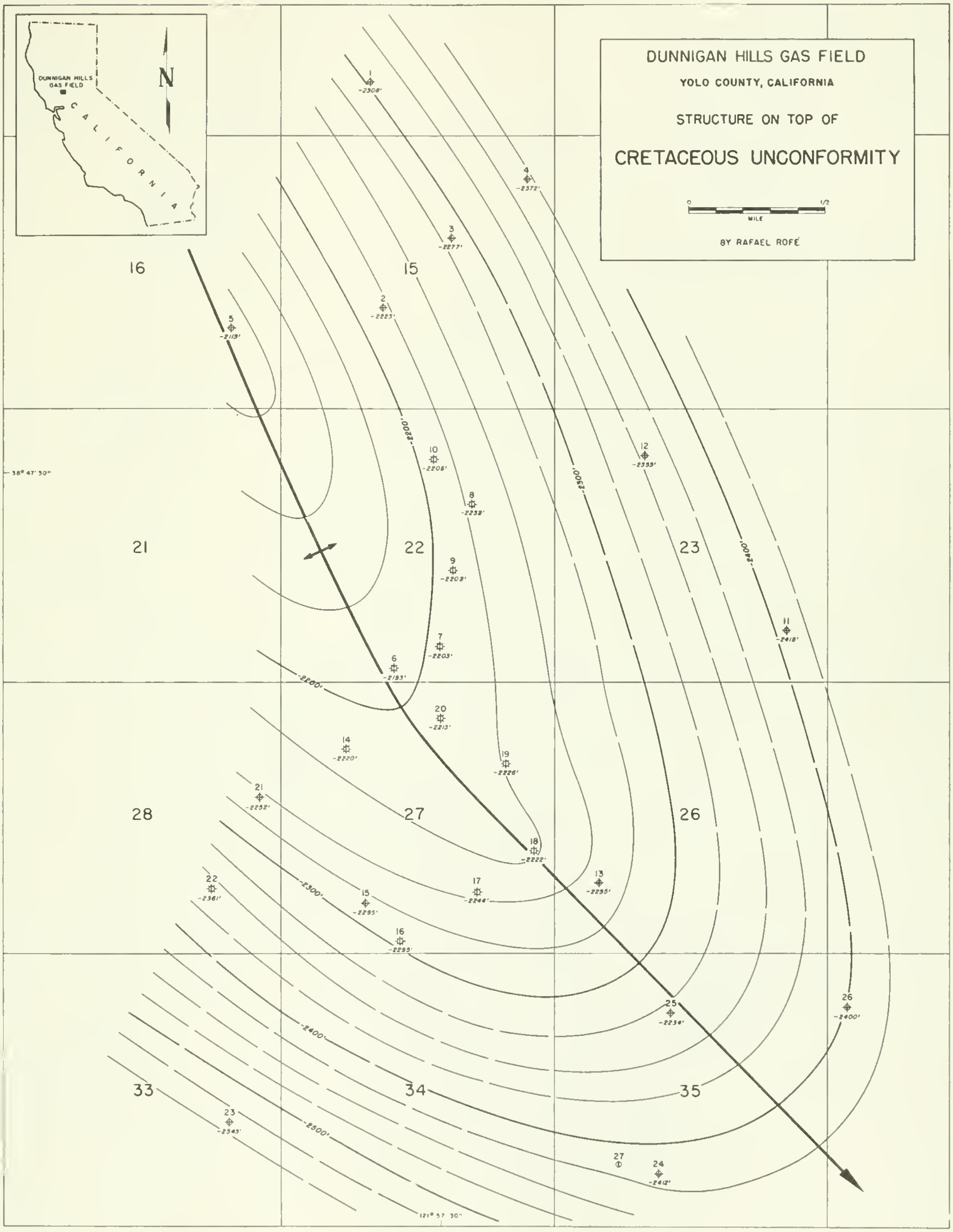
Well	Section	Elevation		Nortonville	Domengine	Capay	Capay Grit	Cretaceous	One-3	Hermle	Dubois	Weldonian	Total Depth
		Ground	Kelly Bushing										
1	10	197	208	1846	1985	2052	2484	2516					3001
2	15	130	137	1682	1807	1860	2329	2360			2517		2800
3	15	133	143	1778	1873	1931	2388	2420			2610		3000
4	15	123	132	1868	1960	2022	2471	2504			2630		3030
5	16	141	151	1623	1726	1776	2230	2264					2810
6	22	268	279	1774	1912	1965	2439	2472		2472			2675
7	22	200	211	1725	1864	1915	2382	2414		2414	2562	3413	3984
8	22	198	208	1762	1904	1955	2413	2446		2446	2573		2680
9	22	274	283	1804	1950	1992	2455	2491		2491	2613		2736
10	22	235	242	1780	1910	1966	2420	2448		2448	2544		2650
11	23	260	273	2015	2144	2192	2653	2690		2828			3600
12	23	154	163	1832	1981	2031	2487	2518		2606	2724		3000
13	26	189	198	1760	1919	1964	2426	2453	2489	2703	2852	3836	4000
14	27	254	261 est.	1785	1922	1954	2446	2480		2480			2750
15	27	250	257 est.	1812	2007	2026	2508	2545		2623	2761		2900
16	27	253	260 est.	1810	2012	2040	2522	2555		2657	2792		2930
17	27	223	234	1745	1946	1980	2453	2478	2478	2651	2793	3754	3794
18	27	216	225	1767	1915	1962	2425	2447	2447	2671	2836		2866
19	27	179	190 est.	1743	1877	1907	2381	2416		2460	2628		3000
20	27	234	244	1778	1908	1944	2421	2457		2457			2679
21	28	208	217	1777	1885	1937	2426	2469				3300	3516
22	28	224	231	1750	2012	2034	2528	2568			2568		2880
23	33	202	210	2010	2216	2228	2712	2753			2960		3395
24	35	219	228	1850	2085	2130	2604	2640	2705	2926	3093		3800
25	35	241	251	1823	2043	2088	2553	2585	2645	2860			3000
26	36	242	253	1890	2120	2166	2623	2653	2768	2983	3188		4001

major fault already described. The three sand zones are shown to be thicker to the south. The One-3 zone is truncated south of the fault and completely removed to the north. On the upthrown side of the fault the Hermle zone is postulated below the unconformity, this is consistent with cross section B-B′. The Dubois zone wedges out to the north and is not present in Well 21.

The structure on the top of the three zones is anticlinal. Figure 14 illustrates the contours on the top of the One-3 zone. The major fault limits the zone to the north where it is completely eroded, and to the west the zone has been truncated. Figure 14 is constructed to give a spatial representation of the geometrical elements. The "truncated zone" represents the top of the Cretaceous unconformity. Here the contours are identical to those of the structural map of the Cretaceous unconformity of figure 13. The outer undulating broken line represents the limit of the total preserved sand. Farther to the east, the zone is completely preserved.

The structural map on the top of the Hermle zone (fig. 15) was also constructed to give a spatial representation. Here the surface of the unconformity is in the inner part of the heavy undulating line, that is the truncated zone. The outer plain line represents the wedge edge of the zone.

The structure on the top of the Dubois zone is indicated on figure 16. With the exception of a small portion at the western edge of the field the zone was not exposed by the post-Cretaceous erosion. Depositional thinning is suggested to the northwest. Although still an anticlinal structure, the complicated contour pattern on the top of the Dubois zone suggests a more irregular deposition.


DUNNIGAN HILLS GAS FIELD
YOLO COUNTY, CALIFORNIA
STRUCTURE ON TOP OF
CRETACEOUS UNCONFORMITY
0
1/2
MILE
BY RAFAEL ROFÉ
DUNNIGAN HILLS GAS FIELD
CALIFORNIA
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16
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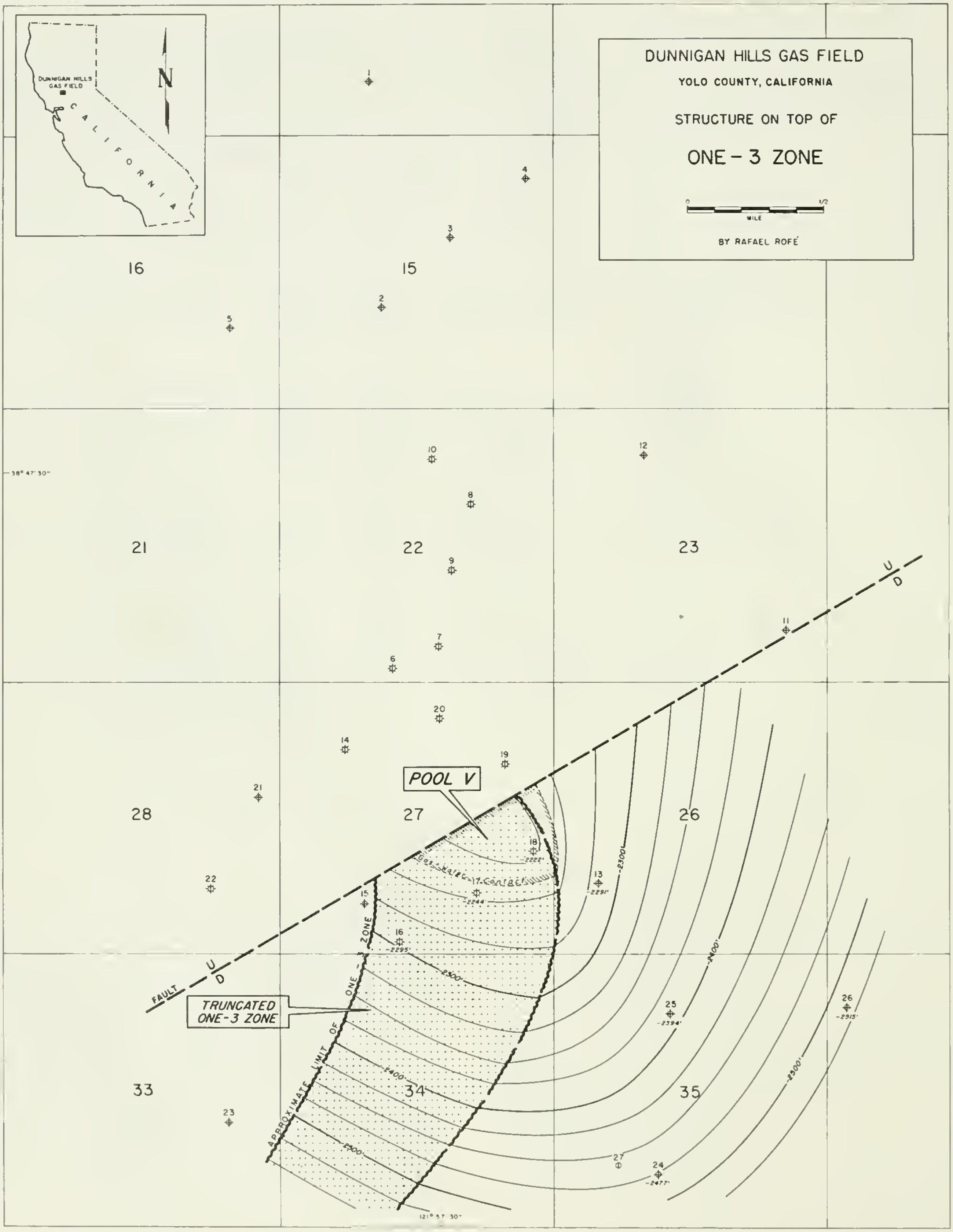
22
23
28
27
26
33
34
35
1
-2308'
2
-2223'
3
-2277'
4
-2372'
5
-2113'
6
-2193'
7
-2203'
8
-2232'
9
-2202'
10
-2205'
11
-2418'
12
-2333'
13
-2235'
14
-2220'
15
-2295'
16
-2295'
17
-2244'
18
-2222'
19
-2226'
20
-2213'
21
-2252'
22
-2361'
23
-2343'
24
-2412'
25
-2234'
26
-2400'
27
-2200'
-2200'
-2300'
-2300'
-2400'
-2400'
-2500'
38° 47' 30"
121° 57' 30"

Figure 13.


DUNNIGAN HILLS GAS FIELD
YOLO COUNTY, CALIFORNIA
STRUCTURE ON TOP OF
ONE-3 ZONE
0
1/2
MILE
BY RAFAEL ROFÉ
DUNNIGAN HILLS GAS FIELD
CALIFORNIA
N
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15
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35
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-2291'
14
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16
-2295'
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-2244'
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-2222'
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23
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-2477'
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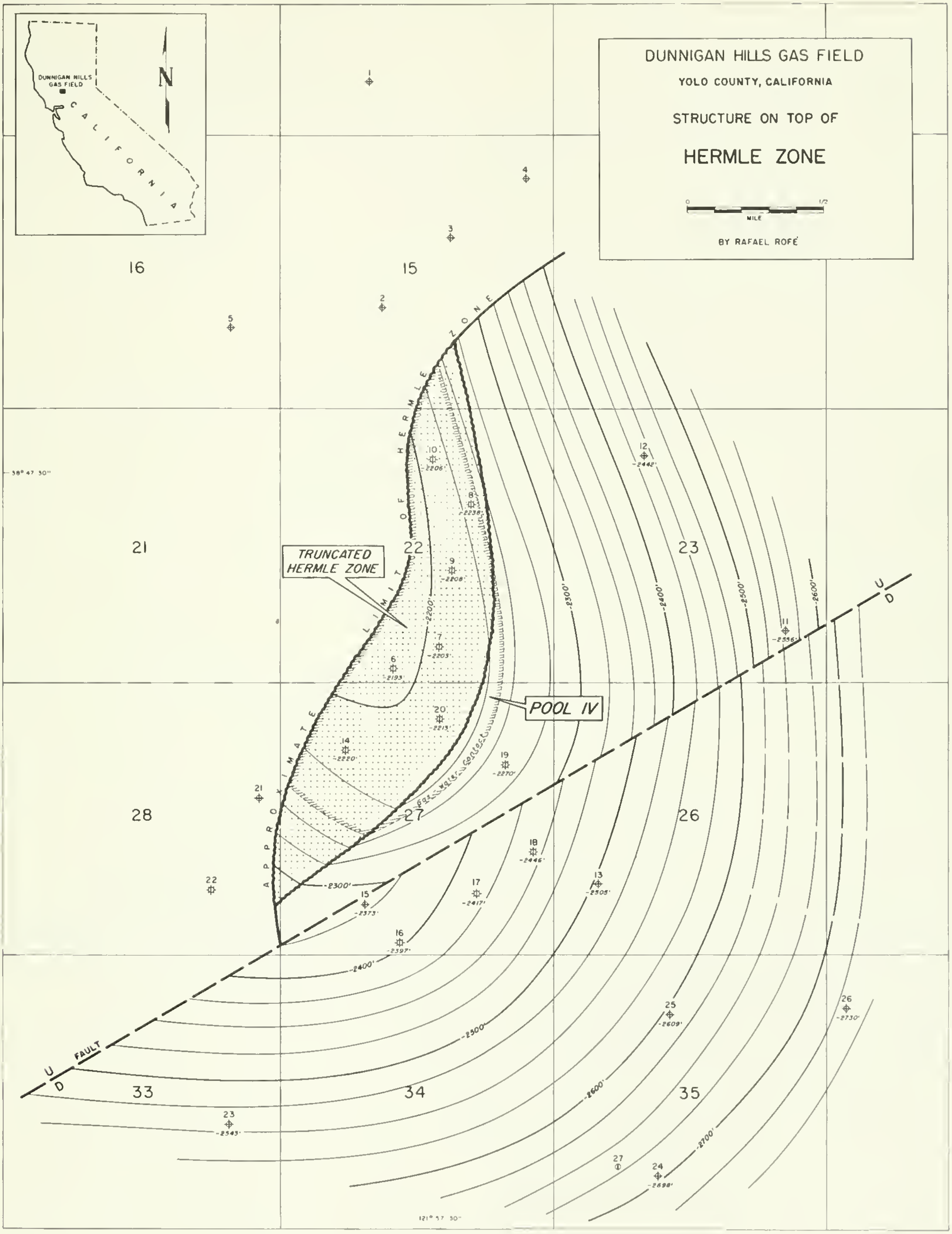
-2394'
26
-2915'
27
38° 47' 30"
121° 57' 30"
U
D
FAULT
POOL V
TRUNCATED ONE-3 ZONE
APPROXIMATE LIMIT OF ONE-3 ZONE
Gas-Water Contact
-2300'
-2400'
-2500'

Figure 14.


DUNNIGAN HILLS GAS FIELD
YOLO COUNTY, CALIFORNIA
STRUCTURE ON TOP OF
HERMLE ZONE
0
1/2
MILE
BY RAFAEL ROFÉ
DUNNIGAN HILLS GAS FIELD
CALIFORNIA
N
38° 47' 30"
121° 57' 30"
16
15
21
22
23
28
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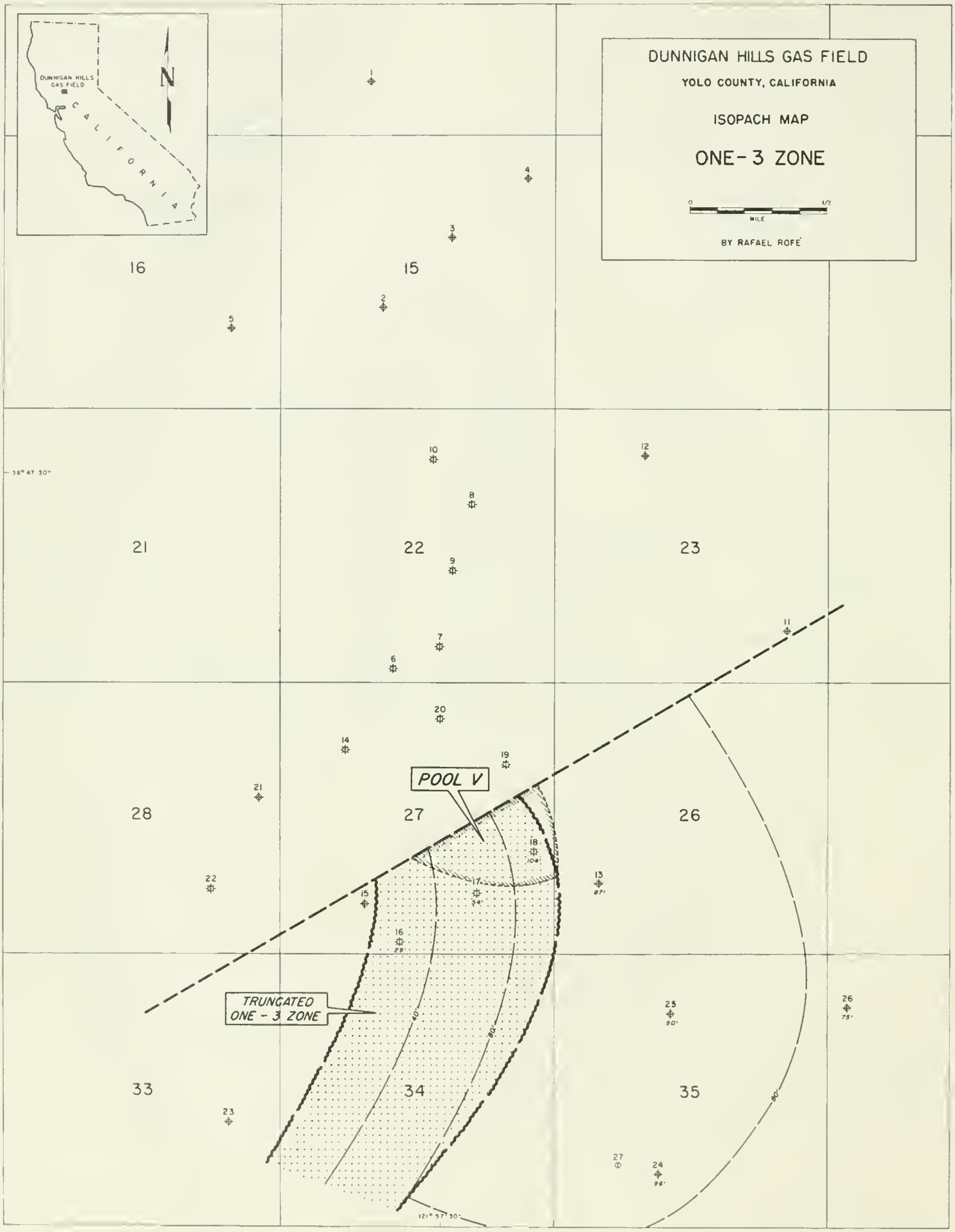
26
33
34
35
TRUNCATED HERMLE ZONE
APPROXIMATE LIMIT OF HERMLE ZONE
POOL IV
Gas-Water Contact
FAULT
U
D
1
2
3
4
5
10 -2206'
8 -2238'
9 -2208'
7 -2203'
6 -2193'
20 -2213'
14 -2220'
19 -2270'
12 -2442'
11 -2556'
21
22
18 -2446'
13 -2505'
17 -2417'
15 -2373'
16 -2397'
25 -2609'
26 -2730'
23 -2543'
27
24 -2698'
-2200'
-2300'
-2400'
-2500'
-2600'
-2700'

Figure 15.


DUNNIGAN HILLS GAS FIELD
YOLO COUNTY, CALIFORNIA
ISOPACH MAP
ONE-3 ZONE
0
1/2
MILE
BY RAFAEL ROFE
N
DUNNIGAN HILLS GAS FIELD
CALIFORNIA
38° 47' 30"
121° 57' 30"
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33
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POOL V
TRUNCATED ONE-3 ZONE
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87'
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29'
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54'
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104'
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96'
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90'
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75'
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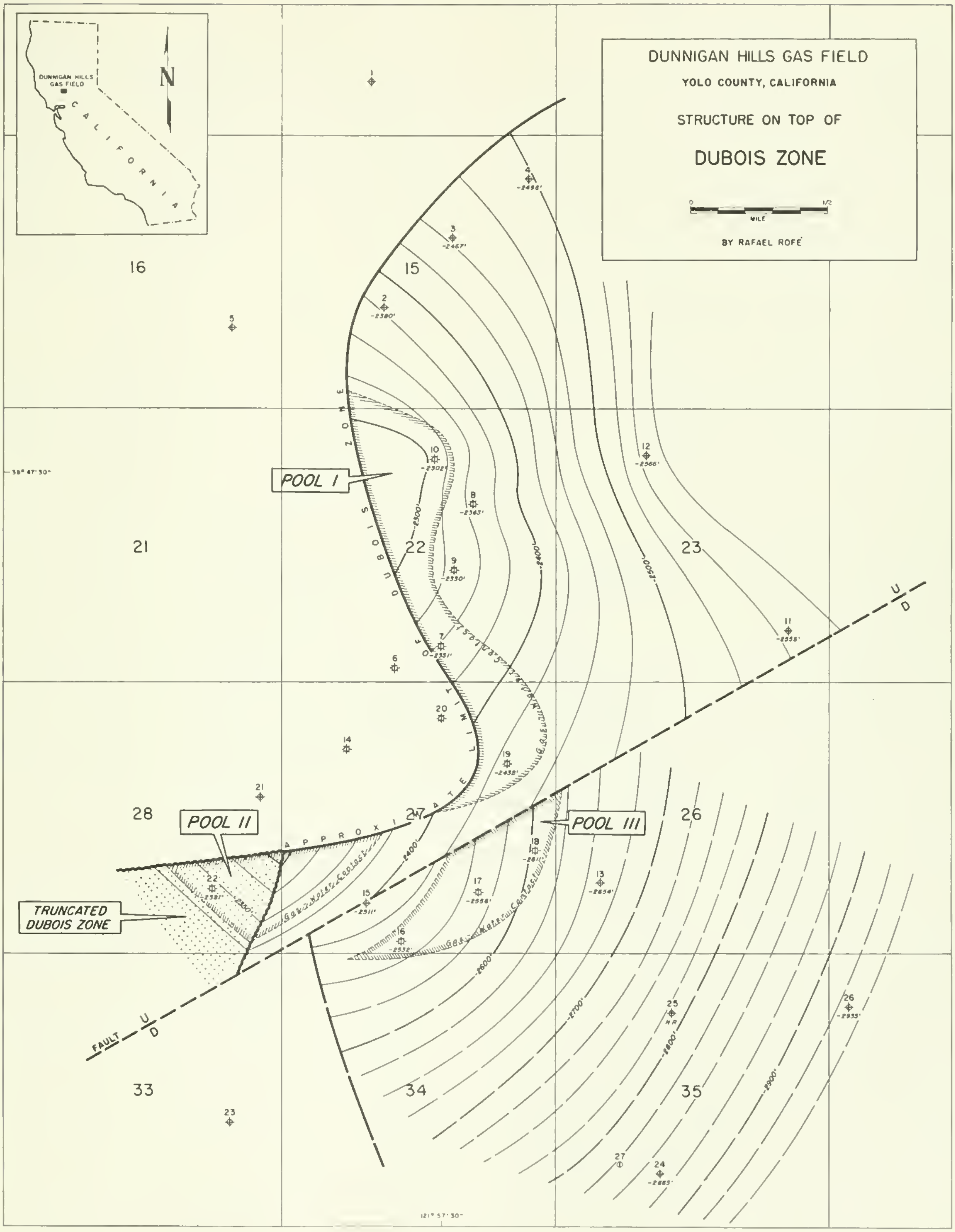
40'
80'
80'

Figure 16.


DUNNIGAN HILLS GAS FIELD
YOLO COUNTY, CALIFORNIA
STRUCTURE ON TOP OF
DUBOIS ZONE
0
1/2
MILE
BY RAFAEL ROFÉ
DUNNIGAN HILLS GAS FIELD
CALIFORNIA
N
POOL I
POOL II
POOL III
TRUNCATED DUBOIS ZONE
APPROXIMATE LIMIT OF DUBOIS ZONE
Gas-Water Contact
FAULT
U
D
38° 47' 30"
121° 57' 30"
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7 -2351'
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15 -2311'
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22 -2381'
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24 -2663'
25 NR
26 -2935'
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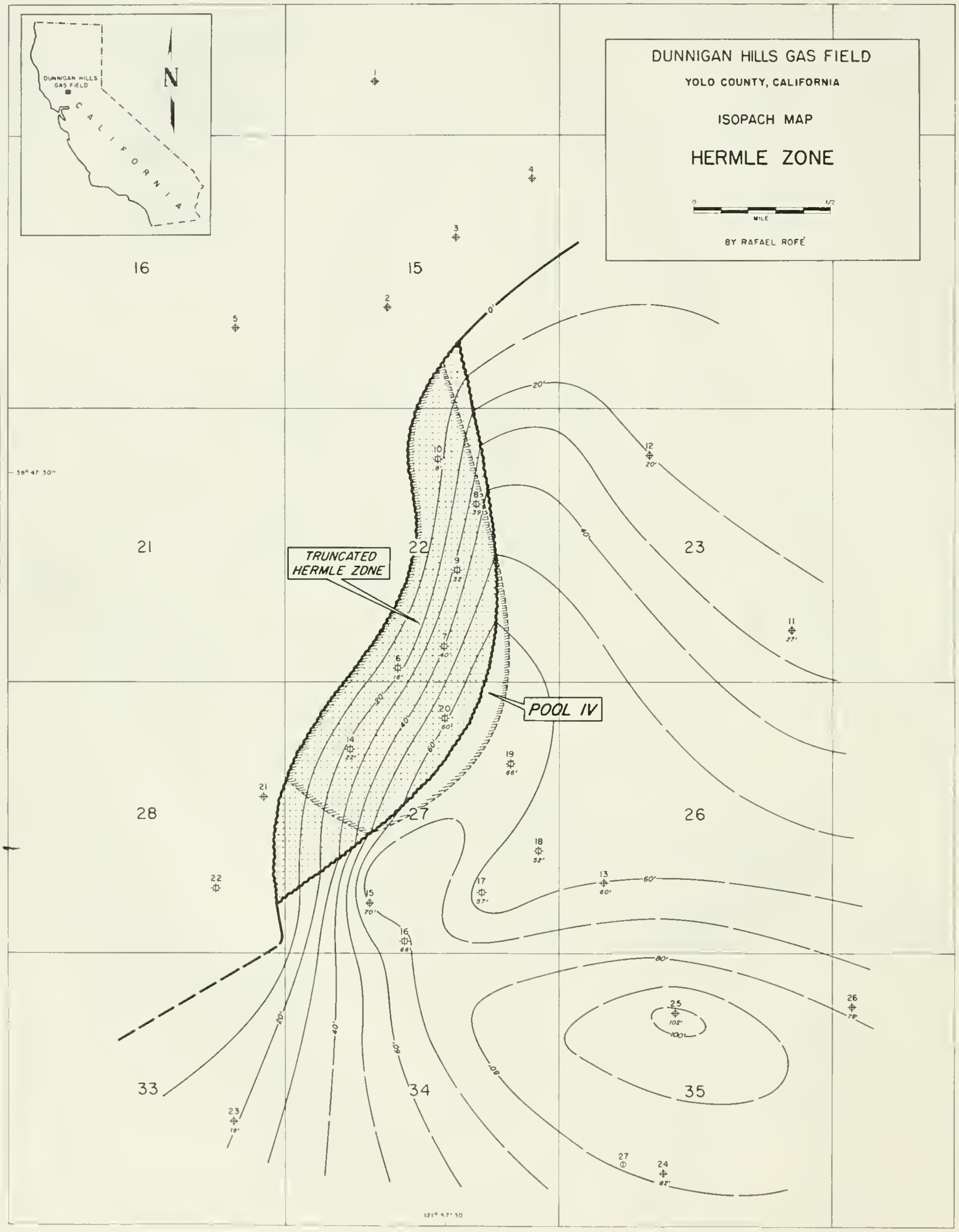
-2300'
-2350'
-2400'
-2500'
-2600'
-2700'
-2800'
-2900'

Figure 17.


DUNNIGAN HILLS GAS FIELD
YOLO COUNTY, CALIFORNIA
ISOPACH MAP
HERMLE ZONE
0
1/2
MILE
BY RAFAEL ROFÉ
DUNNIGAN HILLS GAS FIELD
CALIFORNIA
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34
35
TRUNCATED HERMLE ZONE
POOL IV
38° 47' 30"
121° 57' 30
0'
20'
40'
60'
80'
100'
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8'
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39'
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32'
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40'
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16'
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12
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27'
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66'
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52'
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57'
13
60'
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70'
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66'
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23
18'
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102'
26
78'
27
24
82'
1
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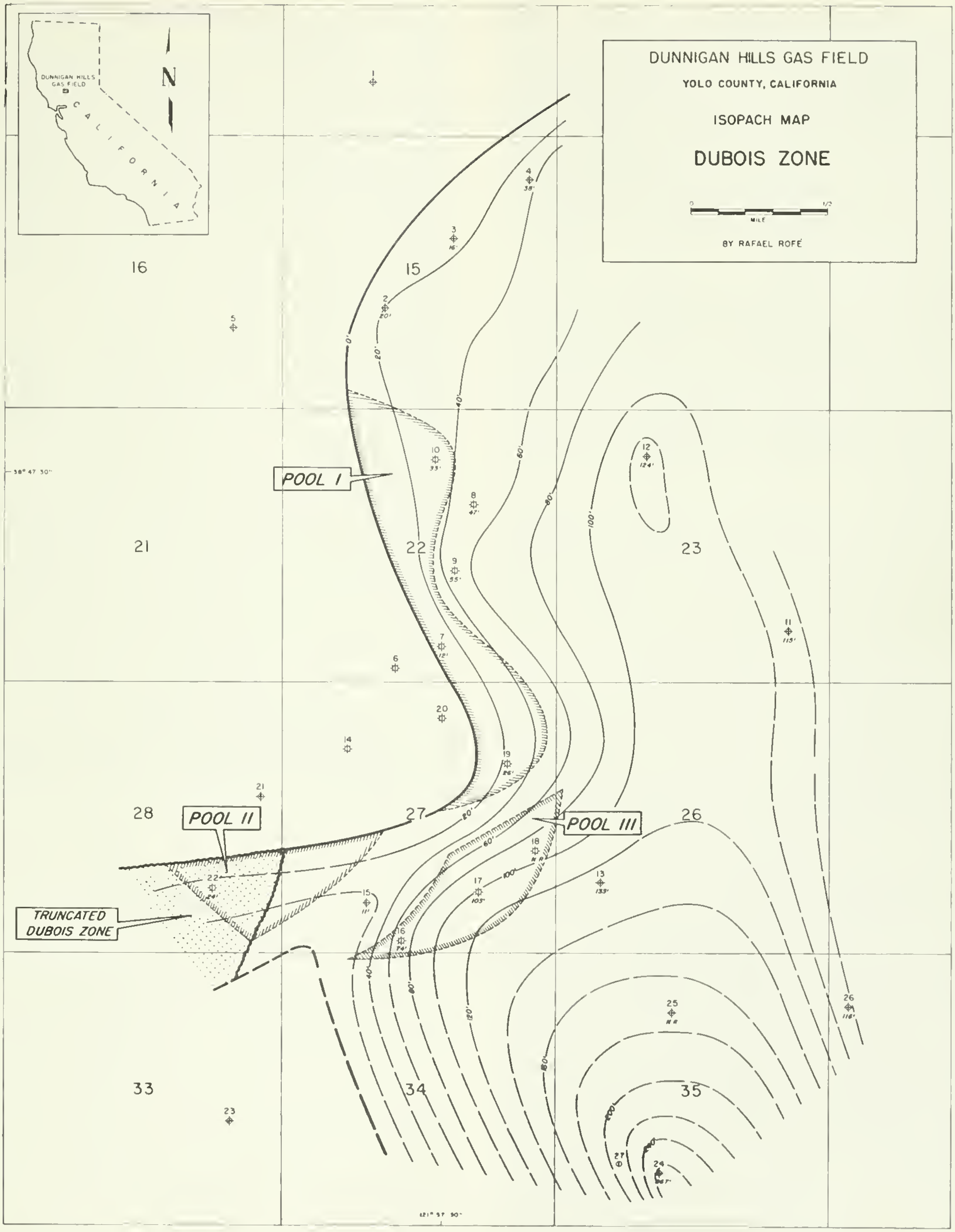
4
5

Figure 18.


DUNNIGAN HILLS GAS FIELD
YOLO COUNTY, CALIFORNIA
ISOPACH MAP
DUBOIS ZONE
0
1/2
MILE
BY RAFAEL ROFÉ
DUNNIGAN HILLS GAS FIELD
CALIFORNIA
N
POOL I
POOL II
POOL III
TRUNCATED DUBOIS ZONE
16
15
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35
38° 47' 30"
121° 57' 30"
0'
20'
40'
60'
80'
100'
120'
180'
200'

Figure 19.

Geological History. During the Cretaceous deposition, a progressive subsidence of the Sacramento Valley caused the Upper Cretaceous seas to transgress eastward to the Sierra Nevada foothills. As suggested by cross section B-B′, the Dubois zone was laid horizontally around a slightly positive area. The age of this slight arching cannot be traced farther back than Weldonian time. Thinning around the positive area, an original primary stratigraphic trap was created in the Dubois zone when the sand was overlain by younger claystones. Later the Hermle and One-3 zones were deposited, progressively masking this positive area.

Figures 17, 18, and 19 illustrate the variations in the thicknesses of the various zones within the field. The Dubois zone thins northward and the indicated approximate limit of deposition outlines the existing positive area at that time. The Hermle zone was more evenly laid down, but shows a bulging to the south and a gradual thinning to the northwest, where the sand was sharply truncated. The positive area still existed, but was considerably flatter. The deposition of the One-3 zone was extremely uniform; no trace of the positive area remained at that time.

At the close of the Cretaceous, the rocks were faulted and tilted toward the southeast. The tilting originated several stratigraphic traps which are still preserved in the Dubois zone. This was followed by an erosional period during which time Upper Cretaceous sediments were truncated, particularly the One-3 zone which was completely eroded north of the major fault.

Throughout northern California there is evidence of a major uncomformity at the base of the Tertiary strata. It is postulated that this pre-Eocene erosion surface was largely developed at the close of the Cretaceous. Since it is believed that Paleocene or lower Eocene deposition did not take place in the area, the Cretaceous erosion surface probably remained a low area of emergence within the Sacramento Valley throughout Paleocene and early Eocene times. It is thus inferred that the uncomformity is Late Cretaceous in age.

After a long period of erosion, gradual subsidence of the Cretaceous land-mass took place as the middle Eocene seas transgressed the area. The basal grit of the Capay formation was evenly deposited on this surface of the unconformity, sealing off all the truncated sands. The impervious cover thus formed created important structural-stratigraphic traps, particularly in the Hermle zone. Deposition of Capay, Domengine, and Nortonville sediments followed without evidence of tectonic activity. Probably no land areas existed in this part of the Sacramento Valley during Oligocene and Miocene times, which might explain the gap between Eocene and Pliocene depositions. In late or post-Eocene time, some rejuvenation of the original positive arching in the Dunnigan Hills area took place, accentuating the anticline. These movements resulted in formation of a few secondary structural traps, as indicated in the Dubois zone in cross section A-A′ (plate 7). Continental deposits were later laid on the eroded surface, but the existing structures were not modified.

Time of Migration and Accumulation of Gas. Geologic considerations would seem to rule out the Eocene sediments as the source-rock for the gas. If the Eocene was the source rock, the gas would have had to migrate downward through the apparently impervious and extensively deposited gritstone of the Capay formation, a most unlikely possibility. Another reason why this is improbable is that the Eocene sediments probably had insufficient overburden pressure to cause the expulsion of the gas from the fine-textured sediments where the minute globules would have been trapped and retained. Therefore, the gas probably originated in nearby Cretaceous sediments.

Lateral or secondary migration, which was probably predominant for the gas accumulations in the Dunnigan Hills, is a function of several factors such as the time of regional tilt and the age of the existing traps, which have to be studied in relation to the geological history of the area.

The following observations on regional tilt in the Cretaceous section are based on a critical analysis of the three cross sections presented. Essentially horizontal during deposition, the Cretaceous strata were tilted southeastward at the close of the period. This probably means that no lateral or secondary migration took place before the close of the Cretaceous. Figure 16 shows, however, that three pools are developed in the Dubois zone. Their

Table 4

PRODUCTION STATISTICS

Year	Number of Wells Shut In	Number of Producing Wells	Production Mcf	Cumulative Production
1949		6	285	856
1950		9	757,241	758,097
1951		12	1,874,456	2,632,553
1952	2	10	1,441,310	3,316,266
1953	2	10	1,037,447	4,353,713
1954	2	10	1,244,812	5,598,525
1955	1	8	1,129,671	6,728,196
1956		9	1,164,179	7,868,939
1957		9	762,022	8,626,656
1958	2	8	371,127	9,041,556
1959	3	7	262,028	9,303,584

position seems to indicate that at the time they formed a single pool. Since no accumulation could take place before the Late Cretaceous, after the transversal fault was formed, the pools on different sides of the fault were not related.

Before migration can take place as a result of regional tilt, a minimum regional dip is required. The structural maps and cross sections indicate an average gradient of 200 feet per mile, one which seems sufficient to allow gas migration through a porous medium, such as sand.

The next step concerns the problem of the age of the trap, since the age of the structure dates the earlier time of accumulation. Logically, the gas cannot accumulate in the reservoir until a trap has been formed. Two general types of traps exist in the Dunnigan Hills gas field. The first is the primary stratigraphic trap, as Pool I in the Dubois zone, which has the age of the first impervious sediments which overlie the potential reservoir. In this case, the first accumulation could have started with the sealing of the reservoir. The time of the Late or post-Cretaceous tilting and the lack of overburden pressure definitely eliminate the possibility of an accumulation during Cretaceous time. The second is a general type of trap, which is a combination stratigraphic-structural trap below the Cretaceous unconformity and a cover of impervious sediments; for instance, Pool IV of the Hermle zone and Pool II of the Dubois zone. This type suggests that the earliest possible time of accumulation is the age of the overlying cap rock: that is, middle Eocene.

Another factor to be considered in dating the time of accumulation is the ability of the trap to hold gas in relation with the pressure—that is, in relation with the depth of burial. Levorsen (1954) showed that in the Oklahoma City field accumulation did not begin until 2,000 feet of sediments were deposited over the potential reservoir. The same relationship cannot be applied with identical proportions in the Dunnigan Hills gas field, but there is an indication that no accumulation took place before Capay time.

The maps and cross sections outline the actual pools with their respective gas-water contacts. A reasonable explanation for their formation cannot be offered in all cases without involving additional factors, such as secondary porosity, cementation, and mineralization, which have not been considered because of a lack of data.

According to the above discussions of the structure and time of migration and accumulation, five pools can be outlined in the Dunnigan Hills gas field. These are tentatively classified according to their type of trap:

Pool I—primary stratigraphic: Locally late compressional movements have produced arching in the reservoir, and created local, secondary structural traps, as shown on Plate 7, in the Dubois zone.

Pool II—secondary stratigraphic: The pool was formed at the unconformity where the Dubois zone was truncated and sealed by the impervious gritstone.

Table 5

MONTHLY AND AVERAGE DAILY PRODUCTION

Date		Total Mcf	Daily Mcf	Water bbl	Number of Producing Wells
1958	Jan	51,037	1,646	30	8
	Feb	15,508	554	12	8
	Mar	69,220	2,233	26	8
	Apr	0	0	0	0
	May	0	0	0	0
	Jun	0	0	0	0
	Jul	0	0	0	0
	Aug	11,397	368	0	7
	Sep	69,145	2,305	0	8
	Oct	65,264	2,105	66	9
	Nov	52,577	1,753	146	9
	Dec	36,979	1,193	190	8
1959	Jan	40,073	1,293	182	9
	Feb	40,997	1,464	242	8
	Mar	15,714	507	169	8
	Apr	0	0	0	0
	May	0	0	0	0
	Jun	0	0	0	0
	Jul	0	0	0	0
	Aug	0	0	0	0
	Sep	44,917	1,497	67	9
	Oct	42,279	1,364	103	8
	Nov	41,207	1,374	44	8
	Dec	36,841	1,189	56	7
1960	Jan	31,866	1,028	78	7
	Feb	25,153	867	67	7
	Mar	25,453	821	69	7

Pool III—combination structural-stratigraphic: The fault became the boundary of the pool and sealed it off from the remaining Dubois zone.

Pool IV—secondary stratigraphic: This important original stratigraphic trap was deeply truncated and sealed off and subsequently created a secondary trap. This is the only pool found in the Hermle zone.

Pool V—combination structural-stratigraphic: Both the unconformity and the fault create the trap on the updip part of the One-3 zone.

Production and Reserves. The natural gas produced in the Dunnigan Hills gas field is a separate and distinct product not associated with petroleum deposits. Dry gas deposits are extremely valuable because they can be conserved indefinitely in place and put into production according to the demand.

The dry gas produced in the Dunnigan Hills gas field consists of about 96 percent methane and 4 percent nitrogen and other gases. The heating value has been determined at 966 BTU per cubic foot, which is slightly lower than for natural gas associated with oil.

Table 4 shows the production from 1949 to 1959. The decline for old wells was estimated at 40 percent after eliminating the production of five wells during the period. The average daily production dropped from 5,100 Mcf in 1951 to 2,070 Mcf in 1957. Table 5 shows the monthly and average daily production for 1958 and 1959, and to March 1960. The wells are generally shut in 4 to 5 months a year during the summer. A net decline in the production can be observed.

The recoverable gas reserves were estimated, as of January 1, 1952, at 11,105,406 Mcf. Assuming this estimate to be correct and considering the cumulative production of 9,303,584 Mcf as of December 31, 1959, approximately 2 million Mcf would remain recoverable. This explains the considerably lower production of the last 3 years.

No further developments are planned within the three actual producing zones, but deep tests are of interest due to the structural conditions in the Cretaceous. These may in time increase the proven reserves.

Conclusions. The Dunnigan Hills were drilled solely on the basis of a structural high indicated by a reflection seismic survey. Gas was discovered in three Upper Cretaceous zones. The gas accumulations were thought to be principally controlled by stratigraphic traps in association with structural elements, such as the major transversal Cretaceous fault and the post-Cretaceous unconformity.

The time of migration and accumulation of gas was determined to be not older than Capay time in the three Upper Cretaceous zones, and five different pools were delineated accordingly. Unfortunately no wells have tested the deeper horizons of the field. The important indication of an arching in the Cretaceous, still clear at Dubois time, enhances the possibility of a more accentuated deeper structure. This favors the wedging out of deeper sand zones around the positive area.

Possible gas accumulations in deep zones are substantiated by a Cretaceous arching around which stratigraphic traps might exist, by a probable good source-rock in the Cretaceous sediments, and by a considerable overburden pressure favoring reservoirs of great potential within small volumes.

The Upper Cretaceous zones seem to have been thoroughly tested, so further shallow tests will probably not substantially increase the known reserves of the field. It is the opinion of the writer that deep zones remain to be tested within the limits of the field where gas accumulations might exist as a confirmation of the favorable factors already mentioned. Therefore, drilling to deeper horizons is recommended as the only possibility for an increase in the Dunnigan Hills gas field reserves.

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Contribution 7

Maine Prairie Gas Field, California

By Sacramento Petroleum Association

The Maine Prairie gas field, Solano County, discovered by Amerada Petroleum Corporation on March 1, 1945 as a result of a seismograph survey, is a multizone dry-gas field consisting of five separate pools. The main, or Wineman pool, which comprises the north two-thirds of the field, is the result of a combination trap and is unique in that up-dip closure is provided by the impermeable Markley Gorge, a late Eocene channel-like feature traceable to the northeast and southwest for many miles.

The Maine Prairie gas field includes approximately 3500 acres and has ultimate recoverable reserves in excess of 80,000,000 Mcf [1]. The practically pure methane gas produced has a heating value of approximately 1000 BTU per cubic foot and is sold exclusively to Pacific Gas and Electric Company.

Location. The Maine Prairie gas field is located 7 miles north of the Rio Vista field, which has the largest dry-gas reserve in California, and 15 miles southwest of Sacramento, the capital city. Subdued topography, with elevations ranging from 5 to 15 feet above sea level, reflects none of the subsurface structure.

History. The Maine Prairie gas field was discovered by Amerada Petroleum Corporation as the result of a seismograph survey. Its first well, I. & L., Wineman No. 1, located in section 26, T. 6 N., R. 2 E., was completed on March 1, 1945 at a depth of 4790 feet in the lower

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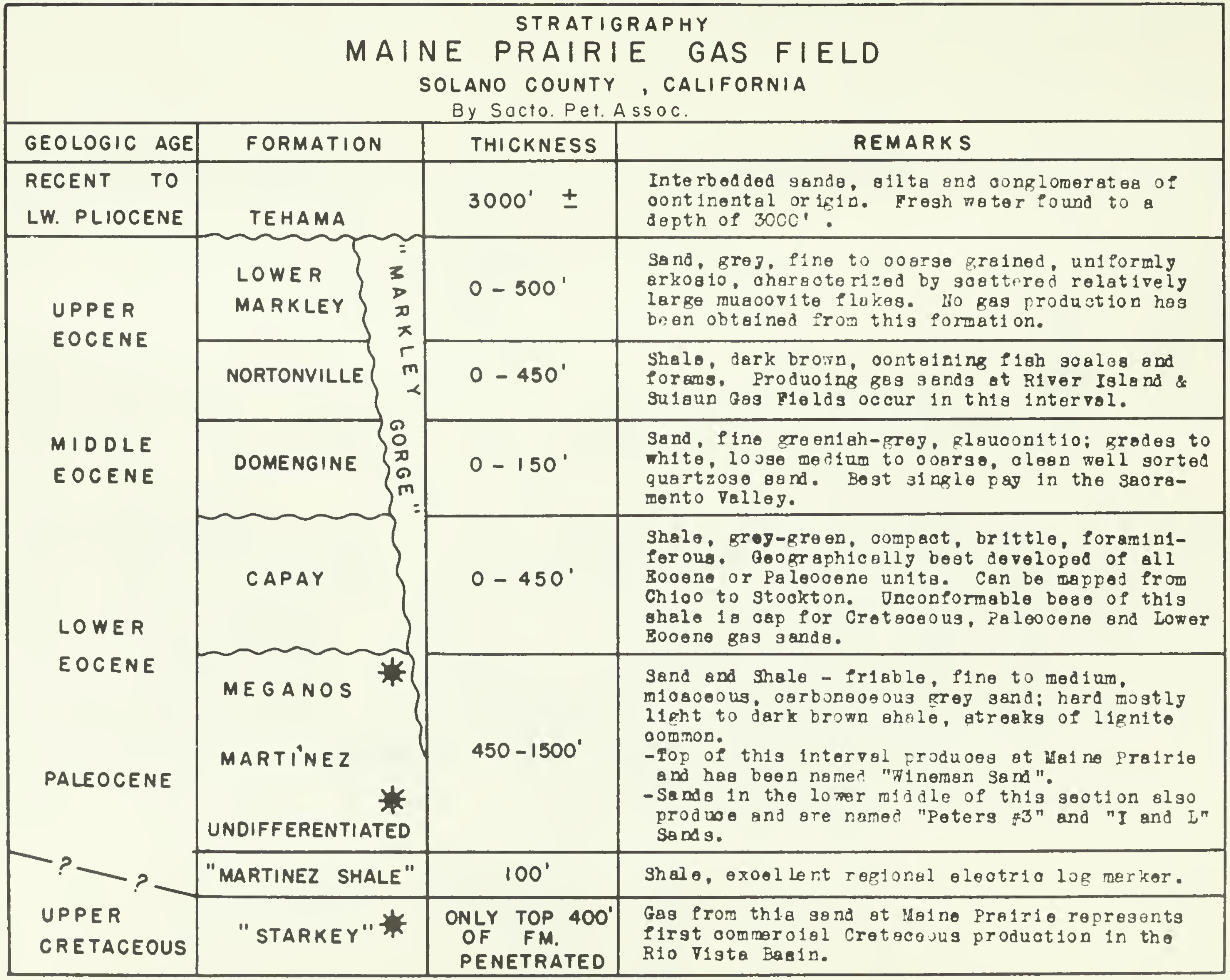
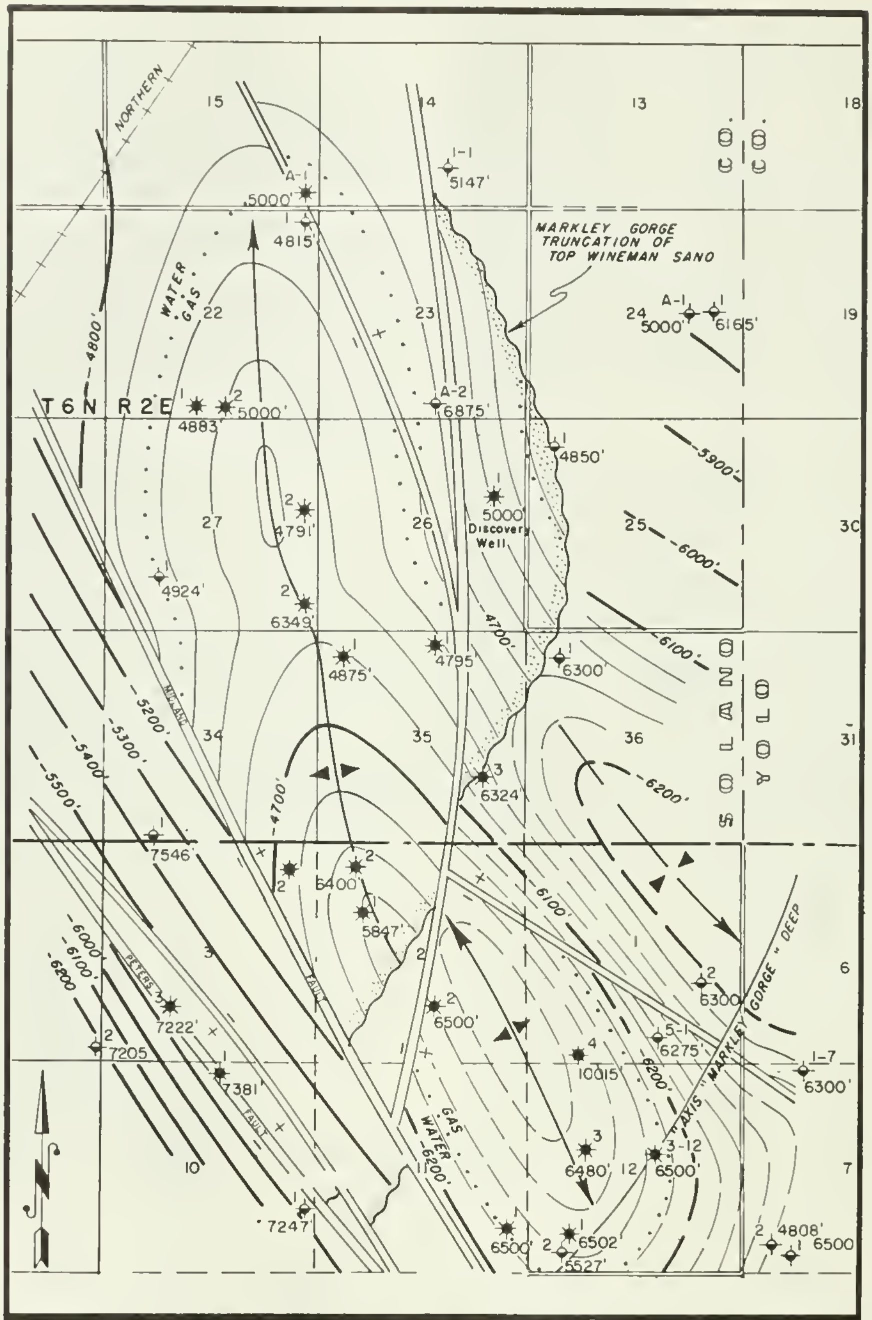
[1] Reserve estimate by F. E. Kasline, California Division of Oil and Gas.



STRATIGRAPHY
MAINE PRAIRIE GAS FIELD
SOLANO COUNTY , CALIFORNIA
By Sacto. Pet. Assoc.

GEOLOGIC AGE	FORMATION	THICKNESS	REMARKS
RECENT TO LW. PLIOCENE	TEHAMA	3000' ±	Interbedded sands, silts and conglomerates of continental origin. Fresh water found to a depth of 3000'.
UPPER EOCENE	LOWER MARKLEY	0 - 500'	Sand, grey, fine to coarse grained, uniformly arkosic, characterized by scattered relatively large muscovite flakes. No gas production has been obtained from this formation.
	NORTONVILLE	0 - 450'	Shale, dark brown, containing fish scales and forams. Producing gas sands at River Island & Suisun Gas Fields occur in this interval.
MIDDLE EOCENE	DOMENGINE	0 - 150'	Sand, fine greenish-grey, glauconitic; grades to white, loose medium to coarse, clean well sorted quartzose sand. Best single pay in the Sacramento Valley.
LOWER EOCENE	CAPAY	0 - 450'	Shale, grey-green, compact, brittle, foraminiferous. Geographically best developed of all Eocene or Paleocene units. Can be mapped from Chico to Stockton. Unconformable base of this shale is cap for Cretaceous, Paleocene and Lower Eocene gas sands.
PALEOCENE	MEGANOS ✸ MARTINEZ ✸ UNDIFFERENTIATED	450-1500'	Sand and Shale - friable, fine to medium, micaceous, carbonaceous grey sand; hard mostly light to dark brown shale, streaks of lignite common. -Top of this interval produces at Maine Prairie and has been named "Wineman Sand". -Sands in the lower middle of this section also produce and are named "Peters #3" and "I and L" Sands.
? — ?	"MARTINEZ SHALE"	100'	Shale, excellent regional electric log marker.
UPPER CRETACEOUS	"STARKEY" ✸	ONLY TOP 400' OF FM. PENETRATED	Gas from this sand at Maine Prairie represents first commercial Cretaceous production in the Rio Vista Basin.

Figure 20. Stratigraphy of the Maine Prairie gas field, Solano County, California.



STRUCTURE MAP

MAINE PRAIRIE GAS FIELD

SOLANO COUNTY, CALIFORNIA

CONTOURS ON BASE CAPAY SHALE ————

CONTOURS ON BASE MARTINEZ SHALE-TOP H&T SAND — —

CONTOUR INTERVAL (WEST MIDLAND FAULT) 100 FEET

(EAST MIDLAND FAULT) 20 FEET

⌖ Dry and abandoned

✷ Gas well

SCALE: 1" = 2000' MARCH 1960

By Socto Pet Assoc

Figure 21.

Eocene Wineman sand, as indicated on Section B-B′ (fig. 23). The well flowed at the rate of 18,997 Mcf of gas per day on a ¾-inch bean. This was apparently an edge well, inasmuch as the production went to water and dry holes have been drilled on three sides of the discovery location.

By the end of 1959 thirty-five wells had been drilled and seventeen were producing. Five separate productive pools had been found. Within the field the following three areas of reference exist: (a) the Wineman area, or north two-thirds of the field; (b) H. & T. area, or south one-third of the field, and (c) the Peters Pocket area, or southwest part of the field in the Midland fault zone.

Despite the success of the seismograph interpretation, it would be unfortunate if all the credit for discovery went to that method. The development of the field required imagination and persistence in unraveling the delicate interrelationships between structure and stratigraphy that could not be wholly defined by the seismic technique.

Stratigraphy. The geologic formations of the Maine Prairie gas field are shown in the columnar section, figure 20.

The Markley Gorge (Davis, D. M., 1953) is an erosional feature best described as a buried canyon or ancient river channel filled with siltstone, shale, tight sand, and conglomerate, which acts as a permeability barrier to the older Wineman sand at the Maine Prairie gas field. This northeast-trending subsurface feature is more than 45 miles long, and 9 miles wide, and reaches a maximum depth of 5,700 feet below sea level. It becomes deeper to the southwest and is in contact with progressively younger sediments in that direction.

Geologists agree the Markley Gorge can be no older than late Eocene. Some (Almgren and Schlax, 1957) feel it is definitely post-Eocene and put forth arguments favoring Gorge development during Oligocene time.

Structure. The structure of the Maine Prairie gas field is a simple anticline with the major axis extending northwest. The fold is symmetrical, with the steepest dips measuring less than 2 degrees.

Faulting is minor except along the Midland fault zone in the southwestern portion of the field. Offsets along individual faults in this zone run as high as 850 feet in the Eocene, and they apparently increase with depth. Characteristically, here as elsewhere, along the Midland fault the Capay shale increases in thickness from 300 to 400 feet on the upthrown east side of the fault to about 900 feet on the downthrown side. This stratigraphic anomaly is interpreted by most geologists to be due to movement during or at the close of Capay deposition. Subsequent slight movements have taken place, but it is believed that virtually all activity had ceased by late Eocene or Markley Gorge time.

It is difficult to date the growth of the Maine Prairie anticline; however, it is safe to assume the forces associated with the Midland fault are at least partially responsible for the fold. There is every indication that the structure we see today at Maine Prairie dates from Eocene time and existed prior to development of the Gorge. In this connection it should be noted that, as displayed on section A-A′, any gas accumulation existing in the Wineman sand prior to Gorge development would have escaped. Gas trapped in the Wineman sand is apparently the result of post-Gorge migration.

Character of Accumulation and Regional Significance. The only gas accumulation at the Maine Prairie field solely controlled by structure is the H. & T. pool. Gas in this blanket sand, which is too deep to be intersected by the Gorge, is controlled by a faulted structural nose. This Cretaceous sand is referred to regionally as "Starkey" and has wide distribution.

In all other pools at Maine Prairie, lateral variations in lithology are of significance in forming the trap. The Wineman pool is controlled by a combination of structure and stratigraphy. The most intriguing aspect of this pool is the fact that the Gorge demonstrates its ability to trap gas. Two wells, located in Secs. 3 and 10, T. 5 N., R. 2 E., in the Midland fault zone, are also productive from the Wineman sand in the Peters Pocket pool. This pool may also have south closure provided by Gorge truncation.

A Meganos-Martinez facies change of regional proportions, coupled with favorable local structure, apparently creates the trap for the accumulation of gas in the Peters No. 3 and I. & L. sands, as indicated on the cross sections.

Production. (Data from California Division of Oil and Gas.) To the end of 1958, 25,245,320 Mcf of gas had been produced from the Maine Prairie gas field. Annual production of gas for each of the last 5 years is as follows:

1954	2,476,213 Mcf
1955	2,826,820 Mcf
1956	2,936,921 Mcf
1957	3,308,786 Mcf
1958	3,557,172 Mcf

Gas Analysis
(average of all zones, all wells)

Methane	96.9 percent
Ethane	1.9 percent
Nitrogen	1.2 percent
Carbon dioxide	0.0 percent
Specific gravity	0.0570
Heating value	1018 BTU/cu. ft.

It appears the field has been almost completely developed in the known Eocene producing horizons. Lower Starkey sand, which is productive at Sycamore Slough gas field, and Winters sand, which is productive at Dunnigan Hills, Winters, Freeport, and most recently at Walnut Grove, have been penetrated by only one well at Maine Prairie.

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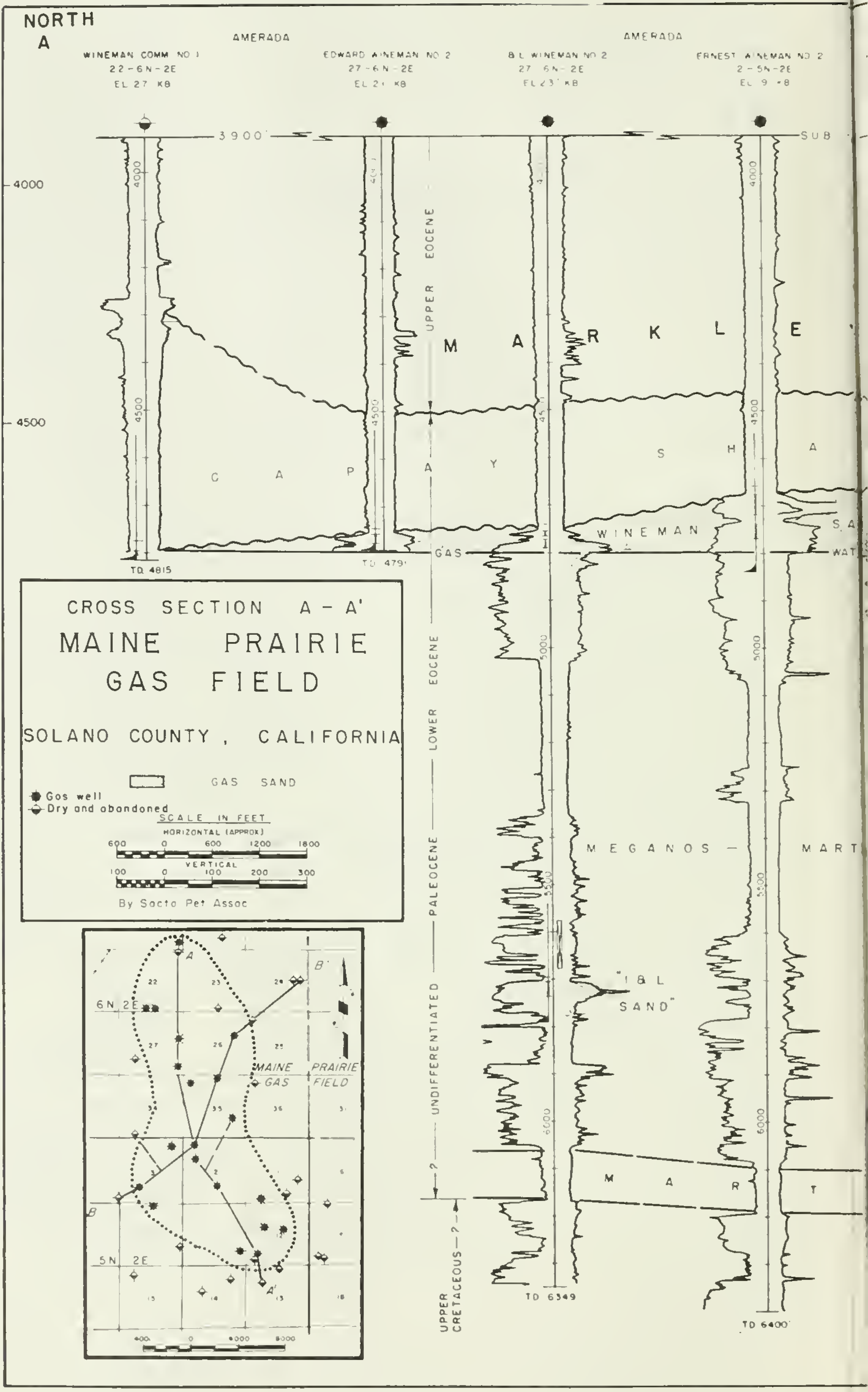
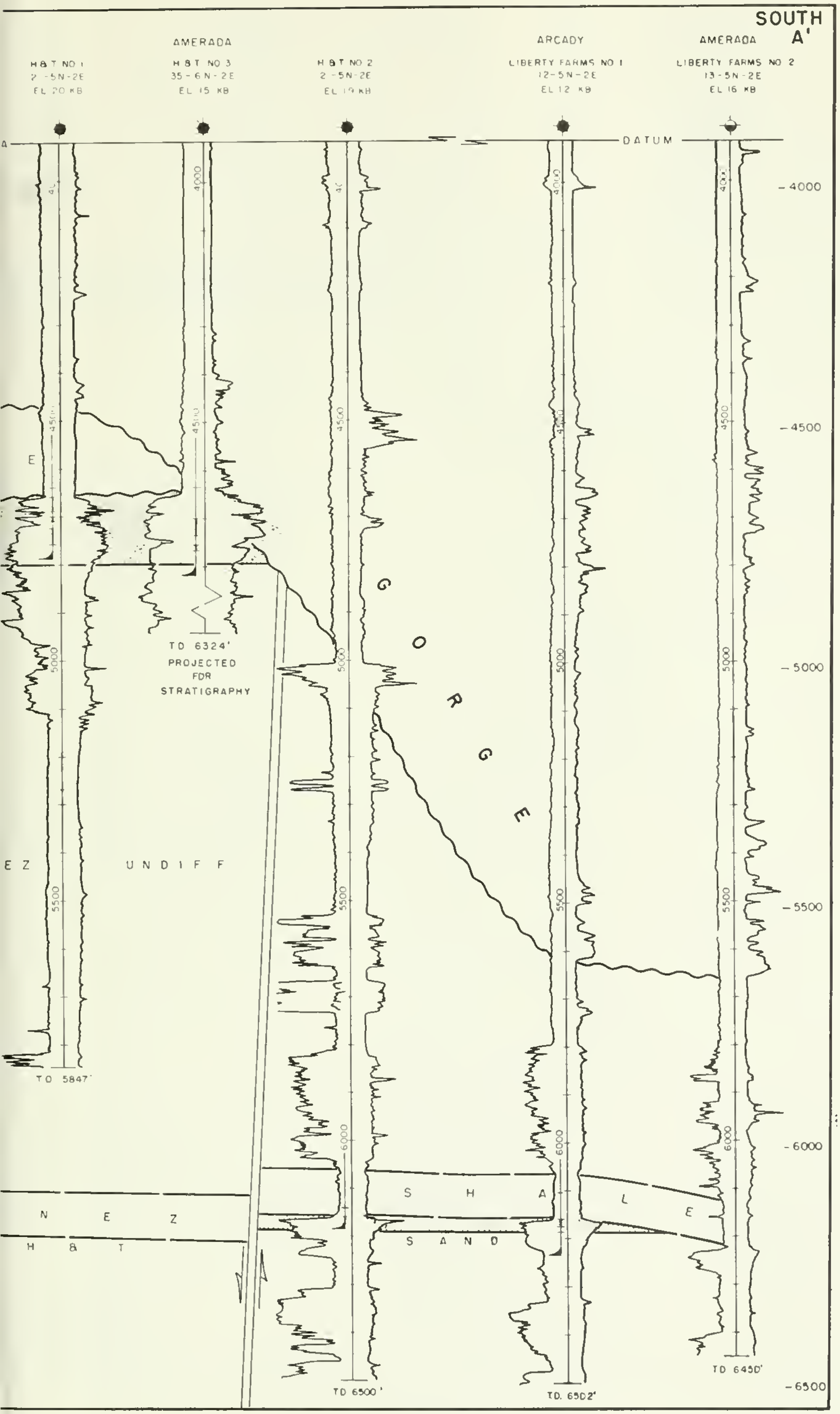

NORTH
A
AMERADA
WINEMAN COMM NO 1
22-6N-2E
EL 27 KB
EDWARD WINEMAN NO 2
27-6N-2E
EL 21 KB
AMERADA
B L WINEMAN NO 2
27 6N 2E
EL 23' KB
ERNEST WINEMAN NO 2
2-5N-2E
EL 9 KB
3900'
SUB
4000
4500
5000
5500
6000
TD 4815
TD 479
TD 6349
TD 6400'
UPPER EOCENE
LOWER EOCENE
PALEOCENE
UNDIFFERENTIATED
UPPER CRETACEOUS
MARKLE
CAPAY
SHA
WINEMAN
GAS
SA
WAT
MEGANOS
MART
"I & L SAND"
MAR
T
CROSS SECTION A - A'
MAINE PRAIRIE GAS FIELD
SOLANO COUNTY, CALIFORNIA
GAS SAND
Gas well
Dry and abandoned
SCALE IN FEET
HORIZONTAL (APPROX)
600
0
600
1200
1800
VERTICAL
100
0
100
200
300
By Sacto Pet Assoc
A
B'
22
23
24
6N 2E
27
26
25
MAINE GAS
PRAIRIE FIELD
35
36
B
5N 2E
A'
15
14
13
18
4000
0
4000
8000

Figure 22.


SOUTH
A'
H B T NO 1
2 -5N-2E
EL 20 KB
AMERADA
H B T NO 3
35-6N-2E
EL 15 KB
H B T NO 2
2 -5N-2E
EL 19 KB
ARCADY
LIBERTY FARMS NO 1
12-5N-2E
EL 12 KB
AMERADA
LIBERTY FARMS NO 2
13-5N-2E
EL 16 KB
DATUM
-4000
-4500
-5000
-5500
-6000
-6500
4000
4500
5000
5500
6000
E
GORGE
TD 6324'
PROJECTED FOR STRATIGRAPHY
EZ
UNDIFF
TD 5847'
SHALE
NEZ
SAND
H&T
TD 6500'
TD 6502'
TD 6450'

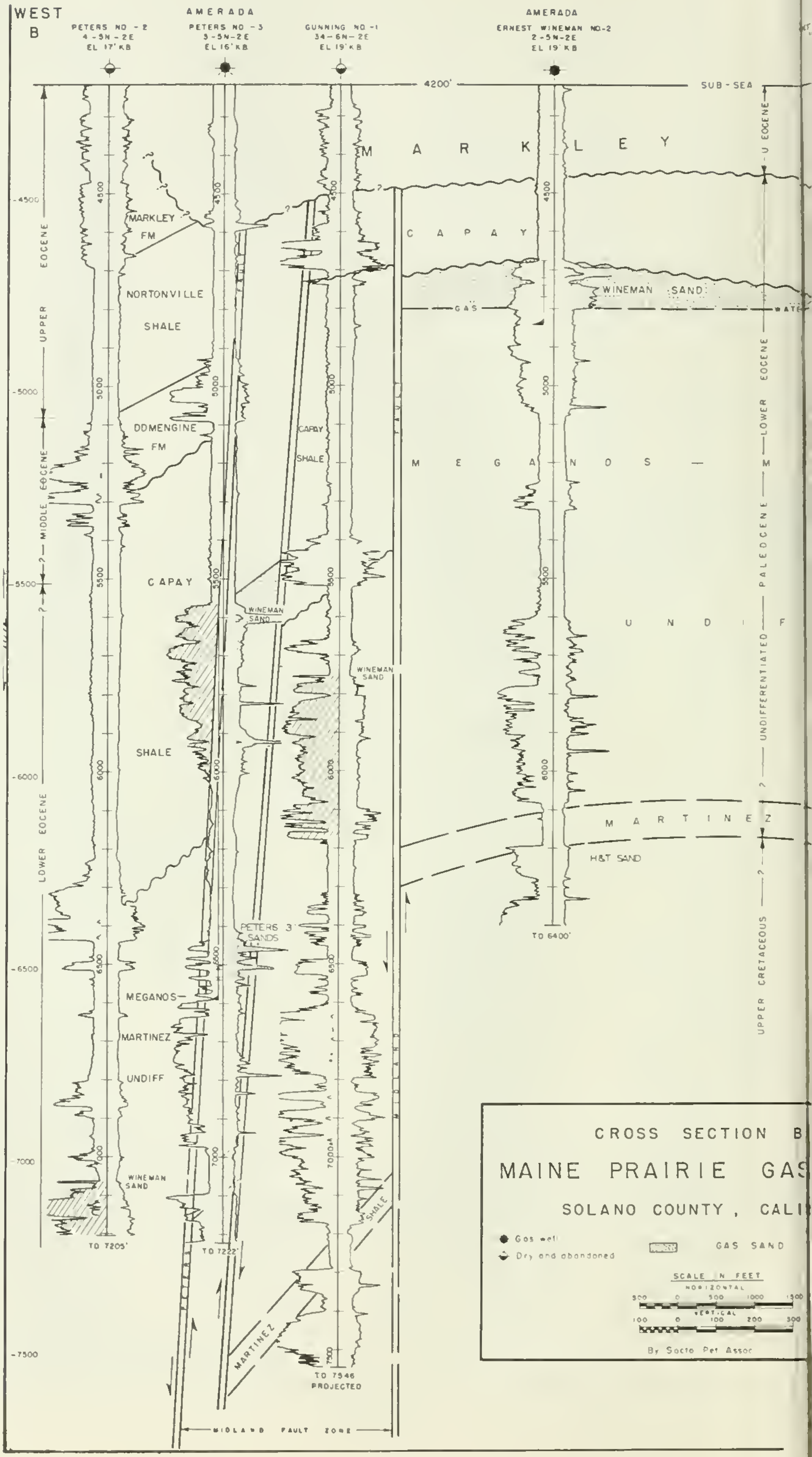
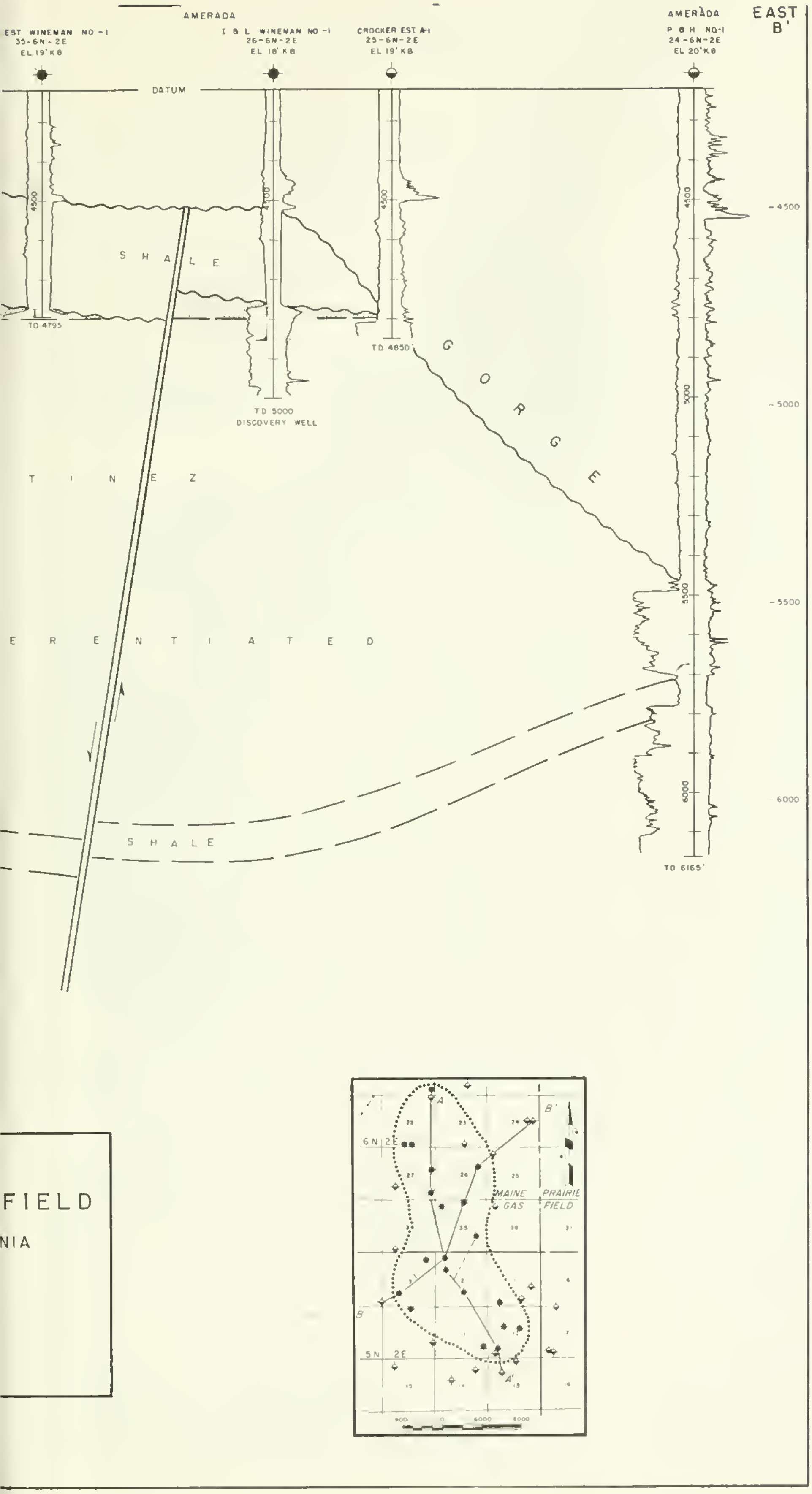

WEST
B
AMERADA
PETERS NO - 2
4 - 5N - 2E
EL 17' KB
PETERS NO - 3
3 - 5N - 2E
EL 16' KB
GUNNING NO - 1
34 - 6N - 2E
EL 19' KB
AMERADA
ERNEST WINEMAN NO-2
2 - 5N - 2E
EL 19' KB
4200'
SUB - SEA
-4500
-5000
-5500
-6000
-6500
-7000
-7500
UPPER EOCENE
? MIDDLE EOCENE ?
LOWER EOCENE
M A R K L E Y
MARKLEY FM
NORTONVILLE SHALE
DOMENGINE FM
CAPAY SHALE
CAPAY
WINEMAN SAND
GAS
WATE
CAPAY SHALE
WINEMAN SAND
PETERS 3 SANDS
MEGANOS
MARTINEZ
UNDIFF
WINEMAN SAND
M E G A N O S — M
U N D I F
M A R T I N E Z
H&T SAND
MARTINEZ
SHALE
FAULT
MIDLAND
MIDLAND FAULT ZONE
TD 7205'
TD 7222'
TD 7546 PROJECTED
TD 6400'
4500
5000
5500
6000
6500
7000
7500
U EOCENE
LOWER EOCENE
PALEOCENE
UNDIFFERENTIATED
UPPER CRETACEOUS
CROSS SECTION B
MAINE PRAIRIE GAS
SOLANO COUNTY, CALI
● Gas well
Dry and abandoned
GAS SAND
SCALE IN FEET
HORIZONTAL
500 0 500 1000 1500
VERTICAL
100 0 100 200 300
By Sacto Pet Assoc

Figure 23.


EAST
B'
AMERADA
EST WINEMAN NO-1
35-6N-2E
EL 19' KB
I & L WINEMAN NO-1
26-6N-2E
EL 18' KB
CROCKER EST A-1
25-6N-2E
EL 19' KB
AMERADA
P & H NO-1
24-6N-2E
EL 20' KB
DATUM
4500
5000
5500
6000
-4500
-5000
-5500
-6000
SHALE
TD 4795
TD 4850'
TD 5000
DISCOVERY WELL
GORGE
TINEZ
ERENTIATED
SHALE
TD 6165'
6N 2E
5N 2E
A
A'
B
B'
MAINE PRAIRIE
GAS FIELD
4000
0
4000
8000

FIELD

NIA

Contribution 8

West Thornton and Walnut Grove Gas Fields, California

By J. H. Silcox
Standard Oil Company of California

This paper presents a case-history of exploration and development on the plunge of the Thornton arch, as specifically related to the West Thornton and Walnut Grove gas fields. These fields are located in the east-central portion of the Delta area of the Sacramento Basin. The Delta area lies within the general boundaries described by the latitude of the city of Sacramento on the north, the Sierran foothills to the east, the Mt. Diablo foothills on the south, and the eastern foothills of the California Coast Ranges on the west. A thick Tertiary and Paleocene clastic section, which is missing due to thinning and truncation in the remainder of the Sacramento Basin, underlies the Delta area. Gas is trapped in these sediments by combinations of folding, faulting, and rapid facies changes. Structural traps predominate. Rio Vista, a complexly faulted dome, which is the largest gas field in the Sacramento Basin, with reserves in excess of 3,000 million Mcf, occupies a position in the center of the Delta area immediately west of the West Thornton and Walnut Grove fields.

The West Thornton and Walnut Grove gas fields (fig. 24) are two of a series of seven gas fields along the west-trending Thornton arch, one of the major structural features in the Sacramento Basin, which extends from Lodi on the east to the east flank of the Rio Vista structure on the west. Production on this trend was first established at Lodi by the Amerada Lodi Community No. 1 well from Eocene Domengine sands in 1943. Subsequently, production was found at Thornton in 1943, Georgiana Slough in 1954, West Thornton in 1956, and Walnut Grove in 1958.

These fields are of interest in that the multiple producing intervals represent many of the pay zones of the entire Sacramento Valley gas province.

Structure. The principal structure of this area is the Thornton anticline and its attendant west-plunging nose (fig. 24). Low-relief anticlinal closure provides a trap for Eocene gas in the Thornton field. West Thornton and Walnut Grove are two of a number of other gas accumulations which are trapped on the west-plunging nose by stratigraphic changes and faults of small displacement. These faults trend in a northwest direction, subparallel to the Midland fault. The Midland fault, which is the major fault of the central Delta area, trends north-northwest through the Rio Vista field and displays normal displacement of over 1,000 feet. This fault is particularly important inasmuch as the effects of its movements are reflected in the Eocene sediments.

Because of the nature of the sedimentary section which usually would place sand against sand in down-to-the-basin faulting, up-to-the-basin faults are believed to be necessary to trap gas in the Domengine and Meganos sands. However, Martinez and Nortonville gas is trapped against down-to-the-basin faults probably because the thin sands in this section come into juxtaposition with shale.

Most of the faults indicated on the subsurface maps have a displacement of less than 50 feet; however, in most cases this presence has been confirmed by reservoir-pressure analysis.

The earliest evidence of structural development of the Thornton arch occurs prior to deposition of the basal Eocene Meganos sand. The greatest growth occurred during upper Eocene time, as evidenced by the absence of Nortonville sediments over the crest of the structure. Further structural deformation since Markley deposition has been minor.

Stratigraphy. The stratigraphic column (fig. 25) in the Walnut Grove-West Thornton area includes rocks of Cretaceous, Paleocene, Eocene and Mio-Pliocene age. The lowermost productive zones are the Winters sands which are a basinal series in the Cretaceous Delta shale unit. They are of D-2- and E-zone age according to Goudkoff's (Goudkoff 1945) classification.

During deposition of the Delta shale and Winters sand series, the Cretaceous seas were regressing to the west and south. This regression continued into C-zone time and is expressed in the stratigraphic column by the thick Starkey regressive sand sequence. The Starkey sands are a series of cyclic beach deposits derived from the east and northeast as the Sierran and northern Sacramento Valley areas were uplifted and eroded. The only production from the Starkey sand is at the south Maine Prairie field.

At the close of Cretaceous deposition there was a short period of quiescence and stability, when the seas readvanced over a wide area, and a thin shale unit was deposited with remarkable uniformity. The top of the Cretaceous has been placed at the base of this shale body and the shale is, therefore, considered to be of Paleocene age, although to date direct fossil evidence is not diagnostic. The Paleocene sea in which the Martinez formation was deposited was confined to a restricted portion of the Delta area by barrier beaches. Behind these beaches, lagoonal, swamp, and flood-plain deposits of sandstone and silt were laid down. The numerous beds of coal and the erratic character of the sediments as shown on electric logs attest to the predominantly nonmarine nature of the Martinez in this area. Occasionally, the sea advanced across the lagoons, and more massive sands were deposited.

In late Paleocene time, the seas readvanced, continuing to do so into early Eocene Meganos time. Contemporaneously, the Midland fault become active and the east block was elevated, exposing the Martinez and possibly a thin lower Meganos section to erosion. Coincident with

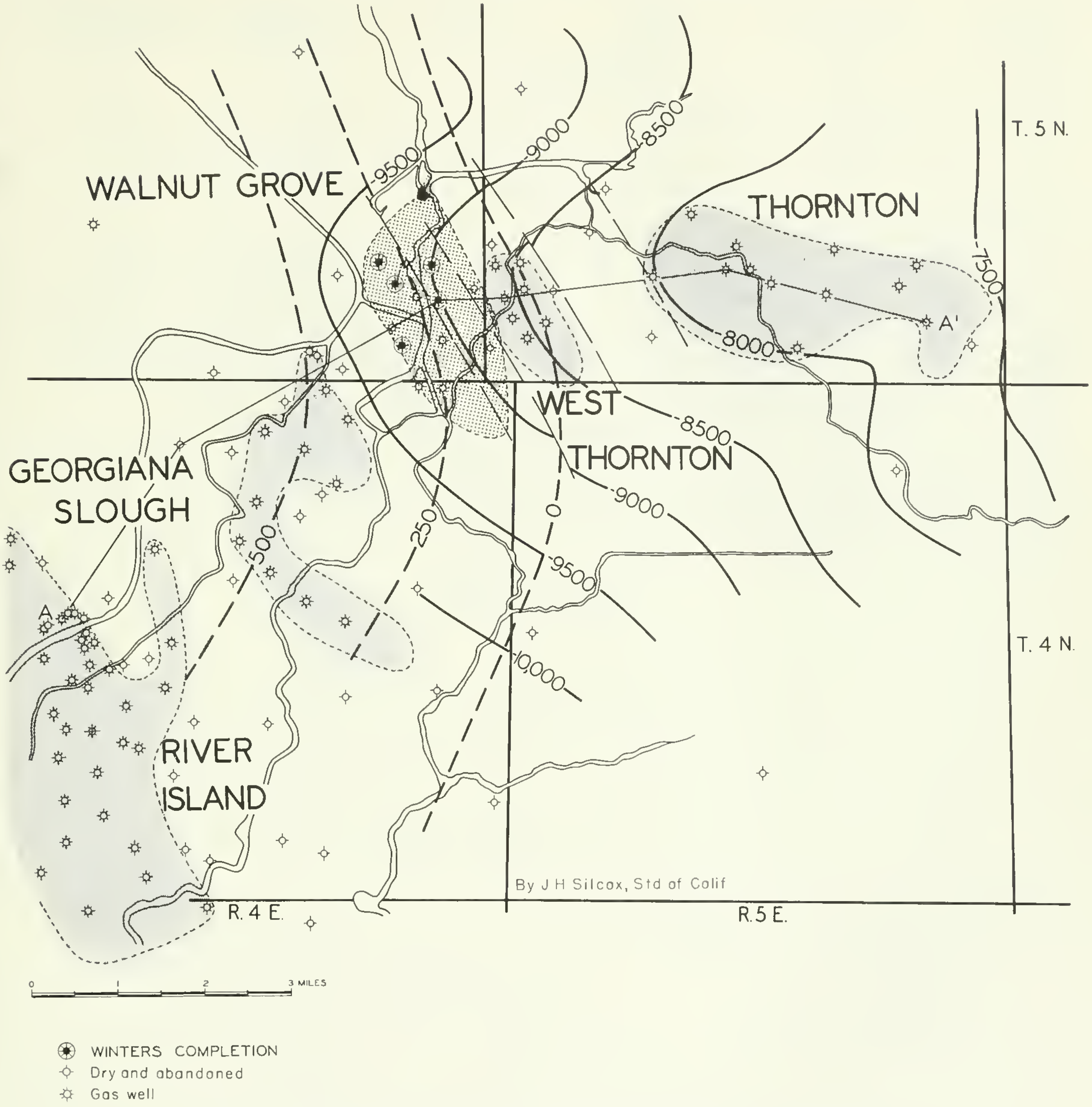


Figure 24. Structural contour map on base of the Delta shale; isopoch map of Winters sand.

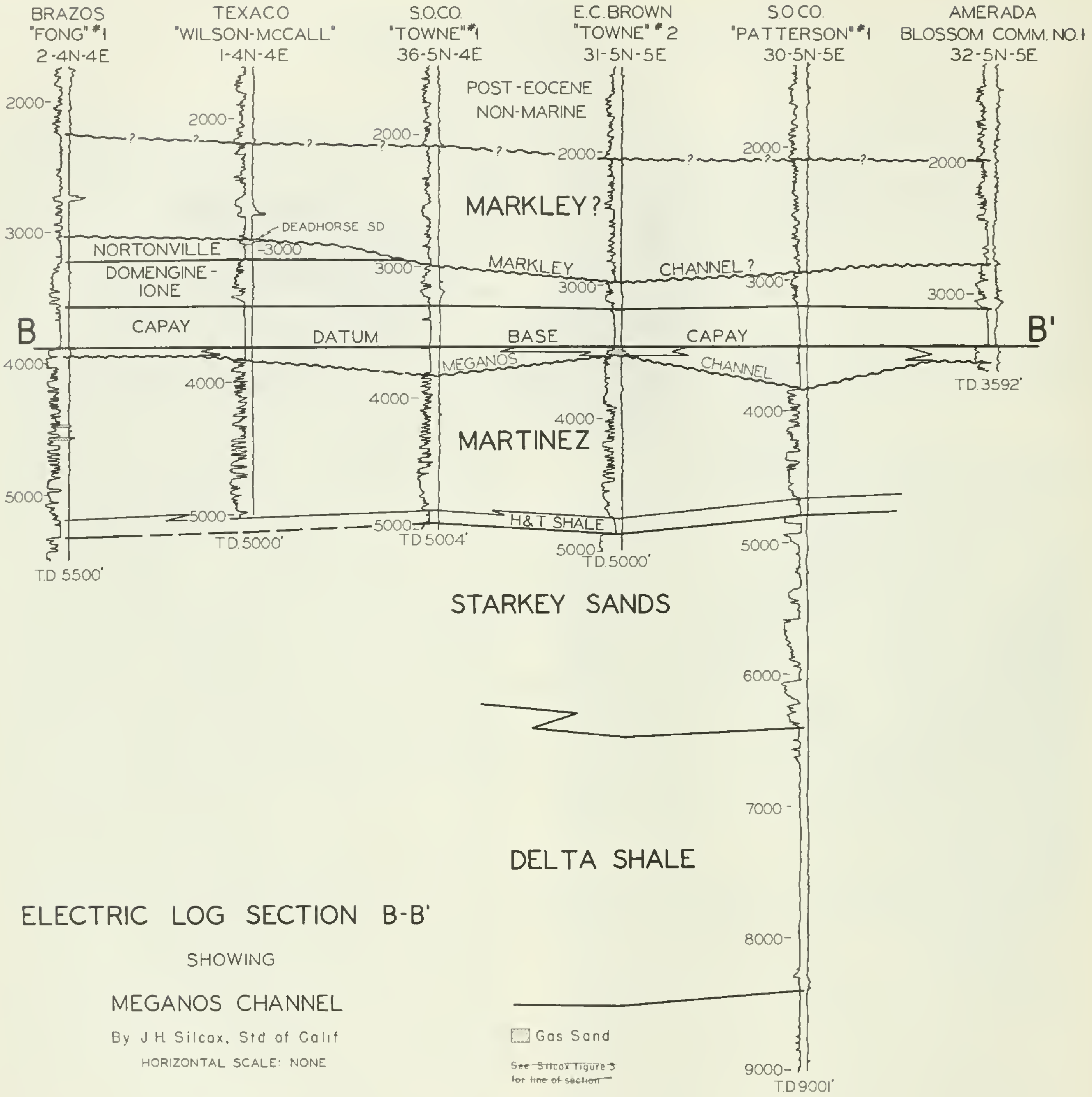


Figure 25. Electric log section B-B′, showing the Meganos channel. For line of section, see figure 26.

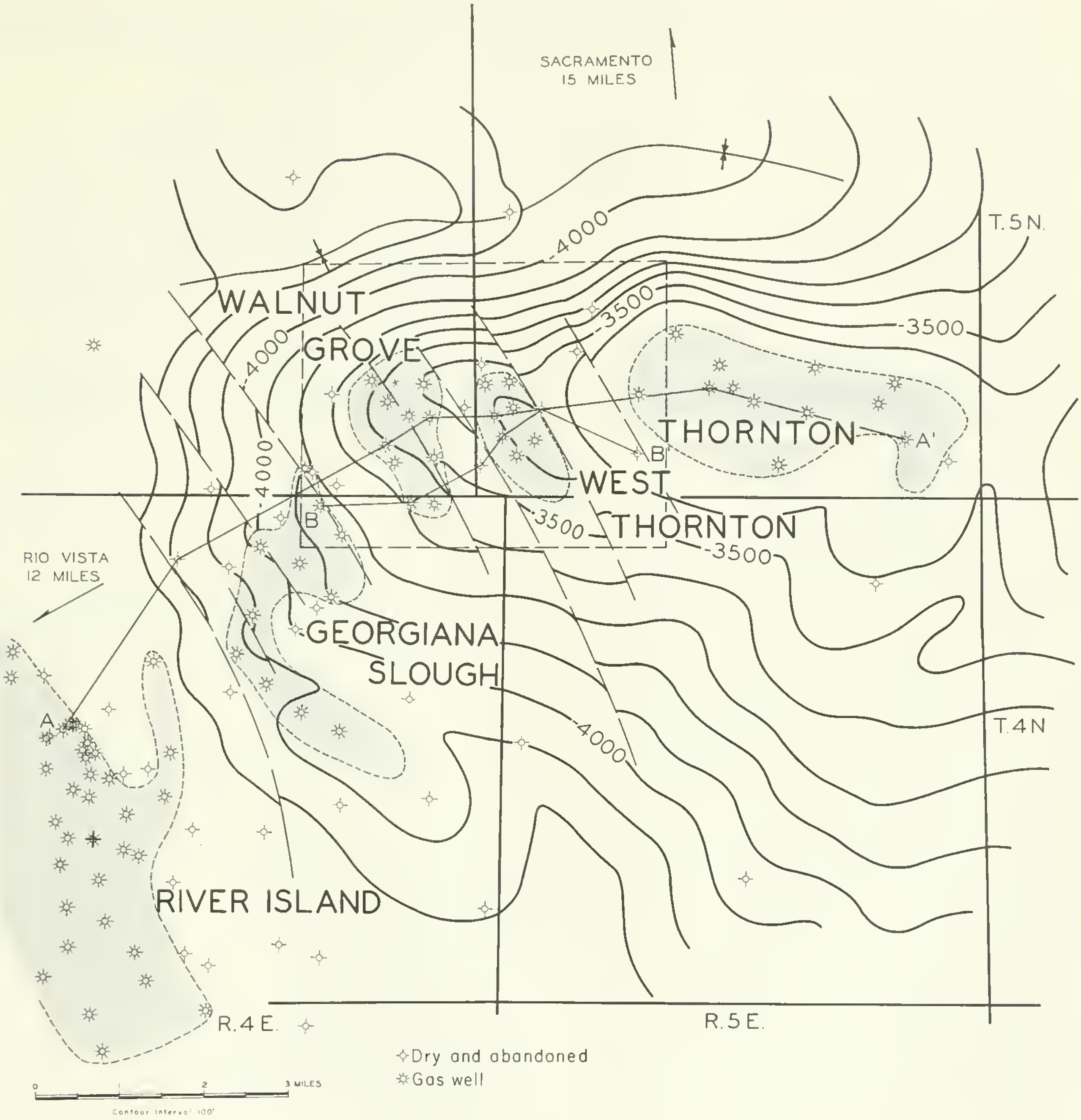


Figure 26. Structure of a portion of the Thornton arch; contours on approximate base of the Capay. By J. H. Silcox, Standard of Calif. (For electric log section B-B', see figure 25.)

upfaulting of the block east of the Midland fault, a meandering channel was being incised into the rising block. At West Thornton, this channel cut approximately 250 feet into the underlying Martinez and apparently exerted an influence on subsequent Meganos sand deposition. The channel "fill" is characterized by a shale facies which is indicative of the relative quiescence that resulted when the Eocene seas inundated the area following late Paleocene uplift.

As the Meganos channel was finally filled, the bench into which it was cut was either at or near wave base, as the Meganos sand is probably the result of in situ reworking of Martinez sands comprising the bench. As such, the Meganos sand is not present in the area affected by the channel. This unique relationship delayed development of the West Thornton gas field for a number of years.

At the close of Meganos time, gradual subsidence allowed the Eocene seas to spread over the entire Sacramento Valley area. The basin remained relatively quiet and the Capay shale was deposited.

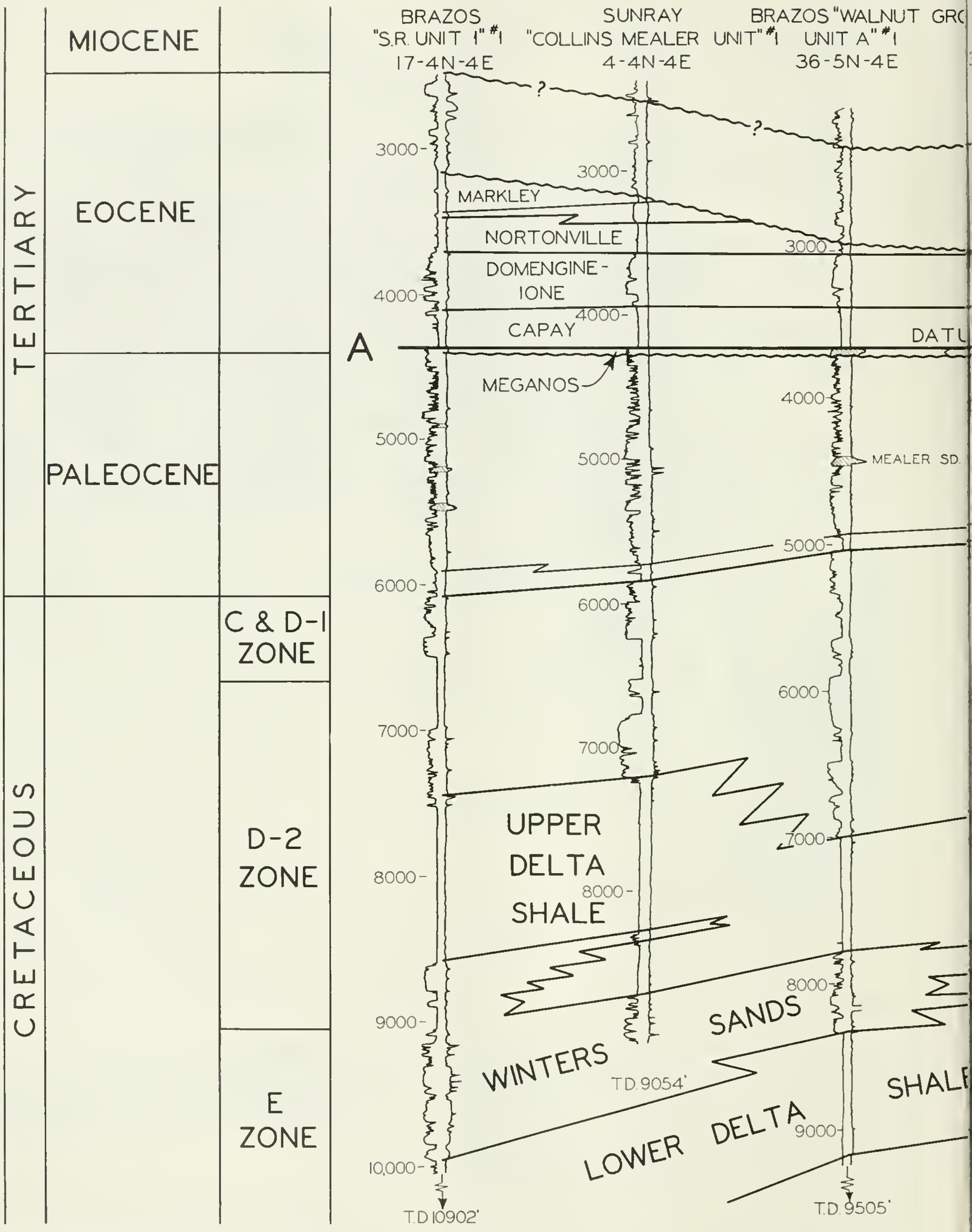
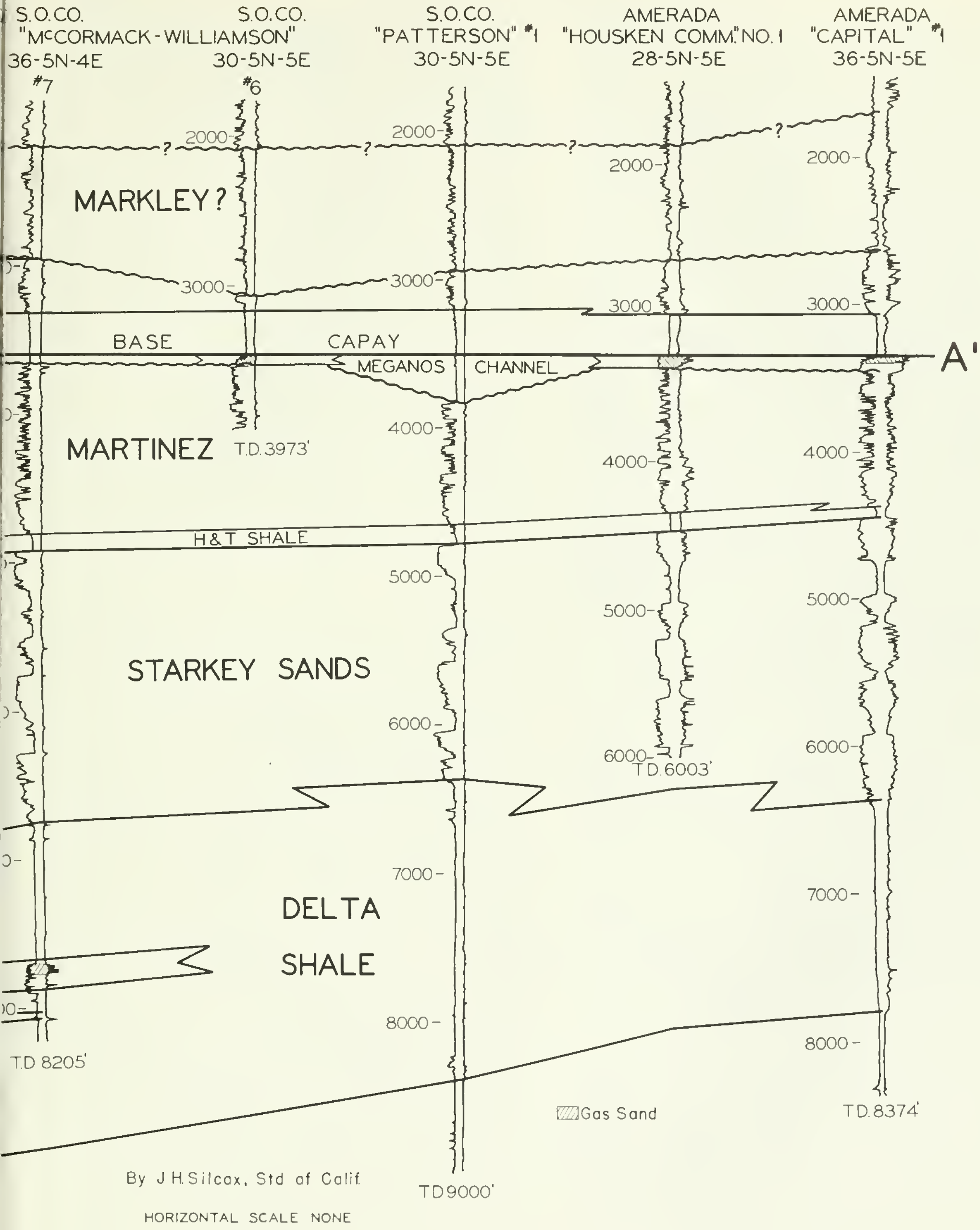


Figure 27. Electric log section A-A', Thornton to River Island. For line of section, see figure 24 or 26.


S.O.CO.
"McCORMACK-WILLIAMSON"
36-5N-4E
#7
S.O.CO.
30-5N-5E
#6
S.O.CO.
"PATTERSON" #1
30-5N-5E
AMERADA
"HOUSKEN COMM." NO. 1
28-5N-5E
AMERADA
"CAPITAL" #1
36-5N-5E
2000
3000
4000
5000
6000
7000
8000
?
MARKLEY ?
BASE
CAPAY
MEGANOS
CHANNEL
A'
MARTINEZ
T.D. 3973'
H&T SHALE
STARKEY SANDS
T.D. 6003'
DELTA
SHALE
T.D 8205'
▨ Gas Sand
T.D. 8374'
TD 9000'
By J H. Silcox, Std of Calif.
HORIZONTAL SCALE NONE

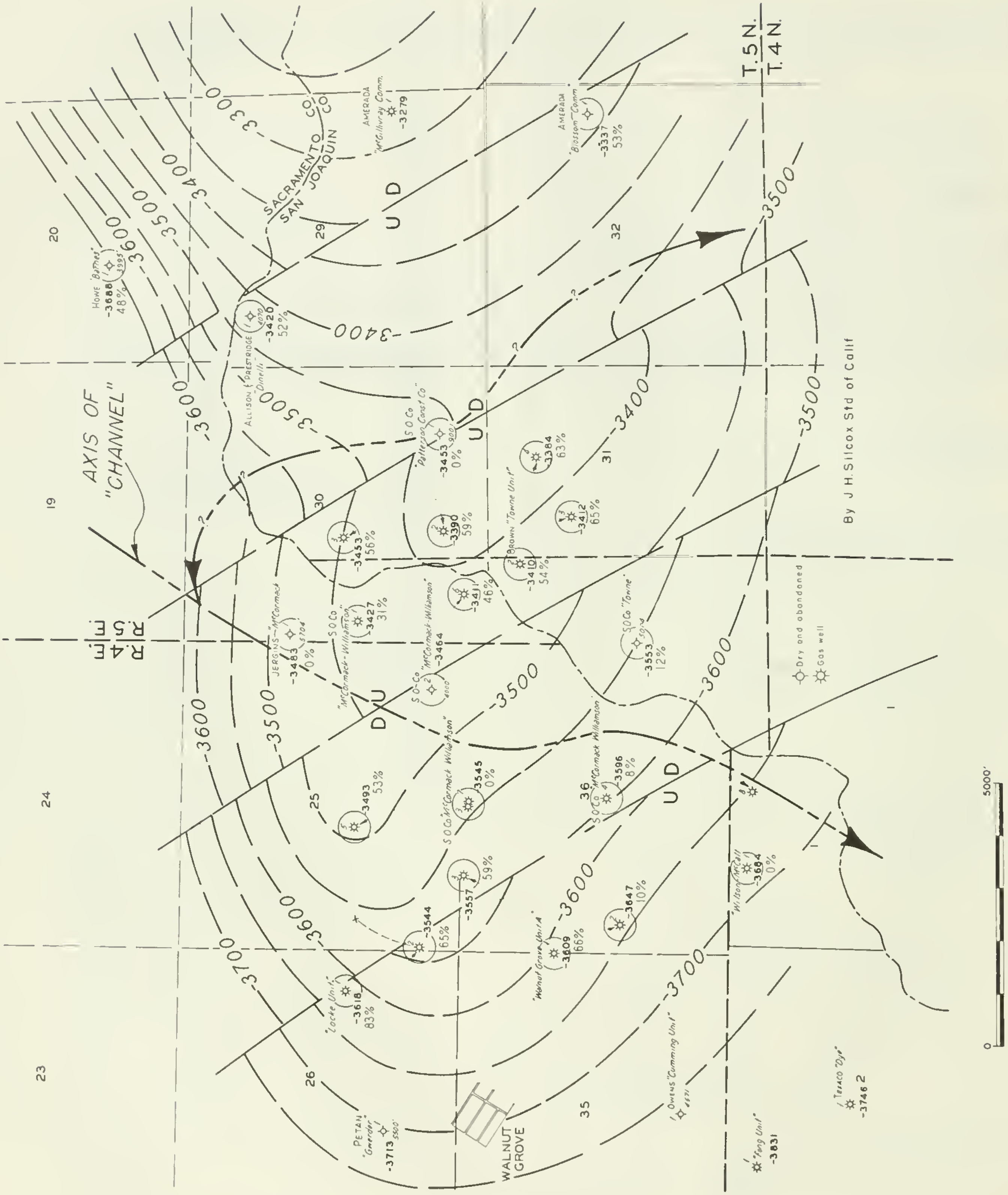


Figure 28. Structural contour map an approximate base of the Capay formation; shows percent net permeable Meganos sand.

During middle and late Eocene time, the margins of the basin experienced mild uplift resulting in the deposition of the Domengine-Ione sand as a broad alluvial fan. Then regional subsidence once again reestablished conditions similar to Capay time and the widespread late Eocene Nortonville shale was deposited. Thin sand stringers are present in the Nortonville and are productive in three wells in the Walnut Grove field.

The late Eocene or Oligocene Markley formation lies unconformably on the Nortonville and Domengine sediments in this area. A localized channel is associated with this unconformity at West Thornton. There is no evidence that this feature is geographically connected with the better-known Markley Channel (Davis, 1953; Almgren and Schlax 1957) to the north, although the age of both features is probably the same.

The nomenclature and age designations presented above are in general use throughout the petroleum industry in the Sacramento Valley. The major disagreement pertains to the Eocene-Paleocene interval. Some workers place the Martinez-Meganos contact lower in the section within the portion referred to here as Martinez. Still others simply lump the interval as Martinez-Meganos. The problem is intricate and requires a lengthy regional analysis, which does not fall within the scope of this paper.

Development of Fields. The West Thornton field was discovered in 1956 by the E. L. Doheny McCormack Williamson No. 1 well on a farmout from the Standard Oil Co. of California. This well was drilled to a total depth of 8808 feet as a follow-up to the Standard Oil Company Patterson Construction Company well No. 1 (fig. 25) which was drilled to explore for Winters sand production on the Thornton arch. Although each of these wells failed to find the Winters sand, the McCormack Williamson No. 1 did penetrate a thin Meganos gas sand approximately 15 feet thick at a depth of 3535 feet and was salvaged in this zone. The Meganos sand development in this well was less than normal, but yielded gas at a rate of 1750 Mcf per day through a ¼-inch choke on production tests, and established production in the West Thornton field.

During 1957, two significant wells were drilled on the plunge of the Thornton arch. The first was the Sunray Collins-Mealer No. 1 (fig. 25) which reached a total depth of 9054 feet, bottoming in Winters sand. Shows were encountered in the Winters and although the well failed to establish production, it narrowed the area of exploratory interest for Winters sand on the Thornton arch. In June 1957, Standard-Doheney spudded their McCormack Williamson No. 2 well down-plunge from the McCormack-Williamson No. 1 in an attempt to extend the Meganos production established in the latter well. At this stage, three-point control existed on the distribution of the Meganos sand (fig. 28) at West Thornton. The Jergins McCormack No. 1 and the Standard Patterson Construction Company No. 1 had no sand, and the E. L. Doheney McCormack Williamson No. 1 had penetrated 15 feet of Meganos sand as previously indicated. Therefore, the down-plunge McCormack-Williamson No. 2 appeared to be a low-risk venture. However, the well bottomed at 4000 feet and the Meganos sand was absent. Possible alternative interpretations, at this time, were that the erratic distribution of the Meganos sand was due either to rapid lateral facies changes or to a pre-Meganos channel similar to the well-known Markley Channel.

With the abandonment of the Standard-Doheny McCormack-Williamson No. 2, drilling activity on the Thornton arch shifted down-plunge. In July of 1958, Brazos drilled their Walnut Grove Unit A No. 1 (fig. 25) to 9505 feet in a test of the Meganos, Martinez, and Winters sands. Good Winters sand development was encountered but found to be nonproductive. The well also penetrated 65 feet of Meganos gas-sand and 45 feet of gas-sand in the Martinez section. It was completed in the Martinez sand for an initial rate of approximately 2000 Mcf per day through a ¼-inch bean. The Walnut Grove Unit A No. 1 thus became the discovery well of the Walnut Grove field and the first well on the Thornton arch to produce from the Martinez formation. This zone was named the Mealer sand by Brazos Oil and Gas Company. In July of the following year, Brazos recompleted the well as a dual completion with the inclusion of the Meganos sand. The latter zone tested at an estimated rate of 1250 Mcf per day through a $^{15}/_{64}$-inch choke.

In November of 1958, Standard and Doheny became active again with their McCormack-Williamson No. 3 well. The McCormack-Williamson No. 7 which is on the figure 25 cross-section is a deeper twin to No. 3, and shows the conditions encountered through the Meganos interval. In the No. 3 well and the subsequent No. 4 well, Standard-Doheny continued to be plagued by the erratic distribution of the Meganos sand. The No. 3 well was completed in a thin stringer of Martinez sand immediately below the missing Meganos sand, while the No. 4 well was completed in a 7-foot finger of the Meganos sand.

In 1959, Brazos recorded a deeper pool discovery when their Locke Unit No. 1 became the second well on the eastside of the Sacramento Basin to produce from Winters sand. The other Winters producer was the Standard Sims No. 1 which was completed in 1950 in the Freeport area some 15 miles to the north. The Locke No. 1 was dually completed from the Winters and Meganos sands.

Three months later, Standard-Doheny extended the Winters production with a new pool discovery from a deeper sand in the Winters interval. This well, the Standard-Doheny McCormack-Williamson No. 5, was tested in the Winters at a rate of approximately 5000 Mcf per day through a ¼-inch bean, and dually completed from the Winters and 45 feet of Meganos sand. Additional thin strigners of Martinez were opened with the Meganos. The total initial production from all zones in this well was 10,720 Mcf per day through ¼-inch chokes.

To date, five wells have been completed in the Winters sand. Figure 27 shows the structure at the base of the

Delta shale with isopachs of the Winters sand. The wells producing from the Winters are indicated within the heavily stippled area which represents the indicated limits of Winters production.

Shortly after Brazos' completion of the Locke Unit No. 1 well, Texaco made a shallow-pool discovery by completing their Wilson-McCall No. 1 (fig. 26) in a Nortonville sand at a depth of 2900 feet. This zone, named the Deadhorse sand, tested 1000 Mcf/d through a $\frac{3}{16}$-inch choke. The Wilson-McCall was subsequently offset (fig. 28) by the Standard-Doheny McCormack-Williamson No. 8 and the Brazos Walnut Grove Unit A-2 wells.

Standard-Doheny's next venture, the unsuccessful Towne Unit No. 1 (fig. 28) encountered a thick shale in place of the Meganos sand and the upper Martinez. At this point, the channel-versus-facies interpretation took a swing in favor of the former. The Standard-Doheny McCormack-Williamson Nos. 1, 2, 3, 4 and Towne Unit No. 1, as well as the Standard Patterson Construction Company No. 1 (fig. 27), appeared to be showing the trend of a meandering channel whose precise course and extent had yet to be defined.

The next well in the West Thornton field, the Standard-Doheny farmout E. C. Brown Towne Unit No. 2, proved to be the most important Meganos test drilled in this field. After drilling to the top of the Starkey sands, Brown completed the well in approximately 50 feet of Meganos sand for 2000 Mcf per day of gas through a $\frac{1}{4}$-inch choke. Since completion of the Towne No. 2 well, brown has completed two additional Meganos wells in the field, each one penetrating in excess of 50 feet of gas sand.

Standard-Doheny have also completed three more Meganos wells, bringing to seven the total number of wells in the field produce from the elusive Meganos sand.

Figure 28 shows the percentage of net permeable Meganos sand penetrated by the various wells. The Standard Patterson Construction Company No. 1 well, the first of the latest cycle of exploration in the West Thornton area, remains an enigma. As a shale well in the Meganos section, it is presently all but isolated. It may be on a tributary to the channel, but whether the channels connect to the north or in some fashion to the south, will only be discovered through additional drilling.

In summary, there are presently 17 wells producing in the Walnut Grove and West Thornton gas fields. Production has been established from the late Eocene Nortonville formation, from the early Eocene Meganos formation, and from the Cretaceous D-2- and E-zone winters sands. Four of the wells are dually completed from Eocene and Cretaceous zones. Since 12 of the 17 wells have been completed during the past 15 months, production data are not diagnostic and, therefore, are not presented.

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GEOLOGY OF THE ARBUCKLE-GRIMES VICINITY, CALIFORNIA

By JOSÉ CORVALÁN
Stanford University, Stanford

and JOHN W. HARBAUGH
Stanford University, Stanford

This paper consists of Plate 10, *Subsurface correlation section through Arbuckle and Sutter gas fields*, and Figure 1, *Map showing location of gas fields, disposition of wells, and line of structure section shown on plate 10*; there is no accompanying text.

Figure 1. Map showing location of gas fields, disposition of wells, and line of structure section shown on plate 10.

McDONALD ISLAND GAS STORAGE FIELD, CALIFORNIA *

By CHARLES A. LEE, Gas Distribution Engineer
Pacific Gas and Electric Company

The Pacific Gas and Electric Company has a gas demand that is widely variable throughout any given year. As the northern and central California population has grown, so has this variation in demand. The existing and proposed supply lines of out-of-state gas necessarily are operated at near-maximum capacity on a year-round basis. It can be seen, then, that additional capacity is needed for winter peak loads; inversely, there is a smaller market for the steady supply during low load periods in the summer months.

Briefly stated, one of the most effective methods for combating this problem lies in storing that surplus supply during off-peak load periods and withdrawing this stored gas during peak-load periods. When the McDonald Island program is complete, 30 billion cubic feet can be stored as in-and-out gas. An average of 150 million cubic feet a day is the planned injection rate, and withdrawal rates will vary between 150 and 400 million scfd (standard † cubic feet per day).

The Standard Oil Company wildcat well McDonald Island Farms No. 1 in 1936 "paid out" with a discovery pressure of 2086 psig (pounds per square inch gauge) at approximately 5150 feet. Five additional wells were drilled within a few years after the original discovery. This development showed the field to be a domed trap, with the sand to have good porosity and permeability. The McDonald Island sand is the producing gas sand of the structure. It is a fine-to-medium, friable gray sand, containing interbedded siltstone and brownish-gray shale, and some streaks of carbonaceous material. Gas was produced during the period 1937-1949 through an 8-inch line from McDonald Island to Roberts Island, and was received at Tracy Terminal Station of the Stanpac gas transmission main.

In 1949-50 Standard drilled five additional development wells and built the combination 16-18 inch main from the island 16 miles west to the Brentwood Terminal Station. At this time it was determined that the field was ideally located and of such a structure to be suited for a gas storage field after depletion of the native reserve, and the wells were rigged for in-and-out metering. Gas was produced from the McDonald Island field by the Standard Oil Company until February 1958 when the pressure declined to 450 psig. During March of 1958 the Pacific Gas and Electric Company and a subsidiary, the Natural Gas Corporation of California, conducted injection tests on the island, using transmission-main pressure from Brentwood Terminal Station. Observations of pressure between March and September of 1958 indicated the possibility of water encroachment into the sand, and on September 5, 1958, Pacific Gas and Electric Company personnel from Stockton Division began injection with an available line pressure of 610 psig at Antioch. On December 11, 1958, Natural Gas Corporation of California completed negotiations with Standard, and the field rights came under Pacific Gas and Electric Company control.

A 3000-HP compressor station at Brentwood was engineered and constructed allowing a maximum line pressure of 867 psig at 75 million scfd. With this source of pressure the field has been brought back to 780 ± psig at present. An ultimate minimum field pressure of 900 psig will be maintained, and operating pressure will range from 900 psig to 1500 psig so that 30 billion cubic feet of gas can be stored. In order to reach a field pressure of 1500 psig, and in order to attain the 400 million scfd production rate, the Pacific Gas and Electric Company plans to drill a total of 16 new gas wells in addition to the five drilled in 1960, and install collection mains thereto; construct a 3000-HP compressor at McDonald Island, which will be in addition to the 2000-HP compressor now being completed; and construct a 2500-HP compressor at Brentwood.

Resumé of Field Data

1. McDonald Island gas field production prior to Pacific Gas and Electric Company acquisition was 148 billion cubic feet.
2. Estimated original gas volume was 178 billion cubic feet.
3. Estimated size, 1600 acres with approximately 81,000 acre-feet of sand.
4. Ground elevation in the field averages 10 feet below Delta water levels. Water is held back by 16-foot-high levees.
5. Peat soil in the field erodes, decomposes, and compacts at an average rate or 4½ inches a year.

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* This paper was originally presented as a talk before the Geological Society of Sacramento January 10, 1961, and is released by courtesy of the Society.

† In California, "standard" pressure base is 14.73 lbs. per sq. in. "Fixed" pressure base is 14.65 lbs. per sq. in.

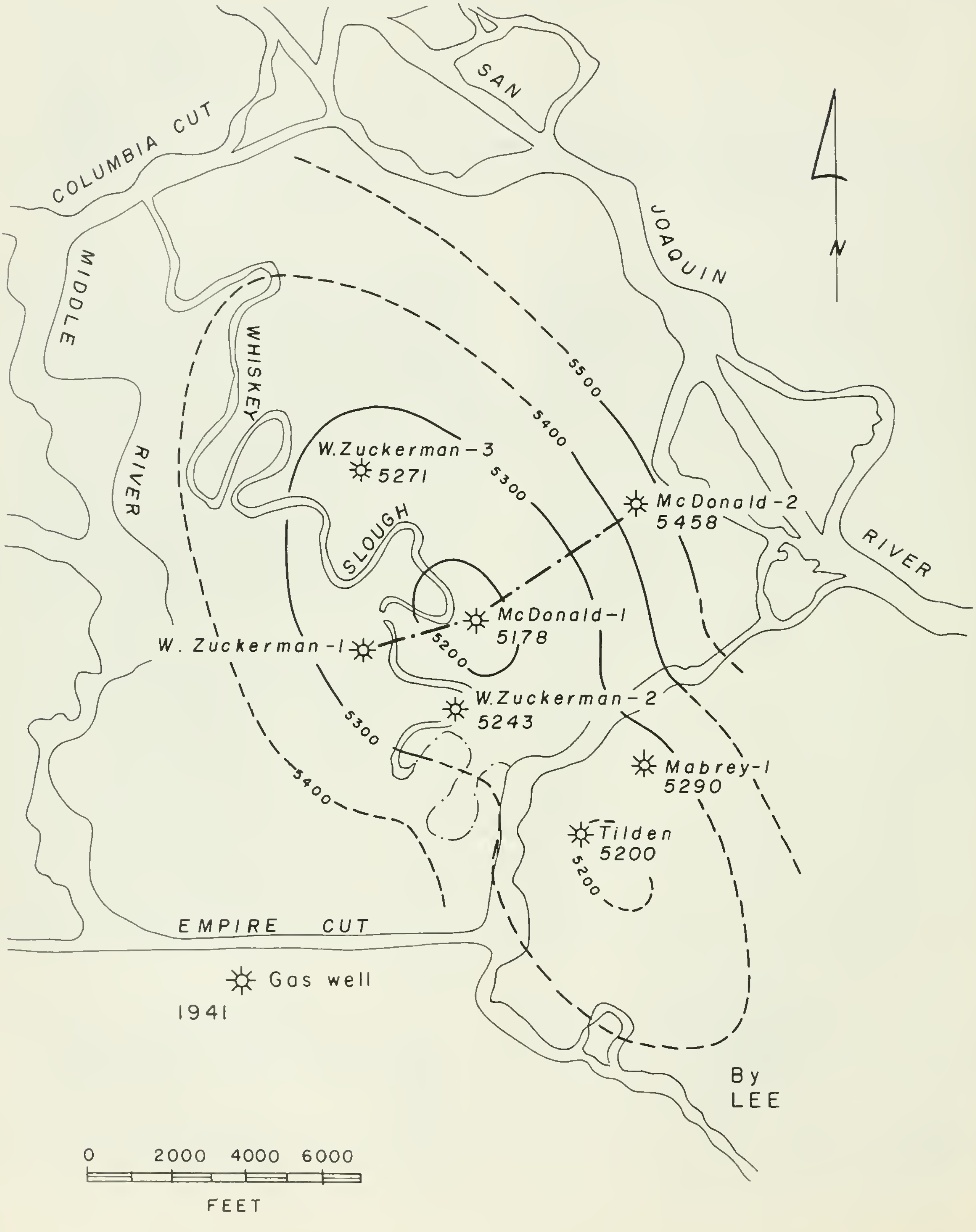

Figure 1. Contours on top of the McDonald sand, McDonald Island gas field, California.

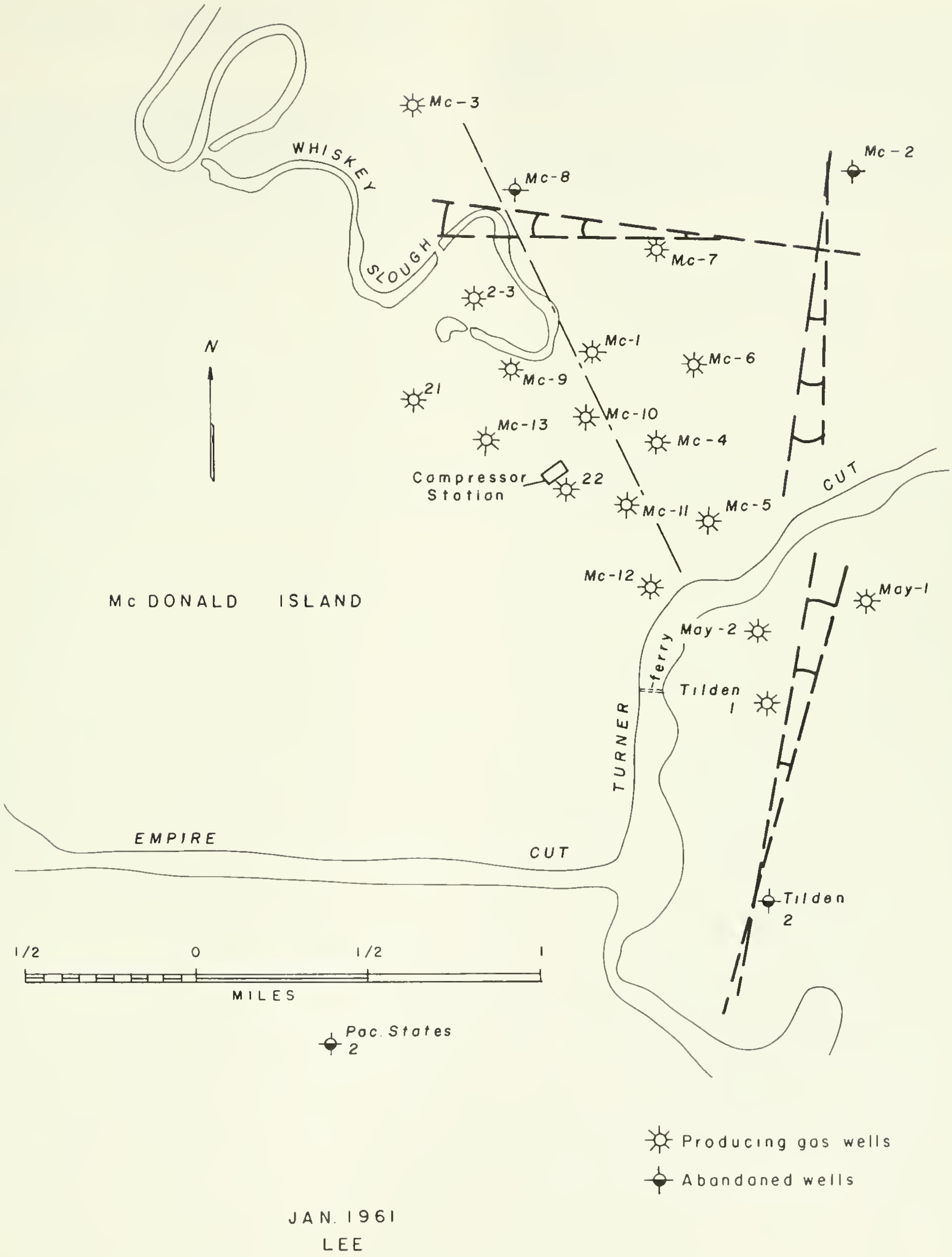

Figure 2. Sketch map showing faulting in McDonald Island gas storage field.

6. The entire operation is designed to be automatic and controlled from Brentwood. The compressors as well as the wells will be controlled by "push-button" operation.
7. Because of the instability of the peat soil, the McDonald Island compressor station has been built on 70-foot cast-in-place cement piles; the area supported by these piles is 80 feet by 100 feet.
8. The compressor at McDonald Island and the well-head controls are designed to operate under a 20-foot head of water. The compressor is elevated above ground level by concrete columns which rest on the pilings.
9. 54 billion cubic feet will remain in the field as cushion gas. This estimated figure stems from the minimum field pressure of 900 psig.

Further information on the McDonald Island gas field will be found in Part III of this bulletin (*maps and data sheets for the oil and gas fields of northern San Joaquin Valley. . .*, by the California Division of Oil and Gas) in which the fields are listed by name, alphabetically.

GEOLOGIC MAP OF SACRAMENTO VALLEY, CALIFORNIA

By F. H. OLMSTED
U.S. Geological Survey, Ground Water Branch

G. H. DAVIS, and others
U.S. Geological Survey, Ground Water Branch

This paper consists of Plate 11, *Geologic map of the Sacramento Valley, California* only; there is no accompanying text.

THE NORTHERN SAN JOAQUIN VALLEY

CONTENTS

For location of gas fields, see Index Map 1, page 75.

VERNALIS GAS FIELD, CALIFORNIA

By **CHARLES F. MANLOVE**
Great Basins Petroleum Co., Bakersfield, California

Abstract. The Vernalis dry gas field is on the west side of the Great Valley of California, 18 miles south of the city of Stockton, California. It was discovered in 1941 by Standard Oil Co. of California as a result of a seismograph survey. One additional producer and one dry hole had been drilled by 1943. Subsurface studies led to renewal of activity in 1958 which has resulted in the drilling of 21 additional gas wells and 17 dry holes in and around the field. Ten new producing zones have been found at depths ranging from 3010 feet in Miocene beds to 4952 feet in Cretaceous. Productive area now covers approximately 3500 acres.

Although the field is anticlinal in form, stratigraphic factors strongly influenced the accumulation of gas and helped to determine local variations in occurrence of gas. The possibility of deeper reservoirs exists.

Many of the wells are completed in two or more zones. Initial open flow potentials ranged from 3000 Mcf per day to 28,900 Mcf per day. Annual production in 1960 was 7,851,414 Mcf. Cumulative production to December 31, 1960, was 18,064,493 Mcf. Original recoverable reserves are estimated to have been in excess of 100,000,000 Mcf.

Acknowledgments. The writer is indebted to R. G. Greene, President, Great Basins Petroleum Co., for permission to publish; to Q. R. Query and M. de Laveaga, Great Basins Petroleum Co.; to Ray Stein, Porter Sesnon et al.; and to M. L. Golding Jr. for drafting.

The Vernalis gas field is in San Joaquin County 16 miles west of Modesto, California, in T. 3 S., R. 6 E. It is 9 miles southeast of the depleted Tracy gas field and 5 miles southwest of the more recently discovered McMullin Ranch gas field.

The first well in the immediate vicinity of Vernalis gas field was drilled in 1932. Union Oil Co. of California's Tracy Land and Water Co. No. 1 well in sec. 14, T. 3 S., R. 6 E., was drilled into the Cretaceous Tracy sand and abandoned at a total depth of 5511 feet. A few gas showings were noted in cores.

Vernalis gas field was discovered in 1941 by Standard Oil Co. of California after a seismograph survey. Standard Oil Co. of California Blewett Community No. 1, in sec. 25, T. 3 S., R. 6 E., was completed January 8, 1941, in the interval 3857 to 3869 feet in an upper Blewett sand of the Cretaceous. Initial rate of production was 9,706 Mcf per day through ⅝-inch bean with flowing pressure of 1141 psig. This well is still producing. Blewett Community No. 2, about 2750 feet southeast of the discovery well, was completed later in 1941 as a gas well in the discovery zone after having been drilled to 5506 feet into the Cretaceous Tracy sand. This well was abandoned in October 1952, because of water encroachment. Standard's Blewett Community No. 3, a mile northwest of the discovery, was drilled into the Tracy sand and abandoned at total depth of 5257 feet in 1943. No more drilling was undertaken in the immediate vicinity of the field for nearly 15 years.

Renewal of activity at Vernalis began in early 1958 with the completion of the Porter Sesnon well Tracy Land and Water Co. No. 13-23 as a gas producer from the uppermost Blewett sand in the interval 3860 to 3885 feet. Since completion of this well, 38 exploratory and development wells have been drilled, of which 21 were gas wells and 17 were dry. Ten additional producing zones of varying extent and thickness have been found and the productive area has been expanded to approximately 3500 acres. Producing depths range from 3010 feet in Miocene to 4952 feet in Tracy sand of the Cretaceous.

The stratigraphic section at Vernalis ranges from Quaternary alluvium at the surface to Upper Cretaceous at deepest penetration.

The Cretaceous section is composed of alternating lenticular sand and shale. Lithologic characteristics of the sand and shale are essentially the same throughout. The sand is grayish-white and gray, very fine grained to medium grained, angular to subangular; it consists mainly of quartz with minor amounts of dark minerals. Commonly, scattered dark carbonaceous grains give the sand a "pepper and salt" appearance. Hard, calcite-cemented sandstone streaks or "shells", from a few inches to more than 10 feet in thickness, are encountered at highly variable intervals throughout most of the sand. These may be the concretionary layers of Cretaceous outcrop areas. The shale is gray to grayish-brown, soft and argillaceous to hard, silty, and thinly bedded. Frequently, very thin laminations of light gray sand produce a banded appearance. Scattered black carbonaceous grains and fragments are generally present.

The upper 500 feet of the Panoche have been penetrated at Vernalis, extending approximately 200 feet into the Tracy sand zone. The upper part of the Tracy sand is variable, changing rapidly from relatively thick sand bodies to thinly interbedded sand and shale beds. It becomes thinner to the west and is largely replaced by

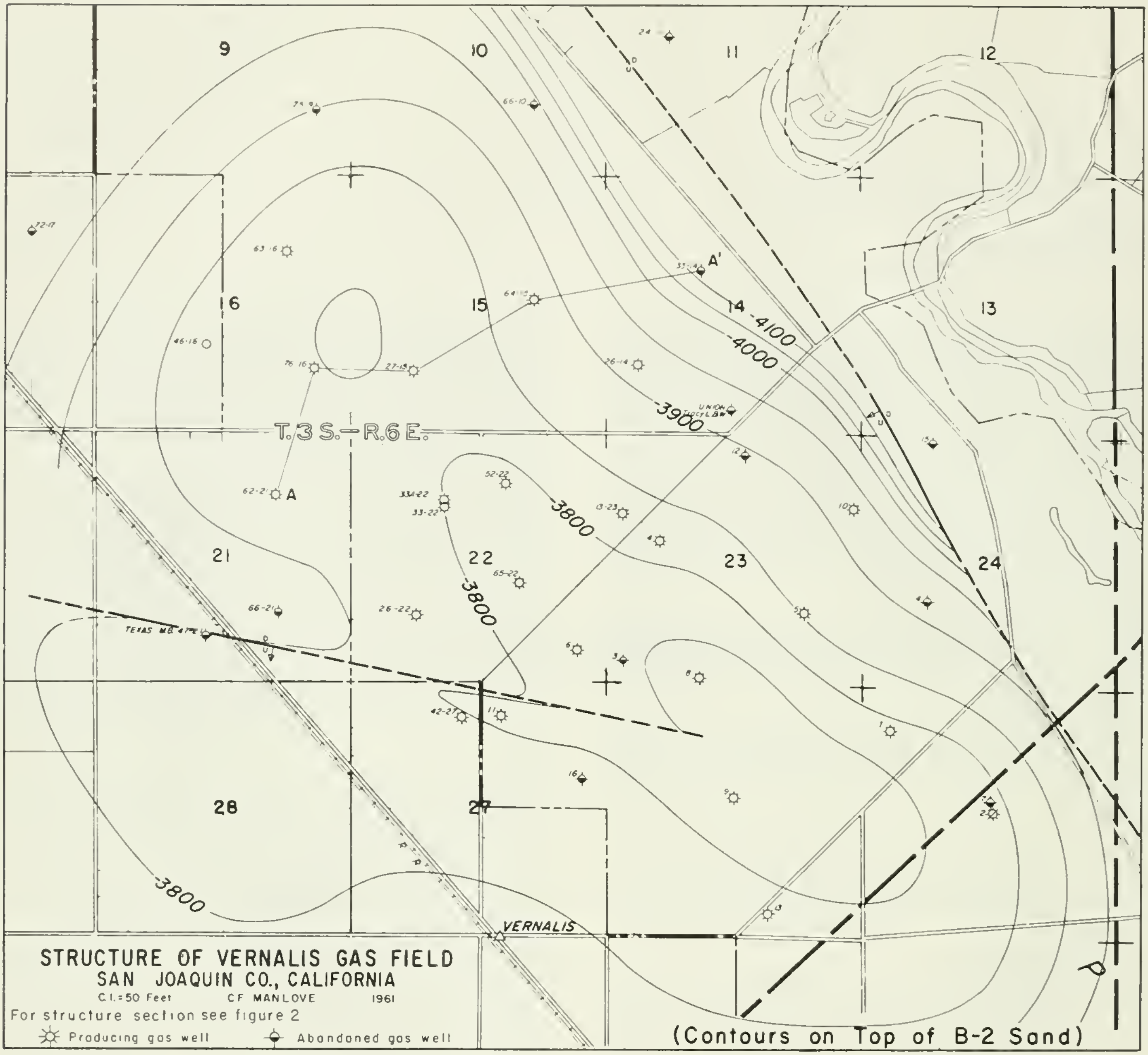

Figure 1. Structural contour map on top of the B-2 sand, Vernalis gas field.

shale at Well No. 74-33, about 1½ miles southwest of the field. The overlying Ragged Valley shale member of the Panoche ranges in thickness from 291 feet to 387 feet, averaging approximately 320 feet. Thin lenticular sand beds are found in this interval. It is conformable with the overlying Blewett sand zone of the Moreno group.

The Moreno group at Vernalis includes the Blewett sand zone and the Azevedo sand zone. The overlying Garzas sand member was eroded from the productive area of the field at the pre-Miocene unconformity.

The Blewett sand zone consists of five sand sub-zones separated by relatively thin shale beds. The sub-zones are highly variable in thickness but, with the exception of the uppermost, are continuous throughout the field. Thickness of the unit increases from 750 feet at the northwest to 1131 feet at the southeast end of the field.

The Azevedo sand zone has a maximum thickness of about 900 feet immediately east and south of the productive limits of the field. Nearly all of the Azevedo section has been removed by erosion at the pre-Miocene unconformity in the western and northwestern parts of the field. The lower part of the Azevedo zone, ranging in thickness from 500 feet to about 600 feet, differs from the Blewett zone in being a predominantly shale and siltstone interval with lenticular sand zones of more limited lateral extent than those of the Blewett.

The Cretaceous at Vernalis is unconformably overlain by 3000 feet to 3800 feet of continental beds of varicolored sand, gravel, and clay ranging in age from upper Miocene at the base to Quaternary alluvium at the surface.

Structure of the Vernalis gas field is of gently folded anticlinal form modified from zone to zone by changing thicknesses. Apparent closure is approximately 150 feet. Highest part of the structure in Blewett zones is generally toward the southeastern end but marked northwestward thinning of the Blewett zone shifts the structural apex decidedly to the northwest end in Ragged Valley shale and Tracy sand zones. A northwest-trending reverse fault, downthrown on the east with 650 feet of vertical displacement, bounds the structure on the east. Movement on this fault may have been as late as Pleistocene. A small reverse fault, downthrown on the east with about 75 feet of vertical displacement, occurs in one well on the southwest edge of the field. It has not been determined whether this fault displaces beds younger than Cretaceous.

The producing zones of the Vernalis field are the Tracy, the Ragged Valley, the Blewett, the Azevedo, and basal upper Miocene sand beds. Subsurface information in the general vicinity of Vernalis indicates the possibility of deeper production in several thousand feet of alternating sand and shale section below the present deepest penetration in the field.

Laboratory analyses of a limited number of conventional core samples of the various producing zones indicate porosity of 27 percent to slightly over 30 percent, air permeability averages of 71 to 321 millidarcies, and interstitial water (percent of pore space) of 40 percent to 45 percent. Permeability of Azevedo sands tends to be lower than that of Blewett or Tracy sands.

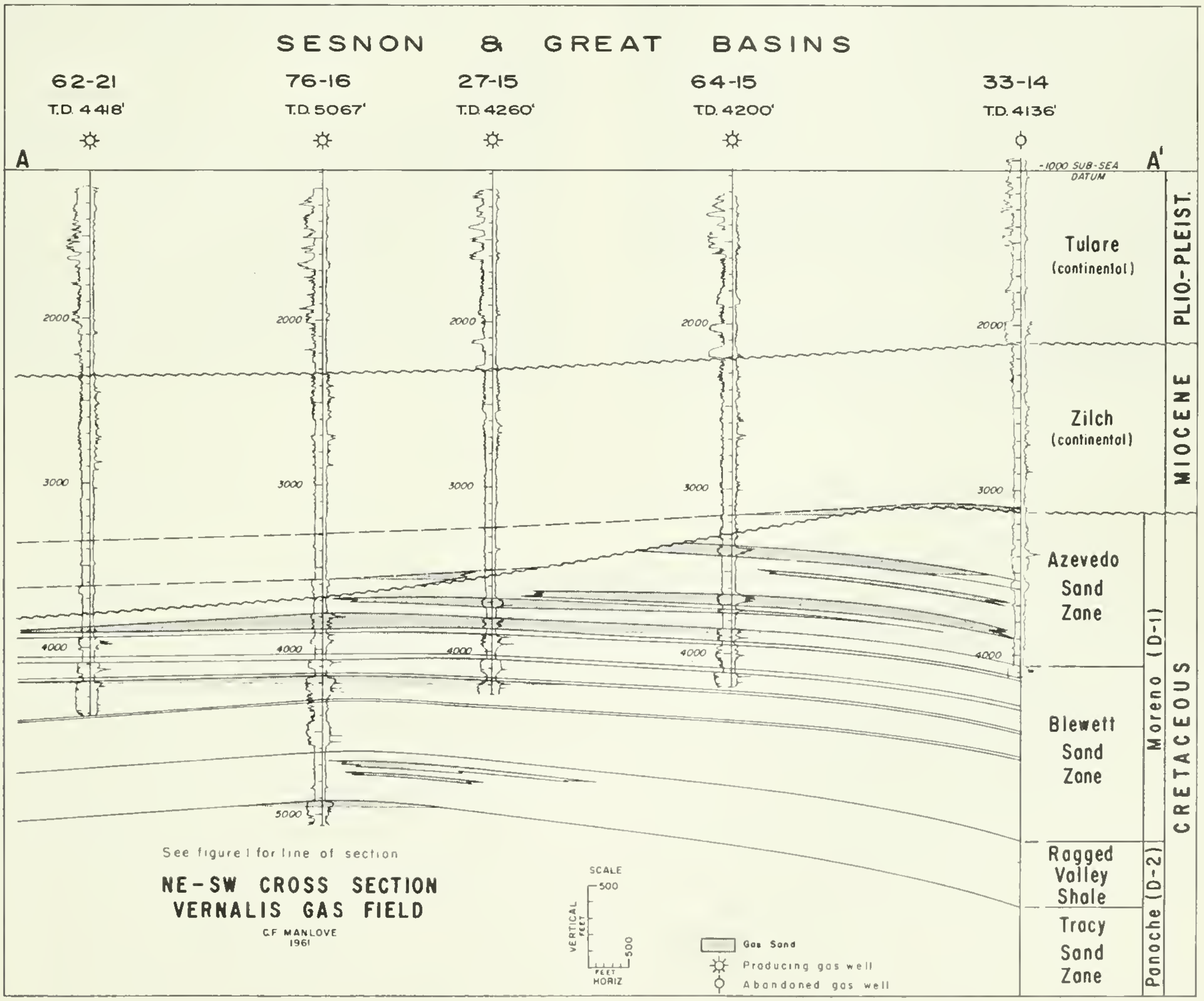

Figure 2. Northeast-southwest cross section through the Vernalis gas field.

Oldest productive zone in the field is the Tracy sand, which produces dry gas from one well near the northwest end of the field. Depth of production is 4918 feet to 4952 feet.

Gas production from Ragged Valley sands has been obtained in a well at the northwest end of the field in the interval 4634 feet to 4761 feet. These sands are lenticular, of limited lateral extent with maximum thickness of about 15 feet in individual lenses.

The Blewett sand zone is divided into five sub-zones. Dry gas production has been found in the four upper sub-zones with productive depths ranging from 3773 feet to 4200 feet. No production has yet been found in the lowest zone. Dry gas is produced from the fourth sand below the top of the zone in the northern one-third of the field. Maximum productive interval is about 45 feet. Although stratigraphic and structural conditions appear favorable, no production has been found in this zone in the southern part of the field. The third sand below the top of the zone produces gas in two relatively small areas at the top of the structure. Maximum productive interval in this sand is approximately 35 feet. The second Blewett sand (B-2 sand of fig. 1), the original discovery zone of the field, is productive in the southeastern two-thirds of the field. Maximum productive interval of this sand is about 85 feet. The uppermost Blewett sand is productive in the northwestern two-thirds of the field. It thins abruptly and disappears completely along the west side and southeast end of the producing area. Maximum productive interval of 95 feet in this sand occurs in the northwestern area.

Four separate lenticular Azevedo sands produce gas from depths ranging from 3357 to 3760 feet. These sands are variable in thickness and lateral extent but together underlie approximately 1000 acres in the central and northeastern area. The thickest sand has a maximum productive interval of 133 feet and an apparent gas-column height of 177 feet. Azevedo sands of comparable development and structural elevation are present in the southern part of the field but are not productive. Most, if not all, of these sands may be truncated at the pre-Miocene unconformity in both northern and southern areas.

Gas production has been found at various levels in continental Miocene beds immediately above the pre-Miocene unconformable surface. The gas apparently has moved along that surface from truncated Cretaceous gas zones into sporadically occurring stratigraphic traps in the base of the Miocene. Gas in one well is in a basal Miocene sand at depth of 3510 to 3560 feet. Three wells on the east side of the field, near the top of the pre-Miocene topographic surface, have been completed as gas wells from basal Miocene at depths of 3010 to 3117 feet. Maximum productive interval is 90 feet. The lateral extent of these accumulations is limited by rapid variations in permeability and thickness of the continental deposits.

Many of the wells in the Vernalis field are dual completions with two or more zones open to production. Tests indicated initial open-flow potentials ranging from 3000 Mcf per day to 28,900 Mcf per day.

Average heating value of Vernalis dry gas is 920 BTU per cubic foot. Average specific gravity is 0.60.

Gas from the field is sold under contract to Pacific Gas and Electric Company. Cumulative production to December 31, 1960, was 18,064,493 Mcf. Annual production during 1960 was 7,851,414 Mcf. Original recoverable reserves are estimated to have been in excess of 100,000,000 Mcf.

CRETACEOUS GEOLOGY OF THE PACHECO PASS AREA, CALIFORNIA

By FREDERICK A. SCHILLING, JR.
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This paper consists of Plate 12, *Generalized geologic section of the San Joaquin Valley, California;* there is no accompanying text.

TYPE PANOCHE GROUP (UPPER CRETACEOUS) AND OVERLYING MORENO AND TERTIARY STRATA ON THE WEST SIDE OF THE SAN JOAQUIN VALLEY

By MAX B. PAYNE
Norris Oil Company, Bakersfield

Plate 13, Preliminary geologic map of the type Panoche group and overlying Moreno and Tertiary strata on the west side of the San Joaquin Valley; Plate 14, Cross section 1; Plate 15, Cross section 2; Plate 16, Cross section 3; Plate 17, Cross section 4; Plate 18, Cross section 5; and Plate 19, Stratigraphic column of measured sections of the Panoche group, accompany this report.

This paper aims to present the stratigraphic details of the Panoche group as mapped from the type section in the Panoche Hills northward to Tracy, in order to clarify the chronological succession and geographic distribution of the units into which the Panoche has been divided. Paleontologic evidence to document the stratigraphy—ammonite localities, and age determinations by Tatsuro Matsumoto—is incorporated on the accompanying map and in the columnar and stratigraphic charts.

Plate 13, *Preliminary geologic map of the type Panoche group (Upper Cretaceous) and overlying Moreno and Tertiary strata on the west side of the San Joaquin Valley*, shows the extent of the several distinct lithogenetic and cartographic units of the Panoche group as found in the type section in the Panoche Hills, Fresno County, and mapped northward to the Tracy area in Alameda County. These units were recognized by Don W. Sutton in 1952 and named by him in an unpublished thesis. Mapping for plate 13 (the six formations of the type section have been traced through this area at odd intervals of time since 1941) was done on topographic sheets, which were then reduced to a common scale.

According to Tatsuro Matsumoto, who bases his conclusions on the ranges of ammonites and inocerami, the Panoche group is Upper Cretaceous in age—Cenomanian to Lower Maestrichtian *. This is confirmed by Lewis Martin, who reached the same conclusion after studying foraminiferal evidence from surface samples.

Panoche sediments are well exposed in an east-dipping homocline with gentle bowing, from Lone Tree Creek near Vernalis to Pacheco Pass and in the Panoche Hills. Eocene sedimentary rocks (undifferentiated) overlie the Panoche group sediments from San Luis Creek north to Lone Tree Creek west of Vernalis in San Joaquin County. Nonmarine sediments have been traced from the Panoche Hills north to the north end of the mapped area, near Tracy.

The measured type section and included fauna have been correlated with various subsurface sections across the Valley by means of lithologic and faunal data from wells. These correlations are shown on the cross sections (pls. 14-18) that accompany this paper.

History. Early-day geologic reports dealt with the Upper Cretaceous of the Pacific Coast as the "Chico group". The Panoche was named as a formation in 1915 and considered equivalent to part of the Chico. The history of the term Panoche began when Anderson and Pack in 1915 (p. 38 and 39) wrote that . . . . "In the original description of the Chico (by Whitney, J. D., California Geological Survey, Paleontology, vol. 1, preface, 1865) no definite type locality was designated, the name being applied to Upper Cretaceous strata occurring on both sides of the Sacramento Valley and along the west side of the San Joaquin Valley . . . . The name is now commonly employed to designate all Upper Cretaceous strata on the Pacific Coast from British Columbia to Lower California that are younger than the Horsetown formation (Lower Cretaceous) and older than the Martinez formation (Lower Eocene). . . . It therefore becomes necessary to consider the Chico in this region as a group which comprises two formations the Moreno and the formation composed of the Upper Cretaceous stata underlying the Moreno, to which the term Panoche is applied". The Panoche formation was named, and the type section was designated by Anderson and Pack (1915, p. 38) as . . . . "in the Panoche Hills between Panoche and Little Panoche Valleys".

There are several reasons to support the conclusion that "Panoche" is a more appropriate name for the group than "Chico". In Big Chico Creek on the west flank of the Sierra Nevada, in T. 23 S., R. 2 E., Butte County, the Chico formation is a fossiliferous sandstone of mid-

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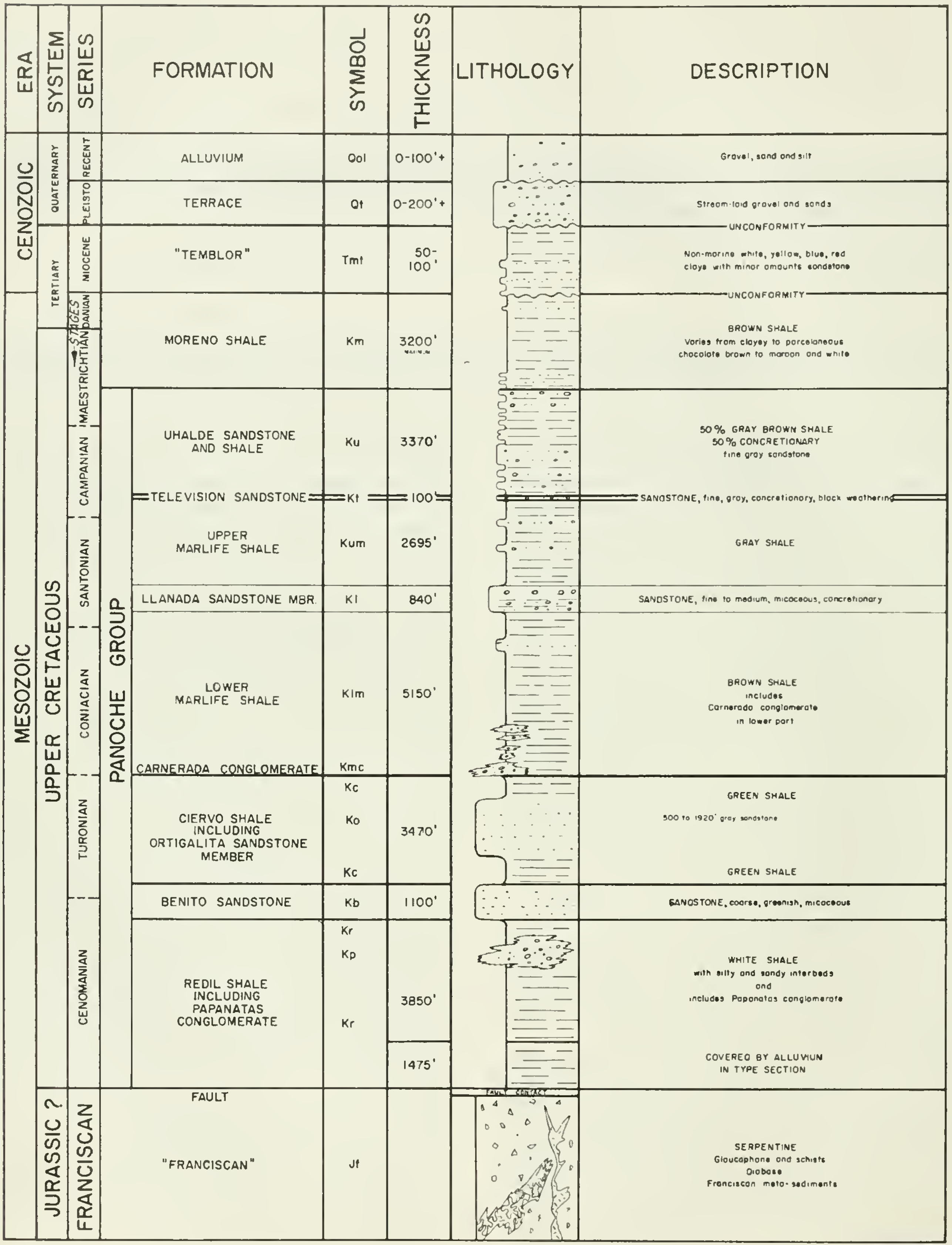
* In a letter to Payne (1959), Schenck wrote that most writers follow the French spelling, Maestrichtian. Many authors, however, prefer *the spelling Maastrichtian*, as it is based on a Dutch geographic name.



ERA	SYSTEM	SERIES		FORMATION	SYMBOL	THICKNESS	LITHOLOGY	DESCRIPTION
CENOZOIC	QUATERNARY	RECENT		ALLUVIUM	Qal	0-100'+		Gravel, sand and silt
		PLEISTO		TERRACE	Qt	0-200'+		Stream-laid gravel and sands
								UNCONFORMITY
	TERTIARY	MIOCENE		"TEMBLOR"	Tmt	50-100'		Non-marine white, yellow, blue, red clays with minor amounts sandstone
								UNCONFORMITY
MESOZOIC	TERTIARY UPPER CRETACEOUS	STAGES DANIAN MAESTRICHTIAN		MORENO SHALE	Km	3200' MAXIMUM		BROWN SHALE Varies from clayey to porcelaneous chocolate brown to maroon and white
		CAMPANIAN	PANOCHE GROUP	UHALDE SANDSTONE AND SHALE	Ku	3370'		50% GRAY BROWN SHALE 50% CONCRETIONARY fine gray sandstone
				TELEVISION SANDSTONE	Kt	100'		SANDSTONE, fine, gray, concretionary, block weathering
		SANTONIAN		UPPER MARLIFE SHALE	Kum	2695'		GRAY SHALE
				LLANADA SANDSTONE MBR.	Kl	840'		SANDSTONE, fine to medium, micaceous, concretionary
		CONIACIAN		LOWER MARLIFE SHALE	Klm	5150'		BROWN SHALE includes Carnerada conglomerate in lower part
				CARNERADA CONGLOMERATE	Kmc			
		TURONIAN		CIERVO SHALE INCLUDING ORTIGALITA SANDSTONE MEMBER	Kc Ko Kc	3470'		GREEN SHALE 500 to 1920' gray sandstone GREEN SHALE
				BENITO SANDSTONE	Kb	1100'		SANDSTONE, coarse, greenish, micaceous
		CENOMANIAN		REDIL SHALE INCLUDING PAPANATAS CONGLOMERATE	Kr Kp Kr	3850'		WHITE SHALE with silty and sandy interbeds and includes Papanatas conglomerate
						1475'		COVERED BY ALLUVIUM IN TYPE SECTION
				FAULT			FAULT CONTACT	
	JURASSIC ?	FRANCISCAN		"FRANCISCAN"	Jf			SERPENTINE Glaucophane and schists Diabase Franciscan meta-sediments

MAX B. PAYNE - 1960

Figure 1. Rock units in the Panoche Hills on the north side of Moreno Gulch, listed in stratigraphic order, highest unit at the top. Original designations in Panoche by Don W. Sutton, 1952.

Coniacian to mid-Campanian age (Tatsuro Matsumoto 1959, 1960). On the east side of the Sacramento Valley the Chico is a sandstone unit equivalent to only a part of the Panoche group. Along the west side of the San Joaquin Valley it appears reasonable to use the term Panoche group as far as the unit can be mapped from the Panoche Hills in outcrop.

Since 1915 when Anderson and Pack first designated and described the Panoche as a formation, no additional detailed work has been published to further the understanding of the 22,020 feet of sedimentary rocks or the included fauna.

In 1952 Don W. Sutton wrote a thesis (unfortunately not published) for the Stanford University Geological Department entitled *Type Panoche formation*, in which various intervals in the Panoche were mapped and named as units. These units are practical and necessary in mapping the individual, persistent, and distinctive beds, and they are especially useful and necessary when mapping areas at some distance from one another, where wide spaces in the section are covered. Along some creeks and canyons a mile or more may intervene along the strike between one exposed section and the next. In these areas the sequence of distinctive units below the covered areas is recognized and mapped, and as more of the upper section is observed in outcrop in the proper sequence, it is again possible to map the higher major lithogenetic units.

Detailed field work in the Panoche Hills was begun by the present writer in 1957, in order to define and delimit the several cartographic units—including several formations of fossiliferous shale, sandstone, and conglomerate of Upper Cretaceous age, totaling 22,020 feet in thickness—of the Panoche. The SEPM-AAPG 1960 Annual Spring Field Trip Guidebook entitled *The type Panoche* was a preliminary report on the Panoche Hills section in which it was proposed that the Panoche group sediments be divided into six formations, including several members and two conglomerates. The full description of the type Panoche will be made available in a publication in which the Panoche is elevated to group rank. The U. S. Geological Survey Committee on Geologic Names has approved and reserved the names of the new formations and members for the Panoche group.

In this paper, the formations, members, and conglomerates of the Panoche group are briefly described in ascending order, from the bottom of the section to the top, as follows: Redil formation, including the Papanatas conglomerate lens; Benito formation; Ciervo formation, including the Ortigalita sandstone member; Marlife formation, including the Llanada sandstone member and Carnerada conglomerate lens; Television formation; and Uhalde formation. The pre-Panoche (Jurassic?) Franciscan rocks comprise a complex of igneous, metamorphic, and sedimentary rocks.

Lower Cretaceous fossils have been reported from many localities where rocks of the various formations of the Panoche group are in fault contact with the Ortigalita thrust. Marshall E. Maddock reports that Lower Cretaceous fossils in the Carbona and Mt. Boardman quadrangles have only been found near the faulting and in association with volcanic rocks.

PANOCHE GROUP

Redil Formation. The name "Redil" was proposed by Sutton in 1952. The Redil formation is 5325 feet of interbedded shale, flaggy sandstone, and siltstone. The coarse, irregularly bedded Papanatas conglomerate lens is in the middle of the Redil shale, which is gray to tan-gray in color but weathers to rounded, whitish-gray slopes. The unit has been mapped 42 miles to a point just north of Romero Creek. In San Luis Creek is one of the thickest exposed sections of this unit. The lower contact is faulted against the Franciscan formation, the upper contact is conformable with the Benito sandstone. A distinctive feature of the Redil formation is the presence, 50 to 100 feet below the upper contact, of a dacite tuff and montmorillonite bed 5 to 10 feet thick. The shale of the formation is well stratified, but not well indurated or cemented; it is firm to crumbly, and easily sampled by hand, and it does not react to acid except where thin limy layers are present. Thinly bedded, flaggy sandstone is plentiful in the Redil. Small Foraminifera have been found, but so far no report on them has been published. The included Papanatas conglomerate is not well cemented but is hard and crumbly. It is in thick, irregular and erratic deposits, and is brick-red with iron-stain; it consists of well-rounded pebbles, cobbles, and boulders as much as several feet in diameter, in a clayey and fine to coarse sand matrix; it contains rock types of many kinds, including numerous volcanic rocks, and some granitic and porphritic types that are foreign to exposed Franciscan rocks supposed to be the source material. The Papanatas conglomerate lens has been reported to contain Cenomanian fossils; Albian fossils have been reported only from hard, limy, boulders in the coarse boulder conglomerate. The Redil formation is believed to be Cenomanian in age, and the limy boulders with Albian fossils are belived to have been reworked. The Redil is the lowest formation of the Panoche group. It extends in fault contact with the Ortigalita thrust fault as far north as Quinto Creek where only a thin section can be seen in outcrop.

Benito Formation. The Benito formation is dull green to greenish-gray sandstone, which commonly weathers to form rounded hills and ridges. It lies between the green Ciervo shale and the white-weathering whitish-gray Redil shale. The lower contact is conformable with the Redil shale, the sandstone is conformable with the overlying Ciervo shale. The type section is 1100 feet thick. The sandstone is medium to coarse grained, very micaceous ($\frac{1}{4}$ mm to 1 mm), friable, fairly well sorted, and contains clay minerals. The Benito sandstone approaches a graywacke by the classification of Gilbert (Williams, Turner, and Gilbert 1954). The grains are angular quartz with mica and feldspar and minor amounts of ferromagnesian minerals. The rock weathers into poor

LISTED IN STRATIGRAPHIC ORDER HIGHEST UNIT AT TOP

TYPE PANOCHE GROUP
FORMATIONS AND MEMBERS IN TYPE SECTION

MAX B PAYNE APRIL 1960 (ORIGINAL DESIGNATIONS FOR UNITS IN PANOCHE BY DON W. SUTTON 1952)

FROM REVISED STANDARD Muller Schenck AAPG Bull V27, No 3 1943 Loeblich Tappan US Nat Mus Bull 215 1957				FORMATIONS AND MEMBERS IN TYPE SECTION MORENO GULCH PANOCHE HILLS ORIGINAL DESIGNATIONS FOR UNITS IN PANOCHE BY DON W SUTTON 1952 NAMES IN MORENO FORMATION FROM MAX B PAYNE - 1951	Formation	Member	Type Locality	Lower Contact	Upper Contact	Dominant Lithology & Color	Thickness In Type Locality	Fossils Present	Name Taken from Geographic Feature
DANIAN	TERTIARY		MORENO SHALE	DOS PALOS SHALE CIMA SOST	MORENO FORMATION ABOVE PANOCHE GROUP								
	UPPER CRETACEOUS			MARCA SHALE									
MAESTRICHTIAN				TIERRA LOMA SHALE									
				DOSADOS SOST & SH									
			PANOCHE GROUP				TOP	OF	PANOCHE		GROUP		
CAMPANIAN		SENONIAN		UHALDE SANDSTONE AND SHALE	Uhalde sandstone and shale		Moreno Gulch	990'S & 2325'W of NE corner of Sec 15, T 14S, R 11E	2325'N & 1660'W of SE corner of Sec 11, T 14S, R 11E	Gray-brown shale & interbedded sandstone 50/50	3370'	Hoplymonites sp Baculites lomaensis Anderson Diplomoceras sp Pachydiscus ganesa Forbes Glyptoxoceras sp Baculites rex Anderson	Uhalde Canyon Sec 8 & 9, T 14S, R 11E Sec 33 & 34, T 13S, R 11E
				TELEVISION SOST	Television sandstone		Moreno Gulch	1080'S & 2570'W of NE corner of Sec 15, T 14S, R 11E	990'S & 2325'W of NE corner of Sec 15, T 14S, R 11E	Black weathering concretionary sandstone	100'		Television Hill NW corner Sec 10, T 14S, R 11E
SANTONIAN				UPPER MARLIFE SHALE	Marlife shale		Moreno Gulch	At SE corner of Section 18, T 14S, R 11E	1080'S & 2570'W of NE corner of Sec 15, T 14S, R 11E	Upper gray shale	2695'	Baculites schencki Matsumoto Anapachydiscus sp Anomia sp Inoceramus cf amakusensis Inoceramus cf ezoensis Yokoyama Scalarites sp Anagaudryceras yamashitai (Yabe) Baculites capensis Woods Pachydiscus buckhami Usher Inoceramus sp	Marlife Plateau Sec 17, 18, 19, 20, 29, 30, T 14S, R 11E
				LLANADA SDST		Llanada sandstone	Moreno Gulch	1490'N & 1490'W of SE corner of Sec 16, T 14S, R 11E	1740'N & 330'W of SE corner of Sec 16, T 14S, R 11E	Concretionary sandstone	840'		Llanada townsite east center Sec 8, T 15S, R 10E
CONIACIAN				LOWER MARLIFE SHALE						Lower brown shale	5150'	Baculites capensis Woods Baculites schencki Matsumoto Inoceramus cf uwajimensis Yehara	
				CARNERADA CGL.		Carnerada conglomerate	South Branch of Moreno Gulch	1400'N & 1660'E of SW corner of Sec 33, T 14S, R 11E	1900'S & 160'W of NE corner of Sec 33, T 14S, R 11E	Red cobble conglomerate	0' to 2200' of interval		Carnerada Canyon Sec 1, 2, 11, T 14S, R 10E Sec 5, T 14S, R 11E Sec 21, 28, 29, 31, 32, T 13S, R 11E
TURONIAN				CIERVO SHALE	Ciervo shale		Papanatas Canyon	580'N & 660'W of SE corner of Sec 13, T 14S, R 10E	1080'S & 200'W of NW corner of Sec 20, T 14S, R 11E	Green shale	600'	Desmoceras (Pseudouhligella) sp	Ciervo Mt in south central Sec 5, T 17S, R 13E
				ORTIGALITA SDST.		Ortigalita sandstone	Papanatas Canyon	1490'N & 1900'E of SW corner of Sec 18, T 14S, R 11E	850'S on E Sec line from NE corner Sec 10, T 14S, R 11E	Brownish green sandstone	570'	Lewesiceras (?) Myrtea sp	Ortigalita Peak in south central Sec 18 T 13S R 10E
				CIERVO SHALE							2300'		
CENOMANIAN				BENITO SANDSTONE	Benito sandstone		Papanatas Canyon	166'S & 2575'W of NE corner of Sec 24, T 14S, R 10E	580'N & 660'W of SE corner of Sec 13, T 14S, R 10E	Green micaceous sandstone	1100'		Benito Hill near center of S line Sec 32 T 14S, R 11E
				REDIL SHALE INCLUDES	Redil shale		Papanatas Canyon Sec. 23 & 24 T 14S, R 10E	1000'S & 580'W of NE corner of Sec 23, T 14S, R 10E	166'S & 2575'W of NE corner of Sec 24, T 14S, R 10E	White weathering shale silty & sandy	5325'		Redil Canyon Sec 25, T 14S, R 10E
				PAPANATAS CONGLOMERATE		Papanatas conglomerate	Papanatas Canyon Sec 24 T 14S, R 10E	1162'S & 330'E of NW corner of Sec 24, T 14S, R 10E	900'S & 2325'E of NW corner of Sec 24, T 14S, R 10E	Red boulder conglomerate	0-950'	Leconteites lecontei Anderson Syncyclonema Spatangoida Stomatolites Beudanticeras cf [illegible] Anderson Turrilites costatus Lamarck Hamites Lechites gaudini (Pictet & Campiche) [illegible]	Papanatas Canyon Sec 23 & 24 T 14S, R 10E
JURASSIC?				FAULT FRANCISCAN									

FOSSIL LISTS AFTER TATSURO MATSUMOTO

NOTE (1) Tatsuro Matsumoto lists Baculites ranges as follows

Baculites rex Anderson	(a ! through Maestrichtian)
Baculites lomaensis Anderson	(early Maestrichtian to late Campanian)
Baculites schencki Matsumoto	Campanian
Baculites capensis Woods	and
Baculites inornatus Colligan	Santonian

NOTE (2) Tatsuro Matsumoto lists these fossils for Marlife Shale

UPPER MARLIFE
- B capensis Woods
- B schencki Matsumoto
- Pachydiscus buckhami Usher
- Anagaudryceras yamashitai (Yabe)

LOWER MARLIFE
- Baculites capensis Woods
- B schencki Matsumoto
- Inoceramus cf uwajimensis

NOTE (3) Tatsuro Matsumoto lists the following fossils in the order and range as shown in the Moreno Shale at right

TIERRA LOMA SHALE	Eubaculites cf ootacodensis Stoliczka or E vagina Forbes
MARCA SHALE	Neophylloceras hetonaiense Matsumoto Phyllopachyceras sp Diplomoceras sp Baculites rex Anderson Baculites lomaensis Anderson Inoceramus sp Neophylloceras hetonaiense Matsumoto var tuberculata Matsumoto

Figure 2.

and roughly bedded layers from 1 to 5 feet in thickness. The Benito sandstone has been mapped through the Panoche Hills and north 40 miles to Garzas Creek. The age of the sandstone is Turonian and Cenomanian, to judge from the fossils it contains.

Ciervo Formation. The Ciervo is a thick, distinctive, green shale including a thick sandstone member designated the Ortigalita sandstone. The resistant, rounded, and subdued topography in shale slopes of this formation is not rugged. The name Ciervo is taken from Ciervo Mountain, 3393 feet in elevation, in the south-central part of sec. 5, T. 17 S., R. 13 E. The Ciervo shale is conformable with the underlying Benito sandstone. The Ciervo shale, including the Ortigalita sandstone, is 3470 feet thick in the type section.

Lithologically the Ciervo is distinct from any other part of the Panoche group. It is greenish to bluish-green, arenaceous and silty with abundant quartz grains and mica flakes and a clayey matrix. The shale is hard, siliceous, and well-bedded. The interbeds—at random intervals—are thin, lime-cemented, iron-stained, platy sandstone 2 or 3 inches to a foot in thickness. The shale tends to break into hard, semi-rounded, semi-conchoidal chunks approximately 2 inches square, a distinctive and characteristic feature of all its outcrops along the west side of the San Joaquin Valley. It gives only a fair reaction with acid.

The Ciervo shale can be traced 80 miles to the north of Del Puerto Creek. Upper to Lower Turonian ammonites are reported from this shale, but many samples washed for Foraminifera have given negative results.

The *Ortigalita sandstone* is a member of the Ciervo shale, and is conformable with it. The upper and lower contacts are gradational. The thickness ranges from 500 feet to 1920 feet in the Panoche Hills. The sandstone is greenish-gray, weathers to a buff brown, is fine to medium grained silty (1/16 mm to ½ mm) graywacke, poorly sorted, with subrounded grains. The sandstone is made up of biotite, quartz, feldspars, and limonite, friable to hard locally and giving only a slight calcareous reaction to acid. The Ortigalita sandstone member of the Ciervo formation is rhythmically bedded, the repetitions being every 1 to 2 feet. It contains scattered concretions as much as 4 feet in diameter. The age of the Ortigalita is considered to be Turonian, since it is included within the Ciervo shale that has yielded Turonian fossils. It has been traced as far north as Orestimba Creek, though it is not always distinguishable within the green Ciervo shale; nor is it distinct from many other sandstones in the section.

Marlife Formation. The Marlife formation is the thick, middle unit of the Panoche group, with a total thickness of 8685 feet. The brown Lower Marlife shale, 5150 feet in thickness, is separated from the gray Upper Marlife shale (2695 feet) by 340 to 840 feet of persistent sandstone, the Llanada sandstone member. The Marlife shale weathers into rounded ridges less rugged than those of the overlying Television sandstone. Sutton (1952) separated and named the unit in manuscript. The name was taken from Marlife Plateau in secs. 17, 18, 19, 20, 29, and 30, T. 14 S., R. 11 E.

The Marlife is conformable with the Ciervo shale. At the base of the Marlife shale, the Carnerada conglomerate lens crops out across most of the Panoche Hills, but locally the lower brown shale of the Marlife rests on the green Ciervo shale without the intervening conglomerate. The Carnerada conglomerate was named by Sutton in 1952.

The Lower Marlife in type section consists of 5150 feet of well-bedded brown shale; except for beds of clay shale, most of the Lower Marlife is sandy and micaceous. It weathers to rounded ridges; concretionary resistant sandstone beds 5 to 50 or more feet in thickness add humps to the otherwise smooth shale ridges. The Lower Marlife is probably 90 percent shale and 10 percent sandstone. The shale is brown to dark gray-brown, with black streaks; chocolate-brown is the usual color in the weathered outcrop. It is silty, finely sandy, and micaceous. The shale does not react with acid.

The Upper Marlife consists of 2695 feet of gray shale. Numerous thin concretionary sandstone beds 1 foot to 10 feet in thickness appear intermittently in the section. The gray shale is conformably overlain by the Television sandstone. The Upper Marlife is a clay shale or mudstone which breaks into small angular chips, and is not as fissile as the Lower Marlife shale nor as resistant. It weathers into low topographic ridges and saddles, and because it is the only thick gray shale unit in the Cretaceous section it can be mapped easily. The gray Upper Marlife shale gives an active and immediate reaction to acid. The Upper Marlife can be mapped for at least 80 miles to the north of Panoche Hills—as far north as Lone Tree Creek. It becomes more sandy to the north of Panoche Hills, and in some canyons sand dominates the section. The Upper Marlife shale is shown in Lewis Martin's chart as equivalent to Goudkoff's G zone *, according to the foraminifers present. Tatsuro Matsumoto considers the Upper Marlife to be early Campanian in age, the upper part of the Lower Marlife Santonian, and the balance of the Lower Marlife Coniacian (Tatsuro Matsumoto, 1959, p. 113, 116, and 125).

The middle unit of the Marlife shale is the *Llanada sandstone* (graywacke) *member*. This is a thick, fine- to medium-grained (⅛ mm to ½ mm), silty and clayey sandstone, with numerous large, black-weathering concretions. It is poorly cemented and friable except for the "case-hardened" concretions which give a very active reaction to acid. This distinctive bed grades downward into the Lower Marlife as well as upward into the Gray Upper Marlife shale. It is a continuous member throughout the Panoche Hills and for at least 80 miles to the north, to Hospital Creek. This distinctive sandstone is a more resistant bed than the over- and underlying shales, and forms a distinct topographic feature.

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* "Zone" refers to local foraminiferal intervals, and not zone of definition.

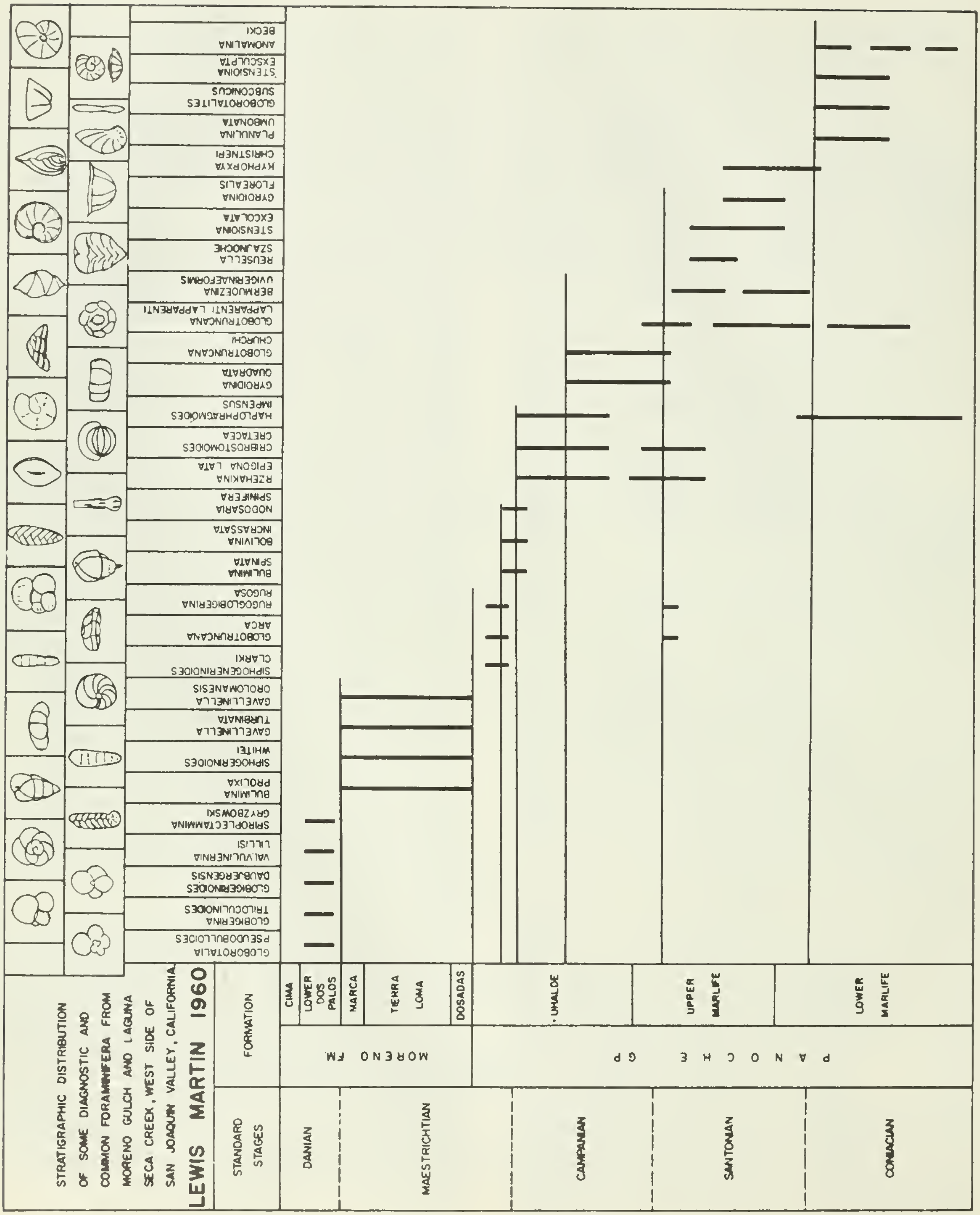

STRATIGRAPHIC DISTRIBUTION
OF SOME DIAGNOSTIC AND
COMMON FORAMINIFERA FROM
MORENO GULCH AND LAGUNA
SECA CREEK, WEST SIDE OF
SAN JOAQUIN VALLEY, CALIFORNIA
LEWIS MARTIN 1960
ANOMALINA BECKI
STENSIONA EXSCULPTA
GLOBOROTALITES SUBCONICUS
PLANULINA UMBONATA
KYPHORXYA CHRISTNERI
GYROIDINA FLOREALIS
STENSIONA EXCOLATA
REUSELLA SZAJNOCHE
BERMUDEZINA UVIGERNAEFORMIS
GLOBOTRUNCANA LAPPARENTI LAPPARENTI
GLOBOTRUNCANA CHURCHI
GYROIDINA QUADRATA
HAPLOPHRAGMOIDES IMPENSUS
CRIBROSTOMOIDES CRETACEA
RZEHAKINA EPIGONA LATA
NODOSARIA SPINIFERA
BOLIVINA INCRASSATA
BULIMINA SPINATA
RUGOGLOBIGERINA RUGOSA
GLOBOTRUNCANA ARCA
SIPHOGENERINOIDES CLARKI
GAVELLINELLA OROLOMAENSIS
GAVELLINELLA TURBINATA
SIPHOGENRINOIDES WHITEI
BULIMINA PROLIXA
SPIROPLECTAMMINA GRYZBOWSKI
VALVULINERIA LILLISI
GLOBIGERINOIDES DAUBJERGENSIS
GLOBIGERINA TRILOCULINOIDES
GLOBOROTALIA PSEUDOBULLOIDES
FORMATION
CIMA
LOWER DOS PALOS
MARCA
TIERRA LOMA
DOSADAS
UHALDE
UPPER MARLIFE
LOWER MARLIFE
MORENO FM
PANOCHE GP
STANDARD STAGES
DANIAN
MAESTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN

Figure 3.

Television Sandstone. The Television sandstone (arenite) is a persistent formarion mapped throughout the Panoche Hills. It is a lithogenetic unit between the thick gray Upper Marlife shale and the shale and sandstone of the Uhalde formation. The Television sandstone forms the highest ridge on the east flank of the Panoche Hills, and is named after Television Hill (elevation 2096 feet) in sec. 9, T. 14 S., R. 11 E. It lies conformably above the gray Upper Marlife shale, and is conformable with the overlying gray-brown shale of the Uhalde formation. The Television sandstone is for the most part about 100 feet thick. It is more resistant than the underlying gray Upper Marlife shale, and forms a strike ridge with a long, gradual dip slope which results in an unusually wide cartographic unit on the map. It is silty to fine grained (1/16 mm to ¼ mm), sub-rounded, and micaceous; the matrix is fairly clean, porous, and friable, and the concretionary layers are hard. The concretions are 1 to 4 feet in diameter. The sandstone gives no reaction to acid except in the concretionary and thin limy layers.

The Television sandstone can be mapped from Panoche Hills northward to Hospital Creek, a distance of about 80 miles, and it maintains about the same thickness throughout this distance.

The age of the Television sandstone is F zone of Goudkoff. Ammonites from beds above and below this sandstone suggested ro Tatsuro Matsumoto an early Campanian age.

Uhalde Formation. The Uhalde is about 50 percent shale and 50 percent concretionary sandstone in alternating beds 100 to 700 feet thick. This gray-brown lithogenetic unit is resistant to weathering, forming the eastern front of the Panoche Hills. The Uhalde sandstone and shale are lithologically and physiographically distinct from the Moreno shale comformably overlying them. The Uhalde is more resistant, forms higher and more rugged terrain with deep canyons, and contains more sand than does the Moreno.

The Uhalde formation was named by Sutton (1952) after Uhalde Canyon. Its measured thickness is 3370 feet, its upper and lower contacts are conformable. The shale is gray-brown on a fresh surface, and wearhers to a grayish color. The sandstone is gray, fine grained, friable, micaceous, well cemented and hard—and concretionary. The concretions, 2 ro 5 feet in diameter of micaceous fine- to medium-grained immature argillaceous sandstone whose good sorting and sporadic stable constituents (sphene and chert) make it arkosic sandstone or arkosic arenite, contain considerable clay in their matrix, more than 10 percent of which may be argillaceous.

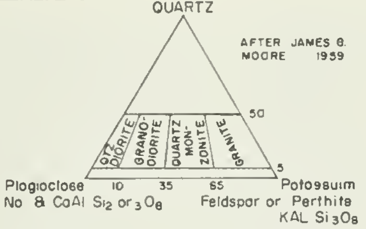
The Uhalde formation has been mapped from Panoche Hills to Hospital Creek, a distance of 80 miles. To the oil industry this is stratigraphically, at present, the most imporrant formation of the Panoche group. Most of the wells drilled for oil and gas in the vicinity have penetrated into the Uhalde section, but few wells have reached G zone in the valley.

The base of the F zone is about 2000 feet below rhe top of the Uhalde. The E zone is about 1000 feet below the top of the Uhalde. The D_2 zone is about 450 feet below the top of the Uhalde, and Lewis Martin questionably placed rhe base of the Maestrichtian stage and top of rhe Campanian with the D_2 zone. Matsumoto, on the basis of ammonite collections, tentatively placed the base of rhe Maestrichtian about a third of the disrance from the top of the Uhalde. This would be near the top of the E zone and base of the D_2 zone of Goudkoff. The upper 450 feet of the Uhalde is D_1 zone.

There is an abrupt physiographic change from the rounded, low-lying Moreno shale topography to the steeper ridges of the Uhalde sandstone and shale. The fauna of the lower two-thirds of the Moreno and about the upper one-third of the Uhalde formation is Maestrichitian. The top of the Maestrichtian is near the top of the Marca shale member of the Moreno formation. The Dos Palos shale (highest member of the Moreno formation) is considered to be Danian, Tertiary. In Lewis Martin's chart of Moreno Gulch the top of the D_1 zone fauna is shown at the top of the Uhalde formation (top of Panoche).

STRUCTURE

The serpentine and Franciscan rocks have been faulted into contact with the Panoche sedimentary rocks from Panoche Hills northward to Hospital Creek and beyond. This same relationship of Franciscan in fault contact with the Upper Cretaceous is shown on the geologic map of California (State Division of Mines 1938), and in the lirerature it has been reported in many places: Vickery (1925), Clark (1935), Taliaferro (1943), Leith (1949), and Briggs (1953). In his report on Ortigalita Peak quadrangle (1953) Briggs named the fault the Ortigalita thrust fault. He referred to Taliaferro (1943, p. 162) as having reported this major faulting from the east side of Mount Diablo to the New Idria area, a distance of 120 miles. The displacement is believed to be at least several thousand feet. The Redil shale in the Panoche Hills is about 3850 feet in thickness. In many of the larger canyons to the north of Panoche Hills as shown on the regional geologic map, all of the Redil shale is missing, and in some canyons the Benito sandstone and part of the Ciervo shale are also faulted out of the section. There must be a displacement of an estimated 5000 feet on the Ortigalita thrust fault in these local areas. Jadeite has been reported in the Pacheco Pass area by E. B. McKee Jr. (1958), and Marshall E. Maddock (written communication, Aug. 20, 1960) found jadeite in the Carbona and Mt. Boardman quadrangles. Anderson and Pack (1915, p. 108-109) about the structure stated that . . . "in the western flank, faults dominate the structure. From a point about 10 miles south of the east end of Livermore Pass southward to Little Panoche Creek there is little to disturb the regularity of the monoclinal structure of the east flank of the range. The bending of the structure lines between Garzas and Salado Creeks



CLASSIFICATION OF GRANITIC ROCKS (MODIFIED) FROM JOHANSSEN 1931

ROCKS & MINERALS

BELIEVED TO BE SIGNIFICANT BY VARIOUS AUTHORS AS INDICATORS OF PROVENANCE

ⓧ NOT YET FOUND OR REPORTED FROM PANOCHE HILLS

ROCKS AND MINERALS	WESTERN SOURCE	EASTERN SOURCE
QUARTZ DIORITE QUARTZ 66.50 %	X	
THE HIGHER IN SILICA THE MORE POTASSIC GRANODIORITE 66.88 % & QUARTZ MONZONITE 69.15 %		X
DACITE TUFF	X	
GLAUCOPHANE	ⓧ	
STAUROLITE		ⓧ
AUGITE PORPHYRY "most common and most striking rocks of the Sierra Nevadas" A Knopf		ⓧ
"Intrusives seem to have begun in West, basic magmas peridotites, pyroxenites and gabbro—gradually extended EASTWARD become more acidic, finally granitic" Lindgren (1915)	Coast Range intrusives of Alaska can be arranged in series of belts progressively richer in SiO_2 & K_2O toward EAST. Alaska compared to Sierra Nevadas. Buddington (1927)	Classification of Rocks, quartz-diorite (tonalite) from granodorite drawn at 10 % potassium feldspar rather than 5 % Johanssen (1931)

Figure 4.

and the small anticline north of Salado Creek alone break the regularity. In the Panoche Hills the strata are folded into a low, broad, elongated dome which scarcely reaches the edge of the valley."

The early Tertiary beds in the Panoche Hills are gently bowed from north to south. The nonmarine Miocene rocks are found around and over the Panoche Hills in gentle folds with a northeasterly to southwesterly trend. They can be traced to the north end of the mapped area on the surface; beneath the surface they can be traced across the San Joaquin Valley in well sections.

PROVENANCE

The source of Panoche sediments as determined from rock types can most reasonably be thought of as from the east. However, certain rock types in the Panoche are not common to the exposed present-day Sierra Nevada batholith, and certain minerals believed to indicate an eastern source are found to be rare or—so far as is known—absent.

The Panoche conglomerates are red in color, have a muddy matrix, and contain pebbles, cobbles, and boulders up to 3 feet in diameter of granite and volcanic rocks. The source of this debris may have been in the west, but the presently exposed granites in the "Coast Ranges of California are 80 to 90 m.y. old" (Knopf 1960, p. 131)—probably too young to have been an available source for most of the Panoche debris, which is 70 to 100 million years old.

The central Valley basement high (the Uhalde formation, Goudkoff's F zone, lies on basement) may possibly be a part of, and as old as "the granites of the foothill region of the Sierra Nevada of 140 m.y. old" (Knopf 1960, p. 131); and "may have been the site of the original beginning of the Sierra Nevada as a parallel mountain chain before restoration and intrusion of the granites of the higher Sierra Nevada of 80 to 90 m.y. old" (Knopf 1960, p. 131). This nearby eastern source could have supplied also the fresh-appearing conglomerate debris to the Panoche conglomerates during floods and wet seasons of the tropical climate (20° C.±) (Durham 1959, p. 9).

GEOLOGIC HISTORY

The intruded, metamorphosed, and contorted rocks of the Franciscan indicate a complex history for which there is little evidence within the Upper Cretaceous sediments.

Upper Cretaceous deposition took place in a geosynclinal trough when the Great Valley was an inland sea. The climate of the Upper Cretaceous, as postulated from terrestial and marine evidence, was subtropical to tropical (Axelrod, 1958, p. 458-459, and Durham 1959, p. 9-11).

The Cenomanian stage began with a near-shore trough 1000 to 2000 meters in depth, as estimated from the 25 to 50 percent fine sand and silt and 50 percent clay (Bruun 1957, pl. 3).

In middle Cenomanian time occassional torrential floods brought masses of stream-rounded pebbles and boulders to the fresh oxidizing environment of red, iron-stained, clayey, groundmass debris of the Papanatas conglomerate. An ammonoid fauna prevailed. Near the end of the Cenomanian, volcanic activity was more pronounced, as evidenced by bentonite and dacite tuff beds in the upper part of the Redil shale.

In late Cenomanian time the sea was turbid. Muddy, medium- to coarse-grained sand with abundant large, fresh, mica flakes was deposited, indicating shallow depth due to in filling along and near the shore line. There was an abundance of volcanic detritus from land of high relief. The detrital material—green, clayey, micaceous, angular-grained sandstone—indicates short transport of the sediments to the sea.

In early Turonian time, siliceous green shale material came from less available sources on a land of low relief. The detritic material consisted of weathered volcanic debris with quartz and included quartz grains. Known faunas consist of ammonites, but no Foraminifera.

An increase in the amount of land detritus, is indicated in middle Turonian time by the deposition of material of the Ortigalita sandstone. In the late Turonian, more green, siliceous sediments were deposited, as variable depositional conditions prevailed.

In early Senonian time the deposition of brown sediments which formed shale of more organic nature, with thin black carbonaceous streaks, was interrupted by ocasional floods of storm-washed boulder debris into the Coniacian sea. Foraminifera, ammonites, pelecypods, and gastropods have all been found. The depth of the sea was bathyal (Bruun 1957, pl. 3)—from 2000 to 3500 meters. In Coniacian time sediments that formed the Lower Marlife brown shale were deposited in a turbid environment; they contained Foraminifera and ostracods. In Santonian time the depositional environment was clear and neritic (Martin Chart 1, 1958). Sediments of the Upper Marlife gray shale were deposited in depths of 500 to 1000 meters (neritic to bathyal) (Bruun, 1957, pl. 3). In Santonian time Upper Marlife was deposited with a G-zone fauna and Foraminifera identified with the lower part of the F zone. Volcanic activity increased for a time in the early Campanian; bentonite appears in the lower part of the Upper Marlife. In Campanian time the depositional environment was turbid. Early Campanian deposits include F-zone Foraminifera; the late Campanian is equivalent to the E zone and the top of the E zone was deposited near the end of the Campanian.

In Maestrichtian time the depositional environment was clear and neritic and the sea bottom varied in depth from neritic to bathyal (about 500 to 1000 meters) (Bruun, 1957, pl. 3). Early Maestrichtian time was represented by the D_2 and D_1 zones, with the top of the E zone at the base of the Maestrichtian.

The Uhalde formation was deposited under variable and recurrent depositional conditions; a few hundred feet of shale were formed, followed by a few hundred feet of sandstone, and then shale again, throughout the entire 3370 feet.

In early Maestrichtian time, ever-changing depositional conditions caused by changes in available source material and relief of the land resulted in alternations of sandstone and shale, repeated many times as in the late Campanian strata. Diatoms did not appear in the Panoche Hills (according to Martin's Chart 1, 1958) until after the beginning of Maestrichtian time, but they persisted throughout the Maestrichtian (Moreno). Foraminifera, radiolarians, and diatoms, are common. Gastropods, pelecypods, and ammonites and inocerami are found. The sea bottom was from 1000 to perhaps 2000 meters in depth (Bruun, 1957, pl. 3).

The upper part of the Panoche sediments (top of the Uhalde) was deposited during early Maestrichtian time, when depositional conditions became more settled. *Acila*, found in these sediments, has been recorded (Schenck 1936, p. 9) as benthonic, comes from depths of less than 500 fathoms, from temperate water between 40° and 70° and is neritic to bathyal. The depth of the sea ranged to as much as 3000 meters (Bruun, 1957, pl. 3). The Moreno shale, above the Panoche, is more organic. Vertebrates ranged the sea and mollusks thrived. Fish, crabs, Foraminifera, diatoms, radiolarians, ammonites and inocerami have all been found in the sediments deposited during Maestrichtian time. The presence of radiolaria indicates (Ladd 1957; Natland 1957, p. 547) marine and oceanic environment between 8 and 800 fathoms, in water temperatures probably lower than 72° F. and higher than 34° F. (Schenck 1943, p. 60).

In late Maestrichtian sediments the last of the local vertebrates are found; the ammonites and inocerami disappeared after the deposition of the Marca shale member of the Moreno formation. Foraminiferal assemblages identified with Goudkoff's C zone are found abundantly in the Marca shale.

In Danian time abundant glauconite was formed during the deposition of the Dos Palos shale (uppermost member of the Moreno formation), which indicates the sea bottom averaged (Ladd 1957, p. 45) 10 to 45 fathoms (probably below 130 fathoms in the tropical waters) in depth. Waters were normally saline, with organic material present. Sedimentation was slow, under weakly oxidizing conditions; glauconite was formed from micaceous minerals and bottom muds rich in iron. Corals in the Cima sandstone (included in the Dos Palos shale) indicate (Ladd 1957; Natland 1957, p. 545) maximum depths of 90 meters at temperatures of 18.5° C. to 25° C. The presence of coral also suggests a clear neritic environment.

Several restricted basins are indicated during Eocene time by the rapid changes in lithology. The *Turritella* cf. *pachecoensis* fauna is synchronous with the Ynezian stage based on Foraminifera (Mallory 1959). Natland describes it as (Ladd 1957; Natland 1957, p. 558-559) "an environment oscillating from shallow marine to continental and lacustrine" and says that "in the Domengine the foraminifera and mollusks indicate a shallow neritic habitat". The climate in the central San Joaquin Valley was tropical, according to Natland (1957, p. 569 referring to Durham, 1950), who stated that the fauna containing *Discocyclina* indicates shallow tropical environment. By mid-Eocene, a widespread sea of more settled conditions prevailed.

In the Panoche Hills the major folding and faulting took place prior to the Relizian stage (Miocene). While much of the southern San Joaquin Valley was under the sea during the Miocene epoch, the Panoche Hills and the central part of the San Joaquin Valley saw no marine embayments during Plio-Pleistocene time and nonmarine rocks were deposited, gently folded, elevated, and eroded during those epochs. Axelrod (1957, p. 36 and p. 40) shows that the approximate annual rainfall in the Panoche Hills area in Mio-Pliocene time was 20 to 25 inches and that temperature underwent a gradual change from 25° C (77° F) in the Eocene to 11.5° C (52° F) at the end of the Tertiary.

EXPLANATION OF MORENO-PANOCHE CORRELATIONS IN SUBSURFACE CROSS SECTIONS

The Moreno-Panoche contact is important to determine in outcrop as well as in subsurface well sections. Criteria used for determining this contact are currently fraught with difficulties due to several frustrating and confusing circumstances. It is therefore necessary to explain the basis for the correlations used in the type outcrop section in the Panoche Hills and in well sections in the Valley.

The faunal equivalent of the Moreno-Panoche boundary, as designated in the type-section outcrop by Anderson and Pack (1915), has been, and still is, a controversial issue. The difficulties of determining this particular horizon are due to several peculiar circumstances, some of which are depositional. Subsurface correlations shown on the cross sections accompanying this paper are based on a fossil fauna which coincides with the fauna found in outcrop, (determined by Lewis Martin in the type section, and used by R. Stanley Beck, consulting paleontologist) as follows:

(1) The Moreno is divided from top downward into the Dos Palos shale (Goudkoff's A and B zones) (Danian, Paleocene-Tertiary); the Marca shale; the Tierra Loma shale; and Dosados sandstone and shale (all considered C zone Cretaceous). D_1 zone marks the top of the Panoche group of the type area in the Panoche Hills, and C zone (flood of *Siphogenerinoicides whitei*, at the top of the Marca shale) marks the top of the Cretaceous as defined in this paper.

(2) The D_1 zone (top of the Panoche as used in the cross sections) is based on the presence of *Siphogenerinoides clarki* ss., *Bulimina prolixa*, and *Valvulineria oralomaensis* when accompanied by *Nodosaria spinifera* and/or *Globotruncana arca. Bulimina prolixa* and *Valvulineria oralomaensis* range from the top of the Marca shale (top of Cretaceous) through C and D_1 zones. These two Foraminifera are not conclusive or definitive by themselves. To make matters worse the *Siphogenerinoides clarki* ss. is often confused with another small, costate, unnamed *Siphogenerinoides* found in the lower Moreno; and north of little Panoche Creek area, *S. clarki* ss. is found above *S. whitei* more often than in its normal sequence. Some workers suspect that fragments of *S. whitei* may have been seen at odd intervals through the upper part of the Panoche, perhaps as low in the section as E zone, or even lower—which may indicate that *S. whitei* made its first appearance relatively early, but did not become prominent and abundant until C-zone time.

Bulimina prolixa is found from the top of the Marca shale (top of Cretaceous) through C zone and D_1 zone. *Valvulineria oralomaensis* is also present through C zone and D_1 zone. These two forms are not always found together or with *Siphogenerinoides* of any species in C zone and D_1 zone. In some wells only *Bulimina prolixa* has been reported in the washed material. *Bulimina prolixa* is believed to be a good indicator for the top of the Cretaceous (in first occurrence) and for C and D_1 zones. It is general practice to identify the C and D_1 zones together as the *Siphogenerinoides* zone or as C and D_1 zone Cretaceous, when only *Siphogenerinoides* is found or when only *Bulimina prolixa* and *Valvulineria oralomaensis* are found. Some companies regard the D_1 zone as indicating lower Moreno. In this report, D_1 zone is used as by R. Stanley Beck (verbal communication June 7, 1960). Beck stated that the C and D_1 zones are impossible to distinguish one from the other unless D_1 zone is found to contain *S. clarki* ss. or *Globotruncana arca* or *Nodosaria spinifera* along with the *Valvulineria oralomaensis* and *Bulimina prolixa. Globotruncana arca* is seldom found with the methods currently used in washing material.

In the outcrop of the type section, Foraminifera are very often missing or unidentifiable, due to extreme weathering and abundanr gypsum and selenite at the surface, but some well sections also only record *Bulimina prolixa* from washed material.

To the north of the type section (as correlated here), the Paleocene overlies the Cretaceous. In the thickest section in Escarpado Canyon the Dos Palos shale (A and B zones) is overlain by beds containing *Turritella pachecoensis*, (Ynezian stage of Mallory). Just north of Little Panoche Creek the Marca shale is near the top of the exposed Moreno (C zone), overlain by *Turritella pachecoensis* beds. In Ortigalita Creek the exposures are poor but only part of the Tierra Loma shale is present. Ammonites found near the top of the exposed Cretaceous section in Garzas Creek have been identified by Matsumoto (1959) as indicating proximity to the Maestrichtian-Campanian boundary; and *Pachydiscus* (which according to Schenck and Muller, written communication is not known above the Panoche) is found above the D_1 zone foraminifers. It is very difficult to determine the extent of Moreno shale from the outcrop north of Los Banos Creek, because of poor exposures near the top of the sections and the local difficulties in correlating between C and D_1 zones, both in outcrop and well sections, if diagnostic Foraminifera other than *Siphogenerinoides* are not present in a given sample. The regional map shows that there is probably very little or no true Moreno shale north of Los Banos Creek in exposed outcrop.

The deep westerly part of the Valley has a thin section of the true Moreno C zone present in the wells as shown in cross-section as far north as the Cretaceous arch near Tracy (Goudkoff, 1945). Another very confusing feature is that due to some circumstances of deposition, the *Siphogenerinoides* are mixed (with *S. clarki* ss. commonly found above *S. whitei*) in the area from Los Banos (Amerada well Carano No. 1) to the Cretaceous arch at Tracy. *S. clarki* ss. was reported above *S. whitei* in the TWA well Soares No. 1, and the Standard well Blewett No. 2 and in other wells in the area.

In contrast to the discrepancies in the faunal sequences of the northern area in the C and D_1 zones, there seems to be general agreement at the present time as to the intervals and sequences of the lower zones D_2, E, F, and G. H zone has so far been used very little, probably because few wells have penetrated this part of the section, and the zone is thus little understood.

CONCLUSIONS

(1) The formations of the type Panoche group have been recognized and mapped from the Panoche Hills northward to the Tracy area.

(2) Panoche group sediments are considered Late Cretaceous (Cenomanian to lower Maestrichtian) in age. Lower Cretaceous fossils are found only in the faulted area near the main Ortigalita thrust fault or in hard, limy boulders in conglomerates along with Cenomanian fossils; here the Lower Cretaceous fossils are considered to have been reworked.

(3) The thickest and most complete section of Upper Cretaceous Panoche in the mapped area is found in the Panoche Hills. The thickest and most continuously exposed section of the lowest formation of the Panoche, the Redil formation, is found in San Luis Creek.

(4) A more westerly Sierran slope may be inferred as a possible source of Panoche sediments during Late Cretaceous time.

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THE SANTA CRUZ MOUNTAINS

CONTENTS

GEOLOGY OF THE NORTHERN SANTA CRUZ MOUNTAINS, CALIFORNIA

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Plate 20, Geologic map of the northern Santa Cruz Mountains, California; Plate 21, Structure sections through northern Santa Cruz Mountains; Plate 22, Columnar sections, Purisima formation, San Mateo County, California; Plate 23, Columnar section for northern Santa Cruz Mountains; and Plate 24, Stratigraphic distribution of megafossils from the Purisima formation, San Mateo County, California, accompany this paper.

ABSTRACT

The northern Santa Cruz Mountains, an oil-producing province, lies largely between the San Andreas fault and the Pacific Ocean and latitudes 37°07.5′ and 37°22.5′ North. The stratigraphy and structure of 185 square miles of this range are described. Most of the rocks are marine sedimentary strata of Late Cretaceous and Tertiary age and volcanic rocks of Oligocene age that together have a composite thickness on the order of 40,000 feet. Two new formations, six new members, and fourteen new structures are named; many errors in the identification, age, thickness, lithology, and stratigraphic relations of previously mapped formations are corrected.

Most of the early and middle Tertiary sediments were probably derived from a landmass, Salinia, west of the present Santa Cruz Mountains and now submerged beneath the Pacific Ocean, whereas Pliocene sediments were derived partly from volcanic rocks of the Sierra Nevada. The environment of deposition in the deepest part of the sedimentary basin, named herein La Honda basin, was probably bathyal during most of the Tertiary period. La Honda basin probably extended eastward across the San Andreas fault to the Palo Alto area, which appears to have a similar stratigraphic sequence and geologic history. Correspondingly, lateral movement of hundreds of miles along the San Andreas fault near its type locality seems unlikely.

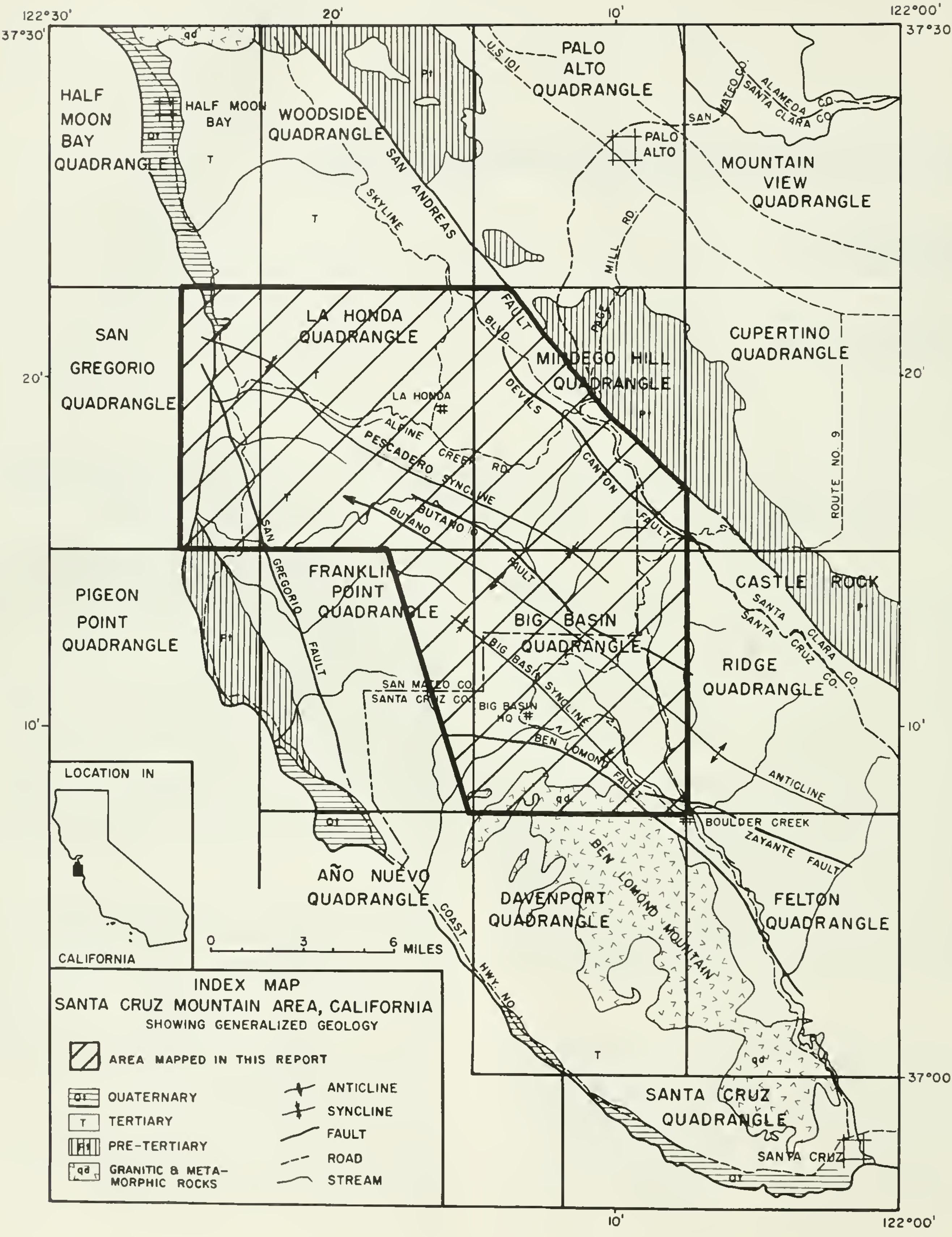
INTRODUCTION

Purpose. Although the Santa Cruz Mountains have been the subject of geologic study since the mid-nineteenth century and are included in a published geologic map (Branner, et al., 1909), recent investigations have indicated the need for more refined geologic information in this area. The renewal of petroleum exploration and production in this district, the availability of detailed topographic maps and aerial photographs, and the application of micropaleontology contributed to the realization that stratigraphic units and geologic structures remained unrecognized or poorly defined. Detailed studies (Touring, 1959; Cummings, 1960; Brabb, 1960) from which this report is drawn have led to a better understanding of the complex geology in this part of the California Coast Ranges.

Location. The Santa Cruz Mountains are the westernmost range of the California Coast Ranges south of San Francisco. The range extends from San Francisco southward to the Pajaro River. This report deals largely with the geology of that part of the range which lies between the San Andreas fault and the Pacific Ocean and latitudes 37°07.5′ and 37°22.5′ north. The location of the region and its division into 7½-minute quadrangles are shown in figure 1.

Geologic setting. Figure 1 is also a generalized geologic map of the region. The oldest exposed rocks, found on Ben Lomond Mountain, are roof pendants of pre-Cretaceous metasediments intruded by quartz diorite (Fitch, 1931). Similar quartz diorite in the Montara Mountain area south of San Francisco has been dated early Late Cretaceous by the potassium-argon method (Curtis et al., 1958). Granite, adamellite, granodiorite, and gabbro are also exposed on Ben Lomond Mountain and are currently being studied by G. W. Leo.

Pre-Tertiary rocks east of the Pilarcitos and San Andreas faults are chiefly eugeosynclinal facies of graywacke, shale, radiolarian chert, limestone, basic volcanic rocks, and serpentine—mapped as Franciscan formation. Although it has long been considered Jurassic in age, the Franciscan formation in this region has yielded fossils in-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20'
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HALF MOON BAY QUADRANGLE
HALF MOON BAY
WOODSIDE QUADRANGLE
PALO ALTO QUADRANGLE
U.S. 101
PALO ALTO
SAN MATEO CO.
SANTA CLARA CO.
ALAMEDA CO.
MOUNTAIN VIEW QUADRANGLE
SAN ANDREAS
SKYLINE
MILL RD.
SAN GREGORIO QUADRANGLE
LA HONDA QUADRANGLE
FAULT
BLVD.
PAGE
MINDEGO HILL QUADRANGLE
CUPERTINO QUADRANGLE
LA HONDA
DEVILS
ALPINE CREEK RD.
PESCADERO SYNCLINE
CANYON
FAULT
ROUTE NO. 9
BUTANO
BUTANO
SAN GREGORIO FAULT
FAULT
PIGEON POINT QUADRANGLE
FRANKLIN POINT QUADRANGLE
BIG BASIN QUADRANGLE
CASTLE ROCK
SANTA CLARA CO.
SANTA CRUZ CO.
RIDGE QUADRANGLE
SAN MATEO CO.
SANTA CRUZ CO.
BIG BASIN SYNCLINE
BIG BASIN HQ
BEN LOMOND FAULT
ANTICLINE
BOULDER CREEK
ZAYANTE FAULT
AÑO NUEVO QUADRANGLE
COAST HWY. NO. 1
DAVENPORT QUADRANGLE
BEN LOMOND MOUNTAIN
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SHOWING GENERALIZED GEOLOGY
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TERTIARY
PRE-TERTIARY
GRANITIC & META-MORPHIC ROCKS
ANTICLINE
SYNCLINE
FAULT
ROAD
STREAM

Figure 1.

dicative only of a Cretaceous age (Schlocker et al., 1954). Other pre-Tertiary rocks are Upper Cretaceous clastic sedimentary strata that crop out in the Pigeon Point area west of the San Gregorio fault, and in the Palo Alto area east of the San Andreas fault. Between these two areas is a sequence of Cenozoic sedimentary and volcanic rocks with an apparent composite thickness in excess of 30,000 feet. These strata have been complexly folded and faulted into northwest-striking structures.

Geography. The Santa Cruz Mountains are moderately rugged in relief, with elevations ranging between sea level and slightly less than 3000 feet. The uplands are characteristically flat or gently rolling, and appear to be remnants of an erosion surface which is now dissected by steep, V-shaped canyons in a youthful stage of development. The area is drained by the San Lorenzo River flowing southward into Monterey Bay, and by Pescadero and San Gregorio Creeks flowing westward into the Pacific Ocean.

The climate is mediterranean with annual rainfall varying locally between 25 and 60 inches or more. Most of the rain falls during the winter months, but summer days are often foggy and wet. Owing to these climatic conditions vegetation is abundant with thick stands of redwood and fir in the valleys and on lower hills, and oak, pine, and chapparal on higher ground.

Previous Work. The earliest recorded geologic observations in this part of California were by Trask (1854) who defined the Coast Ranges and noted "primitive" crystalline rocks as well as Tertiary sedimentary and "trappean" volcanic rocks in the Santa Cruz Mountains. Other reports of early geological reconnaissance which mention the Santa Cruz Mountains include those by Antisell (1856), Blake (1856 and 1858), and Whitney (1865). Ashley (1895) made the first geologic investigation solely concerned with the Santa Cruz Mountains, but most of his proposals were not accepted by later workers. In 1904 Haehl and Arnold reported on the basic igneous rocks in the area; they were the first to apply useful cartographic names to stratigraphic units. Arnold (1906 and 1908) described fossils from a number of formations in the Santa Cruz Mountains and named the San Lorenzo formation, the first Oligocene beds to be recognized in California.

The Santa Cruz folio of Branner, Newsom, and Arnold (1909) was the first systematic description and map of the geology of the Santa Cruz Mountains, and is still a standard reference. In later years, numerous publications appeared, dealing chiefly with the paleontology of strata in this region; they include those by Hobson (1932), Cushman and Hobson (1935), Schenck (1936) and Forrest (1943). Baldwin (1951 and 1953) and Gribi (1957) commented favorably on the oil possibilities of the district. Heavy minerals in some of the Tertiary sandstone were discussed by Beveridge (1960).

Acknowledgments. The writers are particularly indebted to Benjamin M. Page, Joseph J. Graham, and the late Hubert G. Schenck, who directed the dissertations from which this report is drawn. Valuable assistance during various phases of the investigation was provided by Elmo W. Adams, Ralph W. Chaney, Paul S. Day, J. Wyatt Durham, Leo G. Hertlein, Cortez W. Hoskins, C. Osborne Hutton, A. Myra Keen, R. E. and K. C. Stewart, and Charles E. Sturtz. The Ohio Oil Company, Humble Oil and Refining Company, Union Oil Company, Western Gulf Oil Company, Standard Oil Company of California, and Texaco, Incorporated, provided aid and technical services. Financial assistance was provided by the R. H. Anderson Fund for Stratigraphy and the Shell Fund for Fundamental Research. Drafting of illustrations was by G. J. Carter of Eugene, Oregon.

Authors' responsibility in the preparation of this report is summarized in table 1.

STRATIGRAPHY

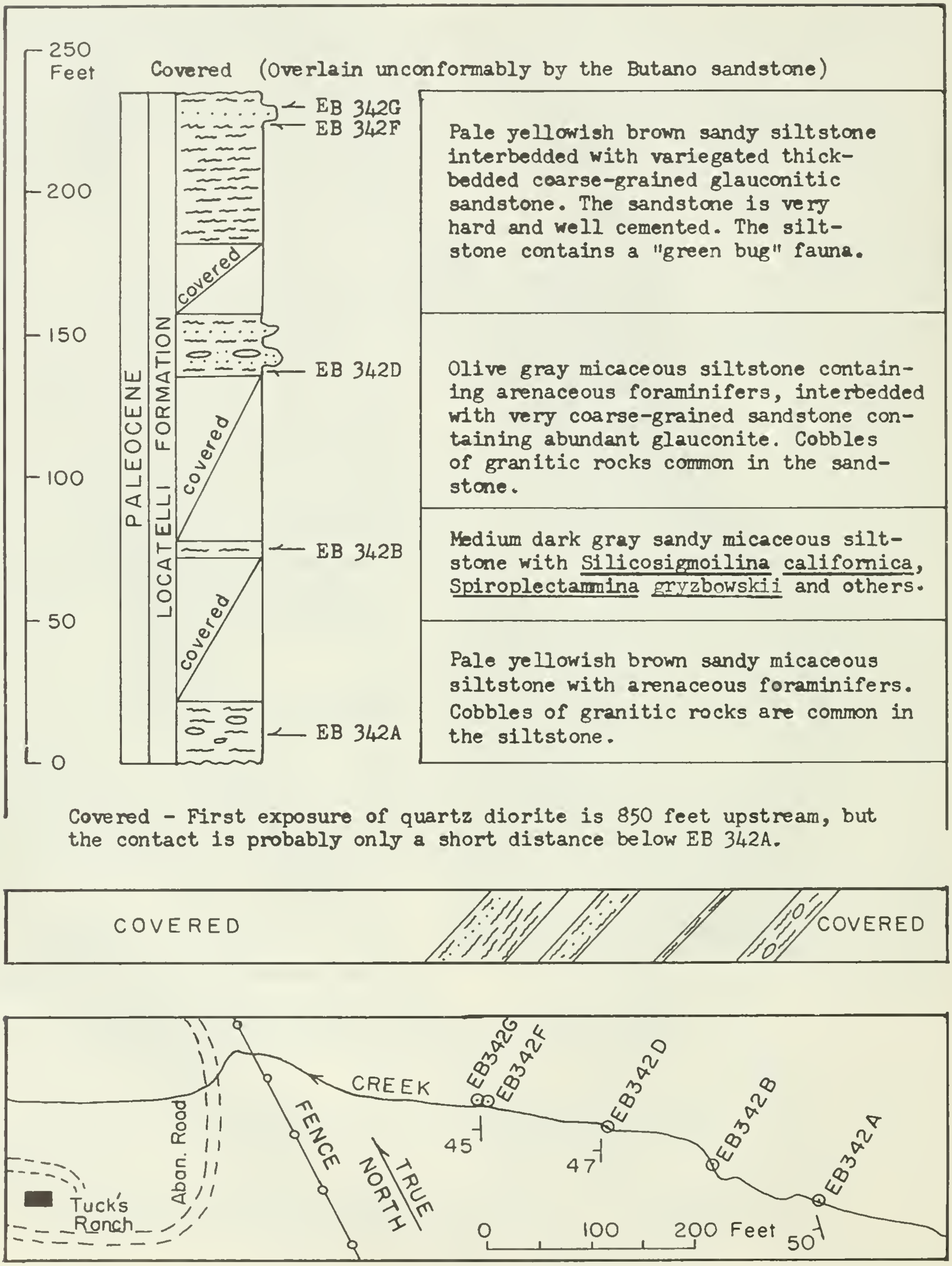
Strata exposed in the northern Santa Cruz Mountains are Cretaceous, Tertiary, and Quaternary in age. The rocks are predominantly marine clastic sediments, although volcanic rocks make up an important part of the section. Locally some of these beds rest nonconformably on Cretaceous crystalline rocks. The strata have an aggregate thickness of approximately 40,000 feet and, in this report, have been divided into ten mappable formations. At least four unconformities are found within this stratigraphic section.

PIGEON POINT FORMATION

Introduction. Sedimentary rocks of Cretaceous age exposed along the Pacific Coast south of Pescadero Beach

Table 1. Responsibility of authors for sections of this report.

Author	Cummings	Touring	Brabb
Map	Mindego Hill and northern Big Basin quadrangles	La Honda and San Gregorio quadrangles	Big Basin and Franklin Point quadrangles
Text	Introduction, Vaqueros and Mindego formations and Woodhams member of the Monterey formation. Structural geology.	Un-named member of the Monterey formation and Purisima formation. Quaternary deposits. Economic geology.	Pigeon Point, Locatelli, Butano and San Lorenzo formations. Geologic history.



Covered (Overlain unconformably by the Butano sandstone)

Pale yellowish brown sandy siltstone interbedded with variegated thick-bedded coarse-grained glauconitic sandstone. The sandstone is very hard and well cemented. The siltstone contains a "green bug" fauna.

Olive gray micaceous siltstone containing arenaceous foraminifers, interbedded with very coarse-grained sandstone containing abundant glauconite. Cobbles of granitic rocks common in the sandstone.

Medium dark gray sandy micaceous siltstone with <u>Silicosigmoilina</u> <u>californica</u>, <u>Spiroplectammina</u> <u>gryzbowskii</u> and others.

Pale yellowish brown sandy micaceous siltstone with arenaceous foraminifers. Cobbles of granitic rocks are common in the siltstone.

Covered - First exposure of quartz diorite is 850 feet upstream, but the contact is probably only a short distance below EB 342A.

Figure 2. Type section of the Locatelli formation along an unnamed tributary of Scott Creek, S½ sec. 17, T. 9 S., R. 3 W.

were first described by Ashley (1895), who named them the Pescadero series. Branner et al. (1909) rejected this name and referred the strata to the Chico formation. Hall et al. (1959) recommended that the name Chico be dropped and proposed the new name Pigeon Point formation. Their type section for the Pigeon Point formation extends from Pescadero Beach in the southwest corner of the area mapped (fig. 1) to midway between Franklin and Año Nuevo Points, about 11 miles southeast of Pescadero Beach. The formation may extend at depth throughout the northern Santa Cruz Mountains, but it has not yet been penetrated by exploratory wells.

Lithology. The Pigeon Point formation, within the area mapped, consists of rhythmically bedded sandstone, siltstone, and shale. Most of the sandstone is medium gray and is in graded beds from a quarter of an inch to 1½ feet in thickness. The sand grains are characteristically angular and consist predominantly of quartz, feldspar, chert, and biotite, and minor amounts of shale, siltstone, sandstone, quartzite, schist, and volcanic rocks. Siltstone and shale interbedded with the sandstone are medium to dark gray and commonly contain coal chips and finely divided carbonaceous material.

Conglomerate is present in the Pigeon Point formation a few miles south of the area mapped. It consists of well-rounded pebbles and cobbles of porphyritic volcanic rocks, chert, and quartzite, as well as angular pebbles, cobbles, and boulders of granitic and metamorphic rocks.

Stratigraphic Relations and Thickness. The base of the Pigeon Point formation is not exposed. The formation is overlain unconformably at Pescadero Beach by the Mindego formation, which at this locality is probably Oligocene (Zemorrian) in age, and by the Purisima formation of Pliocene age 2 miles southeast of Pescadero Beach, beyond the area mapped.

Estimates of the thickness of the Pigeon Point formation range from more than 8,500 feet (Hall et al., 1959, p. 2856) to 9,400 feet (Arnold, 1908, p. 346) and 10,800 feet (Ashley, 1895, p. 299).

Fossils, Age, and Correlation. Fossils in the Pigeon Point formation are listed and discussed by Hall et al. (1959). Some of the formation is Campanian and possibly Maestrichtian in age, but the upper and lower age limits have not been determined. Presumably the formation is entirely Upper Cretaceous.

The Pigeon Point formation is correlative with siltstone that crops out near the Stanford University campus, 17 miles northeast of Pescadero Beach (Graham and Church, 1959), and perhaps with sandstone and shale mapped by Darrow (1951) on the north flank of Montara Mountain, 24 miles northwest of Pescadero Beach. Other California formations of Late Cretaceous (Campanian) age that are correlative with the Pigeon Point formation are listed by Matsumoto (1960, pl. 2).

Provenance and Depositional Environment. The angular clasts of granitic and metamorphic rocks were derived from an area similar to that mapped by Branner et al. (1909) on Ben Lomond Mountain in the southern Santa Cruz Mountains. The porphyritic volcanic rocks are probably reworked from a pre-Campanian conglomerate, but no outcrops of this hypothetical conglomerate have been found. The coarseness of some conglomerates in the Pigeon Point formation, the high feldspar content of the sandstone, and the common carbonaceous material suggest that the source area was a heavily wooded and rugged terrain. Crowell (1957) has suggested that once the sediments reached the ocean, they were transported by turbidity currents. Foraminifera in the shale beds (Touring, 1959, p. 20) suggest that the sediments came to rest in a bathyal environment.

LOCATELLI FORMATION

Introduction. Branner et al. (1909) mapped the Butano sandstone on the north flank of Ben Lomond Mountain as resting unconformably on quartz diorite. A thin siltstone and sandstone unit underlying the Butano and overlying quartz diorite is differentiated in this report and named the Locatelli formation for exposures in the vicinity of Locatelli's ranch. The type section (fig. 2) is along an unnamed tributary of Scott Creek in the S½ sec. 17, T. 9 S., R. 3 W. Outcrops of the Locatelli formation are limited to small patches around the crystalline core of Ben Lomond Mountain.

Description. The characteristic rock of the Locatelli formation is dark gray, massive siltstone. A few beds of sandstone are interstratified with the siltstone in the type section, and the sandstone is considerably thicker and makes up a greater amount of the section in the vicinity of Jamison Creek and its tributaries. A few irregularly shaped pebbles and cobbles of granitic and metamorphic rocks are present in the siltstone and sandstone of the type section. They are more numerous along the Empire Grade road, where they are associated with well-rounded and polished pebbles and cobbles of quartzite, flow-banded rhyolite, and porphyritic volcanic rocks similar to those in the Pigeon Point formation. Glauconite is common in the strata along the type section but it is relatively scarce elsewhere.

The Locatelli formation rests unconformably on the granitic basement rocks of Ben Lomond Mountain and appears to be overlain unconformably by the Butano sandstone and beds of the Monterey formation.

The Locatelli formation is approximately 250 feet thick along Scott Creek and its tributaries, and possibly as much as 800 feet thick in the vicinity of Jamison Creek.

Fossils, Age, and Correlation. Arenaceous foraminifers are relatively common in the Locatelli formation, and calcareous foraminifers, mollusks, and echinoids have been found at a few localities. In the vicinity of Scott Creek the beds contain such characteristically early Tertiary species as *Cibicides martinezensis*, *Tritaxilina colei*, and *Marginulina subbullata*, as well as species ranging from the Cretaceous, like *Silicosigmoilina californica* and *Spiroplectammina gryzbowskii* (synonymous with *Spiroplectiodes clotho* of Laiming, 1940, according to

Mallory, 1959, p. 117). The last two species, as well as *Vaginulinopsis cf. V. plummerae*, and *Vaginulina cf. V. simondsi*, which also are found in the Locatelli formation, were reported by Laiming (1940) as characteristic of the E zone. Smith (1957, p. 143-144) considers the E zone Paleocene and Mallory (1959, p. 18) considers it correlative with the Ynezian stage. Other guide fossils in the Locatelli formation that indicate an Ynezian age are *Bulimina exigua* and *Palmula delicatissima*, inasmuch as Mallory (1959, p. 84-85) thinks they do not range above this stage.

Mollusks and echinoids in the Locatelli formation along Scott Creek are not diagnostic, but *Turritella pachecoensis*, *T. infragranulata*, and *Pseudoperissolax tricarinatus* were collected from the formation along Smith Grade road on the southern part of Ben Lomond Mountain, about 9 miles south of the area mapped. These guide fossils are common in rocks referred to the Paleocene in California and are associated with microfossils of Ynezian age in the type Martinez group or formation (Mallory, 1959, p. 75), about 60 miles north of Ben Lomond Mountain.

Shale, sandstone, and conglomerate on the north flank of Montara Mountain, 13 miles northwest of the area mapped, were referred to the Martinez formation by Lawson (1914); to the Martinez group by Dickerson (1914); and to the "Martinez" formation and an unnamed formation of Upper Cretaceous (?) age by Darrow (1951), but the ages and stratigraphic relations of most of these rocks are still in doubt. Some of the strata contain *Turritella pachecoensis* (C. E. Weaver, unpublished manuscript) indicating that they are correlative with the Locatelli formation, but most are not similar in lithology to the Locatelli because they are rhythmically bedded.

Some of the rocks in the Palo Alto area previously referred by Branner et al. (1909) to the Chico formation are considered Paleocene or Eocene by Thomas (1951) and Eocene by Graham and Classen (1955). A reinterpretation of an unpublished check list of foraminifers from San Francisquito Creek (Stanford University localities M167 and M171) indicates that sandstone and interbedded shale there are probably Paleocene (Ynezian) and correlative with the Locatelli formation.

Part or all of the "Carmelo series" mapped by Lawson (1893a) in the Monterey-Carmel area 35 miles southeast of Ben Lomond Mountain may also be correlative with the Locatelli formation, inasmuch as the rocks are reported by Merriam (1941, p. 69) to contain *Turritella pachecoensis*. Additional correlations of Paleocene (Ynezian) rocks are shown by Mallory, (1959, p. 27-29 and fig. 7).

Provenance and Depositional Environment. Granitic and metamorphic detritus in the Locatelli formation was derived from a terrain similar to the Ben Lomond basement complex on which the formation rests. The well-rounded volcanic clasts were probably derived from the Pigeon Point formation. Foraminifera in the Locatelli formation along Scott Creek and the north flank of Ben Lomond Mountain suggest that the environment of deposition there was open ocean and bathyal, whereas mollusks and echinoids in the formation on the south flank of Ben Lomond Mountain suggest a neritic environment.

BUTANO SANDSTONE

Introduction. The Butano sandstone was named by Branner et al. (1909) for exposures on Butano Ridge. One infers from their description that the entire region bounded by Pescadero Creek, the San Lorenzo River, Gazos Creek Road, and siliceous shale near Butano State Park, is the type area of this formation. Representative sections may be observed in the headwaters of Opal, Little Boulder, and Hoffman Creeks, and along the lumber road from Pescadero Creek to the crest of Butano Ridge, sec. 17, T. 8 S., R. 3 W. The type section for the uppermost 1,700 feet is established herein along Little Boulder Creek. All of these locations are within the Big Basin quadrangle.

The Butano sandstone has a wider distribution than Branner and his associates realized, probably because of the difficulty in recognizing a formation poor in megafossils outside of the type area and because it has the physical characteristics of the Vaqueros sandstone. Surface mapping and subsurface information from exploratory oil wells show that the Butano sandstone underlies most of the area between Montara and Ben Lomond Mountains and crops out at several localities not previously recorded, such as along La Honda and Coal Creeks. On the other hand, sandstone at the mouth of Pescadero Creek was included in the Butano sandstone by Branner et al. (1909) but is here referred to the Mindego formation.

A greenish-gray clay shale exposed at the head of Corte Madera Creek is included in the Butano sandstone, although further study may show that it is correlative with the Locatelli formation. The shale contains a prolific foraminiferal fauna but micropaleontologists do not agree on the age of the fauna other than Eocene or Paleocene.

Lithology. The type Butano sandstone varies in median grain size from 50 millimeters to 5 microns; in color from light gray to grayish black (where fresh) and very pale orange to reddish brown (where weathered); in bedding from less than 3 millimeters to as much as 50 feet; in Trask sorting index from 1.2 to 4.2; in specific gravity from 2.10 to 2.46; in porosity from less than 1 to as much as 25 percent; and in permeability from less than 1 to as much as 35 millidarcies. Most of the formation is light gray or very pale orange, moderately sorted ($S_0=$ 1.6 to 1.9), medium-grained sandstone, in beds from 1 to 10 feet thick. Many of the sandstone beds are graded and a few have small-scale cross-beds, convolute structures, shale chips, slump structures, and load casts. The sandstone generally consists of approximately 52 percent quartz, 30 percent potash feldspar, 10 percent plagioclase feldspar, 5 percent lithic fragments and biotite, and 3 percent clay matrix. Heavy minerals in the Butano sand-

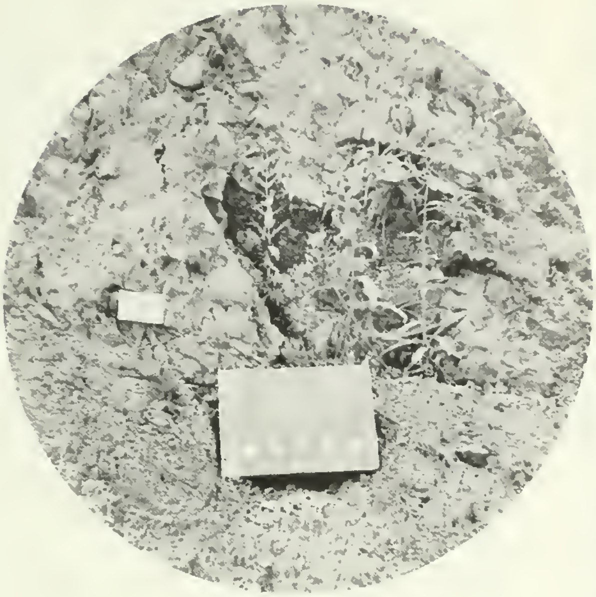


Photo 1. Contact (at base of white card and top of clipboard) between siltstone of the Locatelli formation and overlying cobble and boulder conglomerate facies of the Butano sandstone along Jamison Road, Big Basin quadrangle.

stone are described by Beveridge (1960). Coal chips a few millimeters long and with physical properties similar to those of fusain (Skolnick, 1958) are common as thin laminations in an otherwise massive sandstone sequence. Pebble-and-cobble conglomerate is interstratified with sandstone along Butano Ridge, possibly about 5,700 feet below the top of the formation. The clasts in the conglomerate consist of angular fragments of granitic and metamorphic rocks and well-rounded pebbles and cobbles of quartzite and porphyritic volcanic rocks. Shale interbeds are present throughout the Butano sequence but they are most abundant from 175 to 400 feet below the top of the formation.

There are significant variations in the lithology of the Butano sandstone within the area mapped. The Butano sequence along La Honda Creek, for instance, is finer grained, thinner bedded, and less well sorted than comparable beds in the type area, and a preliminary investigation of the Butano sandstone in Bear Creek, 3 miles east of the area mapped, indicates that the sequence there is also thinner bedded and has more mudstone and shale. Conversely, beds mapped as Butano sandstone on the north flank of Ben Lomond Mountain and along East Waddell Creek contain boulders of granitic rocks, some as large as 7 feet in maximum dimension, as well as many thick beds of cobble, and pebble conglomerate, and are more massive than the type Butano sandstone. Regionally, therefore, the Butano sandstone becomes coarser grained, thicker bedded, and better sorted toward the west and south.

Beveridge (1960) found significant variations in the mineral content of the upper part of the Butano sandstone. Ilmenite, a relatively dense mineral, decreases in abundance, and apatite, a relatively light mineral, increases in abundance north and east from Butano Ridge. Beveridge attributes these variations to sorting and postulates that during deposition of the formation Butano Ridge was closer to shore than Kings Creek and La Honda Creek.

Stratigraphic Relations and Thickness. The Butano sandstone appears to rest unconformably on the Locatelli formation along the north flank of Ben Lomond Mountain (photo 1). The Butano sandstone grades upward

Photo 2. Thin- to medium-bedded Butano sandstone along Butano Ridge.

into the lower shale member of the San Lorenzo formation except at a few localities in the northern part of the area mapped where the contact is intruded by diabase. It is overlapped by the Monterey shale in the western part of the district.

No complete section of the Butano sandstone has been found but the formation is thought to be approximately 9,000 feet thick. The upper 6,000 feet of section crop out on Butano Ridge and the lower 3,000 feet between Scott and East Waddell Creeks. More than 2,500 feet of continuous section can be measured along La Honda Creek and an additional 2,500 feet crops out along the south flank of the Skyline anticline.

Fossils, Age, and Correlation. An oyster fragment and *Propeamussium* cf. *P. interradiatum* are the only mollusks that have been found in the Butano sandstone. The pecten was collected by Stanford University students along La Honda road about 500 feet stratigraphically below the top of the formation. Foraminifera are relatively common in shale interbedded with Butano sandstone, but diagnostic species are mostly restricted to the upper part of the formation.

The Butano sandstone was originally referred to the Oligocene by Arnold (1906, p. 16) but Schenck (1936, p. 69) pointed out that it is Eocene and probably contemporaneous with the type Tejon. The guide fossil *Amphimorphina jenkinsi* indicates that at least the uppermost 35 feet of type Butano sandstone can be referred to the *Amphimorphina jenkinsi* zone of the Narizian stage of Mallory (1959). The highest occurrence in the type Butano sandstone of a lower Narizian or *Uvigernia churchi* zone fauna is a fauna collected by Sullivan (*in* Mallory, 1959, table 16) 108 feet below the top of the formation. No faunas older than Narizian have been collected from the Butano within the area mapped, but the lower 6,600 feet are not well dated.

The Butano sandstone is correlative with some of the sandstone and interbedded shale in the Palo Alto area referred by Thomas (1951) to the Paleocene or Eocene and by Graham and Classen (1955) to the lower or middle Eocene. This correlation is based on a prolific late Eocene (Narizian) fauna collected from the Westridge Road area by C. C. Church, who kindly furnished a list of Foraminifera from this locality (*in* Brabb, 1960, p. 185). The fauna includes *Uvigerina churchi*, *U. grazaensis*, and *Plectofrondicularia packardi multilineata*, to mention only a few of the guide fossils. Other formations of late Eocene (Narizian) age correlative with the Butano sandstone are listed by Mallory (1959, p. 72-73 and fig. 7).

Provenance and Depositional Environment. The clastic detritus that forms the Butano sandstone was probably derived chiefly from potash-rich granitic rocks, such as those cropping out along Carmel Bay (Lawson, 1893a) and on the southwest flank of Ben Lomond Mountain (G. W. Leo, unpublished map). Some detritus also came from metamorphic rocks similar to the schist, gneiss, and marble preserved as roof pendants on Ben Lomond Mountain. The well-rounded pebbles and cobbles of quartzite and porphyritic volcanic rocks in the Butano sandstone were probably derived from the Pigeon Point formation. Beveridge (1960) reached similar conclusions from a study of heavy minerals in the Butano sandstone and added that some of the detritus was derived from the Franciscan formation. No material was found that could not be attributed to a local source.

The detritus in the Butano sandstone and lateral variation in lithology suggest that the source area was a landmass a few miles west of the Santa Cruz Mountains, in what is now the Pacific Ocean. This western landmass was named Salinia by Reed (1933). The angularity and high feldspar content of Butano sand grains suggest that the detritus was mechanically eroded and rapidly transported to the ocean and beneath the zone of wave action. Transportation of the material along the ocean floor was probably accomplished by traction currents near shore aided by slumping and turbidity currents in deeper water. That the sediment came to rest in a bathyal environment is inferred from the lack of neritic mollusks that are common in other Eocene sequences in central California, and from the nature of the Foraminifera fauna, which includes chiefly bathyal and abyssal species. The deepest part of the ocean floor east of Salinia was probably in the vicinity of La Honda—the name La Honda basin is here applied to this depression. Even though La Honda basin was separated from the main part of the Pacific Ocean by Salinia on the southwest, it had unrestricted access to the ocean, probably to the northwest, because planktonic Foraminifera are relatively common in the Butano sandstone.

SAN LORENZO FORMATION

Introduction. The San Lorenzo formation is the name given by Arnold (1906) to shale and fine-grained sandstone beds exposed along the San Lorenzo River and its tributaries. The type section is along the San Lorenzo River 2½ miles north of the town of Boulder Creek. The formation extends throughout most of the area mapped and has been traced on unpublished maps as far south as Corralitos Creek. Nearly all of the outcrops outside of the San Lorenzo River area were referred originally to the Monterey shale by Branner et al. (1909).

Lithology. The type San Lorenzo formation was mapped as two members by Brabb (1960) in a thesis being edited for publication. In this report, however, the members are referred to informally as lower shale member and upper mudstone member.

The lower shale member of the San Lorenzo formation (photo 3) is chiefly olive-gray and grayish-black laminated shale with a few interbeds of light-gray sandstone and siltstone. These rocks are similar mineralogically and texturally to the Butano sandstone and its shale interbeds. The shale weathers to hues of red and brown and commonly has jarosite and gypsum on weathered surfaces. It contains pyrite, carbonate concretions, carbonaceous material, and light olive gray phosphatic lenses. The

Photo 3. Thin-bedded shale in lower member of San Lorenzo formation along Skyline Boulevard. Beds here are overturned.

phosphatic lenses give a few outcrops a dappled appearance.

There are significant variations in the lithology of the lower shale member of the San Lorenzo formation within the southern part of the area mapped. Sandstone and siltstone interbeds are thin and make up less than 1 percent of the total thickness of the lower shale member along the eastern border of the Big Basin quadrangle and on the north flank of the Butano anticline; they are in beds as much as 100 feet thick, and form 10 percent of the section near Big Basin. Like the Butano sandstone, therefore, the lower shale member is more massive, better sorted, and coarser grained toward the west and south.

The upper mudstone member of the San Lorenzo formation (photo 4) is predominantly massive, olive-gray mudstone, siltstone, and very fine-grained sandstone that weather to hues of red, brown, and orange. Spheroidal weathering of the mudstone and siltstone is a common feature and may be mistaken for distorted bedding. Lenticular carbonate concretions, some as much as 10 feet long, are common and are useful with fair reliability for determining the dip of the strata.

The lithology of the upper mudstone member within the southern part of the area mapped ranges from poorly sorted mudstone along the San Lorenzo River to moderately sorted sandy siltstone and very fine-grained sandstone near Kelly Creek in Big Basin. The upper mudstone member is, therefore, better sorted and coarser grained toward the west.

The basal bed of the upper mudstone member is rich in glauconite and phosphate; these minerals are also abundant 220 feet above the base of the member along the San Lorenzo River and 40 feet above the base along Little Boulder Creek. Fossils indicate that the lowest glauconite-phosphate bed is at the base of the Refugian stage and that the higher glauconite-phosphate bed is at the base of the Zemorrian stage. The fossils also indicate that Refugian strata thin progressively westward from 220 feet along the San Lorenzo River to 40 feet along Little Boulder Creek.

Stratigraphic Relations and Thickness. The lower shale member of the San Lorenzo formation grades downward into the Butano sandstone—the upper mudstone member grades upward into the Vaqueros sandstone or, in La Honda area, the Mindego formation. Both members are overlapped by the un-named member of the Monterey shale near the southwestern border of the area mapped and by the Purisima formation in the northwestern part.

Photo 4. Massive, sandy siltstone in upper member of San Lorenzo formation along Little Basin road.

The thickness of the San Lorenzo formation is difficult to determine accurately because the outcrops are discontinuous, the structure complicated, and the attitudes questionable. The best estimate is 1830 feet along Kings Creek, 1 mile east of the area mapped. Branner et al. (1909) reported a thickness of 2,400 feet for the type San Lorenzo formation, but this figure is probably too high. By utilizing the meager structural information available and the glauconite-phosphate beds as datum planes, a thickness of 1720 feet was obtained for the type San Lorenzo formation. A comparable thickness is estimated for the San Lorenzo formation along Coal Creek near the northern boundary of the area mapped, and it seems on the order of 3,000 feet thick along the Weeks Creek syncline and near La Honda. The lower shale member is 790 feet thick in Kings Creek, 750 feet thick along the San Lorenzo River near Riverside Grove, and 650 feet thick on the north flank of the Butano anticline along Little Boulder Creek. The upper mudstone member is 1030 feet thick along Kings Creek and 970 feet thick along the San Lorenzo River near Riverside Grove.

Fossils, Age, and Correlation. Mollusks are common in the type area of San Lorenzo formation. Arnold (1906 and 1908) described most of them and assigned them to the Oligocene. Nearly all of these fossils are from the upper mudstone member and most, if not all are probably from beds assigned by means of microfossils to the Zemorrian stage of Kleinpell (1938). Foraminifera are common in the lower shale member and include planktonic species and benthonic forms like *Amphimorphina jenkinsi*, *Bulimina sculptilis*, *B. microcostata*, and *Gyroidina condoni rotundiformis.* This fauna is correlative with the *Amphimorphina jenkinsi* zone of the Narizian stage of Mallory (1959). Planktonic species are rare in the upper mudstone member but benthonic foraminifers are common. The lower part of the upper mudstone member contains *Uvigerina cocoaensis*, *Planulina haydoni*, and all of the other characteristic Refugian stage microfossils listed by Schenck and Kleinpell (1936). The upper part of the upper mudstone member contains species referred to the Zemorrian stage by Kleinpell (1938, p. 111 and table 10). The San Lorenzo formation also contains *Miogypsina equadorensis* (Graham and Drooger, 1952), a species considered synonymous with *M. panamensis* and Oligocene in age by Cole (1957).

California formations correlative with the lower shale member of the San Lorenzo formation are shown diagrammatically by Mallory (1959, fig. 7, *Amphimorphina jenkinsi* zone). Kleinpell (1938, fig. 14) shows Refugian and Zemorrian strata correlative with the upper mudstone member.

Provenance and Depositional Environment. Shale, mudstone, and sandstone of the San Lorenzo formation were probably derived from the same source, Salinia, as the Butano and Vaqueros sandstones. Foraminifera in the lower shale member indicate that the environment of deposition in late Eocene (Narizian) time was lower bathyal or abyssal and essentially under open ocean conditions. In view of the fact that the basin received more than 9,000 feet of sediment, it must have been continually sinking. The early Oligocene (Refugian) part of the upper mudstone member was deposited in a bathyal environment as indicated by outcrops along the San Lorenzo River and its tributaries and Little Boulder Creek. The late Oligocene (Zemorrian) part was also deposited in a bathyal environment at these same localities and in the Mindego Hill and La Honda quadrangles; and in a neritic environment at Kelly Creek and other localities near Big Basin where pelecypods like *Panope*, *Solen*, *Dosinia*, *Macrocallista*, and *Pitar* are common in the beds.

VAQUEROS SANDSTONE

Introduction. The name "Vaquero" was originally applied by Hamlin (1904) to a thick sequence of clastic sedimentary rocks resting nonconformably on crystalline rocks and underlying the Monterey shale in the vicinity of Los Vaqueros Valley 80 miles southeast of the northern Santa Cruz Mountains. The term Vaqueros was soon applied to sandstone beds underlying so-called Monterey shale in the Santa Cruz Mountains by Haehl and Arnold (1904), Arnold (1906), and Branner et al. (1909). Unfortunately, sandstone beds referred to the Vaqueros by Branner and his associates range in age from Paleocene to late Miocene. Thorup (1941 and 1943) studied the Vaqueros at its type locality and divided beds previously called Vaqueros into five formations, restricting the name Vaqueros to the uppermost 2000 feet of sandstone containing "typical Vaqueros fossils". The term Vaqueros is restricted in this report to a mappable sandstone unit with lithology, fauna, and stratigraphic position similar to the formation in its type area as defined by Thorup (1943).

Vaqueros sandstone is distributed over a large part of the northern Santa Cruz Mountains. It is particularly well developed in the Big Basin and Mindego Hill quadrangles, but is absent over most of La Honda and San Gregorio quadrangles, where it grades laterally into the argillaceous rocks of the San Lorenzo formation.

Lithology. Vaqueros sandstone in this region is composed chiefly of fine- to medium-grained arkosic arenite interbedded with mudstone and shale. The arenite is light gray where fresh and very pale orange or "buff" where weathered. Mudstone and shale interbeds are olive and dark gray where fresh, and weather to various hues of red and brown. In general the lower part of the formation is distinctly bedded; beds of sandstone a few inches to many feet thick alternate with beds of mudstone and shale, as shown in photo 5. In contrast, the upper part of the formation is commonly massive or thick bedded and locally forms cavernously weathered escarpments such as those on the northeast side of Devils Canyon. Measured sections (McCollom, 1959) indicate that the total amount of mudstone and shale interbedded with Vaqueros sandstone increases to the east and north from the southern part of the Big Basin quadrangle.

Mechanical analyses of approximately 50 Vaqueros sandstone samples indicate that the Trask sorting index ranges from as low as 1.2 in sandstone with a median diameter from 62 to 125 microns to as high as 2.8 in sandstone with median diameters of 500 to 1,000 microns. Generally, therefore, the coarser the sandstone the poorer the sorting. This tendency is reversed in finer-grained beds, for siltstone and claystone in the Vaqueros range in sorting from 4.2 to 6.0. Petrographic examination shows that the sand grains are commonly angular and composed of about 60 percent quartz, 25 percent potash feldspar, 5 to 10 percent plagioclase, and 5 to 10 percent lithic fragments. As a rule the grains are poorly compacted and partially cemented with sparry calcite. Near the top of the formation in the Mindego Hill quadrangle, sandstone contains both epiclastic and pyroclastic grains of basalt derived from early eruptions of the volcanic rocks found in the overlying Mindego formation. In the Big Basin area cobbles and boulders of granitic rocks are present in the upper part of the formation. Glauconite is found throughout the sandstone beds but is particularly abundant in the basalt-rich beds. Heavy minerals in Va-

Photo 5. Medium- to thick-bedded Vaqueros sandstone along Highway 9. Dip is vertical. Top of beds is to the left.

queros sandstone have been studied by Beveridge (1960), who reported the following common varieties: zircon, apatite, garnet, ilmenite, leucoxene, epidote, sphene, and magnetite. As this suite is similar to that in the Butano sandstone, the use of heavy minerals in distinguishing the formations is limited.

Stratigraphic Relations and Thickness. Vaqueros sandstone grades laterally and vertically downward into the upper part of the San Lorenzo formation. The contact can be observed at many localities where it is crossed by creeks or roadcuts, such as along Skyline Boulevard in sec. 36, T. 7 S., R. 3 W. and on Highway 9 in sec. 13, T. 8 S., R. 3 W. The Vaqueros is overlain conformably by volcanic and sedimentary rocks of the Mindego formation.

The Vaqueros sandstone is approximately 2,400 feet thick in the vicinity of Saratoga Gap; it thins rapidly to the northwest; and is absent in the section east of Langley and Mindego Hills where Mindego formation rests directly on San Lorenzo formation. Burchfiel (1958) reports at least 4,500 feet of Vaqueros in the southwestern corner of the adjoining Castle Rock Ridge quadrangle.

Fossils. Molluscan fossils, although not abundant, have been collected from Vaqueros sandstone at many localities in the Santa Cruz Mountains. Some of these are indicated on the geologic map. Many of the fossils are fragmentary and randomly oriented in the sandstone, suggesting transportation after initial deposition. Typical species include: *Pecten (Lyropecten) magnolia, Ostrea vaquerosensis, Turritella inezana,* and *Pecten sanctaecruzensis.*

Foraminifera collected from mudstone beds in the Vaqueros include: *Bolivina alazanensis, Cassidulina crassipunctata, Siphogenerina nodifera, Uvigerina gallowayi* and *U. gesteri.*

Age and Correlation. The mollusks mentioned above were considered representative of the *Turritella inezana* zone by Loel and Corey (1932). Foraminifers in the Vaqueros sandstone belong to the Zemorrian stage of Kleinpell (1938), in most cases to the lower Zemorrian or *Uvigerina gallowayi* zone. Yet the position of the Zemorrian stage within the type Tertiary series of Europe is a matter of controversy. Schenck (1935), Kleinpell (1938, p. 181), and Schenck and Childs (1942) considered the Zemorrian stage as probably Oligocene; this dating is provisionally followed here.

Vaqueros sandstone in this area can be traced laterally into the upper part of the San Lorenzo formation in the vicinity of La Honda. The formation is also contemporaneous with at least the lower part of the type Vaqueros sandstone. Correlations with other Zemorrian formations in California are given by Kleinpell (1938, fig. 14), and Weaver et al. (1944).

Provenance. The arkosic character of the Vaqueros sandstone and the thinning and decrease in average grain size of the beds to the north and east suggest that the sand was derived chiefly from crystalline rocks to the southwest. Beveridge (1960) reports that the heavy minerals of the Vaqueros as well as those of the Butano sandstone are nearly identical to those of the Ben Lomond quartz diorite as described by Spotts (1958). Yet, large amounts of potash feldspar in Vaqueros sandstone were probably derived from potash-rich granitic rocks, such as those on the southwest flank of Ben Lomond Mountain.

Depositional Environment. Physical and paleontologic characteristics of the Vaqueros sandstone suggest that it was deposited on a northeastward-sloping surface that became progressively shallower during early Zemorrian time. Beds near the top of the formation are coarse grained and contain heavy-shelled mollusks considered to be indicators of a warm, upper neritic environment. However, where the formation grades laterally into argillaceous rocks, some sandstone may have been displaced into deep water by slumping and turbidity currents as indicated by sandstone with broken, shallow-water mollusks interbedded with mudstone bearing bathyal foraminifers.

MINDEGO FORMATION

Introduction. Mindego formation is the name given in this report to a complex stratigraphic sequence consisting chiefly of interstratified basaltic volcanic rocks, mudstone, sandstone, and carbonate rocks. The name is

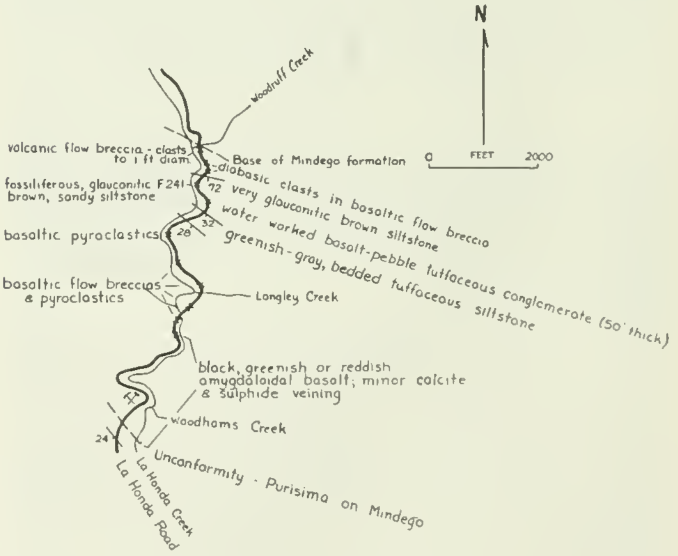
Photo 6. Basalt flow-breccia in Mindego formation near Skyline Blvd.

taken from Mindego Hill which is composed entirely of rocks of this formation and which is thought to have been a locus of eruption for the volcanic rocks. The Mindego formation includes igneous rocks described by Haehl and Arnold (1904) as well as sedimentary rocks mapped chiefly as Monterey shale by Branner et al. (1909). The type section (fig. 3) is along La Honda Creek between the mouth of Woodruff Creek, where the formation is underlain by San Lorenzo formation, and a locality 700 feet downstream from the mouth of Woodhams Creek where the Mindego formation is overlain by the Purisima formation. The formation is also well exposed (fig. 4) in Mindego Creek west and north of Mindego Hill. The Mindego formation crops out chiefly in the Mindego Hill quadrangle, but also in eastern La Honda and northern Big Basin quadrangles. A small area of Mindego formation is present in the San Gregorio quadrangle south of Pescadero and Butano Creeks.

Intrusive sills and small cross-cutting bodies of diabase are found within strata underlying the Mindego formation, principally in the vicinity of Skyline Boulevard in La Honda and Mindego Hill quadrangles. Although they are not included in the Mindego formation, the intrusive igneous rocks are discussed under this heading because of their apparent genetic relationship with Mindego volcanic rocks.

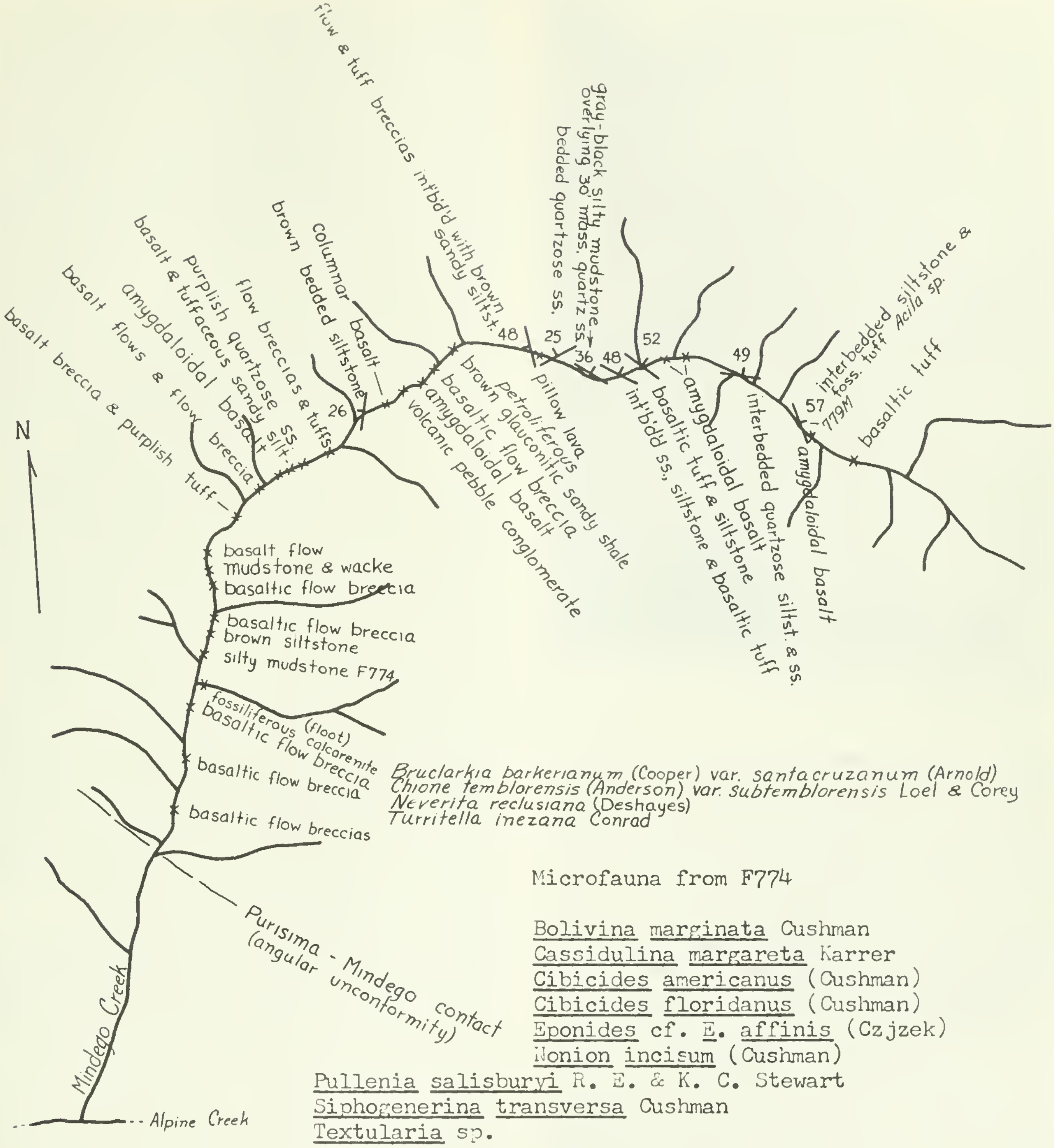
Volcanic Rocks. Basaltic submarine flow-breccia, pillow lava, and lithic tuff are the most characteristic rocks within the Mindego formation. Where fresh they are dark grayish-green to black, but are various shades of red and brown where weathered. The flow-breccia consists of angular fragments, several millimeters to several centimeters in diameter, made up of tiny crystals of plagioclase and pyroxene, and hydrated basic glass (palagonite) cemented with while crystalline calcite (photo 6). Pillow lava, with pillow structures 2 to 5 feet in diameter, is composed chiefly of fragmental, palagonitic glass. Waterlaid lithic tuff, found in the vicinity of Mindego and Langley Hills, is composed of angular to subrounded basaltic and palagonitic lapilli and ash in a carbonate matrix. Locally there are crystalline lava flows, apparently of subaerial origin. Many are massive, but others display vesicular and amygdaloidai structures and poorly developed columnar jointing. The amygdules are as much as 4 inches in diameter and are filled with calcite, quartz, chalcedony, analcite, or prehnite.

Intrusive Rocks. Sills and irregular dikes of diabase that intrude Mindego and older formations appear to be genetically related to basalts of the Mindego formation—many were probably feeders. Superficially they resemble some of the basalt flows but can be distinguished by baked contacts and generally glass-free textures. The diabase displays an intergranular to subophitic texture with grains of feldspar, pyroxene, and iron ore, 1 to 3 millimeters long. The rocks are holocrystalline except on their contacts, where glassy selvages have intersertal textures. Most diabase samples contain 65 percent plagioclase, outwardly zoned from labradorite to andesine and often rimmed with albite or orthoclase, 20 percent pyroxene (augite or titanaugite and pigeonite), 5 percent ilmenite, and 10 percent accessory and secondary minerals including apatite, olivine, biotite, quartz, and patches of isotropic analcite. Near their margins some of the intrusives



Microfauna from fossil locality F241
(by R. E. & K. C. Stewart)
Bolivina marginata Cushman
Buliminella curta Cushman (abundant)
Cyclammina cf. C. incisa (Stache)
Glandulina ? sp.
Gyroidinoides soldanii (Orbigny)
Nodogenerina sanctaecrucis Kleinpell
Nonion sp.
Planulina cushmani (Barbat & von Estorff)
Plectofrondicularia californica Cushman & R. . Stewart
Robulus sp.
Siphogenerina cf. S. kleinpelli Cushman
Uvigerinella obesa Cushman var. impolita Cushman & Laiming (abun.)

Figure 3. Type section of the Mindego formation, La Honda quadrangle, San Mateo County.



Microfauna from F774

Bolivina marginata Cushman
Cassidulina margareta Karrer
Cibicides americanus (Cushman)
Cibicides floridanus (Cushman)
Eponides cf. E. affinis (Czjzek)
Nonion incisum (Cushman)
Pullenia salisburyi R. E. & K. C. Stewart
Siphogenerina transversa Cushman
Textularia sp.
Uvigerinella obesa Cushman
Valvulineria cf. V. casitasensis Cushman & Laiming

Figure 4. Mindego Creek section of the Mindego formation, Mindego Hill quadrangle. Scale approximately 1 inch equals 2,000 feet.

Photo 7. Contorted contact between diabase sill (on left) and San Lorenzo formation along La Honda Road.

are altered to cloudy albite, epidote, sericite, chlorite, and leucoxene. The albitization apparently took place during the intrusion of the diabase into sediments saturated with connate waters. Contact metamorphism of strata intruded by the diabase is limited to a zone several inches to several feet in width that has been hardened and discolored by incipient recrystallization (photo 7).

Sedimentary Rocks. Sedimentary rocks are interstratified with volcanic rocks in the type section of the Mindego formation and make up one-third to one-half of the sequence in that locality. Elsewhere, volcanic rocks are less abundant and the formation consists largely of sedimentary strata. These are chiefly dark brown mudstone and shale, sandstone, conglomerate, and carbonate rocks.

Most of the mudstone and shale is dark brown, calcareous, and hard where fresh, but at some weathered outcrops the shale is light colored, soft, and platy and resembles Woodhams shale. These rocks commonly contain 30 to 40 percent silt-sized grains of quartz, feldspar, and accessory minerals set in a matrix of highly birefringent brown clay, iron oxides, carbonaceous material, carbonates, and collophane. Glauconite is present in many samples and at a few localities is found as "greensand" beds several inches to several feet thick.

Sandstone in the lower part of the Mindego formation is similar to Vaqueros sandstone. It is generally a medium- to coarse-grained, calcareous, arkosic arenite, containing molluscan fossils of the *Turritella inezana* zone and considerable basaltic detritus. Locally, as in Mindego Creek and along the coast near the mouth of Pescadero Creek, the sandstone is interbedded with coarse-grained sedimentary breccia and conglomerate composed chiefly of basaltic rocks. Stratigraphically higher in the Mindego formation the sandstone beds are mostly clay-rich, feldspathic wacke displaying graded bedding and structure suggestive of deposition in deep water by slumping and turbidity currents.

Thin beds and lenses of carbonate rock within the Mindego formation crop out at several localities. Some of these are calcarenites overlying volcanic strata. Many are bioclastic in origin and consist largely of fragments of small pelecypods and bryozoa. For example, along Waterman Creek in sec. 15, T. 8 S., R. 3 W., one of these limestone lenses is more than 1,000 feet long and nearly 100 feet thick and is composed chiefly of broken and compacted oyster shells. Other limestones occur near the summits of Mindego and Langley Hills and in San Gregorio Creek in the vicinity of Redwood Terrace. These limestones were referred to the Eocene by Branner et al. (1909) on the basis of a few molluscan fossils collected from the outcrop in Waterman Creek. These authors evidently believed that Eocene limestone lay at depth below this area and that the outcrops represented blocks torn loose and rafted to their present position by the intruding diabase. However, further study has shown that (1) The fossiliferous carbonate rocks are only within extrusive rocks; (2) the lenses and beds are parallel to the stratification of the enclosing lava flows; (3) the limestone has undergone little or no alteration; (4) tuffaceous debris frequently is present in the carbonates; and (5) microfossils from the limestone are Oligocene (Zemorrian) in age, the same age as the associated volcanic rocks. Therefore the limestone probably represents the accumulation of organic and chemical calcareous material on shallow banks formed by the volcanic rocks.

Within the argillaceous sections of the formation are nodules and beds of brown dolomite as much as several feet thick. They weather to a characteristic yellowish-brown color and project from outcrop surfaces owing to their resistance to erosion. Microscopically the rocks consist of a fine mosaic of anhedral dolomite and siderite (?) with scattered foraminifers and clastic grains.

Stratigraphic Relations. The distribution of rock units within the Mindego formation is complex and beyond the scope of this report to delineate, but further work may allow the division of the formation into several mappable members. In the vicinity of Mindego Hill the formation consists chiefly of volcanic rocks with interbeds of sedimentary rocks. The volume of volcanic rocks decreases in all directions away from Mindego Hill and the amount of sedimentary rocks increases so that in some localities only a small portion of the formation is volcanic in character. Where volcanic rocks are only a minor part of the sequence, as along Highway 9 southwest of Saratoga Gap, the Mindego formation is essentially a mudstone and shale unit conformably underlain by Vaqueros sandstone.

At most localities the Mindego formation rests conformably on Vaqueros sandstone. Where the Vaqueros is too thin to be mapped or is missing, such as in the Langley Hill area, the Mindego formation rests conformably on the Zemorrian (Oligocene) part of the San Lorenzo formation. Along La Honda Creek, 2 miles west of Langley Hill, however, Mindego formation appears to rest unconformably on the Narizian (Eocene) part of the San Lorenzo formation. This unconformity probably extended in a westerly direction to the area south of the mouth of Pescadero Creek, where Mindego formation rests unconformably on the Pigeon Point formation.

The Mindego formation is unconformably overlain by both the Woodhams shale member of the Monterey formation and the basal sandy Tahana member of the Purisima formation (photo 14).

Thickness. The original thickness of the Mindego formation cannot be determined because of the erosional unconformity at the top of the formation. In the type section, the formation is 2,000 feet thick. In the vicinity of Langley and Mindego Hills, it is on the order of 4,000 feet thick. To the southeast of Mindego Hill, in Slate and Oil Creeks, the Mindego formation is on the order of 2,000 feet in thickness.

Fossils. A number of fossil localities within the Mindego formation are shown on the accompanying geologic map. At a few localities megafossils are found in calcareous sandstone interstratified with volcanic rocks and are usually species which are also found in Vaqueros sandstone. These include *Pecten* (*Lyropecten*) *magnolia*, *Turritella inezana*, *Chione temblorensis subtemblorensis*, and *Ostrea vaquerosensis*. Foraminifera are more abundant and are chiefly in the mudstone. Beds in the lower part of the formation contain lower Zemorrian species such as *Bolivina alazanensis*, *Siphogenerina nodifera*, and *Uvigerina gesteri*. Strata higher in the section yield upper Zemorrian species like *Bulimina carnerosensis mahoneyi* and *Siphogenerina pseudococoaensis*, whereas beds near the top of the formation contain lower Saucesian species such as *Bolivina marginata adelaidana* and *Siphogenerina transversa*.

Age and Correlation. The fossils listed in the preceding section indicate that the Mindego formation ranges in age from lower Zemorrian to lower Saucesian. It thus belongs either entirely in the Oligocene series or is transitional between the Oligocene and lower Miocene, depending on the ultimate correlation of the Saucesian stage with the European Tertiary stages, a problem beyond the scope of this report.

Cummings (1960) mapped sedimentary rocks in the Mindego formation as parts of the Vaqueros and Sandholdt formations with intercalated volcanic rocks, but that procedure resulted in details too complex for inclusion in this report. However, sandstone in the Mindego formation that crops out in Peters Creek can be traced southeastward along Long Ridge into sandstone mapped as Vaqueros. Mindego formation is also correlative with the Vaqueros and lower Sandholdt formations at their type areas in the Santa Lucia Mountains.

Locally, the Mindego formation is correlative with strata in the Año Nuevo quadrangle referred to the "Vaqueros? formation" by Hall et al. (1959, fig. 2), inasmuch as S. A. Brooks reports (personal communication) that these shales contain Foraminifera of late Zemorrian age. It is also correlative with a "sand dollar reef" mapped by Page and Holmes (1945) in the Santa Cruz quadrangle, 9 miles south of the area mapped in this report. An echinoid recently collected at that locality (LSJU 3413) was identified by J. Wyatt Durham as *Vaquerosella* cf. *V. coreyi*, indicating that the beds there are probably Saucesian in age.

The Mindego formation is correlative and similar in lithology to basalts and sedimentary strata east of the San Andreas fault in the Palo Alto quadrangle that were reluctantly and incorrectly referred to the Purisima formation by Branner et al. (1909). According to Atchley and Dobbs (1960) and an unpublished map by Thomas (1949), sandstone, shale, and tuffaceous rocks interbedded with the basalt contain *Turritella ocoyana*, *Valvulineria californica* and a "typical Temblor fauna". This fauna suggests a Saucesian age. Shale within this "Middle Miocene unit" mapped by Thomas may also be late Zemorrian in age, to judge from Foraminifera recently collected along Moody Road, 2,000 feet southwest of its intersection with Elizabeth Avenue, Mindego Hill quadrangle.

Depositional Environment. Volcanic rocks of the Mindego formation erupted from submarine vents, apparently in the vicinity of what are now Langley and Mindego Hills, where the volcanics are most voluminous and many cross-cutting "feeders" are found. Initial accumulation was on a neritic sea floor. Subaerial lava flows formed on a periodically emergent volcanic island and fossiliferous sandstone and limestone collected on the banks of shoals surrounding that evanescent island. Continued volcanism was accompanied by subsidence of the sea floor to sufficient depth to allow the deposition of mudstone and shale containing bathyal Foraminifera.

MONTEREY FORMATION

Un-named Member of Monterey Formation

Introduction. The Monterey shale was first described by Blake (1856, p. 328-331), who gave the name to a series of light-colored, diatomaceous and siliceous shale and sandstone beds exposed near Monterey, California, 45 miles south of the area mapped in this report. The formation in the type area has been assigned to the Luisian, Mohnian, and Delmontian stages (Kleinpell, 1938, fig. 14). In the Santa Cruz Mountains, Branner et al. (1909) applied the name to brown chert, mudstone, and shale which were believed to be of Miocene age.

Subsequent investigations have indicated that the term was used erroneously when applied to mudstone and shale of Eocene and Oligocene age more properly assigned to the San Lorenzo and Mindego formations. In addition, the Monterey shale of Branner and his associates includes two siliceous units of Miocene age. The lower one is a complexly folded siliceous shale of middle Miocene age here differentiated and named the Woodhams shale member. The upper one is a more gently folded siliceous mudstone which crops out only in the western part of the mapped area. In this study the unnamed member of the Monterey formation is restricted to the younger siliceous beds and the thin basal sandstone below them (mapped as Vaqueros sandstone by Branner et al., 1909).

Woodhams Shale Member

Introduction. The Woodhams shale member is named for exposures in the vicinity of Woodhams Creek. The type section extends from outcrops near the end of the road in the NE¼ sec. 13, T. 7 S., R. 4 W., 0.87 of a mile S. 56° W. from the crest of Langley Hill, at which place the basal glauconitic siltstone rests unconformably on basalt of the Mindego formation, to the locality along Woodhams Creek near La Honda where the Woodhams shale member is overlain unconformably by the Purisima formation. The type area, as defined here, includes the Woodhams Creek area and the area between Alpine and Slate Creeks where thicker, better exposed, but more structurally complicated sections of the Woodhams shale member are found. The characteristic lithology of the member in the latter area is best observed along Peters Creek and the road to Portola State Park.

Lithology. The Woodhams shale member consists chiefly of porcellaneous shale, siliceous mudstone, impure diatomite, and opaline chert, with minor amounts of siltstone and arkosic sandstone near its base. The porcellaneous shale (photo 8) is remarkably fissile and can be separated into almost paper-thin sheets. The fresh rock is dark brown, but weathered surfaces are very pale orange or almost white. The weathered shale, leached of alkalies and calcite, is light in weight and "punky". Petrographic examination of the shale shows that it is composed of light-brown, isotropic, opaline silica, calcite, and highly birefringent brown clay. The clay particles are oriented with their long dimensions parallel to the bedding planes and account for the lamination and fissility of the shale. A few angular silt-sized grains of quartz, feldspar, and mica, as well as rounded, sand-sized grains of glauconite and collophane, are scattered throughout the shale. Foraminifera, diatoms, and brown organic material are also common. In some localities, as along the road to Portola State Park, the member consists of massive, siliceous mudstone and impure diatomite. The fresh rocks are grayish brown, but weathered outcrops are very pale orange and commonly broken by poorly developed rectangular joints. Opaline chert is in thin beds up to several inches thick at some localities, such as along Alpine and Waterman Creeks. The fresh chert is dark brown, but weathered surfaces are commonly white and chalky.

Near the base of the member the fine-grained rocks grade downward into siltstone and sandstone. In the type section, only a thin glauconitic siltstone containing basalt detritus separates the siliceous shale from underlying basalt of the Mindego formation. Near the town of Boulder Creek in the Big Basin quadrangle, however, the siliceous shale grades downward into as much as 200 feet of medium-grained, arkosic sandstone that rests on quartz diorite.

Stratigraphic Relations and Thickness. The Woodhams shale member rests unconformably on the Mindego formation and older rocks. At the base of the type section it rests disconformably on basalt of the Mindego formation. This disconformable relationship is shown in Slate Creek, 2,000 feet downstream from the Page Mill site, where Woodhams porcellaneous shale member with foraminifers of Relizian age rests on mudstone of the Mindego formation that contains foraminifers of Zemorrian age. At the base of the Woodhams shale member there is a 3-foot-thick bed of conglomerate that consists of elongated pebbles of mudstone, similar to mudstone in the underlying Mindego formation, in a siliceous, silty matrix. In the Big Basin quadrangle the Woodhams shale member rests unconformably on Butano sandstone and quartz diorite.

Over most of the area in which the member is exposed an upper contact is missing, owing to erosion. However, the Woodhams shale member is thought to be overlain

Photo 8. Woodhams shale member of the Monterey formation. Thinly laminated siliceous shale on hilltop in sec. 3, T. 8 S., R. 3 W.

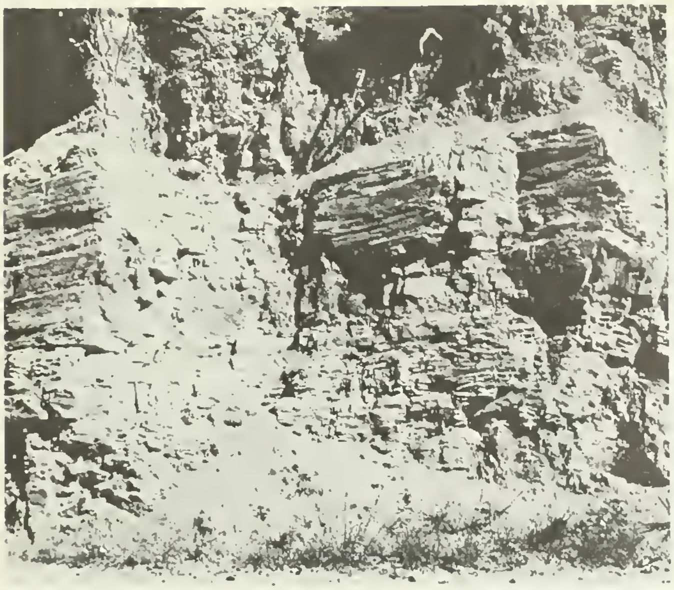


Photo 9. Thin-bedded siliceous mudstone and siltstone of the unnamed member of the Monterey formation along Pescadero Road, southwestern La Honda quadrangle.

unconformably by an un-named member of the Monterey formation in the subsurface sections explored for oil south of La Honda (cross-section B-B′). That it was also overlain unconformably in the southern part of the Big Basin quadrangle is suggested by the erosional remnants of the un-named member of the Monterey shale in that area. At the top of the type section along Woodhams Creek, and at the top of the sections exposed along Alpine and Peters Creeks, the Woodhams shale is unconformably overlain by the lower Tahana member of the Purisima formation.

The thickness of the Woodhams shale member that has been preserved between its unconformable contacts ranges from 500 feet along Woodhams Creek to possibly 1,500 feet along Peters Creek.

Fossils, Age, and Correlation. The only molluscan fossils found in the Woodhams shale member are a few thin-shelled *Pecten (Delectopecten) peckhami.* On the other hand, microfossils are abundant, occasionally making up 50 percent or more of Woodhams strata. The impure diatomite consists chiefly of broken frustules of diatoms of the genus *Coscinodiscus.* Most foraminifers in the Woodhams shale member are representative of the *Siphogenerina branneri* zone (Upper Relizian stage) and include *Siphogenerina branneri*, *Anomalina salinasensis*, and *Buliminella henryana.* Other assemblages are more characteristic of the Luisian stage and include *Bolivina advena ornata*, *Rodulus miocenicus*, *Valvulineria ornata*, and *V. miocenica.* These foraminifers indicate a middle Miocene age for the Woodhams shale member. The member is thus correlative to the upper part of the type Sandholdt formation in Reliz Canyon and to part of the Monterey shale at its type area. It is also correlative with siliceous shale exposed about half a mile southwest of Los Altos Country Club in the Palo Alto-Los Altos area. This shale, previously referred to the Purisima formation by Branner et al. (1909), contains *Siphogenerina branneri* and other foraminifers of Relizian age. Correlation with other formations of Relizian and Luisian age is given by Kleinpell (1938) and Weaver et al. (1944).

Depositional Environment. Diatoms in much of the Woodhams shale member suggest that opaline silica in these rocks was derived from diatoms and other siliceous organisms and redistributed during diagenesis, as described by Bramlette (1946). The organic siliceous debris must have accumulated where clastic sedimentation was slow, perhaps, according to Bramlette, because of an arid climate, interior drainage, and low relief in the adjoining land mass. The foraminifers in the Woodhams shale member suggest that the site of deposition was an upper bathyal open-sea environment.

Lithology. The un-named member of the Monterey formation consists principally of alternating beds of siliceous and diatomaceous mudstone, and sandy siltstone or very fine-grained sandstone. The siliceous mudstone is pale yellowish brown to grayish brown on fresh surfaces, and white, very pale orange, and light brown where weathered. Beds range in thickness from a fraction of an inch to as much as 6 inches and are, for the most part, uniform and continuous. In many localities the un-named member is a true claystone, but more often it contains tiny grains of quartz, feldspar, and mica, as well as fragments of volcanic tuff. Diatoms are locally present, and with an increasing content of these organisms the siliceous mudstone grades to a chalky impure diatomite. With an increase of opaline silica the mudstone grades to porcellanite, becomes brittle, and exhibits

Photo 10. The Chalks in western Big Basin. Weathered shale of the unnamed member of the Monterey formation appears white and forms conspicuous outcrops on ridges.

Photo 11. White rhyolitic tuff and very fine-grained greenish-gray lithic arenite of the Tohana member of the Purisima formation north of the mouth of San Gregorio Creek. Unconformably overlying the Tohana member are Quaternary sand and gravel of the marine terrace.

a conchoidal fracture. The weathered rock has a relatively low specific gravity due to a myriad of microscopic pores.

The sandy siltstone is pale yellowish brown to brownish gray and commonly contains scattered small grains of mica and glauconite. Individual siltstone beds range from a fraction of an inch to nearly 6 inches in thickness; some of the coarser beds, properly called very fine-grained sandstone, are very finely cross-bedded. Oblate spheroidal concretions with diameters up to 4 feet are present locally.

At the base of the member there is a light-gray to greenish-gray, coarse-grained, feldspathic sandstone that is typically glauconitic. In the southern part of La Honda quadrangle this basal sandstone is 5 feet thick, but near Big Basin the sandstone thickens to nearly 200 feet, and contains bitumen. It is not mapped separately here.

Stratigraphic Relations and Thickness. The un-named member of the Monterey formation unconformably overlies the quartz-diorite, Locatelli, Butano, San Lorenzo, and Vaqueros formations. Remnants of the formation on Ben Lomond Mountain suggest that it once rested unconformably on the Woodhams shale member and was removed during subsequent erosion. The un-named member is conformably overlain by the Purisima formation. This contact is well exposed in Pescadero Creek west of Memorial Park.

The thickness of the un-named member is variable. On Ben Lomond and Pine Mountains in the Big Basin quadrangle it is only a few hundred feet thick. On the other hand, a test well drilled by The Texas Company near Santa Cruz penetrated 9,000 feet of siliceous mudstone and a basal sandstone that rest on a granitic basement. The evidence suggests that the un-named member thickens rapidly west of Ben Lomond Mountain and that the thickening continues northward into La Honda and San Gregorio quadrangles.

Fossils, Age, and Correlation. Fish remains, Radiolaria, and diatoms are common in the un-named member of the Monterey formation, but foraminifers are scarce and not diagnostic. *Delectopecten lompocensis* collected by R. Fiske in the SW¼ sec. 8, T. 8 S., R. 4 W. from beds about 1,000 feet stratigraphically above the base of the formation is the only known mollusk from the formation.

The un-named member in the northern Santa Cruz Mountains is believed to be of late Miocene or possibly early Pliocene age. Stratigraphic relationships show that the unit is probably younger than the Luisian stage and older than the basal, early Pliocene part of the Purisima formation. It may be Delmontian, inasmuch as it is similar lithologically to Member 1 of the type Monterey shale of Galliher (1931), which is referred to the Delmontian stage by Kleinpell (1938, p. 131).

The un-named member of the Monterey formation is probably correlative with siliceous and diatomaceous shale exposed near the intersection of Arastradero and Page Mill Roads in the Palo Alto area. This shale (referred to the Purisima formation by Branner et al. (1909)), contains *Virgulina subplana* and other foraminifers suggestive of a Delmontian age. Correlation with other formations of Delmontian age is shown by Kleinpell (1938, fig. 14).

PURISIMA FORMATION

Introduction. Haehl and Arnold (1904, p. 22) gave the name Purisima formation to "an extensive series of conglomerates, fine-grained sandstones and shales," which the authors said were typically developed in the vicinity of Purisima Creek in what is now the Half Moon Bay quadrangle. The upper limit of the Purisima formation was defined as the base of the Merced formation of Lawson (1893b) although the two formations are never in contact, except perhaps at Point Año Nuevo where the beds overlying the Purisima have been mapped as Merced (Branner et al., 1909). Arnold's distinction between the Merced and Purisima was based on paleontologic rather than lithologic evidence; recent investigations show that most rocks mapped as Merced away from the type area are more properly assigned to the Purisima formation (Hall, et al., 1959, p. 2857; Glen, 1959, p. 164).

The first geologic map showing the distribution of the Purisima formation in the Santa Cruz Mountains was the Santa Cruz folio (Branner et al., 1909), and except for a few minor revisions that distribution is accepted in this report. The formation is exposed in a nearly triangular area from the coastal towns of Half Moon Bay and Pescadero to an apex near the headwaters of Pescadero Creek. The Purisima formation also occurs on the west side of the San Gregorio fault from the San Gregorio quadrangle southward to Año Nuevo Bay, and between the Pilarcitos and San Andreas faults in the Mindego Hill quadrangle.

Nearly continuous exposures of the Purisima formation are in the sea cliffs from Pescadero Creek to a point about 4½ miles north of the San Gregorio quadrangle. There are extensive outcrops in Pescadero Creek near the east edge of La Honda quadrangle, but in most other areas exposures are discontinuous.

The Purisima formation can be divided into five members which from youngest to oldest are:

Tunitas sandstone member
Lobitos mudstone member
San Gregorio sandstone member
Pomponio mudstone and siltstone member
Tahana sandstone and siltstone member

Broadly speaking, the Tunitas, Lobitos, and San Gregorio members represent the upper sandstone of Branner et al. (1909, p. 5); the Pomponio member is equivalent to the middle diatomaceous shale; and the Tahana member is equivalent to the lower standstone.

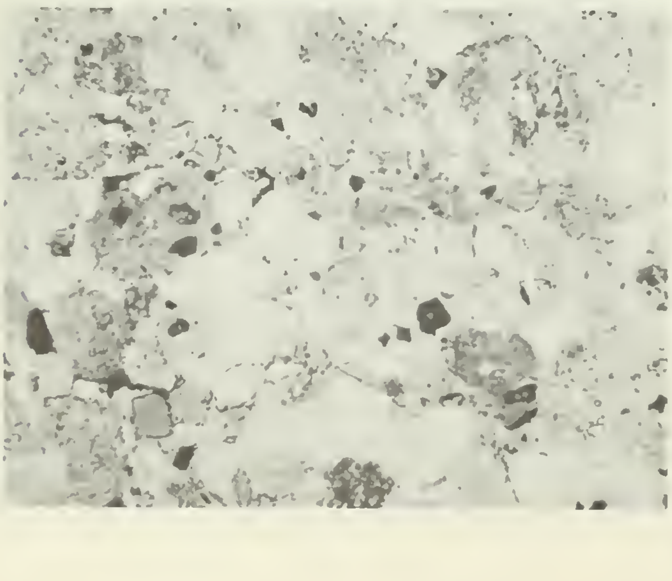
Tahana Member

Introduction. The name Tahana member is given in this report to 2,150 feet of sandstone and siltstone particularly well exposed on the south flank of the Pescadero syncline in San Gregorio, La Honda, and Mindego Hill quadrangles. The name of the member is taken from Tahana Gulch in sec. 26, T. 7 S., R. 5 W., but the type section is in sect. 36 about 1½ miles to the southeast, where contacts with the underlying Monterey shale and the overlying Pomponio member are present. Unfortunately, the type section is poorly exposed and therefore two supplementary sections are designated. The lower part of the member is exposed in Pescadero Creek and an unnamed southward-flowing tributary near the center of sec. 34, T. 7 S., R. 4 W., and the upper part of the member is well exposed between the mouths of Pomponio and Pescadero Creeks in the San Gregorio quadrangle (pl. 22).

Lithology. Most of the Tahana member is composed of medium-grained to very fine-grained sandstone and siltstone. Dark-gray silty mudstone is fairly common in the Pescadero Creek section and would undoubtedly be more common elsewhere if exposures were better. Beds of white rhyolitic tuff up to 8 feet in thickness was prominent in the sea cliffs near the mouth of San Gregorio Creek (photo 11). Pebbly conglomerate beds are near the base of the member from the vicinity of Memorial Park eastward.

Most Tahana sandstone is greenish gray to dark greenish gray, fine grained, friable, massive, poorly bedded or locally crossbedded. Most detrital grains consist of plagioclase feldspar (principally andesine) and volcanic rock fragments that are commonly of andesitic and less frequently of basaltic composition. Quartz is usually present but rarely predominant. Cuspate shards of volcanic glass and clasts of light-gray pumice are common and locally present to the exclusion of all other detritus. The glassy material is colorless to light brown and isotropic, and has an index of refraction of 1.50 to 1.54. Glauconite is abundant in some sandstone beds near the base of the member. Heavy minerals may constitute as much as 13 percent of some sandstone beds; green hornblende, reddish-brown basaltic hornblende, enstatite, hypersthene, biotite, and glaucophane are commonly found. Calcite and/or chlorite often completely fills intragranular interstices as a secondary cement. The detrital grains are angular but well sorted and much of the sandstone is properly called volcanic arenite.

Photo 12. Photomicrograph of "blue" sandstone in Tahana member of Purisima formation along Towne fire trail. Angular grains of quartz, plagioclase, andesite, green and brown hornblende, and hypersthene in a matrix of nontronite? and chlorite.



In the Mindego Hill quadrangle the Tahana member contains "blue" sandstone beds similar to those in the Etchegoin, Jacalitos, and Neroly formations. This sandstone is very friable and has a bluish-gray color. Approximately one-half of the detrital material consists of angular to rounded grains of pilotaxitic hypersthene andesite and glassy volcanic detritus. About 15 percent of the grains are plagioclase feldspar and less than 10 percent are quartz. The sand grains are loosely bound together with a matrix of highly birefringent yellow clay which appears to be an iron-rich montmorillonite (nontronite) and yellow-green, weakly birefringent chlorite (photo 12). Because volcanic constituents are abundant in the sandstone, it is inferred that the clay content is an alteration product of an original tuffaceous matrix.

Tahana sandstone east of the Pilarcitos fault in the northern part of the Mindego Hill quadrangle is somewhat anomalous when compared to that farther west. Here quartz is more common, chert is a noticeable constituent, and there are only scattered volcanic clasts. This sandstone is normally cemented with calcite, which is in large poikilitic patches.

In the sea-cliff section, Tahana sandstone contains interbedded concretionary lenses that are resistant to weathering and contain abundant megafossils. Tahana sandstone near the base of the member is locally micaceous and carbonaceous along Pescadero Creek.

Siltstone in the Tahana member is equally as abundant as sandstone in some sections. Dark greenish-gray on fresh surfaces, it weathers to dark yellowish-orange and light brown, commonly with yellow jarosite along fracture planes in beds where glauconite is abundant. At most localities the siltstone appears massive, but in well-exposed sea cliff sections scour-and-fill structures are common. These structures average 3 to 4 inches in length and width, and three-quarters of an inch in depth, and are filled with very fine-grained, well-sorted sand. Mineralogy of the siltstone is similar to that of the Tahana sandstone.

The Tahana member also contains beds of mudstone and claystone. These are dark gray, massive, micaceous, and contain tiny grains of glauconite, glass shards, and other clastic grains similar to those in Tahana siltstone, as well as abundant clay minerals. These fine-grained beds in the upper part of the Tahana member grade laterally eastward into impure diatomites, such as those exposed on Pescadero Road in the vicinity of the San Francisco Y.M.C.A. Camp.

Near the top of the Tahana member there are several prominent beds of white, rhyolitic tuff. The thickest bed

Photo 13. Conformable contact between Monterey shale (left) and lithic arenite and siltstone of the Tahana member of the Purisima formation (right). Beds dip steeply north along Pescadero Creek in La Honda quadrangle.

is exposed at the mouth of San Gregorio Creek on the north bank (photo 11). Hutton (1952, p. 96) reports that it consists principally of finely comminuted rhyolitic glass with an average index of refraction of 1.500. The tuff beds also contain very minute grains of plagioclase, green hornblende, and basaltic hornblende. Some tuffaceous sandstone beds above the principal white tuff bed at the mouth of San Gregorio Creek contain rounded pebbles and cobbles of light gray pumice up to 6 inches in diameter.

Along Pescadero Creek from the vicinity of Memorial Park eastward, there are several beds of sandy conglomerate and pebbly sandstone about 1,000 feet above the base of the Tahana member. The pebbles are sub-rounded and about 1 inch in maximum diameter. They are composed of vari-colored chert, white quartz, and dark-gray basalt and were deposited in a clean sandy matrix containing neritic megafossils. This conglomeratic section is approximately 100 feet thick and is the most significant conglomerate bed in the Tahana member. There is also a thin basal conglomerate (less than 1 foot thick) which is found locally where the Tahana member unconformably overlies basalt flows of the Mindego formation. This discontinuous basal conglomerate consists chiefly of basaltic pebbles and is locally derived.

Photo 14. Glauconitic siltstone and mudstone of Tahana member of Purisima formation dipping southwest along La Honda Road north of La Honda. Massive darker rocks (right) are basalt flows and flow-breccia of the Mindego formation. The contact is conformable.

Localities of Purisima formation fossils illustrated in photos 15, 16, 17, and 19.

Number	Quadrangle	Location
467-7	San Gregorio	Sea cliff 700′ S of mouth of Pomponio Creek
469-3	San Gregorio	Sea cliff 2700′ N of mouth of Pomponio Creek
469-5	San Gregorio	Sea cliff 1900′ N of mouth of Pomponio Creek
470-1	San Gregorio	Sea cliff 3550′ N of mouth of Pomponio Creek
470-2	San Gregorio	Sea cliff 4250′ N of mouth of Pomponio Creek
482-3	San Gregorio	Sea cliff 4000′ S of mouth of Tunitas Creek
631	Half Moon Bay	In Purisima Creek 1950′ E and 400′ S of SW corner of sec. 16, T. 6 S., R. 5 W.
633	Half Moon Bay	In Purisima Creek 2200′ E and 700′ S of SW corner of sec. 16, T. 6 S., R. 5 W.
634	Half Moon Bay	In Purisima Creek—200′ above last
639	Half Moon Bay	In Lobitos Creek 900′ ENE of State Hwy. 1 crossing
645-1	Half Moon Bay	Sea cliff at mouth of Purisima Creek
645-3	Half Moon Bay	Sea cliff 1150′ N of mouth of Purisima Creek
653	Woodside	Tunitas Creek 600′ N and 250′ E of SW corner of quadrangle
657	Woodside	Tunitas Rd. 1000′ N of S edge of quadrangle
672	San Gregorio	San Gregorio Rd. 250′ W of E edge of quadrangle
685-3	Half Moon Bay	Sea cliff 3000′ S of mouth of Arroyo Cañada Verde
692	Half Moon Bay	Sea cliff 500′ N of mouth of Lobitos Creek
696	Half Moon Bay	Sea cliff 2900′ S of mouth of Purisima Creek
700-1	Half Moon Bay	Sea cliff 3250′ N of mouth of Purisima Creek
701	Half Moon Bay	Sea cliff 1850′ N of mouth of Purisima Creek
711	La Honda	San Gregorio Rd. 1900′ E and 550′ N of SW corner of sec. 18, T. 7 S., R. 4 W.
726	La Honda	El Corte de Madera Creek 7300′ N of San Gregorio Rd. crossing

Stratigraphic Relations and Thickness. The Tahana member of the Purisima formation conformably overlies the unnamed member of the Monterey formation in the southern part of La Honda quadrangle. The contact is well exposed in Pescadero Creek in the SW¼ Sec. 33, T. 7 S., R. 4 W. (photo 13). One and one-half miles east of this locality the Tahana member overlaps the unnamed member of the Monterey formation, resting unconformably on the Woodhams shale member of the Monterey formation and the Mindego and San Lorenzo formations (photo 14). The Tahana member is conformably overlain by the Pomponio member of the Purisima formation.

In the west-central part of La Honda quadrangle, the maximum thickness of the Tahana member is 2,150 feet. The member thins to the east and to the north. Part of the thinning may be due to a change of facies from diatomaceous mudstone to siliceous mudstone with the siliceous mudstone having been mapped with the overlying Pomponio member.

Fossils. Microfossils and megafossils of many different types are common in the Tahana member. Foraminifera, sponge spicules, fish fragments, echinoid spines, diatoms, and ostracods are all found in the finer-grained sediments of the member. Microfossils collected from the sea cliff section south of Pomponio Creek are listed on plate 22. Megafossils include echinoderms, barnacles, mollusks, and marine vertebrate bones. Most are listed on plate 24, and several are illustrated on photo 15. A few leaves and abundant carbonaceous fragments are present in sandstone beds near the base of the member. Goodwin and Thomson (1954) did not study any Purisima sediments which belong to the Tahana member.

Photo 15 (opposite). Megafossils from the Tahana member of the Purisima formation. (Figures natural size unless otherwise noted).

No. 1. *Pecten (Patinopecten) Purisimaensis* Arnold
Right valve; .64 times natural size;
Locality No. 469-5M; San Gregorio quadrangle

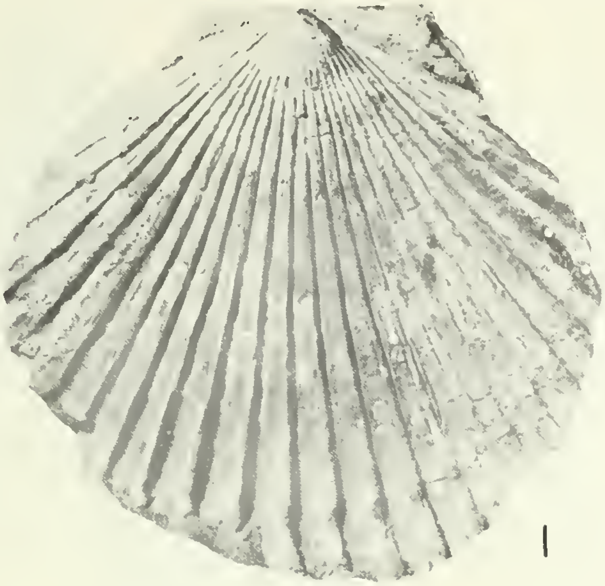
No. 2. *Chlamys parmeleei* (Dall)
Left valve; .95 times natural size;
Locality No. F467-7M; San Gregorio quadrangle

No. 3. *Macoma brota* Dall var. *lipara* Dall
Left valve;
Locality No. 470-1M; San Gregorio quadrangle

No. 4. *Pecten (Patinopecten) healeyi* Arnold
Right valve; .70 times natural size;
Locality No. 470-2M; San Gregorio quadrangle

No. 5. *Aletes aquamigerus* Carpenter?
Locality No. F467-7M; San Gregorio quadrangle

No. 6. *Modiolus directus* Dall
Right valve, nearly complete; .72 times natural size;
Locality No. 469-3M; San Gregorio quadrangle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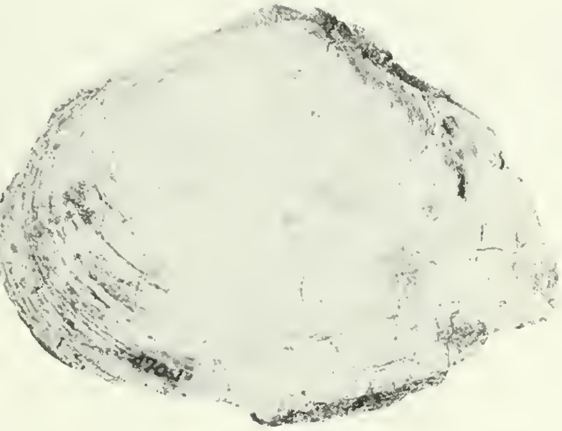
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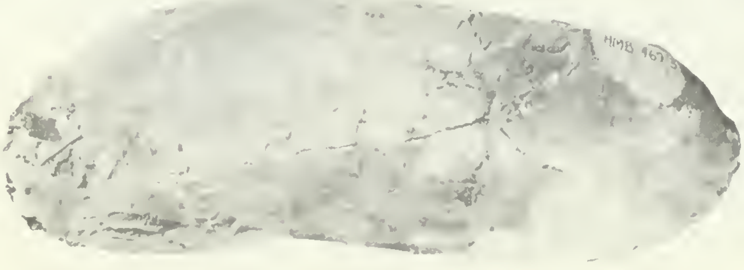
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Pomponio Member

Introduction. The name Pomponio member of the Purisima formation is herein given to a sequence of siliceous siltstone and mudstone typically exposed on both sides of Pomponio Creek for about 2 miles east of the San Gregorio fault. The thickness of the member in this type section is approximately 2,300 feet. A supplementary but less complete section is fairly well exposed on the south side of a hill (elevation, 830 feet) in the E ½ sec. 22, T. 7 S., R. 5 W.

Lithology. In the type area the Pomponio member consists of alternating beds of soft mudstone and hard silicified mudstone, siltstone, and porcellanite, but the siliceous beds form the greater percentage of strata. The siliceous beds are medium gray on unweathered surfaces; weathered surfaces are white or light gray. Each bed is normally 2 to 6 inches thick, but locally some beds are as thick as 12 inches. The softer mudstone, in beds from a fraction of an inch to 6 inches thick is dark gray. Silt-sized grains scattered throughout the mudstone have a mineralogic composition similar to those in the underlying Tahana member.

The lower half of the Pomponio member changes facies only slightly within the area in which it is exposed. However, the upper half of the member grades laterally into massive, dark-gray, concretionary, fossiliferous mudstone that overlies a sequence of 6 beds of very fine-grained, well sorted, fossiliferous sandstone near the mouth of Purisima Creek in the Half Moon Bay quadrangle. This facies change in the upper part of the Pomponio member is recognized because it is between the siliceous beds in the lower part of the member and the sandstone beds of the overlying San Gregorio member.

Stratigraphic Relations and Thickness. The contact between the Pomponio member and the underlying Tahana member is sharp and conformable where siliceous mudstone overlies volcanic arenite. Field relations in the eastern part of La Honda quadrangle indicate that there may be a minor amount of interfingering at this boundary. The contact with the overlying San Gregorio sandstone member is also conformable and is well exposed in the sea cliffs in the Half Moon Bay quadrangle. Between its conformable contacts in Pomponio Creek the member is 2,300 feet thick.

Fossils. The fossil content of the Pomponio member is not uniform. In the type section alternating mudstone and siliceous beds are nearly barren of diagnostic fossils. Only a few diatoms, crushed arenaceous foraminifers, and sponge spicules have been noted. On the other hand, 10 miles northeast of the type section near the mouth of Purisima Creek, sandstone and mudstone beds in the upper part of the member are abundantly fossiliferous, and the lower siliceous beds contain Foraminifera, a few mollusks, and bones of marine vertebrates. Megafossils in the sandstone beds of the upper half of the Pomponio member have been extensively collected by paleontologists, who have often referred to the beds as the "upper sandstones" (Ashley, 1895; Martin, 1916). Megafossils collected during this investigation are listed on plate 24 and some are illustrated on photos 16 and 17. Microfossils in the member were described by Goodwin and Thomson (1954); the stratigraphic occurrence of several collections of foraminifers made during this study are shown on plate 3.

San Gregorio Member

Introduction. Massive sandstone which crops out near the coast along the axis of the Pescadero syncline is herein named the San Gregorio member of the Purisima formation. The name is derived from the village of San Gregorio, immediately to the south of this area in which the member is well exposed. The type section is in the sea cliffs approximately 2,500 feet south of the mouth of Purisima Creek in the Half Moon Bay quadrangle (fig. 5). The entire member is exposed at this locality.

Photo 16 (opposite). Megafossils from the Pomponio member of the Purisima formation. (Figures natural size unless otherwise noted)

No. 1. *Bittium* cf. *B. voncauverense* Doll and Bartsch
4.7 times natural size;
Locality No. F701M; Half Moon Bay quadrangle

No. 2. *Nassarius* cf. *N. paroinguis* (Hinds)
4.7 times natural size;
Locality No. F701M; Half Moon Bay quadrange

No. 3. *Crepidula princeps* Conrad
.71 times natural size;
Locality No. 711; La Honda quadrangle

No. 4. *Miapleiana aregonensis* Arnold
.70 times natural size;
Locality No. F701M; Half Moon Bay quadrangle

No. 5. *Pecten* aff. *P. healeyi* Arnold
Right valve;
Locality No. 639M; Half Moon Bay quadrangle

No. 6. *Pecten (Patinapecten) löhri* Hertlein
Right valve;
Locality No. 726M; La Honda quadrangle

No. 7. *Mitrella gauldii* (Carpenter)
2.5 times natural size;
Locality No. F701M; Half Moon Bay quadrangle

No. 8. *Balanus* cf. *B. nubulis* Darwin
2.34 times natural size;
Locality No. 634M; Half Moon Bay quadrangle

No. 9. *Neptunea stantani* (Arnold)
Locality No. 645-1M; Half Moon Bay quadrangle

No. 10. *Balanus* cf. *B. aquila Pilsbry*
Locality No. 633M; Half Moon Bay quadrangle

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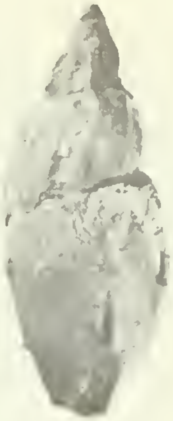

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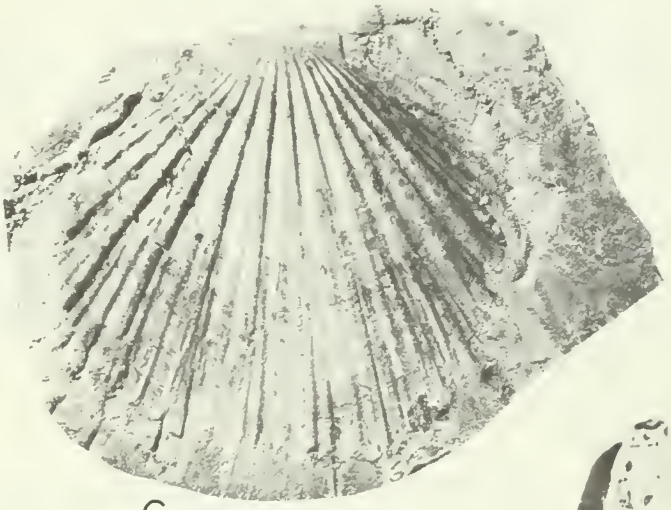

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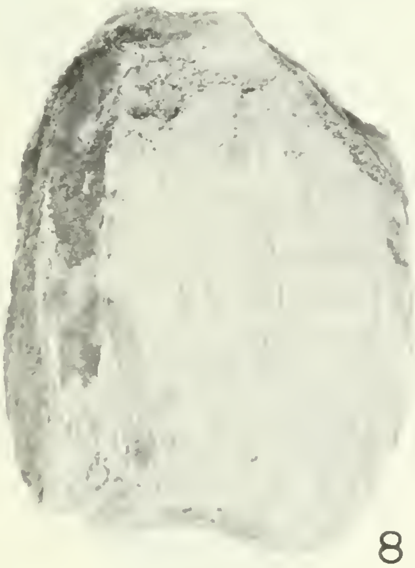

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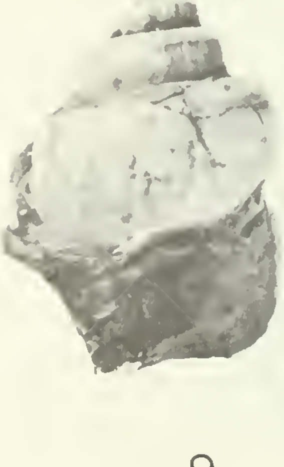

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Lithology. The San Gregorio sandstone is greenish gray where fresh but weathers to a light brown. It is mostly massive, fine- to coarse-grained sandstone, with irregularly distributed small pebbles of vari-colored chert and basic volcanic rocks. In mineral content the sandstone is nearly identical with sandstone in the Tahana member, although the average grain size in the San Gregorio sandstone is greater. Chlorite and calcite cement are common and irregular calcareous concretions are locally abundant. About 10 feet below the top of the member there is a bed of debris consisting of megafossils and small concretions. The San Gregorio sandstone is a homogenous unit, both laterally and vertically, although grain size increases slightly southward from the type section.

Stratigraphic Relations and Thickness. The San Gregorio sandstone overlies the Pomponio member conformably and is in turn conformably overlain by the Lobitos mudstone (photo 18). Both relationships are well exposed at the type section.

In the type section the San Gregorio member is 150 feet thick, but it thickens to 450 feet in the axial portion of the Pescadero syncline.

Fossils. Megafossils are locally abundant in the San Gregorio member. Those found during this investigation are listed on plate 24 and several are illustrated in photo 19. No microfossils were collected during this study although Goodwin and Thomson (1954, table 1, p. 171) may have found Foraminifera in the San Gregorio member, for the sandstone bed which they show about 2,500 feet above the base of their section is clearly the San Gregorio sandstone.

Lobitos Member

Introduction. Lobitos member is the name given here to massive, silty mudstone overlying the San Gregorio sandstone member near the axis of the Pescadero syncline. The type section is located about 3,500 feet south of the mouth of Purisima Creek and consists of mudstone which immediately overlies the type section of the San Gregorio sandstone (fig. 5). The member is named for Lobitos Creek in the Half Moon Bay quadrangle, along which the mudstone is exposed.

Lithology. The Lobitos mudstone is dark gray where fresh and shows no indication of bedding, except for fossiliferous lenses and concretions. Upon weathering, the mudstone takes on a reddish or yellowish-brown color, particularly along bedding planes and joints. The mudstone is micaceous and silty; glass shards and very fine grains of glauconite locally are common. One white tuff bed about 2 inches thick in south of the mouth of Tunitas Creek.

Stratigraphic Relations and Thickness. The contact with the underlying San Gregorio sandstone is conformable and sharp, but the contact with the overlying Tunitas sandstone is gradational; the Lobitos mudstone grades vertically upward into very fine-grained sandstone of the Tunitas member. The maximum thickness of the Lobitos member is 450 feet.

Fossils. Both megafossils and microfossils are common in fresh exposures and a list of the megafossils collected from the Lobitos member is given on Plate 24. Goodwin and Thomson (1954, table 1) found abundant Foraminifera in their four highest samples which were collected from this member.

Tunitas Member

Introduction. Massive, very fine-grained sandstone beds which are exposed along the sea cliffs for 3 miles north of the mouth of Tunitas Creek are herein named the Tunitas sandstone member of the Purisima formation. The type section is approximately 4,100 feet south of the mouth of Purisima Creek where the sandstone overlies the type section of the Lobitos member (fig. 5).

Photo 17 (opposite). Megafossils from the Pomponio member of the Purisima formation. (Figures natural size unless otherwise noted)

No. 1. *Protothaca tenerrima* (Carpenter)
Left valve; .80 times natural size;
Locality No. 645-1M; Half Moon Bay quadrangle

No. 2. *Macoma nasuta* (Conrad)
Right valve;
Locality No. 631M; Half Moon Bay quadrangle

No. 3. *Lucinoma annulata* (Reeve)
Left valve;
Locality No. 711M; La Honda quadrangle

No. 4. *Thracia trapezoides* (Conrad)
Left valve;
Locality No. 645-1M; Half Moon Bay quadrangle

No. 5. *Schizothaerus pajaroanus* (Conrad)
Left valve; .80 times natural size;
Locality No. 657M; Woodside quadrangle

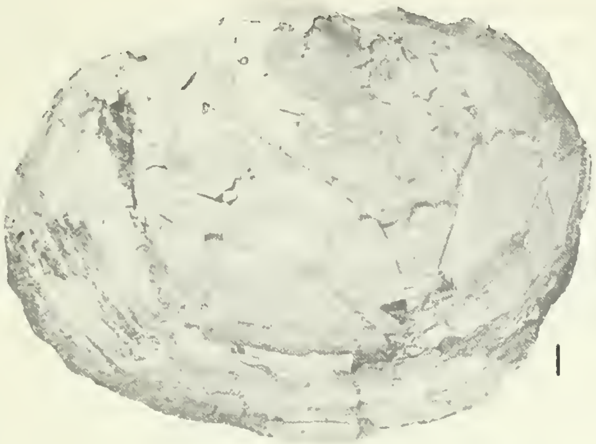
No. 6. *Acila castrensis* (Hinds)
Left valve; 2.5 times natural size;
Locality No. 645-3M; Half Moon Bay quadrangle

No. 7. *Yoldia thraciaeformis* (Storer)
Left valve; 1.9 times natural size;
Locality No. F685-3M; Half Moon Bay quadrangle

No. 8. *Crepella columbiana* Dall
Left valve; twice natural size;
Locality No. 653M; Woodside quadrangle

No. 9. *Anadara trilineata* (Conrad)
Right valve;
Locality No. 700-1M; Half Moon Bay quadrangle

No. 10. *Balanus* cf. *B. aquila Pilsbry*
Right valve showing minor variation;
Twice natural size;
Locality No. 653M; Woodside quadrangle



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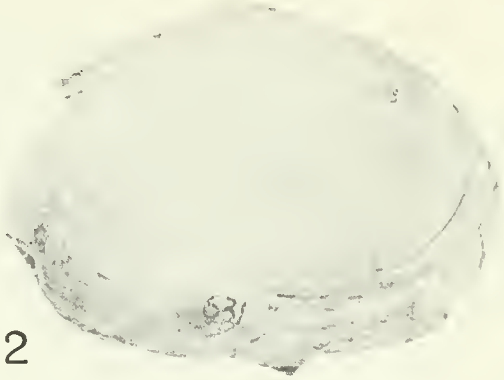

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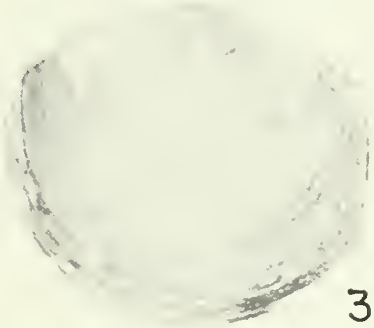

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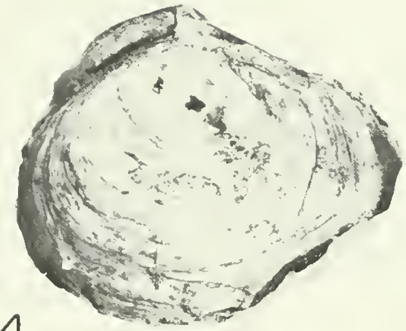

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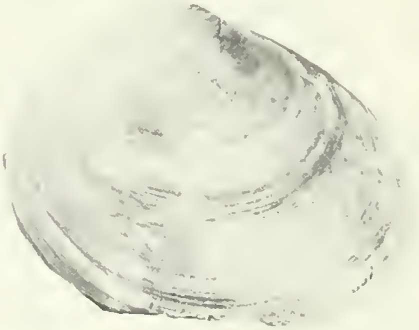

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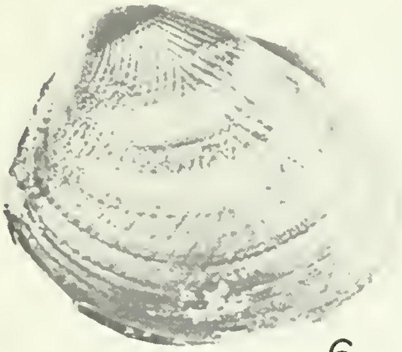

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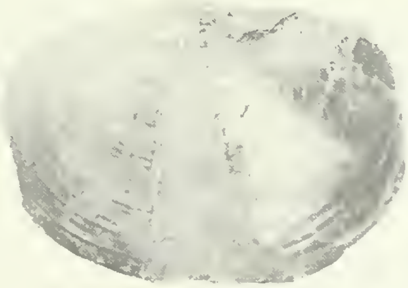

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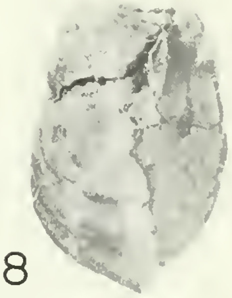

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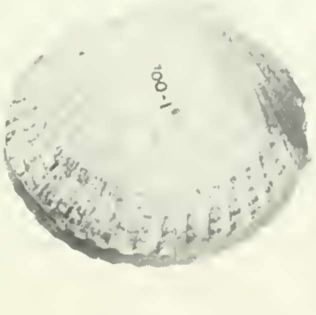

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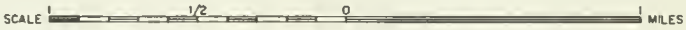
GEOLOGIC MAP – COASTAL SECTION
HALF MOON BAY QUADRANGLE
SAN MATEO COUNTY, CALIFORNIA

December 1957 R.M.T



EXPLANATION

RECENT

Qls
Landslides

PLEISTOCENE

Qt
Marine terrace

UNCONFORMITY

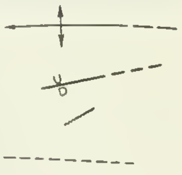
PLIOCENE Purisima fm.

Tptu
Tunitos sandstone member

Tpl
Lobitos mudstone member

Tpsg
San Gregorio sandstone member

Tpp
Pomponio member – siltstone and siliceous mudstone



Structural axis – dashed where uncertain

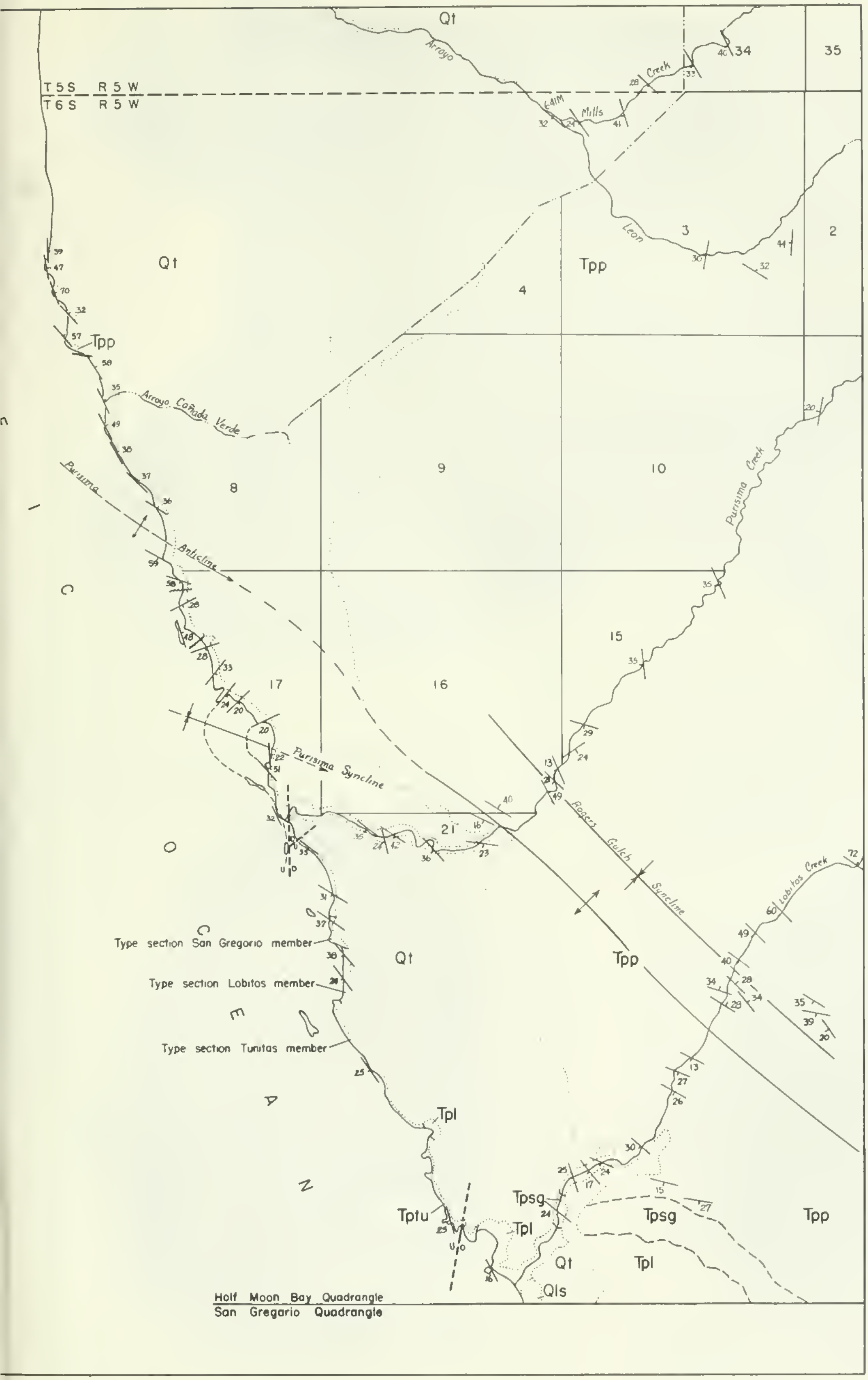
Fault – dashed where uncertain

Sheared zone showing approximate trend

Inferred trace of beds

Cummings, Touring & Brabb, 1961

Figure 5.



Qt
Arroyo
Creek
Mills
Leon
T 5 S R 5 W
T 6 S R 5 W
34
35
3
2
4
Tpp
Qt
Tpp
Arroyo Cañada Verde
Purisima Anticline
8
9
10
Purisima Creek
15
17
16
Purisima Syncline
21
Rogers Gulch Syncline
Lobitos Creek
O
C
E
A
N
Type section San Gregorio member
Type section Lobitos member
Type section Tunitas member
Qt
Tpp
Tpl
Tptu
Tpsg
Tpl
Tpsg
Tpp
Qt
Tpl
Qls
U
D
Half Moon Bay Quadrangle
San Gregorio Quadrangle

Photo 18. Massive dark-gray mudstone of the Lobitos member, Purisima formation, overlying concretionary sandstone of the San Gregorio member. Fossil debris and small concretions form a light-colored bed about 5 feet below the top of the San Gregorio sandstone. This sea cliff south of Tunitas Creek is about 135 feet high.

Lithology. The Tunitas sandstone is greenish-gray where fresh and shows few indications of bedding. Where weathered it is light gray to very pale orange. It is very fine grained and well sorted, and is composed principally of feldspar and andesitic rock fragments similar to those in other sandstones in the Purisima formation.' The sandstone is locally cemented with calcite or chlorite and weathered surfaces exhibit irregular concretionary structures.

Stratigraphic Relations and Thickness. The Tunitas member overlies the Lobitos mudstone member conformably, the contact being gradational over a thickness of approximately 5 feet. The top of the member is overlain by Pleistocene terrace deposits with an angular unconformity.

The member is 250 feet thick in the type section and at least 400 feet thick along the axis of the Pescadero syncline on Star Hill in the northern part of the San Gregorio quadrangle. In the Half Moon Bay quadrangle, the member dips seaward at 25 degrees, and an additional, but unknown thickness may be present offshore.

Fossils. Well-preserved megafossils are common in fresh exposures of the Tunitas member. A list of the fossils collected during this study is given in Plate 24.

Thickness of the Purisima Formation

The maximum thickness of the Purisima formation is 5,650 feet, a figure which agrees closely with the 5,400 feet given by Branner et al. (1909, p. 5) for the formation northeast of Pescadero. Crandall (1943, p. 479) reported a thickness of 9,500 feet near Purisima Creek

Photo 19 (opposite). Megafossils from the San Gregorio and Lobitos members of the Purisima formation. (Figures natural size unless otherwise noted)

No. 1. *Cryptomya californica* (Conrad)
Left valve; twice natural size;
Locality No. 482-3M; San Gregorio quadrangle
San Gregorio member

No. 2. *Macoma calcarea* (Gmelin)
Right valve;
Locality No. 672M; San Gregorio quadrangle
San Gregorio member

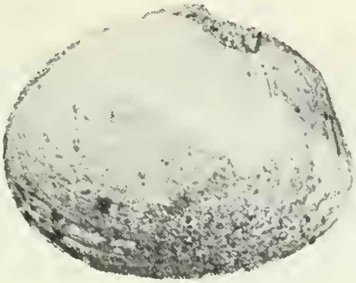
No. 3. *Calyptraea fastigiata* Gould
Twice natural size;
Locality No. F692M; Half Moon Bay quadrangle
Lobitos member

No. 4. *Dendraster* cf. *D. ashleyi* (Arnold)
Locality No. 482-3M; San Gregorio quadrangle
San Gregorio member

No. 5. *Scutellaster oregonensis* (W. B. Clark)
1.67 times natural size
Locality No. 482-3M; San Gregorio quadrangle
San Gregorio member

No. 6. *Ostrea* cf. *O. erica* Hertlein
.9 times natural size;
Locality No. 696M; Half Moon Bay quadrangle
San Gregorio member

No. 7. *Dendraster gibbsii* (Rémond)
Locality No. 482-3M; San Gregorio quadrangle
San Gregorio member



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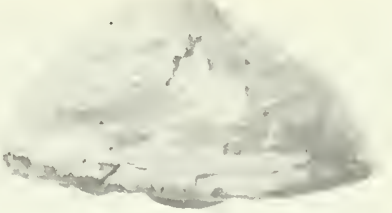

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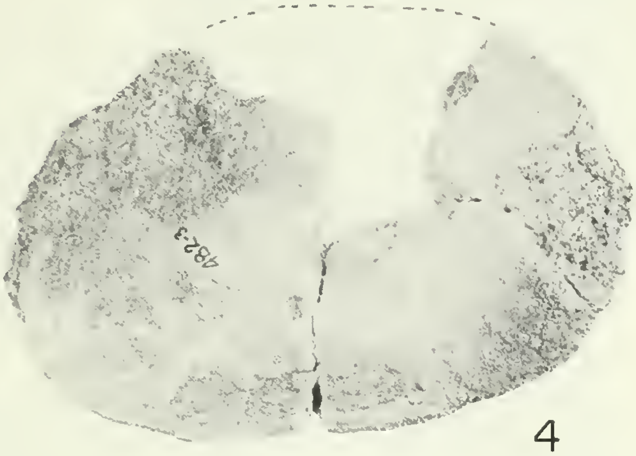

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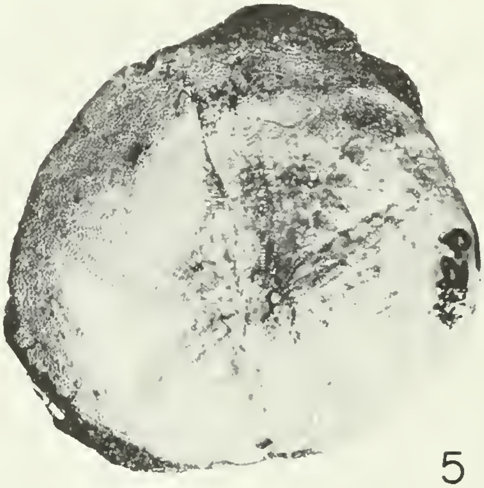

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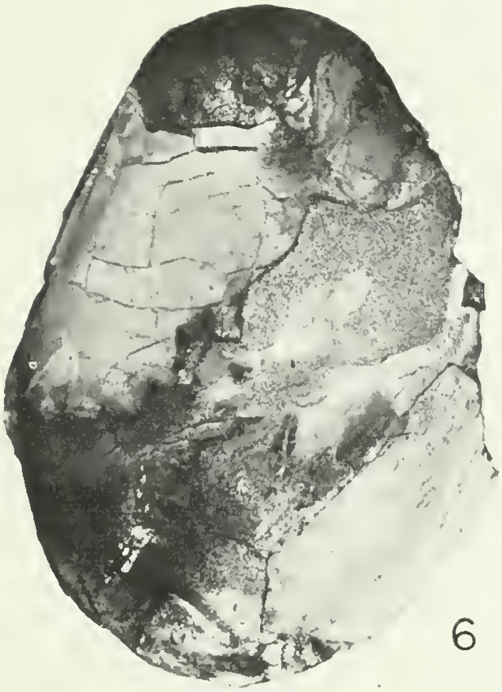

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north of the map area, but this excessive thickness is believed to have resulted from an incorrect interpretation of a deep well drilled on the Purisima anticline.

Maximum thicknesses of members of the Purisima formation are summarized below:

Tunitas sandstone member	400 feet
Lobitos mudstone member	450 feet
San Gregorio sandstone member	350 feet
Pomponio member	2,300 feet
Tahana member	2,150 feet
Total	5,650 feet

Provenance of Clastic Material in the Purisima Formation

Sandstone members of the Purisima formation contain a large percentage of volcanic rock fragments which in order of frequency of occurrence are: (1) sand-size particles of andesite, (2) shards of rhyolitic glass, (3) sand, pebbles, and cobbles of light-gray pumice, and (4) sand- and pebble-size grains of basalt. Associated with these rock fragments is a rich and distinctive assemblage of heavy minerals, in which hypersthene, green hornblende, and reddish-brown basaltic hornblende are abundant. These constituents distinguish the Purisima formation from all older lithologic units in the Santa Cruz Mountains.

Branner and his associates (1909, p. 5) believed that most of the volcanic detritus in the Purisima formation was derived from the "diabase" which crops out nearby (basalt in the Mindego formation and intrusive diabase of this report). However, with the exception of a thin, locally developed, basal conglomerate in the Tahana member, very little of the detritus in the Purisima formation resembles Mindego basalt or the related intrusive diabase. For example, the most common ferro-magnesian mineral in basalt of the Mindego formation is augite, but augite is not common among heavy minerals in Purisima sandstone. On the contrary, the most common heavy minerals in the Purisima (hypersthene, green hornblende, and basaltic hornblende) have not been recorded from the Mindego basalt or the intrusive diabase. The most abundant plagioclase feldspars in the Purisima formation are prominently zoned andesine and labradorite. Plagioclase of similar composition in basalt of the Mindego formation is not as strikingly zoned as it is in the Purisima sandstone. Thus, the heavy minerals in Purisima sandstone were derived from a source other than the Mindego formation.

Doell (1956, p. 158) noted a heavy mineral assemblage, similar to the one described above, in the lower Purisima formation southeast of Santa Cruz and suggested it was derived from volcanic rocks in the Sierra Nevada. The most likely eastern source of the andesitic volcanic detritus in the Purisima is the Mehrten formation, described by Piper et al. (1939, p. 61) and later extended to include most late Miocene and early Pliocene andesitic mudflow breccia from the Taylorsville region in Plumas County southward nearly to Yosemite National Park (Curtis, 1954, p. 455). Durrell (1944, p. 260) studied the andesite near Blairsden, 65 miles east of Chico, and reported that hypersthene, basaltic hornblende, and green hornblende were abundant. The minerals he describes match those in the Purisima formation. In a later study Durrell (1959, p. 177) referred the andesitic mudflow breccia to his Penman formation and gave evidence for transportation of material toward the west, southwest, or south. Both Curtis and Durrell indicated that the Mehrten formation and its equivalents were once more widely distributed in the Sierra Nevada than at present. The source appears to have been large enough to have supplied all the andesitic material in the Purisima formation and possibly in all the other Pliocene formations in central California where this type of detritus is abundant.

The origin of the rhyolitic tuff, glass shards, and the pebbles and cobbles of pumice which are common in the Tahana member of the Purisima is not definitely known. Similar tuffaceous beds in the Pliocene rocks of Kettleman Hills may possibly have been derived from centers of Pliocene volcanism in the Coast Ranges north of San Francisco, or from the Mount Lassen area (Woodring et al., 1940, p. 78). The presence of about 1,000 feet of pumiceous pyroclastics in the Pliocene Pinole tuff on the east side of San Francisco Bay suggests nearby centers of volcanism, but none have been positively located (Weaver, 1949, p. 118-121).

Ecologic Significance of Purisima Fossils

Megafossils and microfossils are found throughout the Purisima formation; only in the lower part of the Pomponio member are there unfossiliferous rocks. A few beds contain disconnected pelecypod valves indicating their movement and concentration by wave action, but most pelecypod fossils in the Purisima formation have both valves together as they were when the animal was alive, indicating that final burial took place at or near the spot where the animal lived. This suggests that the fossils can be used successfully to indicate environments of deposition for the five members of the Purisima formation.

An analysis of the present depth ranges of living species represented in the Purisima megafauna suggests that the individual members of the formation were deposited at slightly different depths. The Tahana member has no commonly occurring species that are restricted to the uppermost neritic and littoral zones. On the other hand, nearly all of the species in the Tahana member that are now living at the latitude of San Francisco are found in water depths between 20 and 40 fathoms. Slightly shallower-water faunas are in the Tahana member in the eastern part of La Honda quadrangle and in the Mindego Hill quadrangle.

The Pomponio member in its type area is nearly barren of fossils, suggesting deposition in an environment unsuitable for benthonic organisms—perhaps a poorly oxygenated sea floor at lower neritic or upper bathyal depths. However, 8 miles to the north in the Half Moon Bay quadrangle, the lower part of this member contains a few fossils, notably *Yoldia*, which suggest deposition at depths of 40 to 50 fathoms. The upper part of the Pomponio member near the mouth of Purisima Creek in the Half Moon Bay quadrangle contains an abundant benthonic fauna characteristic of depths between 20 and 40 fathoms. The megafauna thus implies a shallowing of the sea floor in this vicinity during deposition of the Pomponio member. On the other hand, Bandy (1955) suggested that the *Uvigerina juncea* assemblage of Goodwin and Thomson (1954), collected from the upper Pomponio and Lobitos members, is a deeper-water fauna (1,000 to 5,000 feet) than that of the lower Pomponio *Elphidiella hannai* zone (0 to 300 feet).

The sea floor during the deposition of the San Gregorio sandstone member was shallow enough to allow the appearance of genera such as *Ostrea*, *Cryptomya*, *Olivella*, and *Dendraster*, suggesting that depths were on the order of 10 to 20 fathoms. These shallow-water forms are chiefly in the upper part of the member.

Although mollusks in the Lobitos member may be a facies-controlled fauna of mud-dwelling species, water depths at the time of Lobitos deposition are believed to have been deeper (20 to 40 fathoms) than those during San Gregorio deposition. In the Tunitas member some species reappear that suggest accumulation of the member at depths of 15 to 25 fathoms.

Many living species represented in the Purisima megafauna no longer live off the central California coast but have withdrawn northward, some as far as the Gulf of Alaska. At least one, *Chlamys parmeleei*, has a very close living relative now restricted to the northwestern Pacific near Japan.

Correlation and Age. Megafossils collected from the Purisima formation during this investigation (pl. 24) suggest correlation with marine Pliocene formations from Santa Maria, California, to Coos Bay, Oregon. In the Santa Maria district, the upper part of the Tinaquaic sandstone member near the top of the Sisquoc formation contains fossils which are remarkably similar to those in the Tahana member and sandy parts of the Pomponio member of the Purisima formation. The Careaga sandstone in the same district contains many species which are also found in the Purisima, but it seems best correlated with the Pomponio and younger members.

Woodring et al. (1940, p. 108) correlated the Purisima formation with the San Joaquin and Etchegoin formations of the San Joaquin Valley using fossil lists of Martin (1916). However, most of Martin's fossil collections from the Purisima were made in the upper part of the Pomponio member and younger beds. The Tahana member of the Purisima probably correlates with the Jacalitos formation of the San Joaquin Valley—a formation considered to be lower Pliocene in age. Both the Jacalitos and the Tahana member of the Purisima overlie siliceous shale and mudstone which are referred to the Monterey formation, or lateral equivalents of it. Woodring et al. (1940, p. 50) also reported abundant grains of hypersthene, augite, and hornblende andesite in the Pliocene formations at Kettleman Hills, in addition to "blue" sandstone and white vitric tuff.

The Neroly formation of the Tesla quadrangle, located about 45 miles east-northeast of San Gregorio, is composed of a lower "blue," andesitic sandstone and conglomerate 700 feet thick, and an upper clay shale with minor "blue" sandstone and conglomerate that is about 2,000 feet thick (Huey, 1948, p. 42-47). The lower part of the Neroly is apparently the near-shore or nonmarine equivalent of the Tahana member of the Purisima and represents, as does the Tahana, the first influx of abundant hornblende and hypersthene andesite debris from the Sierra Nevada, for the underlying Cierbo formation is quartzose and has an entirely different suite of heavy minerals. The upper part of the Neroly may be equivalent to the Pomponio member, both being predominantly mudstone sequences.

Rocks mapped as Merced formation on Pillar Point near Half Moon Bay by Branner et al. (1909) are a part of the Purisima formation (Glen, 1959, p. 163) and can be correlated with the Pomponio member. The lower part of the type Merced formation in the San Francisco area probably correlates with the Tunitas, Lobitos, and San Gregorio members of the Purisima formation. The presence of the genus *Scutellaster* in both the lower Merced and the San Gregorio sandstone may confirm the correlation, although part of the lower Merced is probably younger than any of the Purisima. The upper Merced, north of the Thornton landslide, is considered early Pleistocene in age by Glen.

The Purisima formation probably correlates with the Eel River, Rio Dell, and Scotia Bluffs formation of the Wildcat group in Humboldt County, California. Glauconitic sandstone in the Eel River formation overlying diatomaceous mudstone of the Pullen formation (Ogle, 1953, p. 13) is lithologically similar to the sequence of the Tahana member of the Purisima formation overlying the Monterey shale in the northern Santa Cruz Mountains. Ogle (p. 42) also reported abundant hornblende in the Eel River formation, whereas it is rare or absent in the Pullen formation. The middle member of the Rio Dell formation consists of alternating thin beds of fine-grained sandstone and partly diatomaceous mudstone or siltstone. A lithologic correlation with the low Pomonio member is suggested, especially since both sequences are overlain by fossiliferous sandstone. *Scutellaster oregonensis* in the lower part of the Scotia Bluffs sandstone, suggests a correlation of that formation with the San Gregorio sandstone member. The upper part of the Scotia Bluffs may correlate with the Lobitos and Tunitas members.

If the above-mentioned correlations are correct, the Purisima formation is most probably of Pliocene age, with the base of the Tahana member being near the base of the Pliocene series, in the sense that the term Pliocene is used for marine formations in California. In the Santa Cruz folio (Branner et al., 1909, p. 6) the lower Purisima (Tahana member) was assigned to the upper Miocene because fossils collected from pebble beds cropping out in Pescadero Creek near the mouth of Jones Gulch in La Honda quadrangle were similar to fossils in the lower Etchegoin group. At that time the lower Etchegoin

Photo 20. Conglomerate, sandstone, and mudstone of Santa Clara formation dipping northeast along Alpine Road above Corte Madero Creek.

group or Jacalitos (Woodring, et al., 1940, p. 27) was thought to belong to the upper Miocene, but workers now consider it to be of early Pliocene age. Doell (1956) correlated the Neroly formation with the lower Purisima formation by means of lithology, heavy minerals, and remnant magnetism. This suggests that the lower "blue" sandstone member of the Neroly may be more properly referred to the lower Pliocene than to the upper Miocene of California, and is equivalent to similar sandstone in the Etchegoin and Jacalitos formations ("stages"), rather than occurring below them as some recent correlation diagrams show (Savage, 1955, fig. 3; Axelrod, 1957, fig. 3).

The upper age limit of the Purisima formation is in doubt, for the top of the formation has been eroded away and the Tunitas or uppermost member is unconformably overlain by late Pleistocene terrace deposits. Tentatively, the Tunitas member is considered to be no younger than late Pliocene because some of the fossils it contains, like *Miopleiona oregonensis* and *Neptunea purisimaensis* have not been found in the Pleistocene of California. The work of Glen (1959) would suggest that the youngest beds in the Tunitas member are somewhat older than the highest beds in the lower Merced formation at its type locality.

SANTA CLARA FORMATION

Introduction. The earliest reference to beds called Santa Clara was by Cooper (1894) who described Santa Clara "lakebed" deposits of the San Francisco Bay area. No type section was designated. Branner et al. (1909) used this term in the Santa Cruz Mountains for gravel, sand, and clay presumably younger than the Purisima formation; this usage is followed here.

In the area described in this report, the Santa Clara formation is confined to a narrow zone adjacent to the San Andreas fault (photo 20). In addition, two small exposures of gravel containing characteristic Santa Clara debris cap hills along Russian Ridge in the Mindego Hill quadrangle.

Lithology. The Santa Clara formation is composed of poorly consolidated, interbedded conglomerate, sandstone, and mudstone. These are in irregular and lenticular beds several feet thick, in which poorly sorted, coarse sand and gravel are most conspicuous. The beds where fresh are gray to greenish brown; where weathered they are pale orange and reddish brown. The sand and gravel particles are composed of dark-colored chert, graywacke, altered basalt and diabase, greenstone, and glaucophane schist, as well as quartz and feldspar. Large boulders composed of an older, well-indurated conglomerate are conspicuous in the coarsest beds. The cobbles in this conglomerate include porphyritic acidic volcanic rocks, granite porphyries, and quartzite set in a hard, sandy matrix. Because of their hardness the boulders are very resistant to weathering and are commonly found in the streams draining areas of Santa Clara outcrop. Their presence in streams above which no Santa Clara is now exposed is evidence of the once more extensive distribution of the formation.

Stratigraphic Relations and Thickness. The Santa Clara formation rests with angular unconformity on the Purisima formation and older rocks. The lower contact is poorly exposed in several small creeks that drain into Corte Madera Creek from the southwest. The Santa

Photo 21. Lobe-shaped earthflows on southwest side of ridge between Mindego Hill and Alpine Creek Road.

Clara formation is not overlain by younger strata in this area.

A maximum thickness of 1,800 feet of Santa Clara formation is exposed along the ridge between Corte Madera and Los Trancos Creeks. The gravel along Stevens Creek and the hilltop outcrops on Russian Ridge are only a few tens of feet to several hundred feet thick.

Age and Correlation. Although no diagnostic fossils were collected from the formation in this vicinity, its stratigraphic position and apparent correlations indicate a late Pliocene to early Pleistocene age. Since the Santa Clara formation unconformably overlies the Tahana member of the Purisima formation, and because the Santa Clara beds are steeply dipping, it is inferred that the formation is younger than early Pliocene and older than late Pleistocene. It may be the continental equivalent of the upper Merced formation, which Glen (1959, p. 162) assigned to the lower Pleistocene.

Provenance. The predominance of chert, graywacke, greenstone, and glaucophane schist in the Santa Clara gravel beds suggests that most, if not all, of the formation was derived from a "Franciscan" terrane. That the source area was not far removed is indicated by the large size of some of the boulders in the conglomerate beds. It is reasonable to expect that the source for these beds was the "Franciscan" complex immediately to the east across the San Andreas fault. The specific source of the hard conglomerate boulders in the Santa Clara is not known.

TERRACE DEPOSITS

There are two types of terraces in the San Gregorio, La Honda, and Half Moon Bay quadrangles. Most prominent and extensive are marine terraces, cut in several older formations, at different elevations on the west side of the Santa Cruz Mountains. They are well developed near Santa Cruz where they were studied in detail by Bradley (1957). Along the larger streams, nonmarine stream terraces have developed, again at various levels probably related to the marine terraces.

A prominent marine terrace extends from the northern end of the San Gregorio quadrangle into the Half Moon Bay quadrangle. This terrace reaches a maximum elevation of 190 feet near the mouth of Lobitos Creek and slopes northward toward the town of Half Moon Bay. The wave-cut platform of this terrace slopes gently seaward near the mouth of Tunitas Creek. The terrace material overlies older rocks unconformably, has a maximum thickness of 35 to 40 feet, and consists largely of interbedded coarse sand and gravel. Pebbles, cobbles, and boulders in the terrace gravel consist of granitic rocks believed to be from Montara Mountain, intrusive diabase and basalt from the Mindego formation, and siliceous shale and mudstone from the Monterey formation. There are also a few clasts of metamorphic rock, sandstone, quartz, chalcedony, and water-worn bones. No invertebrate fossils were discovered, and while no proof of marine origin was found in this area, it is believed that the terrace sediments were deposited by a retreating sea.

South of Pescadero Creek a fossiliferous marine terrace truncates the Mindego and Pigeon Point formations. This terrace is lower than the terrace north of Tunitas Creek, but the elevation difference is believed to be due to subsequent warping. Both terraces were probably developed during the same stillstand.

The marine terraces are presumed to be Pleistocene in age, for they rest unconformably on beds as young as late Pliocene. Bradley (1956) submitted shell material from a terrace in the vicinity of Santa Cruz for Carbon-14 dating to Broecker and Kulp (1956, p. 161) who reported that the age of the terrace was greater than 37,000 years.

Stream terraces are found along Tunitas, San Gregorio, and Pescadero Creeks. The lower beds in these terraces are composed of gravel and sand consisting chiefly of diabase and basalt from the Mindego formation. The upper beds are composed of fine silt which grades upward into Recent alluvium.

In the vicinity of Memorial Park, an elevated terrace is present along Pescadero Creek upstream from the point where the creek crosses the axis of the Butano anticline. Development of this terrace was apparently due to a local base level caused by uplift of the Butano anticline, for Pescadero Creek has been superimposed on the structure forming a canyon where it cuts into Butano sandstone. Terraces downstream from the axis of the anticline are not elevated and merge with Recent alluvium.

LANDSLIDES

Landslides or earth flows are common in areas underlain by incoherent formations. They range in size from a few square yards to nearly a square mile. Only the larger ones have been mapped. Large landslides are most commonly developed in areas underlain by the San Lorenzo, Mindego, and Monterey formations, and by the Tahana, Pomponio, and Lobitos members of the Purisima formation.

Many of the larger landslides are characterized by irregular, convex, hummocky surfaces, a prominent, lobate toe, and a steep scarp above the head of the slide (Photo 21).

STRUCTURAL GEOLOGY

Introduction. The area discussed in this report is part of a structurally complex downwarp, the axis of which more or less coincides with the axes of the Pescadero and San Lorenzo synclines. This large downwarp is cut by the San Andreas fault on the northeast and is bounded, in part, by the Ben Lomond massif on the southwest. Between these structures the strata have been compressed into folds and broken by many high-angle reverse faults, some of large displacement, and by a few normal faults of relatively small displacement. Principal structures have a subparallel, northwest-striking arrangement, similar to that of structures throughout the Coast Ranges.

The intensity of folding and faulting appears to be a function of the age of rocks, their lithology, and relation to major structures. Strata older than late Miocene are, as a rule, more intensely deformed than younger rocks. Where the stratigraphic section is dominantly sedimentary, as along the eastern boundary of this area, the beds are tightly folded and cut by many faults. Some of these folds are nearly isoclinal. In contrast, the region around La Honda where volcanic rocks of the Mindego formation make up a large part of the stratigraphic section is characterized by large, open folds and few faults. This may be the effect of greater rigidity of the volcanic rocks. In a broad sense, the intensity of folding and faulting of all strata increases in the vicinity of major faults such as the San Andreas and San Gregorio.

These observations are not in agreement with the opinion of some geologists who believe that the intensity of deformation of Coast Ranges strata is related to the type of basement rocks on which they rest. Reed (1933, p. 29), for example, stated that sedimentary strata resting on granitic rocks are little disturbed, whereas the Franciscan "basement" and overlying sedimentary rocks are highly deformed. If this is true for California in general, the northern Santa Cruz Mountains are exceptional.

Structural mapping in this district, as in all regions, must be done with particular attention to stratigraphy and evaluation of outcrops. False impressions may be obtained from drag folds in incompetent beds and from large masses of rock displaced by slumping and landsliding, inasmuch as these have dips which are not representative of major structures.

Folds. The most prominent fold in the area covered by this report is Pescadero syncline, which can be traced from the coast in the northern part of the San Gregorio quadrangle southeastward more than 15 miles across the San Gregorio, La Honda, Mindego Hill, and Big Basin quadrangles to its termination against Brush Creek fault. The trace of the axial plane is approximately N. 60° W.; the axial plane is inclined to the southwest; and the axis plunges to the northwest at an angle of several degrees.

Another large structure, located immediately beyond the north boundary of the area mapped, is Sky Londa anticline. The axis is in the Woodside quadrangle and strikes nearly due east. The Butano sandstone is exposed in the core of this fold and San Lorenzo and Mindego formations on the south limb. Between this anticline and Pescadero syncline are several smaller folds. The largest of these is the Woodruff anticline, which can be traced from the headwaters of the San Lorenzo River northward through Devils Canyon and across Langley Hill. The fold is symmetrical with steep dips on either limb; where it crosses Alpine Creek Road it is compressed into a fan fold with both limbs slightly overturned. Local reversals of plunge suggest closures of several hundred feet or more. South and west of the town of La Honda are the small La Honda and Haskin Hill anticlines. Both strike about west-northwest and are open, symmetrical folds. They are the sites of two small oil fields.

Butano anticline, a major structure, strikes northwest to west-northwest and can be traced from the southern La Honda quadrangle, where it disappears under younger strata, across Big Basin quadrangle and for several miles beyond. The fold is asymmetrical and has its axial plane dipping steeply to the southwest. The southwestern limb has a moderate dip and the northeast limb is steep and locally overturned. The axis plunges both to the northwest and southeast at angles of 5 to 20 degrees and indicates closure in excess of 1,000 feet.

On the southwest limb of the Butano anticline are two smaller and subparallel folds, Big Basin syncline and Johansen anticline. Both strike northwest across Big Basin and Franklin Point quadrangles and die out in Purisima formation in La Honda quadrangle. They are asymmetrical, with steepest dips found between their two axes, and they plunge to the southeast and northwest.

Along the eastern border of this area are a number of short, plunging folds that strike northwest. One of these is the Oil Creek anticline in the northeastern Big Basin quadrangle where a small oil field is located. Other minor folds in this area include the Riverside syncline and Camp Campbell anticline.

The San Lorenzo syncline and Waterman Gap anticline are relatively minor structures in the Big Basin quadrangle but they apparently are the most important folds in the adjoining Castle Rock Ridge quadrangle (fig. 1). The San Lorenzo syncline has been traced on unpublished maps as far south as Corralitos.

Ben Lomond massif, extending from the vicinity of Santa Cruz into the southern Big Basin quadrangle, was considered a fault block by Branner et al. (1909) because of its step northeast face along Ben Lomond fault. However, periclinal dips of strata away from the crystalline core and geomorphic evidence lead Rode (1930) and the writers to believe that Ben Lomond Mountain is a faulted, asymmetrical, doubly plunging anticline involving the basement complex.

Faults. The San Andreas fault forms the northeastern boundary of the area mapped in this report. A detailed investigation of this well-known fault was beyond the scope of this investigation, but a few observations were made. The fault strikes approximately N. 40° W. across the Mindego Hill quadrangle and where it crops out consists of a sheared zone several hundred to more than one thousand feet wide. Its trace is physiographically expressed by the long, straight valleys of Stevens, Los Trancos, and Corte Madera Creeks as well as by sag ponds and other forms of fault-zone topography.

The type of movement along the San Andreas fault and the amount of displacement are controversial. The fault developed more than 13 feet of right-lateral, strike slip (fault terminology after Hill, 1959) near Mussel Rock in the San Francisco area in 1906 (Lawson et al., 1908). Hill and Dibblee (1953) and Curtis et al. (1958) postulate more than 300 miles of right-lateral strike separation since Jurassic-Cretaceous time, largely from evidence in southern California. Smith (1959) and Higgins (1961) suggest that strike separation in central California has been on the order of 12 to 15 miles since late Pliocene or early Pleistocene time, but Smith believes that separation since late Pleistocene time has been minimal.

No conclusive evidence as to the displacement on the San Andreas fault was developed during this study, but several observations are pertinent. The basin in which the Cenozoic rocks southwest of the fault accumulated must have extended some distance to the north and east over what is now the fault zone, for more than 10,000 feet of neritic and bathyal marine sediments adjoin the fault. Furthermore, no large areas of Franciscan rocks were exposed nearby until Plio-Pleistocene time, when abundant Franciscan detritus appeared in sediments of this area. Thus, an apparent dip separation of more than 10,000 feet has developed along the fault since Plio-Pleistocene time. Comparison of this area with that across the fault in the Palo Alto and adjoining quadrangles shows a striking similarity in stratigraphic sequence and geologic history. From Paleocene to Pleistocene time the age and lithology of rock units in each area are remarkably alike, including the Oligo-Miocene basalt of the Mindego formation. In view of these similarities, post-Eocene lateral displacement along the San Andreas in this region, measurable in hundreds of miles, seems improbable.

The Pilarcitos fault extends from the northwestern part of the Mindego Hill quadrangle in a northwesterly direction to the San Francisco region where it trends into the ocean near San Pedro Valley. Lawson (1914) mapped the northern part as a thrust fault, but Smith (1959) believes that it is a right-lateral fault with at least 3 miles of strike separation developed since middle Pleistocene time. Smith's view seems reasonable inasmuch as the Pilarcitos fault trends into and is paralled to the San Andreas fault. The straight fault trace and shear zones observed in Damiani Creek and Hamms Gulch indicate that the fault surface is nearly vertical.

Skyline and Devils Canyon faults are parallel to the San Andreas fault and cut the limbs of Skyline anticline. Both are reverse faults with maximum dip separation of 1500 feet or more. Skyline fault dips to the northeast and Devils Canyon fault to the southwest.

The northeast limb of the Butano anticline is cut by the Butano fault system. These bifurcating reverse faults strike northwest and separate moderately folded strata to the southwest from tightly folded and faulted strata to the northeast. The faults crop out at several localities along Pescadero Creek and dip steeply to the southwest. Combined dip separation along these faults is at least 1,000 feet and locally may be as much as 6,000 feet.

On the northern end of Ben Lomond Mountain are a group of northwest and west-northwest-striking normal faults. Most important of these is the Ben Lomond fault. The faults appear to dip steeply to the northeast and cut both the Ben Lomond quartz diorite and lower Tertiary sedimentary rocks. Stratigraphic evidence and gravity measurements suggest dip separations of 3,000 to 10,000 feet along these faults.

The San Gregorio fault zone strikes northwestward across the San Gregorio quadrangle and extends for more than 10 miles southward through the Franklin Point and Año Nuevo quadrangles. The trace suggests that the fault surface is nearly verticle. Hill and Dibblee (1953, pl. 1) include it with faults which have or possibly have a substantial strike separation, but this is unlikely inasmuch as the Tahana member of the Purisima formation has been mapped on both sides of the fault.

Structural Analysis. The contrast in stratigraphy and structural complexity in various parts of the Santa Cruz Mountains suggests that the areas bounded by the San Andreas, Pilarcitos, San Gregorio, and Ben Lomond faults have behaved more or less independently from adjacent fault-bounded blocks, as pointed out by Lawson (1914) and Clark (1930). Parallel, northwest-striking reverse faults and folds indicate that compressional shortening of strata within this block has taken place under a relatively constant stress orientation. Folds and faults in this area strike 5 to 15 degrees west of the San Andreas fault, which roughly coincides with the 15-degree angle postulated by Moody and Hill (1956) for the angle between a major wrench fault and second-order folds and reverse faults.

GEOLOGIC HISTORY

Pre-Cenozoic

Too little is known about pre-Late Cretaceous metamorphic rocks in this region to speculate about their geologic history except that they indicate accumulation under relatively stable tectonic conditions. They were originally quartzose sandstone, shale, and relatively pure limestone. These rocks were probably metamorphosed during the intrusion of granitic rocks in early Late Cretaceous time; they were eroded and the granitic pluton uncovered by Late Cretaceous (Campanian) time when the northern Santa Cruz Mountains sank to a bathyal depth. At least 8,500 feet of conglomerate, sandstone, and mudstone were deposited before the sedimentary rocks may have been folded, uplifted, and locally eroded away during the Laramide revolution.

Cenozoic

Paleocene (Ynezian). The region subsided and was inundated by the sea during the Paleocene. Gravel, sand, and mud derived perhaps in part from the Pigeon Point formation of Late Cretaceous age and from granitic and metamorphic rocks were washed into the ocean to form beds now called the Locatelli formation. Little is known about local paleogeography except that the area had unrestricted access to the open ocean and that the sea floor probably sloped upward from bathyal depth in the northern Santa Cruz Mountains to neritic depth in the southern Santa Cruz Mountains.

Late Paleocene (Bulitian) and early and middle Eocene (Penutian and Ulatisian) rocks seems to be missing, at least locally, from the Santa Cruz Mountains. The region may have been affected by diastrophism during this interval.

Late Eocene (Narizian). Sedimentation resumed in Late Eocene (Narizian) time with the deposition of sand and mud and the local development of conglomeritic beds. Approximately 3,000 feet of these clastics were deposited when rejuvenation of the source area or other factors resulted in another influx of boulders, cobbles, and pebbles. They were followed by 6,000 feet of fine- to medium-grained sand and interbedded mud that now form the Butano sandstone, and by several hundred feet of laminated mud referred to the lower shale member of the San Lorenzo formation.

Local paleographic features are inferred from the lithology and faunas of the formations. The northern Santa Cruz Mountain area was probably a distinct sedimentary basin, here named La Honda basin, bounded on the southwest by a crystalline landmass called Salinia by Reed (1933) and open to the ocean on the northwest. The eastward extent of this basin has not been determined, but it apparently extended across the San Andreas fault at least as far as the Palo Alto area. The basin must have been continually sinking because faunas near the top of the late Eocene (Narizian) sequence suggest somewhat colder and deeper water than those stratigraphically lower in the sequence. The common presence of pyrite, phosphate, and carbonaceous material in the rocks indicates that reducing conditions prevailed on the basin floor.

The influx of terrigenous material slowed and eventually ceased near the end of late Eocene (Narizian) time, a factor favoring the formation of glauconite and phosphate.

Early Oligocene (Refugian). The formation of glauconite and phosphate probably continued during the early Oligocene, perhaps as long as the time required for the deposition of some of the Oligocene stages in other areas of the world. Presumably the bottom of La Honda Basin remained at a bathyal depth during this interval. Sedimentation began again with the introduction of silt and clay and resulted in the incorporation of glauconite and phosphate in the basal deposits. The influx of sediments may have been the result of mild diastrophism that uplifted the borders of La Honda Basin. These land areas were probably more extensive than during late Eocene time because the faunas in the upper mudstone member of the San Lorenzo formation indicate that La Honda Basin had restricted access to the open ocean. When a few hundred feet of mud had been deposited, the influx of sediments stopped and conditions were favorable again for the formation of glauconite and phosphate.

Late Oligocene (Zemorrian). Several interpretations of the late Oligocene record are possible. La Honda Basin may have been uplifted differentially during mild, post-Refugian and pre-Zemorrian diastrophism, an event previously recorded by Kleinpell (1938, p. 109) at a number of localities in California. Sedimentary rocks of Refugian age may have been eroded completely from the western margin of the basin and at least as far east as the western part of Big Basin, Camp Pomponio along Pescadero Creek, and La Honda oil field; and eroded partly from eastern Big Basin and Little Boulder Creek areas. An alternate and likely explanation for the westward thinning of strata referred to the Refugian is that the area west of Camp Pomponio, Big Basin, and La Honda was a site of little or no sedimentation during the early Oligocene (Refugian). When sedimentation resumed in late Oligocene (Zemorrian) time, glauconite and phosphate formed since the late Eocene (Narizian) in the western part of La Honda Basin as well as since mid-Oligocene time in the south-central part of La Honda Basin, were incorporated in the basal Zemorrian beds. Fine silt and clay were deposited in a bathyal environment in the San Lorenzo River area and in the Mindego Hill quadrangle whereas silt and fine sand were the chief deposits in west Big Basin where the environment is thought to have been neritic.

After 750 feet (when compacted) of mud and silt had accumulated during early Zemorrian time in the San Lorenzo River area near Riverside Grove, coarse sand derived from a rising landmass west and southwest of the area mapped was washed into the basin and distributed progressively farther eastward and northward to develop the Vaqueros sandstone. The thickening of the Vaqueros sandstone in the vicinity of Saratoga Summit and the discovery by Beveridge (1960) that the Vaqueros in that area contains glaucophane and more diopside and magnetite than at other localities in the northern Santa Cruz Mountains suggest that some of the sand in the Vaqueros in that area was eroded from a rising Franciscan terrain along the east border of La Honda Basin. Very little sand from either source reached the area near La Honda, where silt and clay continued to be deposited in a bathyal environment.

Near the end of the deposition of sand that now forms the Vaqueros sandstone, volcanic activity began in the vicinity of Langley and Mindego Hills. Thick layers of pillow lava, flow-breccia, and tuff were built up on the basin floor and eventually reached the surface of the sea. Bioclastic limestone was deposited on shallow banks associated with these volcanic islands. In deeper parts of La Honda Basin volcanic rocks were interstratified with sand and mud. During the same period of volcanic activity, diabase sills were intruded into the partly consolidated sediments a few thousand feet below the bottom of the basin.

Land areas bordering La Honda Basin evidently subsided in late Zemorrian time: the water encroached at least as far west as Pescadero Beach, where conglomerate and sand were deposited; as far south as Año Nuevo Point (Hall et al., 1959, fig. 3), where sand and mud were laid down; and perhaps eastward across the San Andreas fault to the Adobe Creek area near Palo Alto where mud was deposited.

Oligocene or Early Miocene (Saucesian). Volcanism and subsidence of the region continued in Oligocene or early Miocene (Saucesian) time. Clay, silt, sand, and dolomite were deposited in the east-central part of the district and volcanic rocks in the northern part of the area mapped in this report. The bottom of La Honda Basin was probably at a bathyal depth in the vicinity of Oil Creek and Peters Creek, and sloped upward in a southerly direction to a shallow neritic depth on the south flank of Ben Lomond Mountain where the echinoid "reef" described by Page and Holmes (1945) was deposited. It may also have sloped upward in a northeasterly direction to a neritic depth in the Palo Alto area where sand, silt, and clay were laid down.

Middle Miocene (Relizian and Luisian). La Honda Basin was apparently uplifted in late Saucesian or early Relizian time and much of the veneer of late Zemorrian and early Saucesian sediment was eroded from the central and southern part of the area mapped.

In late Relizian and early Luisian time, the basin sank again to a lower neritic or bathyal depth and locally collected more than 1,000 feet (when compacted) of siliceous mud and, near Ben Lomond Mountain at least, 200 feet of basal sand. The basin had unrestricted access to the open sea and may have extended eastward across the San Andreas fault to Los Altos area where siliceous mud was also deposited.

Strata deposited in La Honda Basin were folded, faulted, and uplifted during Miocene diastrophism. The age of this deformation is not known with precision but it is post-Luisian and probably pre-Delmontian. It may have been pre-Mohnian, for Kleinpell (1938, p. 127-128) pointed out that strata of Mohnian age lie with angular discordance on Luisian and older rocks at a number of localities in California. Butano anticline and probably most of the other folds in the Santa Cruz Mountains as well as the Ben Lomond fault were initiated during this diastrophism. The region was then eroded to a surface of relatively low relief.

Late Miocene (Delmontian). The basin subsided in late Miocene (Delmontian?) time and some areas were covered by the ocean. The extent of the transgressing sea is not known, but it included the western and southern part of the area mapped in this report and may have included all of the district as far north and east as Matadero Creek near Stanford University. Sand was deposited at the base of the sequence and was followed by several hundred to several thousand feet of siliceous mud along the western border of the area.

Pliocene. Subsidence of La Honda Basin continued in Pliocene time, flooding the region as far east as Stanford University. The deepest part of the basin was evidently in the vicinity of Pomponio Creek. The sea floor subsided continually as more than 5,600 feet (when compacted) of sand, silt, and siliceous mud was deposited at neritic depth. Simultaneously, vitric tuff from volcanoes somewhere on the east side of San Francisco Bay, and crystal and lithic tuff fragments from the Mehrten formation in the Sierra Nevada were blown and washed into the basin.

Late Pliocene, Pleistocene, and Recent. Diastrophism during late Pliocene and early Pleistocene time folded, faulted, and uplifted the strata in La Honda Basin. A range composed of rocks of the Franciscan formation was elevated on the northeastern boundary of the area, probably due to activity along the San Andreas fault, and coarse clastic detritus was spread westward (and eastward) as alluvial deposits over truncated older strata. Mid-Pleistocene diastrophism called Pasadenan by Stille

(1936), intensified previously formed structures in the Tertiary strata and locally deformed the early Pleistocene beds to nearly vertical dips. Warping of even the lowest marine terrace, youthful topography, and recurrent seismic activity in this region indicate that diastrophism is still in progress.

ECONOMIC GEOLOGY

Petroleum and Natural Gas. Indications of petroleum and natural gas have been known in the northern Santa Cruz Mountains for more than a century (Trask, 1854). A number of oil and gas seeps were encountered during this investigation. The largest is an oil seep in Waterman Creek near the axis of the Oil Creek anticline where trickles of high-gravity, sweet-smelling, green oil issue from fractured San Lorenzo shale and produce a scum several inches thick on pools in the creek. A smaller seep was found along San Lorenzo River where the axis of the Oil Creek anticline is cut by the Brush Creek fault. Other seeps were found in siltstone of the Mindego formation in Slate Creek and in the Tahana member of the Purisima formation along Pescadero and Tarwater Creeks.

There are two known gas seeps. One bubbles through a large pool in Peters Creek. The other has been cased through the stream gravels in El Corte de Madera Creek and can be ignited. A small amount of salt water rises with the gas.

At least 100 separate test wells for oil and gas have been drilled in the northern Santa Cruz Mountains within the area covered by the accompanying geologic map. The only drilling operations which reached a depth of more than 1,000 feet are shown on the map. In many instances the locations can be readily determined and these vary somewhat from those shown by Davis (1955, pl. 5). The sources of information for most of the older wells include Haehl and Arnold (1904, p. 28), Bush (1925, p. 5-26), Senior (1929, p. 251-252), and Jennings and Hart (1956, p. 81). Recent locations were taken from petroleum-industry trade journals and scouting-service bulletins.

The earliest drilling operation within the area was in 1894 at a site west of La Honda, although several years earlier limited oil production had been established a short distance to the north on Purisima Creek (Goodyear, 1888, p. 99-101).

During the 1920s, after minor oil production was obtained near the mouth of Bogess Creek west of La Honda, 11 test wells were drilled before interest waned. Prior to 1944 all drilling was conducted by small operators, but in that year the Richfield Oil Company drilled their Souza No. 1 well 5 miles west of La Honda on San Gregorio Creek and obtained the first oil "shows" from the Butano formation. In October 1955, the Union Oil Company discovered the Oil Creek field in northeastern Big Basin quadrangle and completed the Costa No. 1 well for about 35 barrels per day from the Butano sandstone, but subsequent drilling proved disappointing. Cumulative production of the Oil Creek field to the end of 1960 was 47,900 barrels. Late in 1956 the Neaves Petroleum Company discovered the small La Honda oil field in the vicinity of the old noncommercial wells near the mouth of Bogess Creek. La Honda oil field now has seven producing oil wells and drilling is completed. The producing beds are Butano sandstone beds and the structure is a large northwest-trending anticline which was folded prior to the deposition of the Monterey and Purisima formations. The best well in the field is La Honda No. 3 which had an initial production in excess of 200 barrels of 32° API oil per day. The cumulative production of the field to the end of 1960 was 460,630 barrels.

In August 1959, the South La Honda field was discovered by the Neaves Petroleum Company on the Haskin Hill anticline. At the time of this writing, 10 wells are producing an average of 275 barrels of oil per day. Production is believed to be from sandstone beds in the Mindego and Butano formations. Cumulative production for the field to the end of 1960 was 107,320 barrels.

Road Metal. A number of quarries have been operated in the northern Santa Cruz Mountains for road metal. Basalt breccia of the Mindego formation is particularly suitable because its fragmentary nature allows it to be quarried and used with little or no crushing. This material usually has a high percentage of fines, compacts well, and forms a durable road surface. Siliceous mudstone beds from the Pomponio member of the Purisima formation and from the Monterey shale have been quarried for road metal in the vicinity of San Gregorio. Cretaceous conglomerate strata are quarried for gravel in the area south of the San Gregorio quadrangle.

Water Resources. High annual rainfall and adequate ground water storage capacity at higher elevations in the northern Santa Cruz Mountains provides ample water supply in this area. Even during the dry summer months the larger streams maintain a rather constant discharge, thanks to many perennial springs. The principal aquifers in the region are the intrusive diabase and the volcanic rocks of the Mindego formation. These rocks owe their storage capacity and permeability to many closely spaced fractures and joints. Porous sandstone strata in the Butano, Vaqueros, and Purisima formations also act as aquifers.

Miscellaneous. Hutton (1952) studied black sands which occur locally along the beaches of the San Gregorio quadrangle, and reported that they are composed largely of ilmenite and magnetite. They have not been exploited commercially. Siliceous pebbles from the Cretaceous conglomerate south of the mouth of Pescadero Creek were formerly cut and polished commercially as semi-precious gem stones (Davis, 1955, p. 418).

Well-bedded, weathered siliceous shale of the Woodhams formation has been quarried on Langley Hill, probably for use as decorative stone, but there has been no recent activity at this deposit.

No commercial aggregate plant operates within the area, but local ranchers obtain small amounts of sand and gravel from creek beds.

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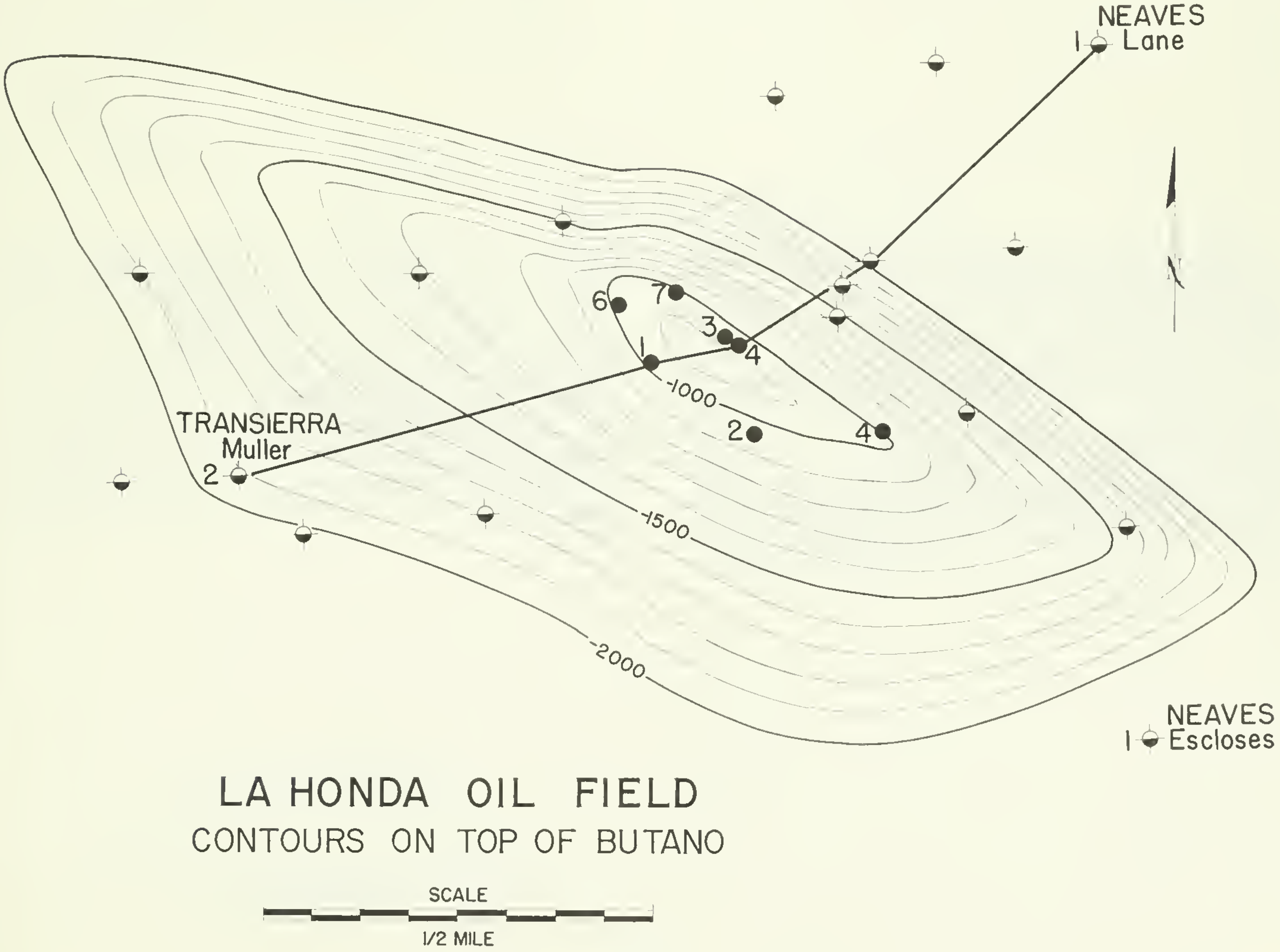
LA HONDA OIL FIELD, CALIFORNIA

By HAROLD L. FOTHERGILL, Geologist
Union Oil Company of California

La Honda oil field is located in San Mateo County in the Santa Cruz Mountains. The discovery well of the Eocene pool was the Neaves-Union Lane No. 2, completed in October 1956, from the interval 1728-1741 feet, with production coming from the Butano sandstone of Eocene age. The initial production flowing was 90 B/D, 15 percent cut, 32.8°, 50 Mcf. The pool extent was delineated rapidly with the drilling of six additional flowing wells, some of them whipstocked.

Figure 1.



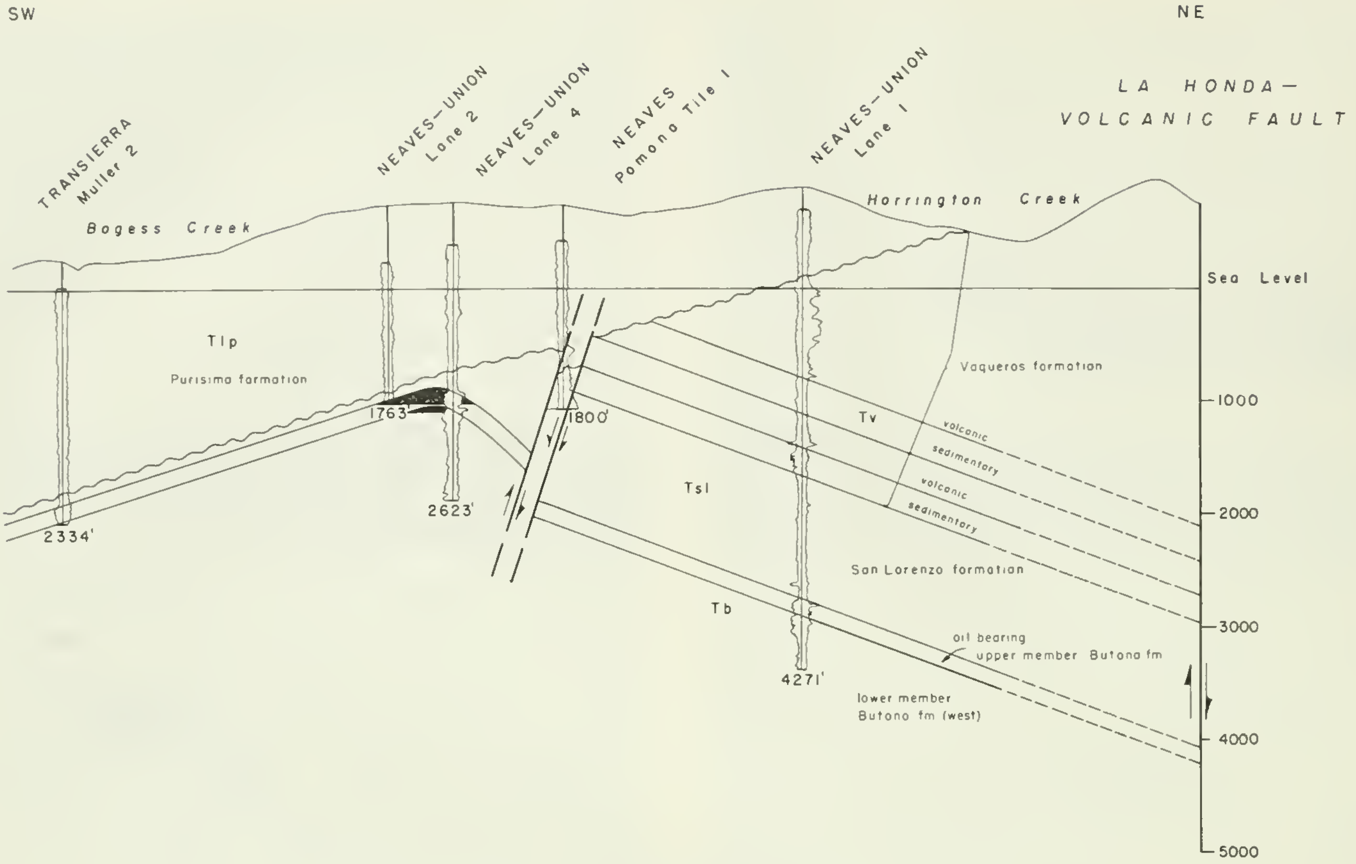


Figure 2. Cross section through La Honda oil field; for location, see figure 1.

The best well in the pool was completed flowing with an initial production of 750 B/D, clean 32.8° oil through an open bean. At the peak of production the pool was producing 900 B/D under restricted choke.

The areal extent of the pool is approximately 20 acres. As of January 1, 1961, the field had produced a total of approximately 475,000 barrels net oil; at that time it had a daily rate of 225 barrels net oil.

The surface geology shows a west-dipping homocline in the exposed Purisima (Pliocene) beds. The producing structure is anticlinal under the Pliocene unconformity; there is no surface evidence of this hidden fold. The discovery was based on dipmeter results and stratigraphy of the Neaves-Union Lane No. 1 well.

The stratigraphic section in the field consists of the Purisima, San Lorenzo, and Butano formations.

Thirteen additional wells, all dry and abandoned, have been drilled in the immediate area by Neaves-Union, as well as by other operators. The information from these wells shows the accumulation to be at the very top of a large anticlinal structure hidden beneath the Purisima formation.

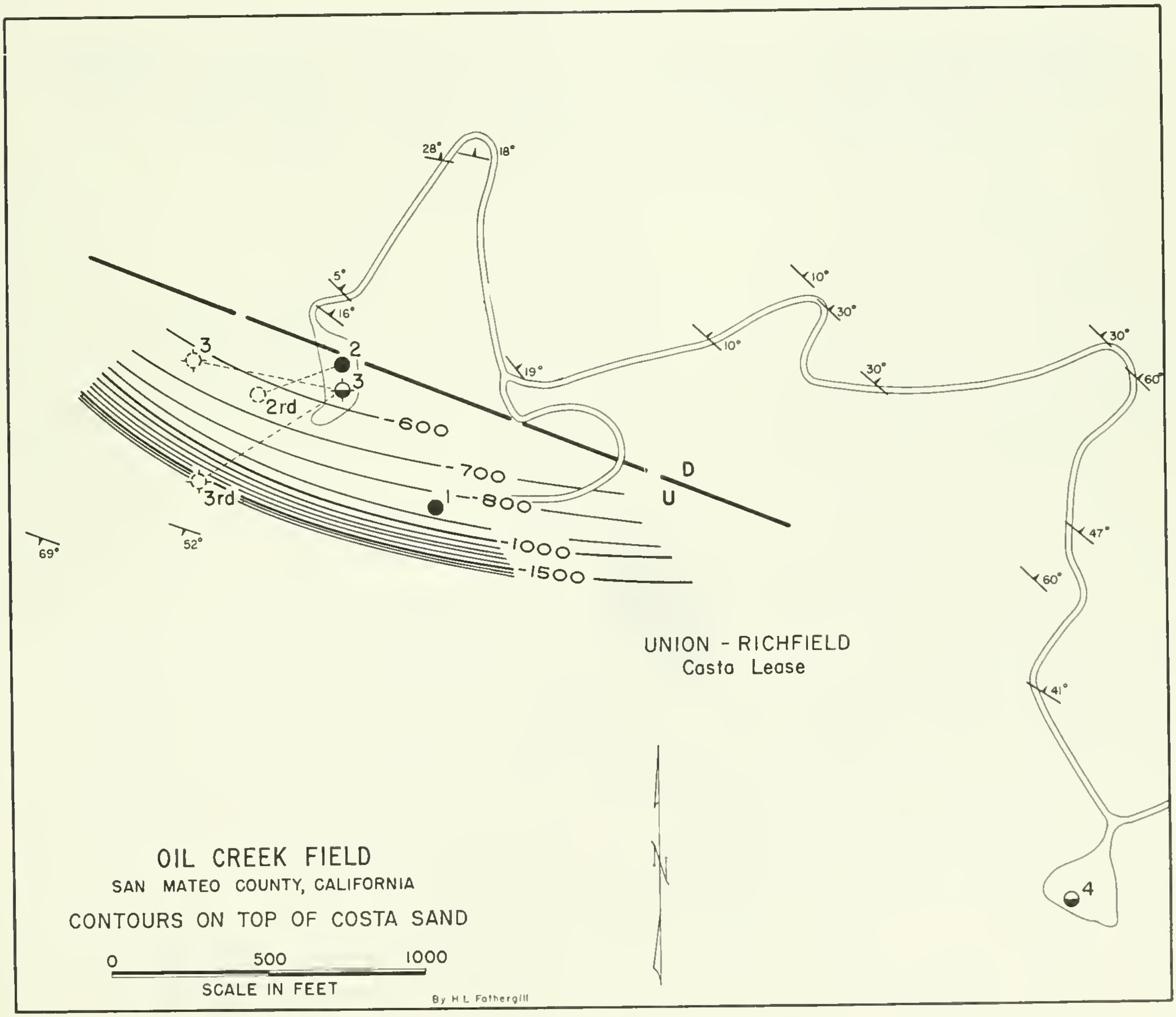
OIL CREEK OIL FIELD, CALIFORNIA

By HAROLD L. FOTHERGILL, Geologist
Union Oil Company of California

The Oil Creek field is located in the southeast corner of San Mateo County, in the Santa Cruz Mountains. The discovery well was the Union-Richfield Costa No. 1, completed in October 1955, from the interval 2055-2206 feet, with production coming from the Butano sandstone of Eocene age. The initial production on the pump was 100 B/D, 10 percent cut, 43.2°, 45 Mcf. As of January 1, 1961, the well had produced a total of approximately 45,000 barrels net oil and had a daily rate of 12 barrels net oil.

The surface structure is anticlinal and was delineated in the field by close coordination of surface mapping and paleontological control. The subsurface structure is that of a faulted anticline or a bowing against a fault.

Figure 1.

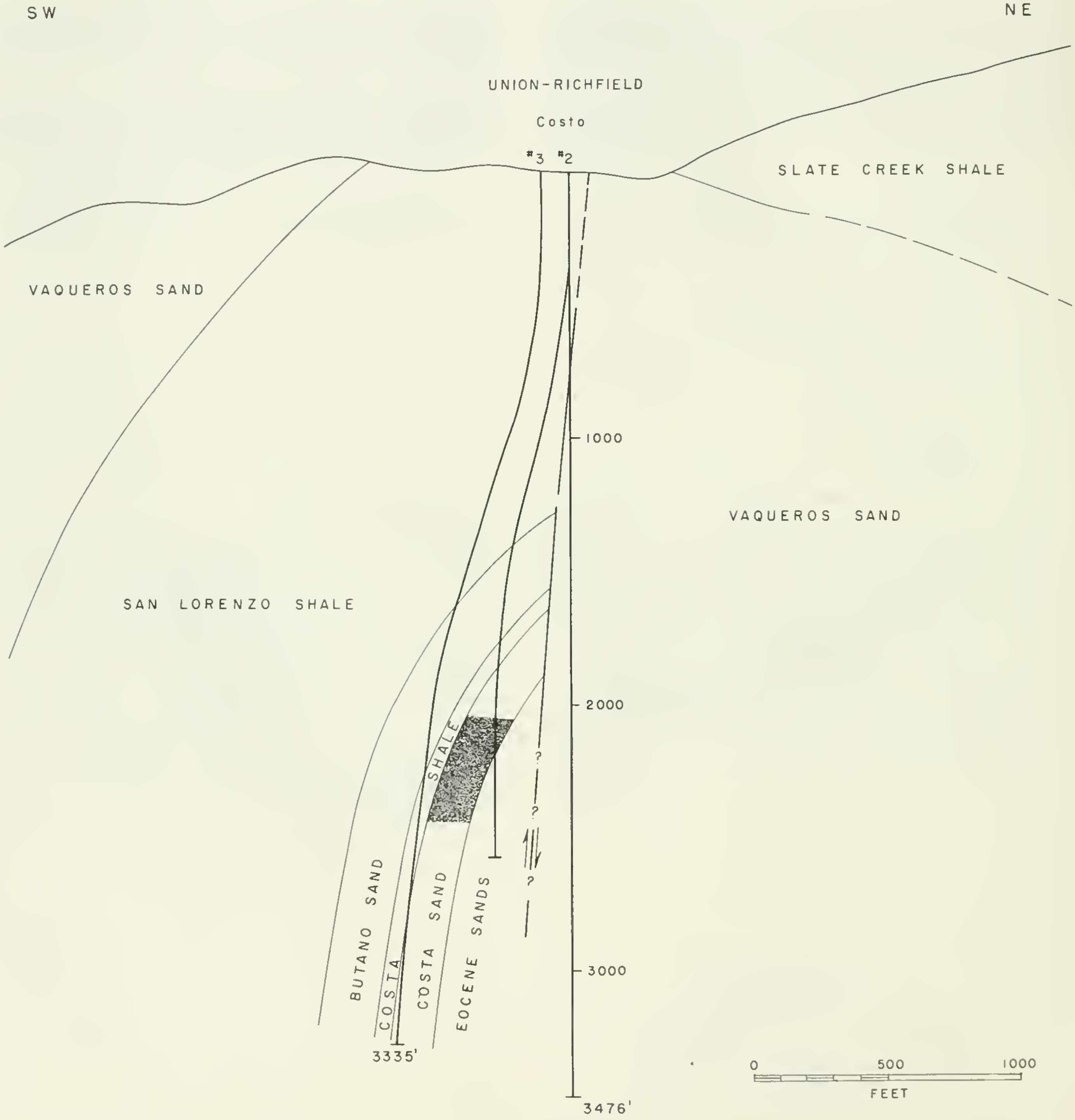


The stratigraphic section in the field consists of the San Lorenzo and Butano formations.

Five wells have been drilled in the field but only the discovery well proved to be commercial. The second well encountered a major fault and bottomed in the down-thrown side, the third and fourth wells were high and in the gas cap, and the fifth well was low and wet.

Exploration is difficult, not only because of the complex structural conditions, but because surface exposures are limited by the thick growth of trees and underbrush.

Figure 2. Cross section through the Union-Richfield wells Costa 2 and 3, Oil Creek field.



PART III

MAPS AND DATA SHEETS FOR THE OIL AND GAS FIELDS OF NORTHERN SAN JOAQUIN VALLEY, SACRAMENTO VALLEY, AND NORTH COASTAL REGION

CONTENTS

MAPS AND DATA SHEETS FOR THE OIL AND GAS FIELDS OF NORTHERN SAN JOAQUIN VALLEY, SACRAMENTO VALLEY, AND NORTH COASTAL REGION

By CALIFORNIA DIVISION OF OIL AND GAS
E. H. MUSSER, State Oil and Gas Supervisor
E. R. MURRAY-AARON, Chief Deputy

Reprinted from *California Oil and Gas Fields*, October 1960, pages 356-493.

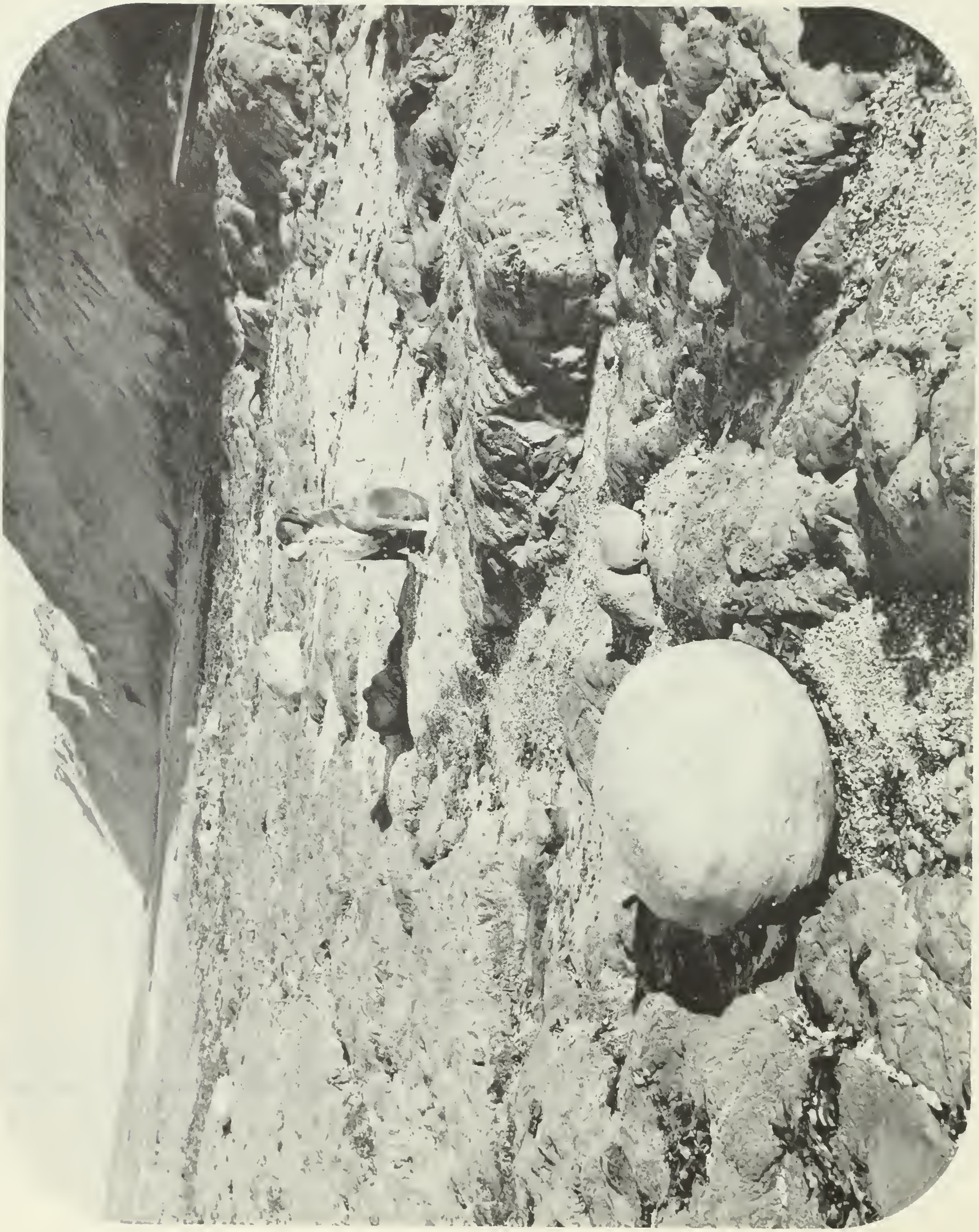
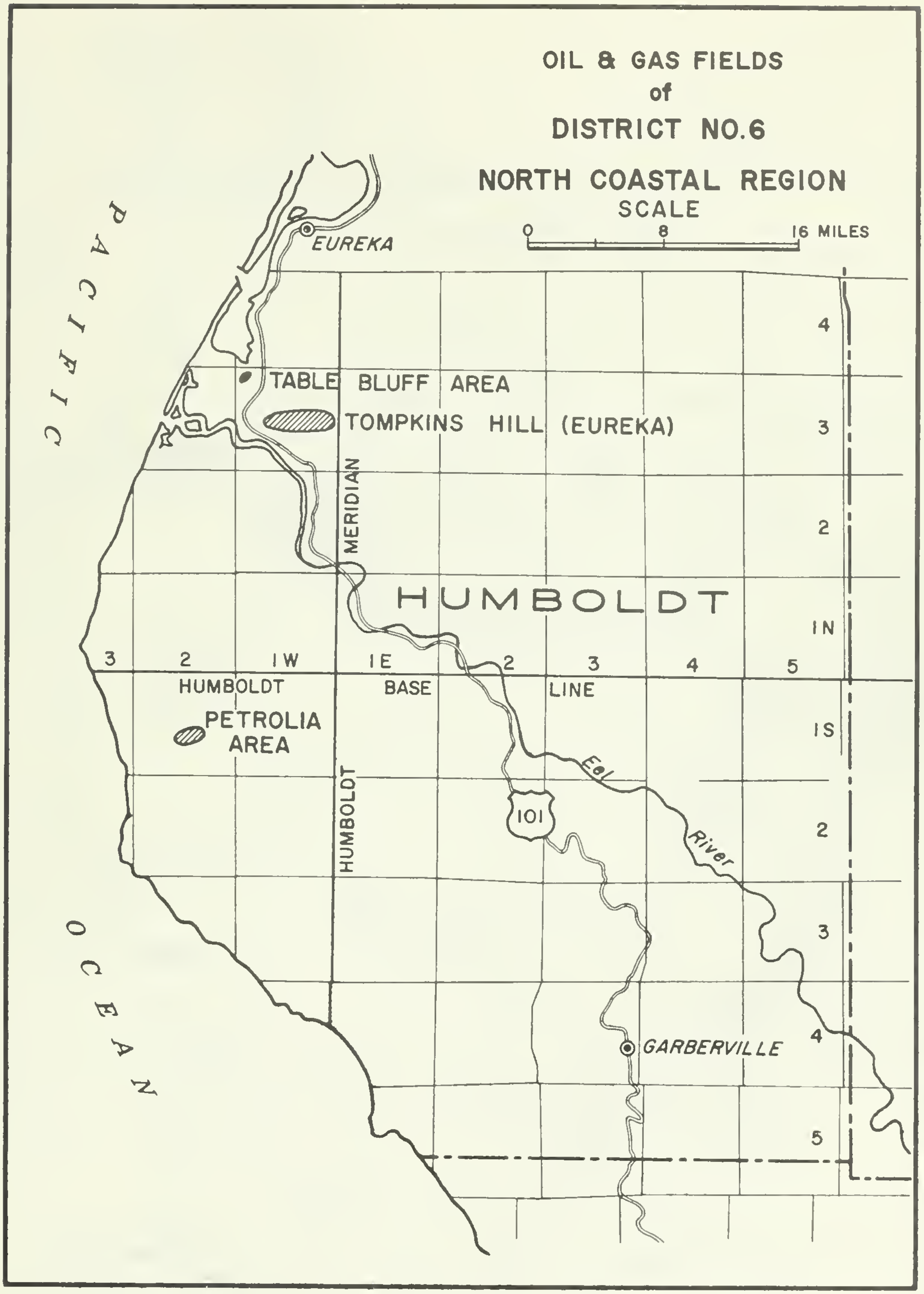


Photo 1. Duxbury reef, near Bolinas, Marin County, at low tide. Exploration for petroleum in this region began as early as 1865, attracted by asphalt seeps, heavy oil, and gas.
Photo by Sarah Ann Davis


OIL & GAS FIELDS
of
DISTRICT NO.6
NORTH COASTAL REGION
SCALE
0
8
16 MILES
EUREKA
PACIFIC
OCEAN
TABLE BLUFF AREA
TOMPKINS HILL (EUREKA)
MERIDIAN
HUMBOLDT
4
3
2
IN
IS
2
3
4
5
3
2
IW
IE
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4
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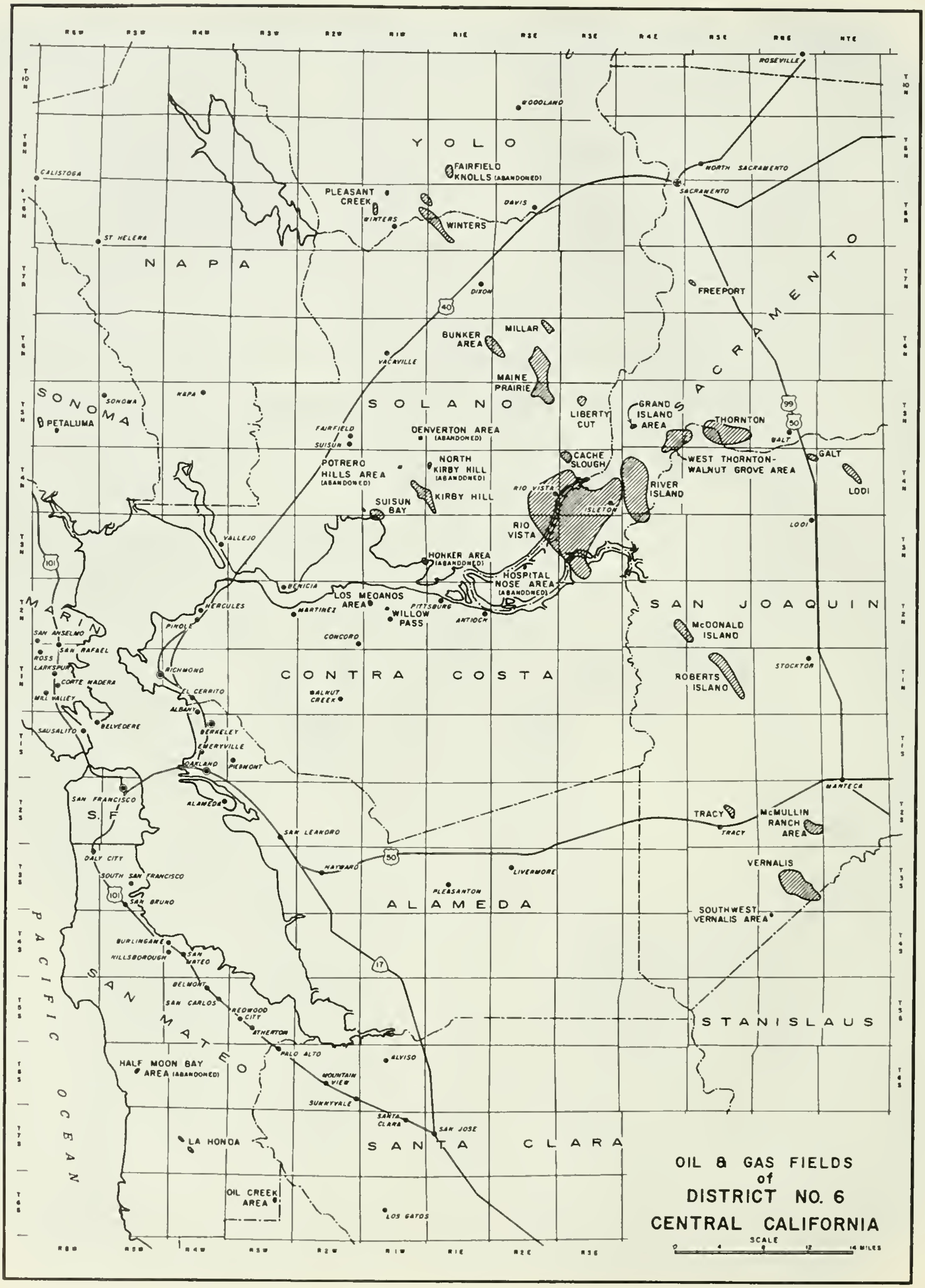
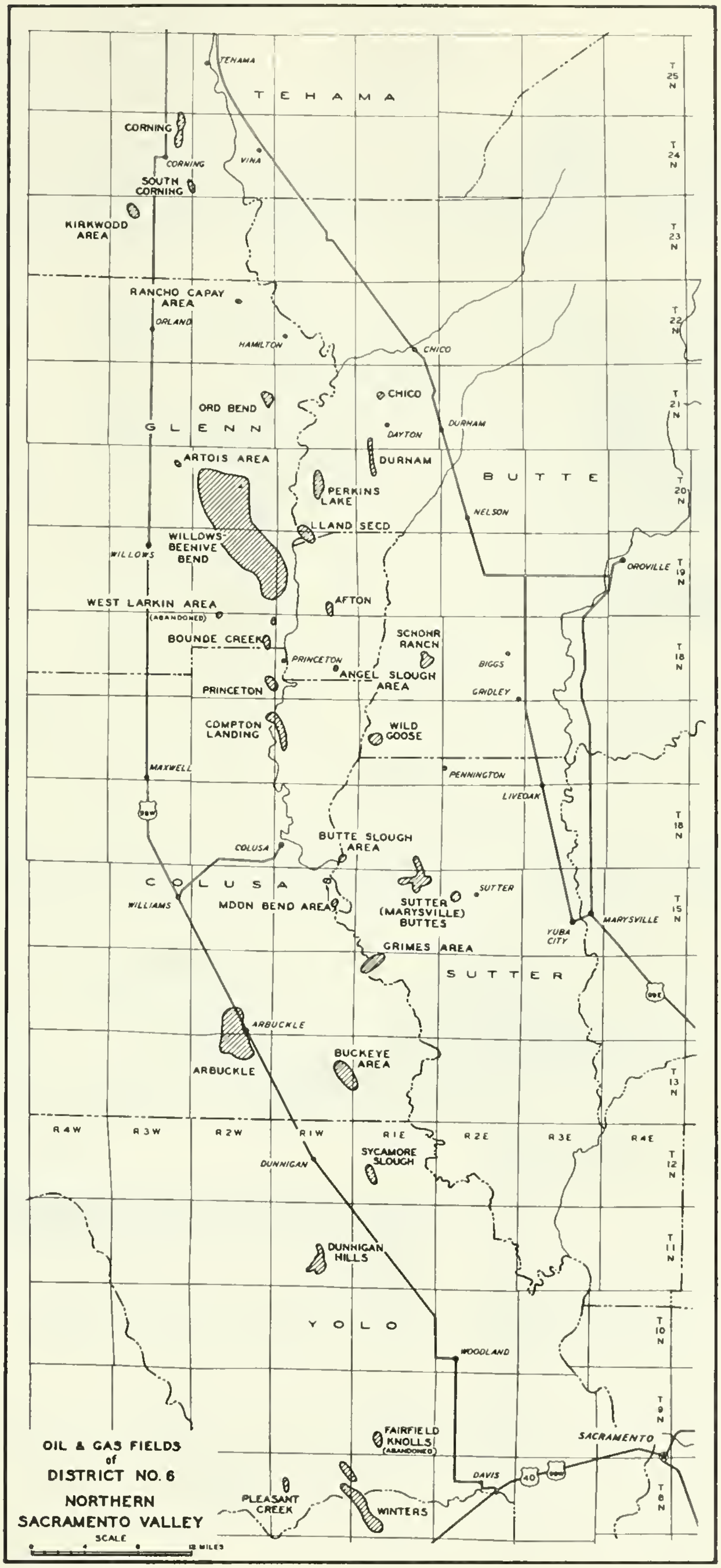
HUMBOLDT
BASE
LINE
PETROLIA
AREA
HUMBOLDT
Eel
River
101
GARBERVILLE

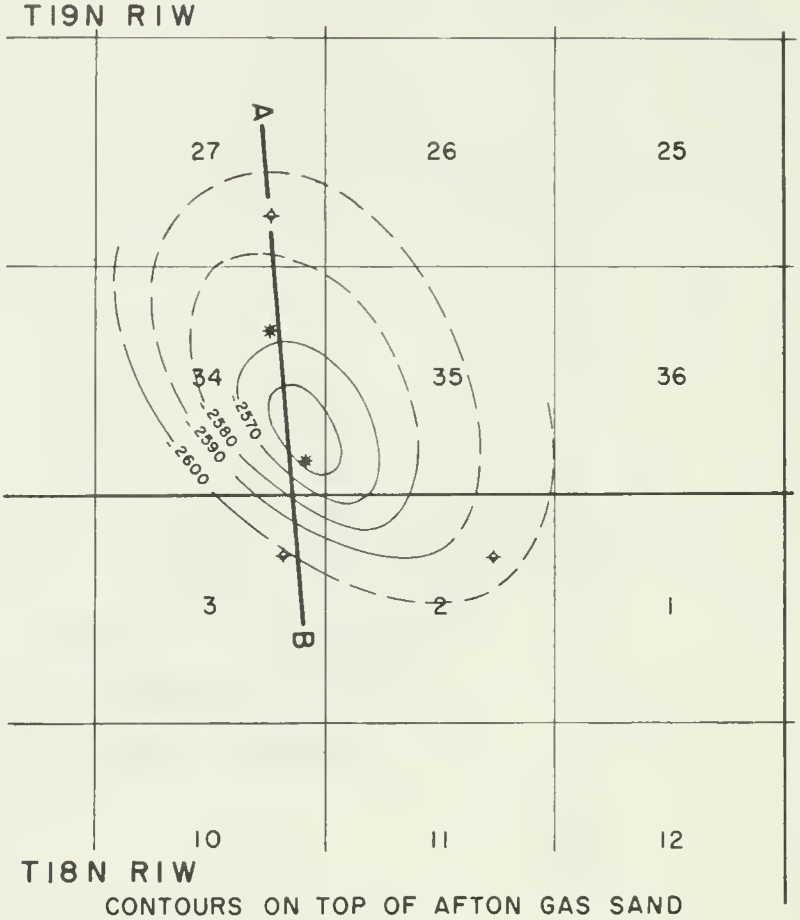


OIL & GAS FIELDS
of
DISTRICT NO. 6
CENTRAL CALIFORNIA

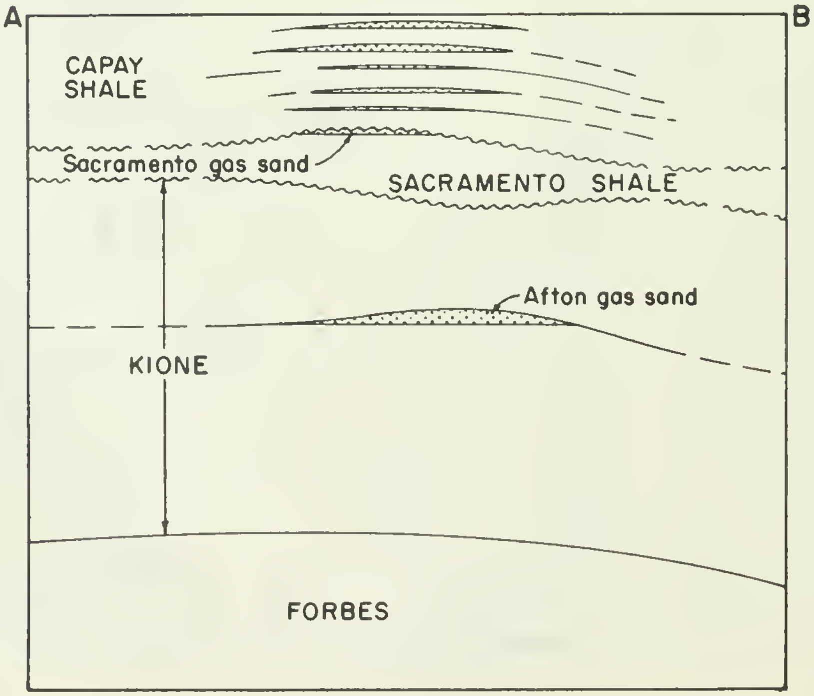

OIL & GAS FIELDS
of
DISTRICT NO. 6
NORTHERN
SACRAMENTO VALLEY
SCALE
0
4
8
12 MILES
TEHAMA
GLENN
BUTTE
COLUSA
SUTTER
YOLO
TEHAMA
CORNING
CORNING
VINA
SOUTH CORNING
KIRKWOOD AREA
RANCHO CAPAY AREA
ORLAND
HAMILTON
CHICO
CHICO
ORD BEND
DURHAM
DAYTON
ARTOIS AREA
DURNAM
PERKINS LAKE
NELSON
LLAND SECD
WILLOWS-BEEHIVE BEND
WILLOWS
OROVILLE
WEST LARKIN AREA
(ABANDONED)
AFTON
BOUNDE CREEK
SCHOHR RANCH
PRINCETON
BIGGS
ANGEL SLOUGH AREA
PRINCETON
GRIDLEY
COMPTON LANDING
WILD GOOSE
MAXWELL
PENNINGTON
LIVEOAK
99W
BUTTE SLOUGH AREA
COLUSA
SUTTER
WILLIAMS
MOON BEND AREA
SUTTER (MARYSVILLE) BUTTES
YUBA CITY
MARYSVILLE
GRIMES AREA
99E
ARBUCKLE
ARBUCKLE
BUCKEYE AREA
R 4 W
R 3 W
R 2 W
R 1 W
R 1 E
R 2 E
R 3 E
R 4 E
DUNNIGAN
SYCAMORE SLOUGH
DUNNIGAN HILLS
WOODLAND
FAIRFIELD KNOLLS
(ABANDONED)
SACRAMENTO
DAVIS
40
99W
PLEASANT CREEK
WINTERS
T 25 N
T 24 N
T 23 N
T 22 N
T 21 N
T 20 N
T 19 N
T 18 N
T 18 N
T 15 N
T 13 N
T 12 N
T 11 N
T 10 N
T 9 N
T 8 N

AFTON GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium & Victor	150
	Tehama	1550
EOCENE	Ione	110
	Capay Capay gas sand	370
UPPER CRETACEOUS	Sacramento gas sand Sacramento	170
	Afton gas sand Kione	960
	Forbes	1940 (drilled)



CONTOURS ON TOP OF AFTON GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

AFTON GAS FIELD
Glenn County

LOCATION 4-1/2 miles northeast of Princeton.

DISCOVERY DATA Richfield Oil Corp. well No. "Afton Community 1" 1 (now Buttes Gas & Oil Co. well No. "Afton Community 1" 1), Sec. 34, T. 19 N., R. 1 W., M.D.B.& M. Completed February 14, 1944, flowing gas from the interval 2,648-2,660 at the average rate of 5,700 Mcf/d.

STRUCTURE Dome.

ELEVATION 85 BASE OF FRESH WATERS 1,300 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Capay	1,830	30	Eocene	Capay	770	1,540
Sacramento	2,170	28	U. Cretaceous	Sacramento	770	1,540
Afton	2,650	25	U. Cretaceous	Kione	770	1,540

DEEPEST WELL DATA The discovery well. T.D. 5,247 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	4
Cumulative Gas (Mcf.)	4,098,848	Total Wells Completed	2
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	2
1959 Average Gas (Mcf/d)	226	Maximum Proved Acreage	160
Peak Production (1949) (Mcf.)	821,134		

USUAL CASING PROGRAM
10-3/4" cem. 550
4-1/2" cem. through gas zone and shot-perforated for production

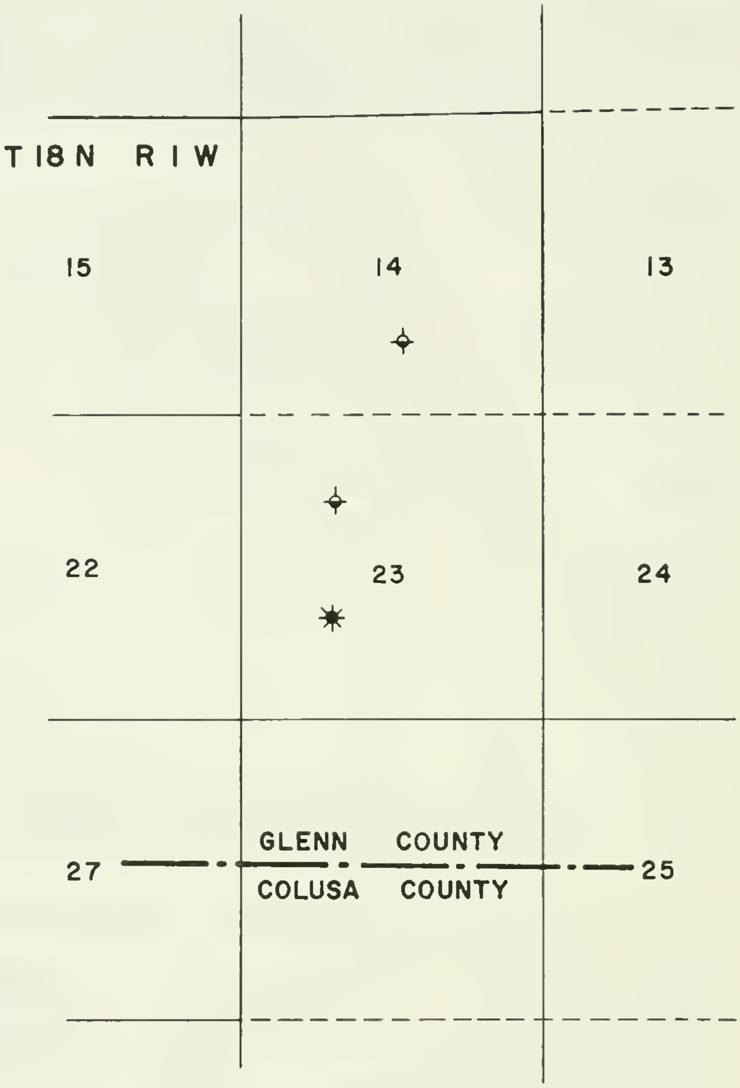
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in December 1947.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 33, No. 2 (1947)

ANGEL SLOUGH GAS AREA

EPOCH	FORMATION		Thickness (Feet)
PLIOCENE — RECENT	Alluvium		1400±
	Tehama		
EOCENE	Ione		650
	Capay		350
UPPER CRETACEOUS	Kione	Wild Goose sands ▨	1400
	Forbes		2450
	Dobbins		360
	Guinda		310 (drilled)



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

ANGEL SLOUGH GAS AREA
Glenn County

LOCATION 3-1/2 miles east of Princeton.

DISCOVERY DATA Humble Oil & Refining Co. well No. "John R. Hulen, et ux" 1, Sec. 23, T. 18 N., R. 1 W., M.D.B.& M. Completed June 16, 1960, flowing gas from the interval 2,383-2,396 at the average rate of 2,884 Mcf/d through a 24/64-inch bean under a flow pressure of 365 psi.

STRUCTURE Anticline (?)

ELEVATION 80 BASE OF FRESH WATERS - SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Wild Goose	2,383	15	U. Cretaceous	Kione	-	-

DEEPEST WELL DATA The discovery well. T.D. 7,019 in Guinda (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	-	Total Wells Drilled	-
Cumulative Gas (Mcf.)	-	Total Wells Completed	-
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	-
Peak Production	-		

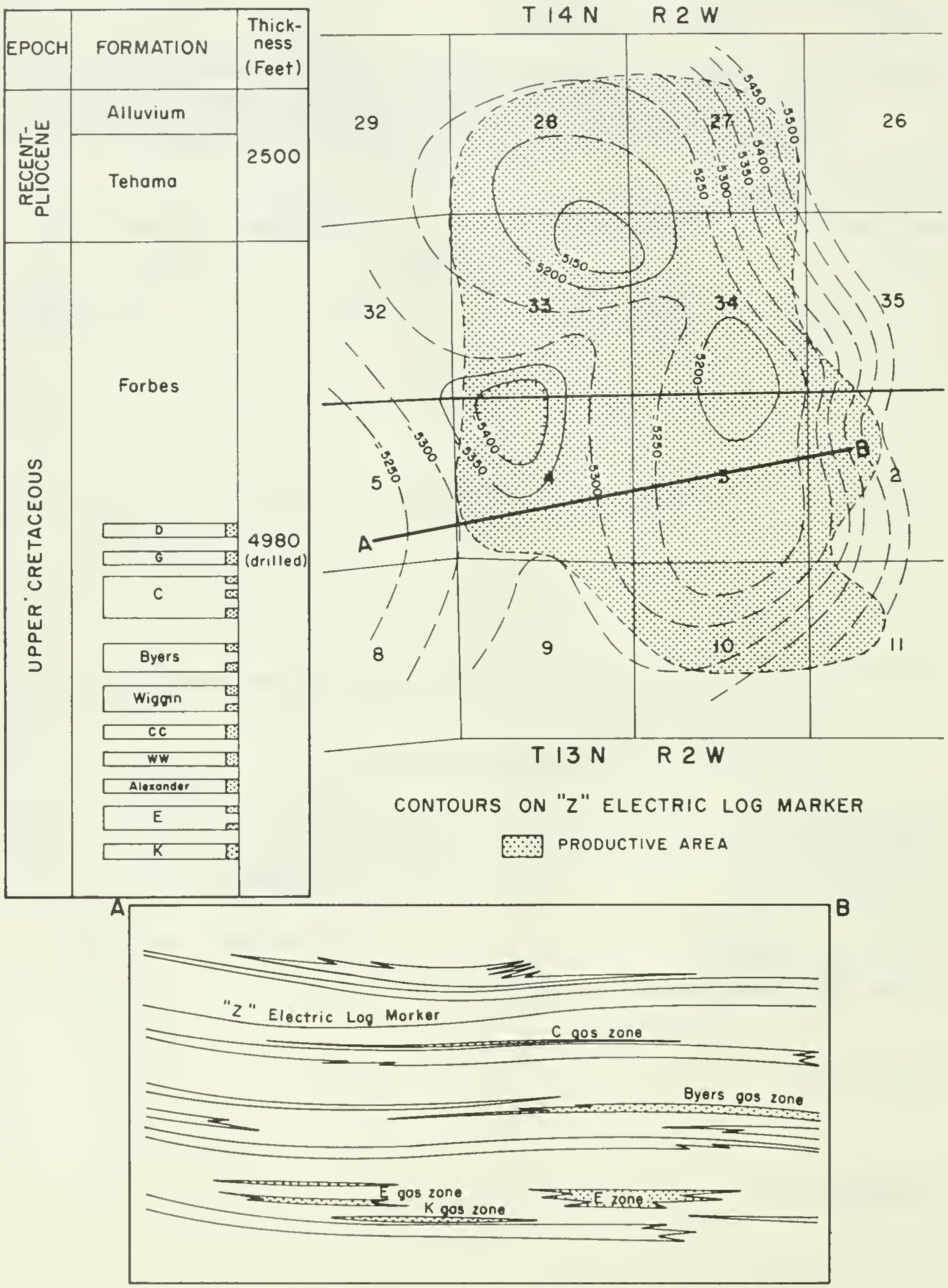
USUAL CASING PROGRAM
10-3/4" cem. 500-600
7" cem. through gas zone and shot-perforated for production

BOP EQUIPMENT Required

MISCELLANEOUS -

REFERENCES -

ARBUCKLE GAS FIELD



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

ARBUCKLE GAS FIELD
Colusa County

LOCATION 9 miles northwest of Dunnigan and adjacent to U.S. Highway 99 W.

DISCOVERY DATA Western Gulf Oil Company well No. "Arbuckle Unit-C" 1, Sec. 3, T. 13 N., R. 2 W., M.D.B.& M. Completed February 3, 1957, flowing gas from intervals 5,581-5,608 and 5,873-5,910 at the average rate of 7,780 Mcf/d through a 1/2-inch bean under a flow pressure of 1,245 psi.

STRUCTURE Small folds on regional terrace.

ELEVATION 140-220 BASE OF FRESH WATERS 1,400 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
D	4,430	90	U. Cretaceous	Forbes	1,000	520-690
G	5,410	30				
C	5,550	30-80				
Byers	5,900	50				
Wiggin	5,990	60				
CC	6,015	5				
WW	6,060	30				
Alexander	6,180	30				
E	6,270	80				
K	6,400	25				

DEEPEST WELL DATA Western Gulf Oil Company well No. 1 "Alexander", Sec. 34, T. 14 N., R. 2 W. T.D. 7,479 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	22
Cumulative Gas (Mcf.)	7,418,893	Total Wells Completed	16
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	11
1959 Average Gas (Mcf/d)	10,287	Maximum Proved Acreage	2,560
Peak Production (1959) (Mcf.)	3,754,691		

USUAL CASING PROGRAM
9-5/8" cem. 1,900
5-1/2" cem. through gas zones and shot-perforated for production

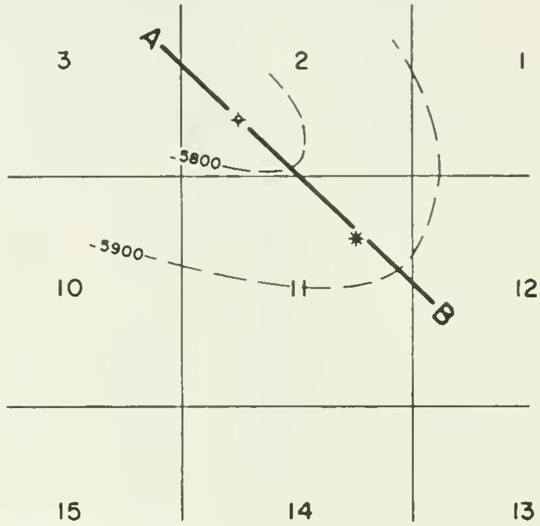
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in January 1958.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 43, No. 2 (1957)

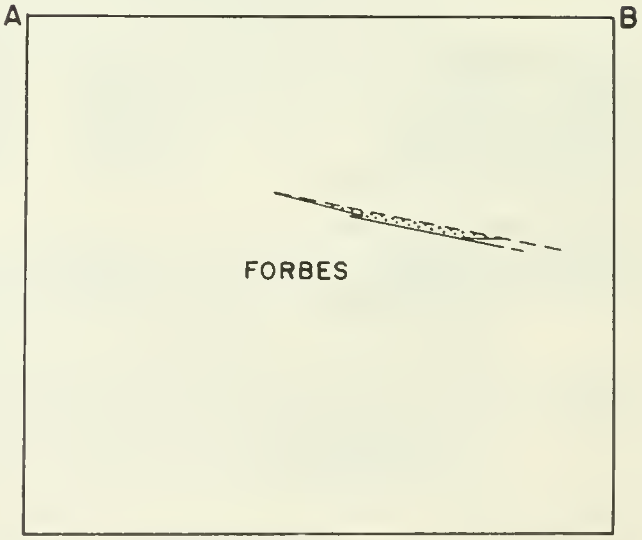
ARTOIS GAS AREA

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium Tehama	2100
EOCENE (?)	undifferentiated sediments	500
UPPER CRETACEOUS	Kione	1450
	Forbes	3100
	Dobbins	200
	Guinda	90 (drilled)



T20N R3W

CONTOURS ON TOP OF GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

ARTOIS GAS AREA
Glenn County

LOCATION 2 miles southeast of Artois and 2-1/2 miles northwest of Willows-Beehive Bend gas field.

DISCOVERY DATA Sunray Mid-Continent Oil Co. well No. "Sunray-McCulloch-Coast Expl. Von Bargen" 1, Sec. 11, T. 20 N., R. 3 W., M.D.B.& M. Completed November 29, 1959, flowing gas from the interval 5,885 to 5,905 at the average rate of 1,285 Mcf/d.

STRUCTURE Nose (?) Gas accumulation due to updip lensing.

ELEVATION 155 BASE OF FRESH WATERS 2,100 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
(un-named)	5,880	20	U. Cretaceous	Forbes	1,010	-

DEEPEST WELL DATA The discovery well. T.D. 7,447 in Guinda (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	1
Cumulative Gas (Mcf.)	1,600	Total Wells Completed	-
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	4	Maximum Proved Acreage	40
Peak Production (1959) (Mcf.)	1,600		

USUAL CASING PROGRAM

9-5/8" surface casing cem. 1,500
5-1/2" cem. through gas sand and shot-perforated for production

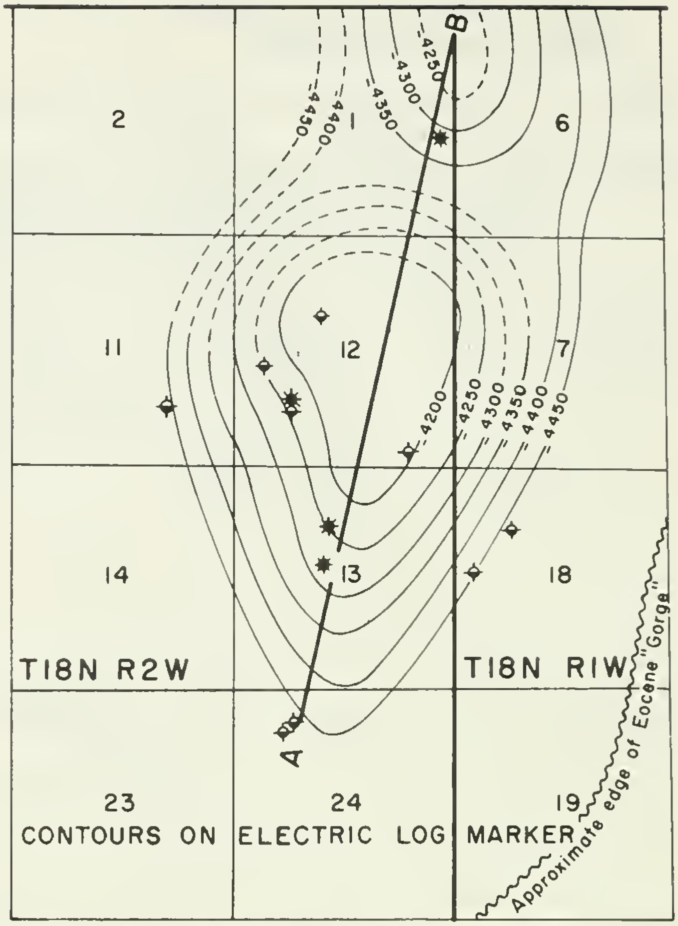
BOP EQUIPMENT Required

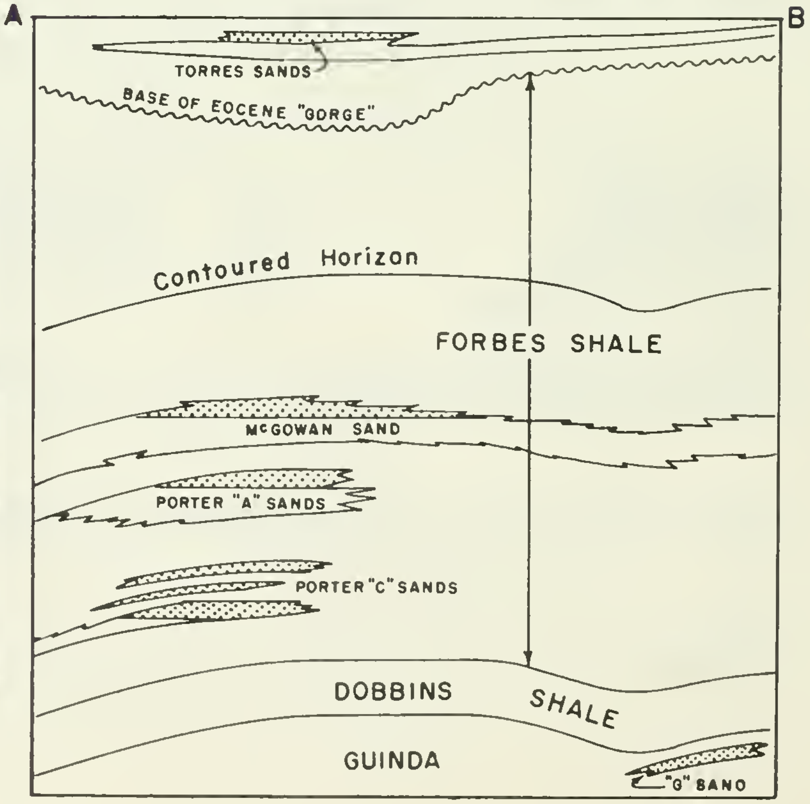
MISCELLANEOUS The well is shut-in pending (September 1960) an outlet for the gas.

REFERENCES -

BOUNDE CREEK GAS FIELD

EPOCH	FORMATION		Thickness (Feet)
RECENT	Alluvium		100
PLIOCENE	Tehama		1700
EOCENE	"GORGE" FILL		1700
		Torres sand	150
UPPER CRETACEOUS	Forbes		3700
		McGowan sand	250
		Porter sands A, C	1100
	Dobbins		300
	Guinda		400 (drilled)
		"G" sand	80





CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

BOUNDE CREEK GAS FIELD
Colusa and Glenn Counties

LOCATION 2 miles west of Princeton.

DISCOVERY DATA Humble Oil & Refining Co. well No. "Mamie H. Porter et al" 2 (now "Bounde Creek Gas Unit 1" 1), Sec. 13, T. 18 N., R. 2 W., M.D.B.& M. Completed September 9, 1956, flowing gas from intervals between 5,980 and 6,248 at the average rate of 3,980 Mcf/d.

STRUCTURE Sand lenses and updip lensing on anticline.

ELEVATION 75 BASE OF FRESH WATERS 1,800 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Torres	2,840	30	Eocene	"Gorge" fill	990)	900
McGowan	4,990	80	U. Cretaceous	Forbes	990)	
Porter A	5,450	100	U. Cretaceous	Forbes	990)	
Porter C	5,980	165	U. Cretaceous	Forbes	990)	
"G" sand	6,965	35	U. Cretaceous	Guinda	990)	

DEEPEST WELL DATA The discovery well. T.D. 7,529 in Guinda (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0
Cumulative Gas (Mcf.)	3,042,440
1959 Average Oil (b/d)	0
1959 Average Gas (Mcf/d)	7,272
Peak Production (1959) (Mcf.)	2,654,168

Total Wells Drilled	8
Total Wells Completed	4
Producing Wells (1959 Aver.)	3
Maximum Proved Acreage	280

USUAL CASING PROGRAM
9-5/8" or 10-3/4" cem. 1,800
5-1/2" cem. through gas sands and shot-perforated for production

BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in January 1958. Sudden increased pressure gradients are encountered in drilling below 5,000, requiring mud weight as high as 135 lb. per cu. ft.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 45, No. 1 (1959)

BUCKEYE GAS AREA

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium	3270
	Tehama	
EOCENE	Capay	280
UPPER CRETACEOUS	Starkey-Winters	600
	Sacramento	430
	Kione	400
	Forbes	4400 (drilled)

CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

BUCKEYE GAS AREA
Colusa County

LOCATION 8 miles southeast of Arbuckle.

DISCOVERY DATA Western Gulf Oil Co. well No. "F.J. Strain" 1 (now well No. "Wilkins Unit A" 1), Sec. 14, T. 13 N., R. 1 W., M.D.B.& M. Completed January 1, 1960, flowing gas from the interval 8,468-8,487 at an initial rate of 2,450 Mcf/d through a 9/16-inch bean under a flow pressure of 1,800 psi.

STRUCTURE Anticline with stratigraphic pinchout.

ELEVATION 37 BASE OF FRESH WATERS 2,300 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
"F" sands	8,150	50	U. Cretaceous	Forbes	1,015	-

DEEPEST WELL DATA Western Gulf Oil Co. well No. "Wilkins Unit A" 2, Sec. 13, T. 13 N., R. 1 W. T.D. 9,382 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	1
Cumulative Gas (Mcf.)	0	Total Wells Completed	1
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	-
Peak Production	-		

USUAL CASING PROGRAM
9-5/8" cem. 2,000
5-1/2" cem. through gas zone and shot-perforated for production

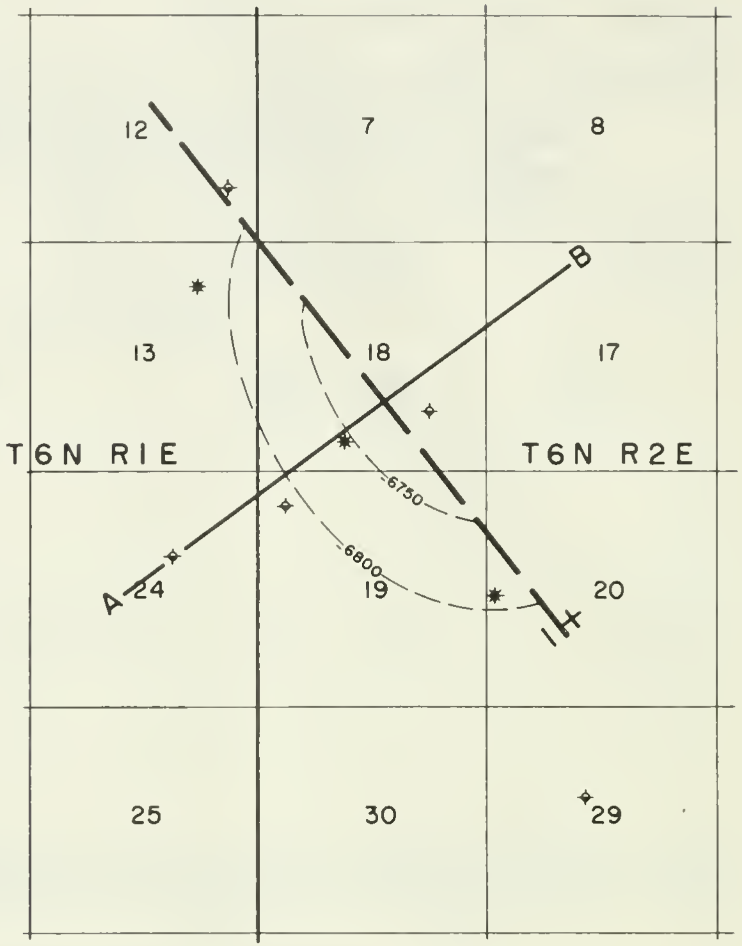
BOP EQUIPMENT Required

MISCELLANEOUS The wells are shut-in awaiting an outlet for the gas.

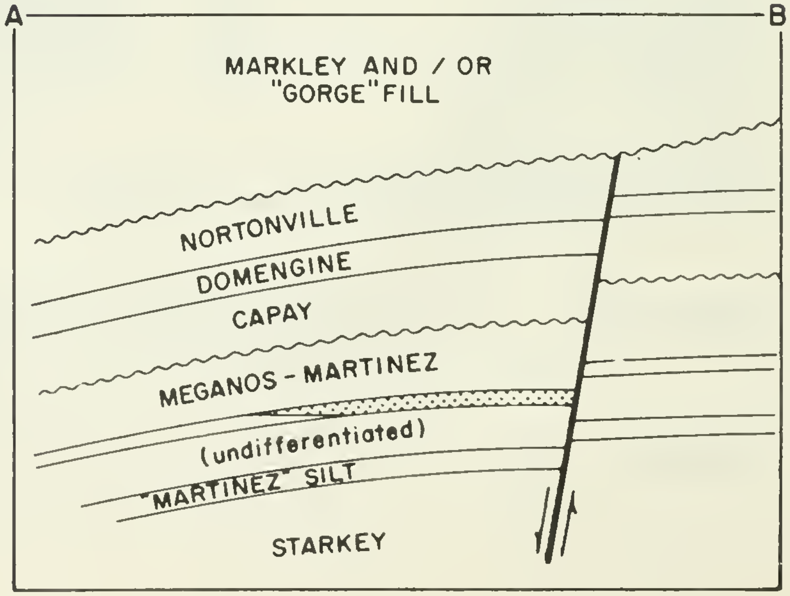
REFERENCES

BUNKER GAS AREA

EPOCH	FORMATION	Thickness (Feet)
POST — EOCENE	Undifferentiated Sediments Predominantly Nonmarine	3150
EOCENE	Markley and/or "Gorge" Fill	1260
	Nortonville	400
	Domengine	150
	Capay	750
PALEO-CENE	Meganos-Martinez (undifferentiated) ▨	1150
UPPER CRETACEOUS	"Martinez" silt	50
	Starkey	900 (drilled)



CONTOURS ON TOP OF GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

BUNKER GAS AREA
Solano County

LOCATION 6 miles southeast of Dixon.

DISCOVERY DATA G.E. Kadane & Sons well No. "Maine Prairie Gas Unit A" 1, Sec. 20, T. 6 N., R. 2 E., M.D.B.& M. Completed June 4, 1960, flowing gas from the interval 6,831-6,845 at an initial rate of 3,425 Mcf/d through a 1/4-inch bean under a flow pressure of 2.250 psi.

STRUCTURE Probable fault trap.

ELEVATION 25 BASE OF FRESH WATERS 2,500-3,100 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
(Unnamed)	6,825	25	Paleocene	Meganos-Martinez (undiff.)	-	-

DEEPEST WELL DATA Union Oil Co. of California well No. "Union-Amerada-Pedrick" 1, Sec. 12, T. 6 N., R. 1 E. T.D. 7,690 in Starkey (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	-	Total Wells Drilled	-
Cumulative Gas (Mcf.)	-	Total Wells Completed	-
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	-
Peak Production	-		

USUAL CASING PROGRAM
9-5/8" cem. 600
5-1/2" cem. through gas zone and shot-perforated for production

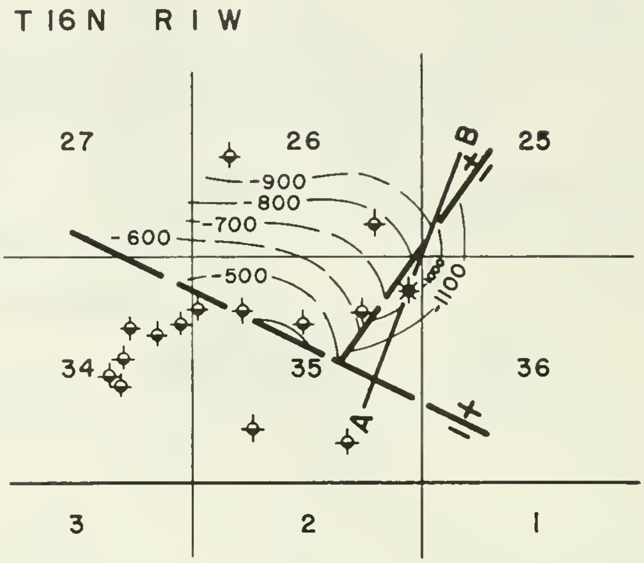
BOP EQUIPMENT Required

MISCELLANEOUS The wells are shut-in awaiting an outlet for the gas.

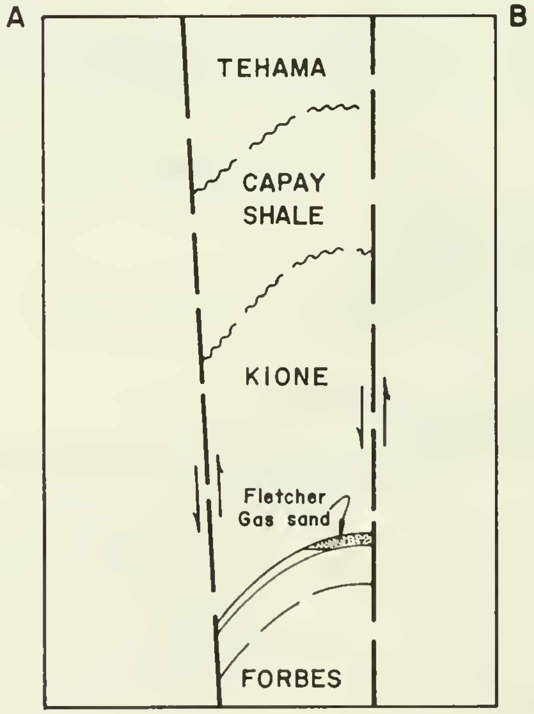
REFERENCES

BUTTE SLOUGH GAS AREA

EPOCH	FORMATION	Thickness (Feet)
RECENT to PLIOCENE	Alluvium	550
	Tehama	
EOCENE	Capay shale	450
UPPER CRETACEOUS	Kione	1000
	Fletcher ▨	
	Forbes and Older	5650
Basement Complex		500 (drilled)



CONTOURS ON TOP OF KIONE



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

BUTTE SLOUGH GAS AREA
Colusa County

LOCATION 4 miles east of Colusa and 1 mile northeast of Moon Bend Gas area.

DISCOVERY DATA Humble Oil & Refining Co. well No. "Belle Fletcher" 3 (now Colusa Ranch well No. "Belle Fletcher" 3), Sec. 35, T. 16 N., R. 1 W., M.D.B.& M. Completed October 3, 1955, flowing gas from the interval 1,815-1,850 at the average rate of 478 Mcf/d under a flow pressure of 635 psi.

STRUCTURE Faulted anticline.

ELEVATION 66 BASE OF FRESH WATERS 200 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Fletcher	1,815	35	U. Cretaceous	Kione	-	-

DEEPEST WELL DATA Amerada Petroleum Corp. well No. "Calif. Lands Colusa" 1, Sec. 34, T. 16 N., R. 1 W. T.D. 8,152 in basement complex (?).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	15
Cumulative Gas (Mcf.)	0	Total Wells Completed	1
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	40
Peak Production	-		

USUAL CASING PROGRAM
7" cem. 500
5-1/2" cem. through gas zone and shot-perforated for production

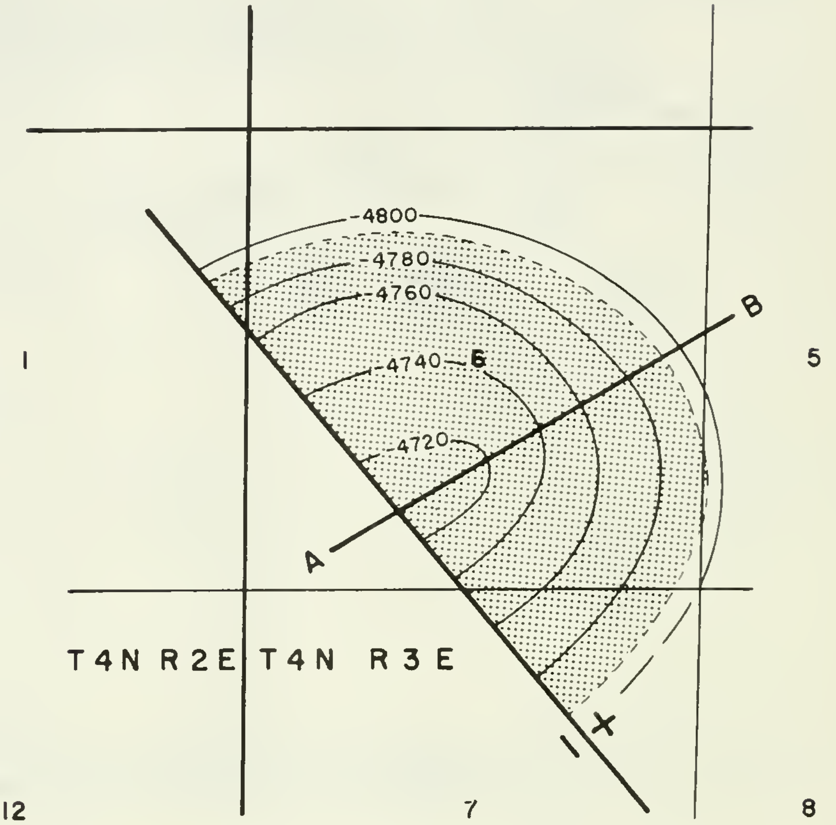
BOP EQUIPMENT Required

MISCELLANEOUS Formerly included in Moon Bend Gas area. Well is shut-in awaiting an outlet for the gas.

REFERENCES -

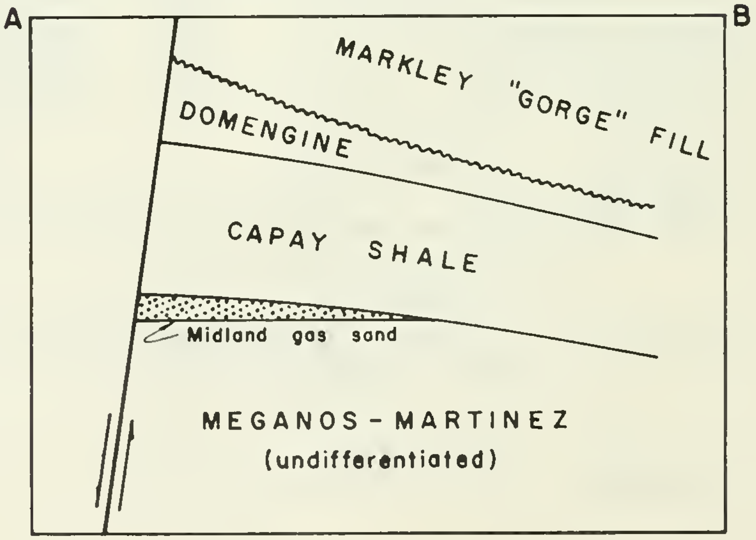
CACHE SLOUGH GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments Predominantly Nonmarine	3100
EOCENE	Markley "Gorge" Fill	800 TO 1430
	Domengine	150
	Capay	300
PALEOCENE	Midland gas sand	
	Meganos-Martinez (undifferentiated)	2150
UPPER CRETACEOUS	"Martinez" silt	90
	Starkey	750 (drilled)



CONTOURS ON TOP OF MIDLAND GAS SAND

▨ PRODUCTIVE AREA



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

CACHE SLOUGH GAS FIELD
Solano County

LOCATION 3 miles north of Rio Vista and adjoining Rio Vista gas field.

DISCOVERY DATA Standard Oil Co. of California well No. "California Packing Corp." 2, Sec. 6, T. 4 N., R. 3 E., M.D.B.& M. Completed March 2, 1945, flowing gas from the interval 4,765-4,790 at the average rate of 14,867 Mcf/d through a 5/8-inch bean under a flow pressure of 1,814 psi.

STRUCTURE Faulted nose.

ELEVATION 7 BASE OF FRESH WATERS 2,300 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Midland (Cal Pack)	4,730	35	Eocene-Paleocene	Meganos-Martinez (undiff.)	1,000	1,000
(unnamed)	5,335	5	Eocene-Paleocene	Meganos-Martinez (undiff.)	-	-

DEEPEST WELL DATA Standard Oil Co. of California well No. "Peter Cook" 12, Sec. 6, T. 4 N., R. 3 E. T.D. 7,730 in Starkey (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	9
Cumulative Gas (Mcf.)	10,825,616	Total Wells Completed	6
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	1,061	Maximum Proved Acreage	300
Peak Production (1948) (Mcf.)	2,558,328		

USUAL CASING PROGRAM
9-5/8" cem. 600
5-1/2" cem. through gas sand and shot-perforated for production

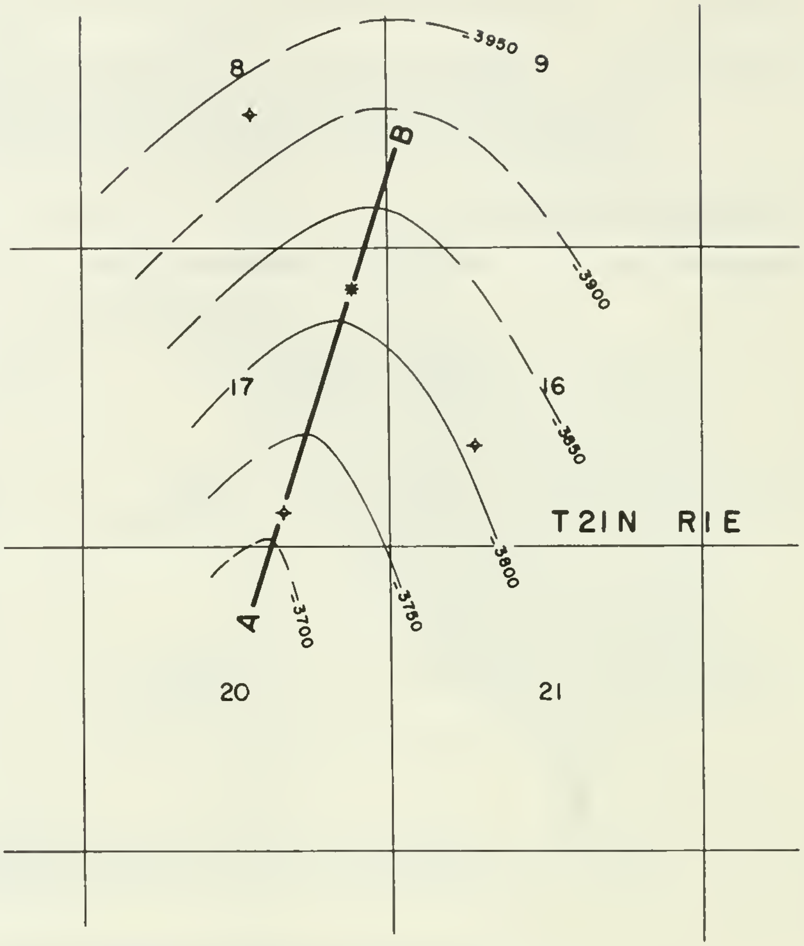
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in December 1947.

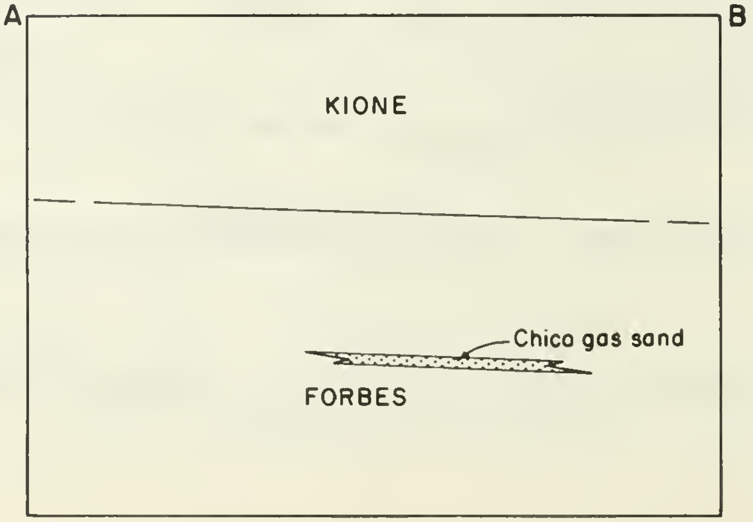
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 31, No. 2 (1945) and Vol. 33, No. 2 (1947)

CHICO GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium & Victor	150
	Tehama	1700
	Basalt	90
EOCENE	undifferentiated	250
	Capay	250
UPPER CRETACEOUS	Kione	1550
	Chico gas sand Forbes	1280
	Dobbins	500
	Guinda	510
	Funks	280
	Sites	470
Basement Complex		20 (drilled)



CONTOURS ON BASE OF KIONE



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

CHICO GAS FIELD
Butte County

LOCATION 4 miles southwest of Chico.

DISCOVERY DATA Richfield Oil Corp. well No. "Chico" 1 (now Buttes Gas & Oil Co. well No. "Estes" 1), Sec. 17, T. 21 N., R. 1 E., M.D.B.& M. Completed January 1, 1944, flowing gas from the interval 4,365-4,390 at the average rate of 2,070 Mcf/d.

STRUCTURE Nose. Gas accumulation in updip lens.

ELEVATION 142 BASE OF FRESH WATERS 1,400 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Chico	4,365	20	U. Cretaceous	Forbes	865	480

DEEPEST WELL DATA The discovery well. T.D. 7,005 in basement complex.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	3
Cumulative Gas (Mcf.)	1,194,028	Total Wells Completed	1
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	81	Maximum Proved Acreage	160
Peak Production (1947) (Mcf.)	221,381		

USUAL CASING PROGRAM
11-3/4" cem. 500
7" cem. through gas zone and shot-perforated for production

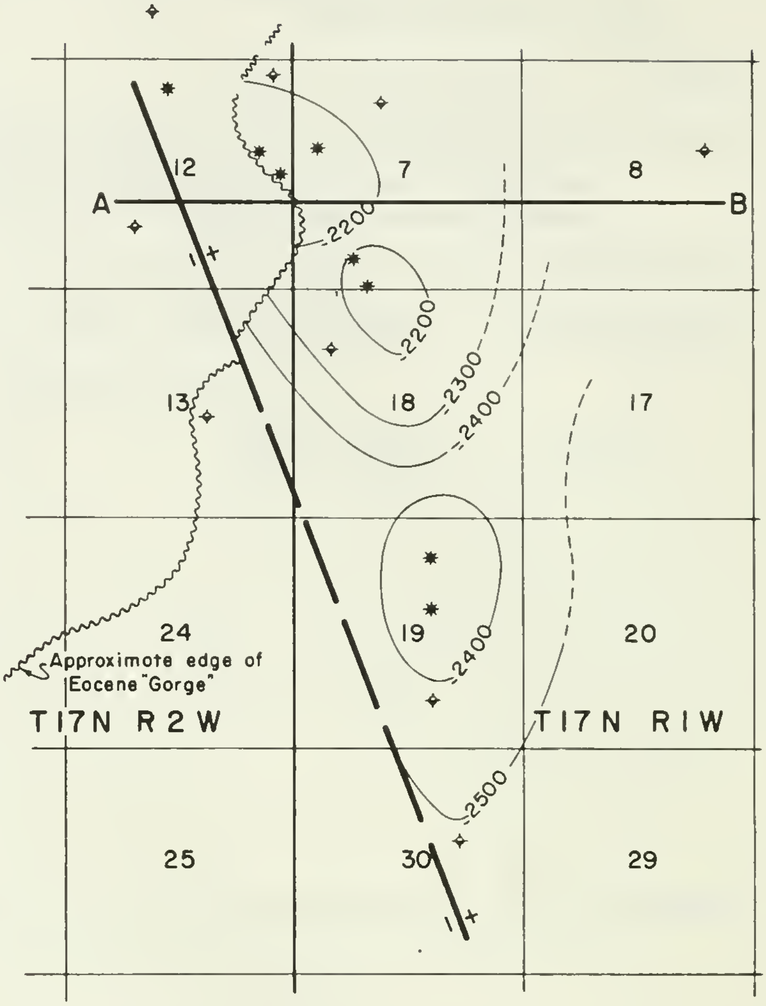
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in September 1946.

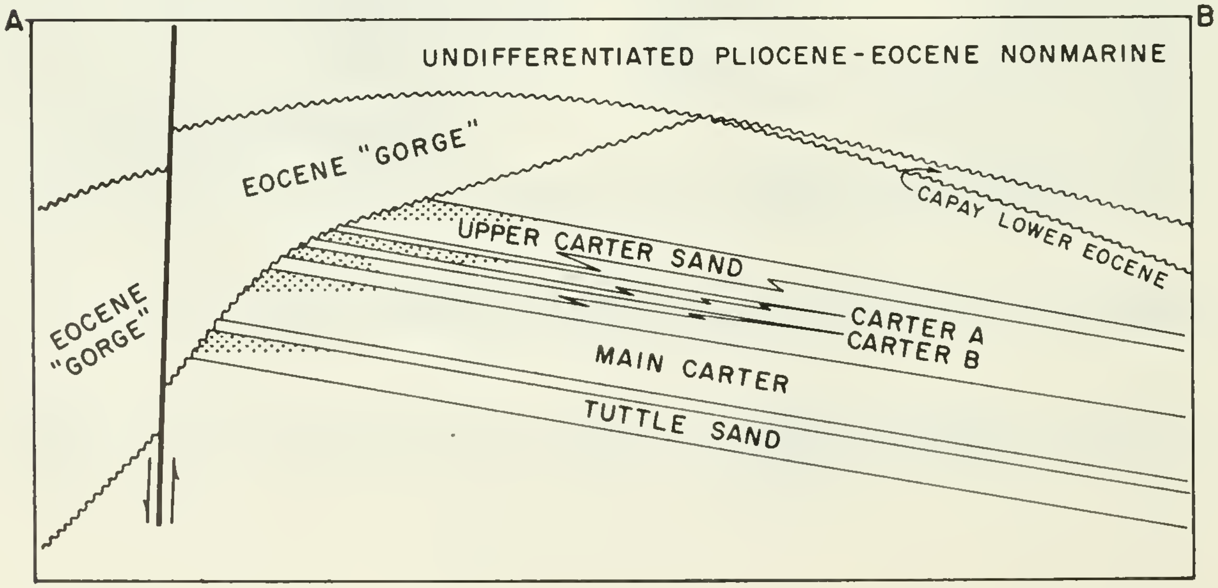
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 38, No. 2 (1952)

COMPTON LANDING GAS FIELD

EPOCH	FORMATION				Thickness (Feet)
RECENT	Alluvium				100
PLIOCENE-EOCENE	Tehama-Nonmarine (undifferentiated)				1800
EOCENE	"Gorge" Fill				0 to 1100
	Capay				0 to 60
UPPER CRETACEOUS	Kione	Wild Goose Series	Carter sands	Upper	100
				A	40
				B	20
				Main	220
			Tuttle sand		100
					400
	Forbes				920 (drilled)



CONTOURS ON TOP OF MAIN CARTER SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

COMPTON LANDING GAS FIELD
Colusa County

LOCATION 4 miles south of Princeton.

DISCOVERY DATA Honolulu Oil Corp. well No. "Honolulu-Humble Tuttle Unit" 1, Sec. 12, T. 17 N., R. 2 W., M.D.B.& M. Completed July 19, 1955, flowing gas from intervals between 2,380-2,395 at the average rate of 1,400 Mcf/d through a 16/64-inch bean under a flow pressure of 1,002 psi.

STRUCTURE Truncated anticline.

ELEVATION 70-90 BASE OF FRESH WATERS 1,800 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Upper Carter	2,020	40	U. Cretaceous	Kione	810	-
Carter A	2,190	20-40	U. Cretaceous	Kione	810	-
Carter B	2,230	20-40	U. Cretaceous	Kione	810	-
Main Carter	2,250	40	U. Cretaceous	Kione	810	-
Tuttle	2,550	40	U. Cretaceous	Kione	921	-

DEEPEST WELL DATA Richard S. Rheem, Oper., well No. "Zumwalt" 1-12, Sec. 12, T. 17 N., R. 2 W. T.D. 4,000 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	14
Cumulative Gas (Mcf.)	1,985,557	Total Wells Completed	8
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	8
1959 Average Gas (Mcf/d)	2,515	Maximum Proved Acreage	310
Peak Production (1958) (Mcf.)	1,018,044		

USUAL CASING PROGRAM
9-5/8" cem. 600
5-1/2" cem. through gas sands and shot-perforated for production

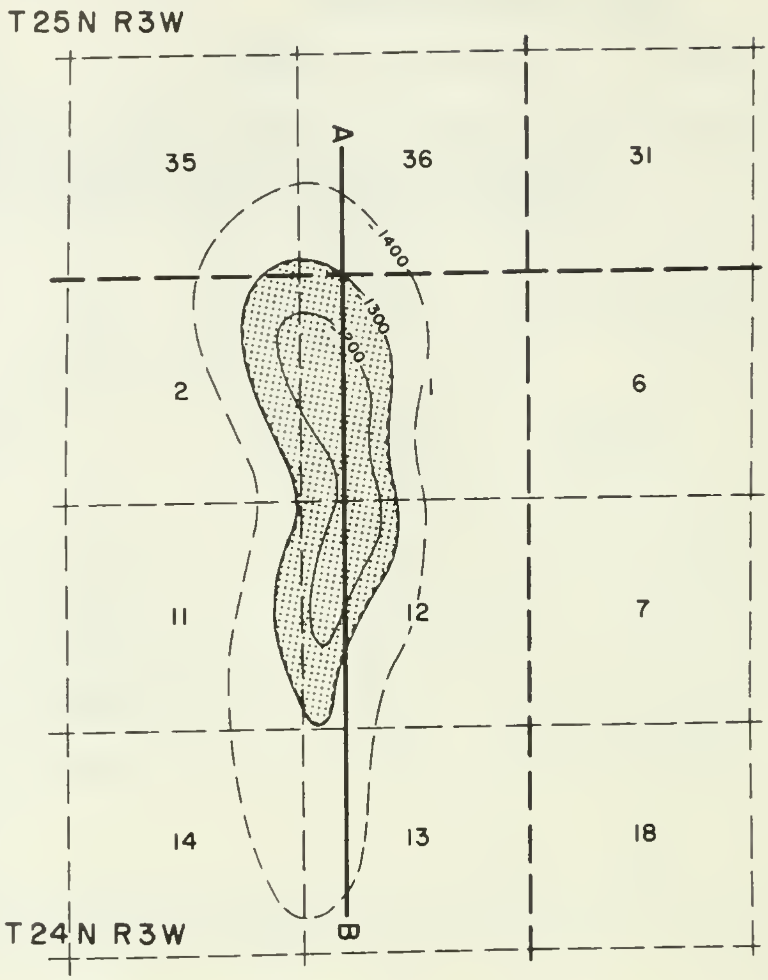
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in September 1957.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 44, No. 2 (1958)

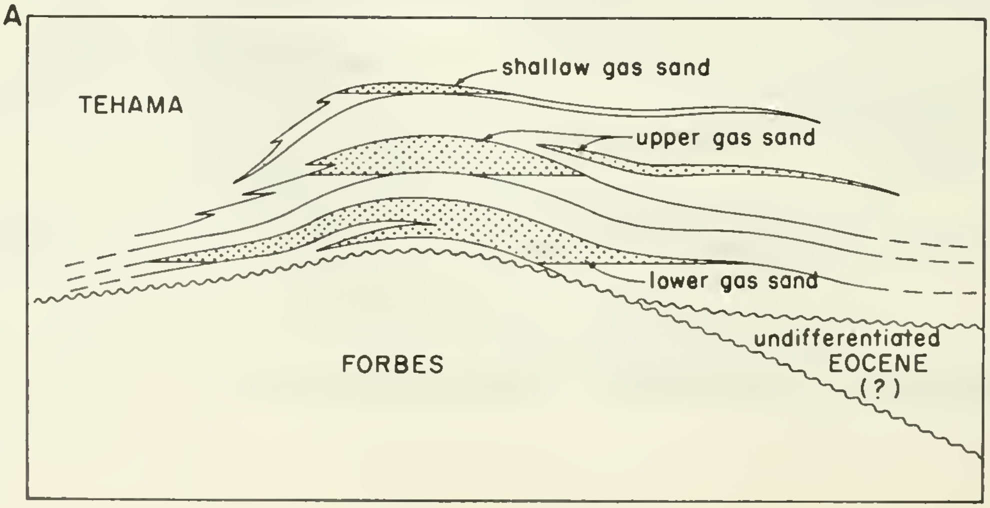
CORNING GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
PLEISTOCENE - PLIOCENE	Red Bluff	0 - 50
	Tehama shallow ▨ upper ▨ lower ▨	1550
EOCENE	undifferentiated	0 to 240
UPPER CRETACEOUS	Forbes	2330
	Dobbins	150
	Guinda	760
	Funks	1400
	Sites	2270
	Yolo	760 (drilled)



CONTOURS ON TOP OF LOWER GAS SAND

▨ PRODUCTIVE AREA



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

CORNING GAS FIELD
Tehama County

LOCATION 1 mile northeast of Corning.

DISCOVERY DATA The Superior Oil Co. well No. "Saldubehere" 1, Sec. 12, T. 24 N., R. 3 W., M.D.B.& M. Completed October 21, 1944, flowing gas from the interval 1,200-1,504 at the average rate of 17,676 Mcf/d.

STRUCTURE Anticline.

ELEVATION 295 BASE OF FRESH WATERS 1,000 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Shallow	1,100	35	Pliocene	Tehama	760	290 to 820
Upper	1,220	5-100	Pliocene	Tehama	760	
Lower	1,450	15-120	Pliocene	Tehama	760	

DEEPEST WELL DATA The discovery well. T.D. 9,225 in Yolo (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	19
Cumulative Gas (Mcf.)	5,741,961	Total Wells Completed	12
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	6
1959 Average Gas (Mcf/d)	2,983	Maximum Proved Acreage	660
Peak Production (1955) (Mcf.)	1,349,947		

USUAL CASING PROGRAM
10-3/4" cem. 500
7" combination string landed through gas zone and
cem. through ports above the zone
with perforations opposite gas sand

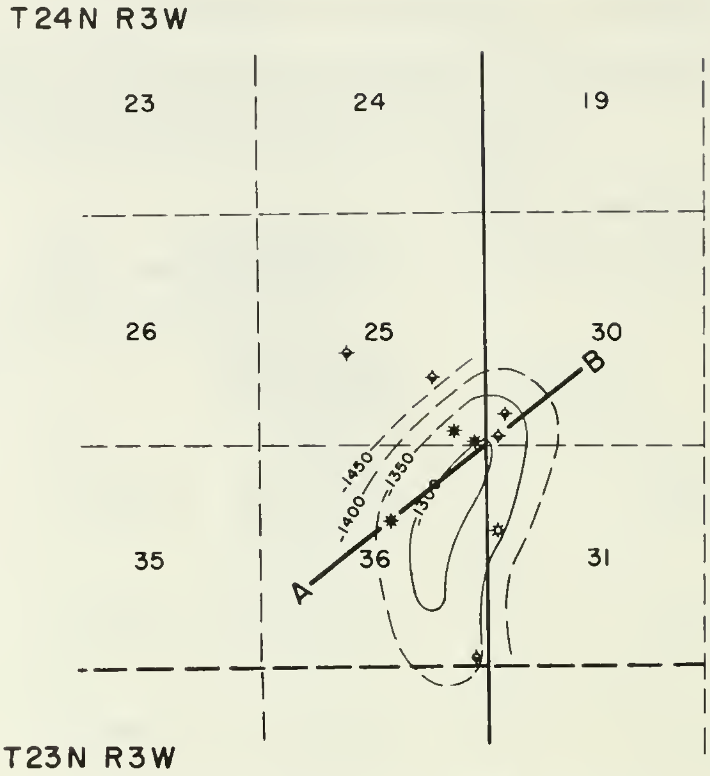
BOP EQUIPMENT Required

MISCELLANEOUS The most northerly gas field in the Sacramento Valley. Commercial gas deliveries began in July 1954.

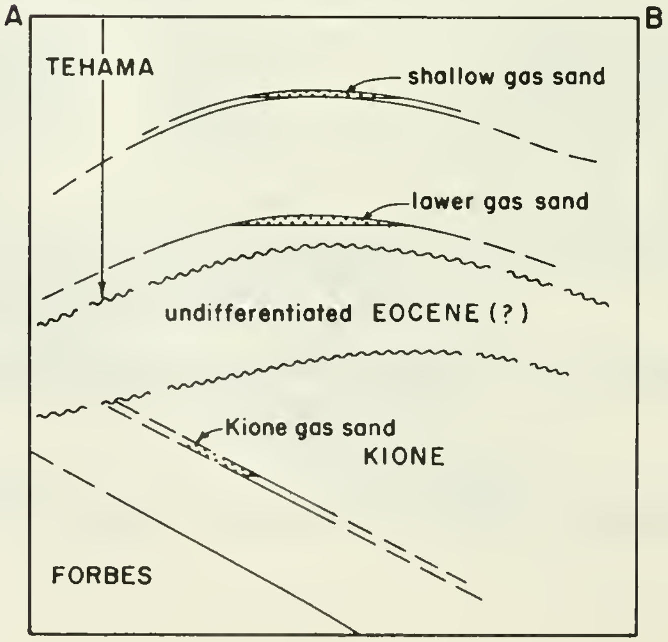
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 30, No. 2 (1944)

SOUTH CORNING GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
PLEISTOCENE-PLIOCENE	Red Bluff	0-50
	Tehama shallow ▨ lower ▨	1650
EOCENE	undifferentiated	300
UPPER CRETACEOUS	Kione gas sand ▨ Kione	400 to 900
	Forbes	2400±
	Dobbins	500
	Guinda	1300
	Funks	300
	Sites	900 (drilled)



CONTOURS ON TOP OF LOWER GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

CORNING, SOUTH, GAS FIELD
Tehama County

LOCATION 2 miles southeast of Corning.

DISCOVERY DATA The Buttes Oilfields, Inc. (now Buttes Gas and Oil Co.) well No. "Saldubehere-Buttes" A, Sec. 25, T. 24 N., R. 3 W., M.D.B.& M. Completed February 6, 1951, flowing gas from the interval 1,425-1,435 at the average rate of 1,955 Mcf/d through a 3/8-inch bean under a flow pressure of 636 psi.

STRUCTURE Anticline.

ELEVATION 314 BASE OF FRESH WATERS 1,100 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Shallow	1,190	10	Pliocene	Tehama	870	-
Lower	1,560	40	Pliocene	Tehama	870	-
Kione	2,340	15	U. Cretaceous	Kione	940	-

DEEPEST WELL DATA Northern Counties Petroleum Co. well No. "Ewers-Mooney" 1, Sec. 25, T. 24 N., R. 3 W. T.D. 8,253 in Sites (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	9
Cumulative Gas (Mcf.)	556,303	Total Wells Completed	4
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	80
Peak Production (1956) (Mcf.)	218,595		

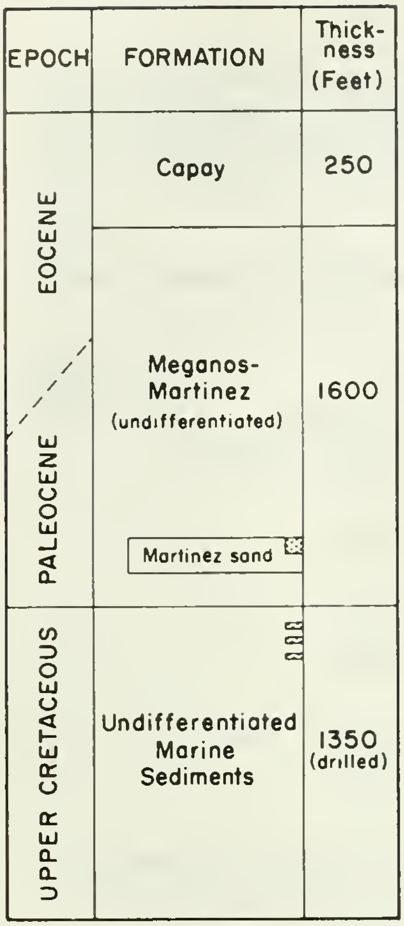
USUAL CASING PROGRAM
9-5/8" cem. 500
5-1/2" cem. through gas zone and shot-perforated for production

BOP EQUIPMENT Required

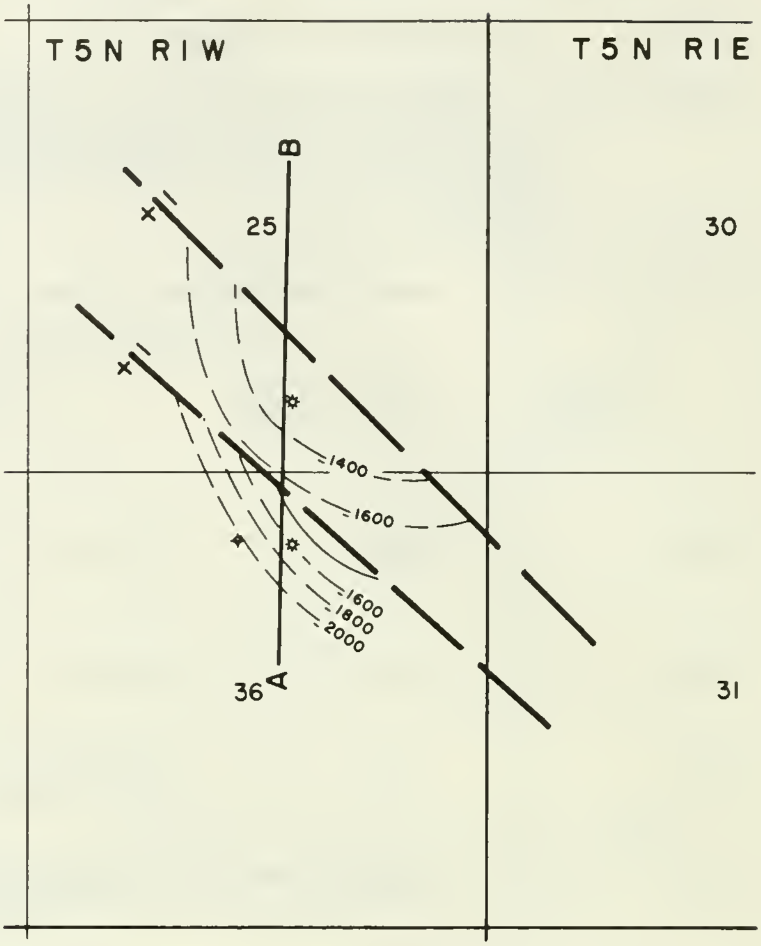
MISCELLANEOUS Commercial gas deliveries began in July 1954.

REFERENCES -

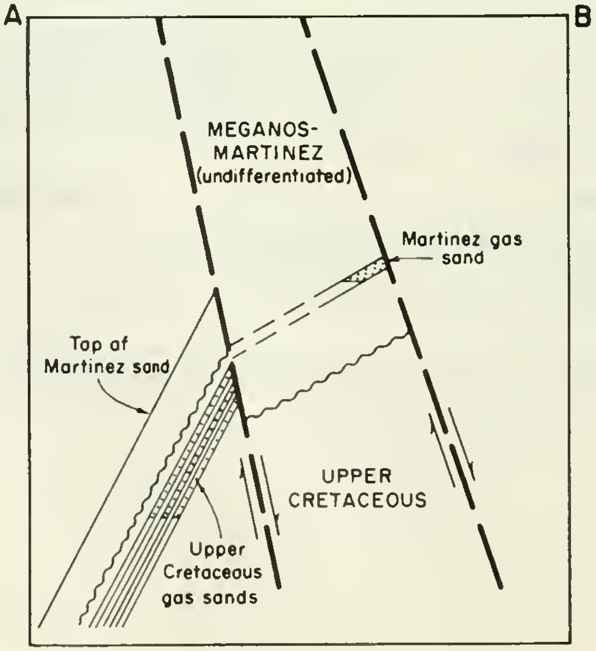
DENVERTON GAS AREA
(Abandoned)



EPOCH	FORMATION	Thickness (Feet)
EOCENE	Capay	250
EOCENE PALEOCENE	Meganos-Martinez (undifferentiated) Martinez sand	1600
UPPER CRETACEOUS	Undifferentiated Marine Sediments	1350 (drilled)



CONTOURS ON TOP OF MARTINEZ SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

DENVERTON GAS AREA
(Abandoned)
Solano County

LOCATION 2 miles northwest of Denverton and 6-1/2 miles east of Fairfield.

DISCOVERY DATA Honolulu Oil Corp. well No. "McCormack Estate" 1, Sec. 36, T. 5 N., R. 1 W., M.D.B.& M. Completed June 1, 1948, flowing gas from the interval 1,898-2,150 at the average rate of 845 Mcf/d.

STRUCTURE Faulted nose.

ELEVATION 35 BASE OF FRESH WATERS 100-900 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Martinez	1,425	10	Eocene-Paleocene	Meganos-Martinez (undiff.)	-	-
Cretaceous	1,898	15	U. Cretaceous	-	-	-

DEEPEST WELL DATA Honolulu Oil Corp. well No. "McCormack Estate" 1, Sec. 36, T. 5 N., R. 1 W. T.D. 3,001 in Upper Cretaceous.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	3
Cumulative Gas (Mcf.)	231,525	Total Wells Completed	2
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	40
Peak Production (1950) (Mcf.)	99,910		

USUAL CASING PROGRAM
11-3/4" cem. 500
5-1/2" or 6-5/8" cem. through gas zone and shot-perforated for production

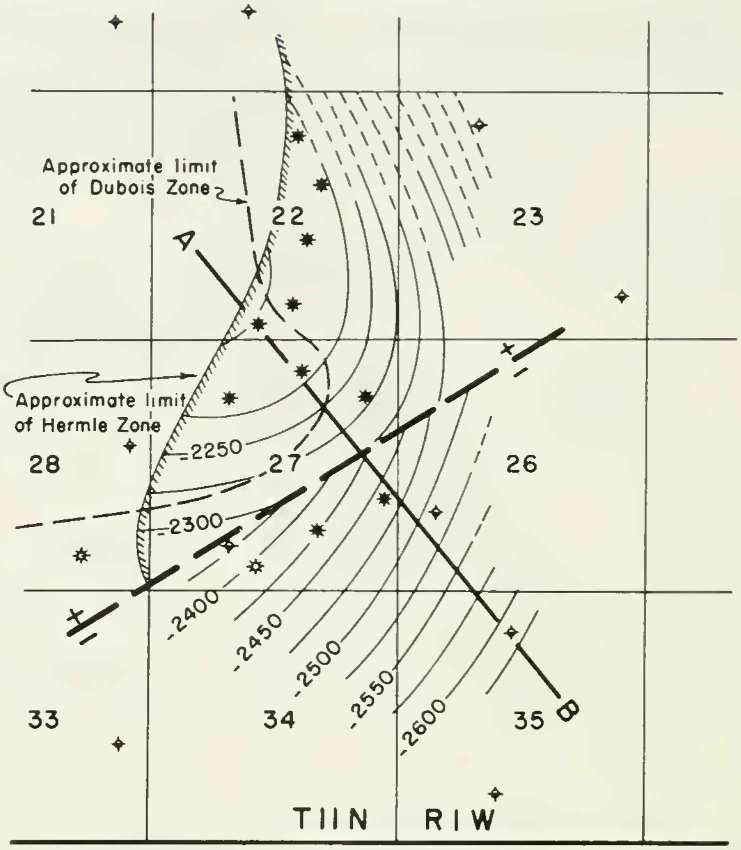
BOP EQUIPMENT Required

MISCELLANEOUS The area was abandoned in 1953.

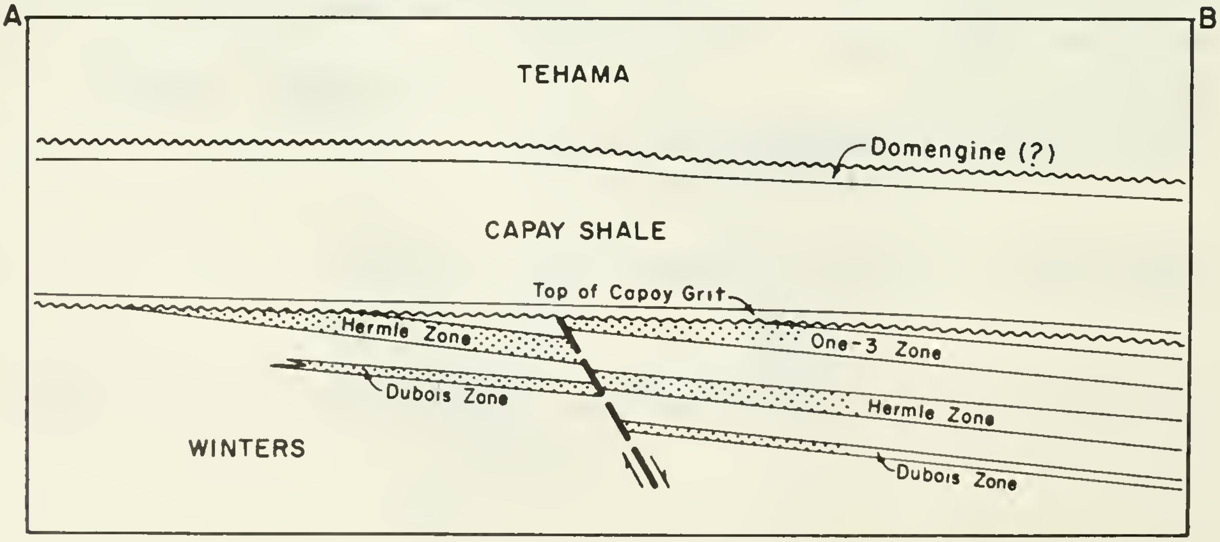
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 34, No. 2 (1948)

DUNNIGAN HILLS GAS FIELD

EPOCH	FORMATION		Thickness (Feet)
PLIOCENE	Tehama		2000
EOCENE	Domengine (?)		20-60
	Capay		480 to 500
UPPER CRETACEOUS	Winters	One-3 Hermle Dubois	550
	Sacramento		800
	Kione		200 (drilled)



CONTOURS ON TOP OF HERMLE ZONE



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

DUNNIGAN HILLS GAS FIELD
Yolo County

LOCATION 12 miles northwest of Woodland.

DISCOVERY DATA The Texas Co. well No. "Hermle" 1 (now Texaco Inc. well No. "Dunnigan Unit One" 1), Sec. 22, T. 11 N., R. 1 W., M.D.B.& M. Completed February 14, 1946, flowing gas from intervals 2,400-2,460, 2,570-2,580, and 2,612-2,620 at the average rate of 3,030 Mcf/d through a 3/8-inch bean under a flow pressure of 984 psi.

STRUCTURE Truncated nose.

ELEVATION 190-285 BASE OF FRESH WATERS 1,800 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
One-3	2,450	40	U. Cretaceous	Winters	970	320
Hermle	2,550	65	U. Cretaceous	Winters	970	340
Dubois	2,700	30	U. Cretaceous	Winters	970	480

DEEPEST WELL DATA The discovery well. T.D. 4,022 in Kione (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	24
Cumulative Gas (Mcf.)	9,303,584	Total Wells Completed	12
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	5
1959 Average Gas (Mcf/d)	718	Maximum Proved Acreage	900
Peak Production (1952) (Mcf,)	1,441,810		

USUAL CASING PROGRAM

9-5/8" cem. 500
5-1/2" casing cem. through gas sands and shot-perforated for production

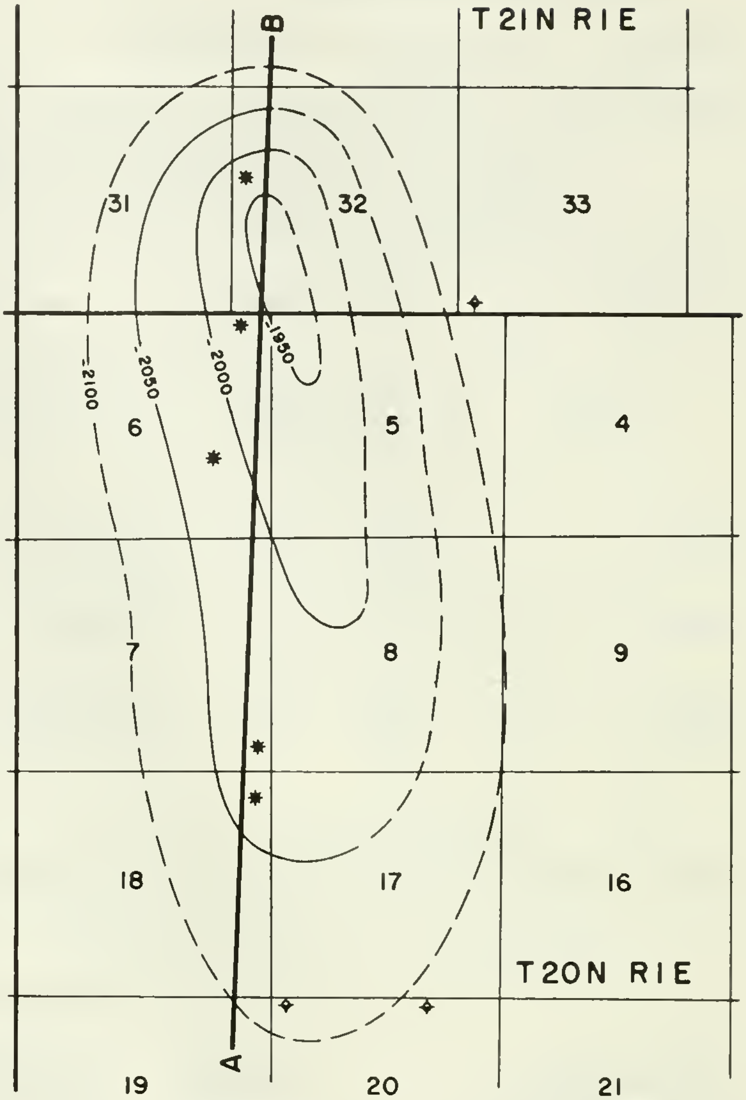
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in January 1950.

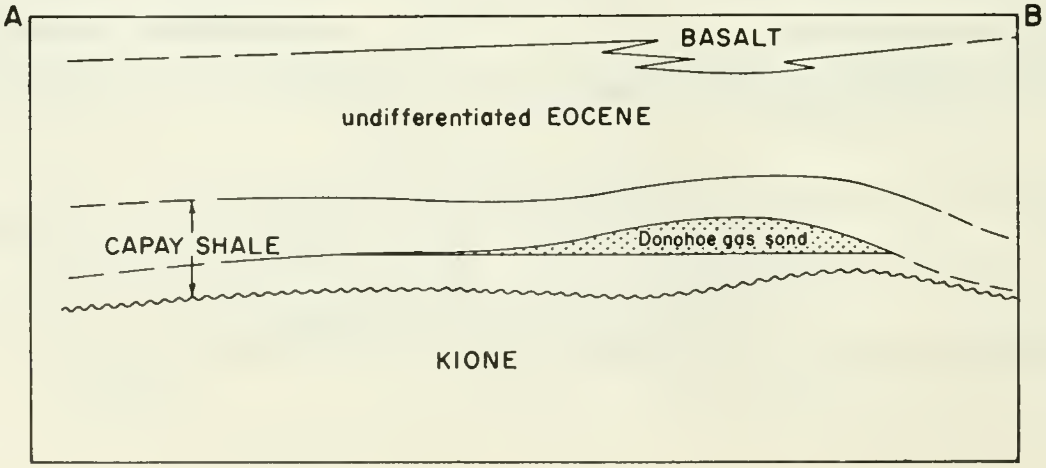
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 37, No. 2 (1951)

DURHAM GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium & Victor	150
	Tehama	1380
	Basalt	150
EOCENE	undifferentiated	420
	Capay Donohoe gas sand	270
UPPER CRETACEOUS	Kione	730
	Forbes	1700
	Dobbins	200
	Guinda	1080 (drilled)



CONTOURS ON TOP OF DONOHOE GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

DURHAM GAS FIELD
Butte County

LOCATION 8 miles southwest of Chico.

DISCOVERY DATA Standard Oil Co. of California well No. "Donohoe Fee" 1, Sec. 6, T. 20 N., R. 1 E., M.D.B.& M. Completed July 16, 1946, flowing gas from the interval 2,140-2,176 at the average rate of 10,937 Mcf/d through a 7/8-inch bean under a flow pressure of 824 psi.

STRUCTURE Anticline.

ELEVATION 120 BASE OF FRESH WATERS 1,150 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Donohoe	2,130	35	Eocene	Capay shale	720	20

DEEPEST WELL DATA The discovery well. T.D. 6,000 in Guinda (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	4
Cumulative Gas (Mcf.)	6,684,013	Total Wells Completed	4
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	4
1959 Average Gas (Mcf/d)	2,599	Maximum Proved Acreage	1,720
Peak Production (1959) (Mcf.)	948,739		

USUAL CASING PROGRAM
9-5/8" cem. 1,400
5-1/2" cem. through gas zone and shot-perforated for production

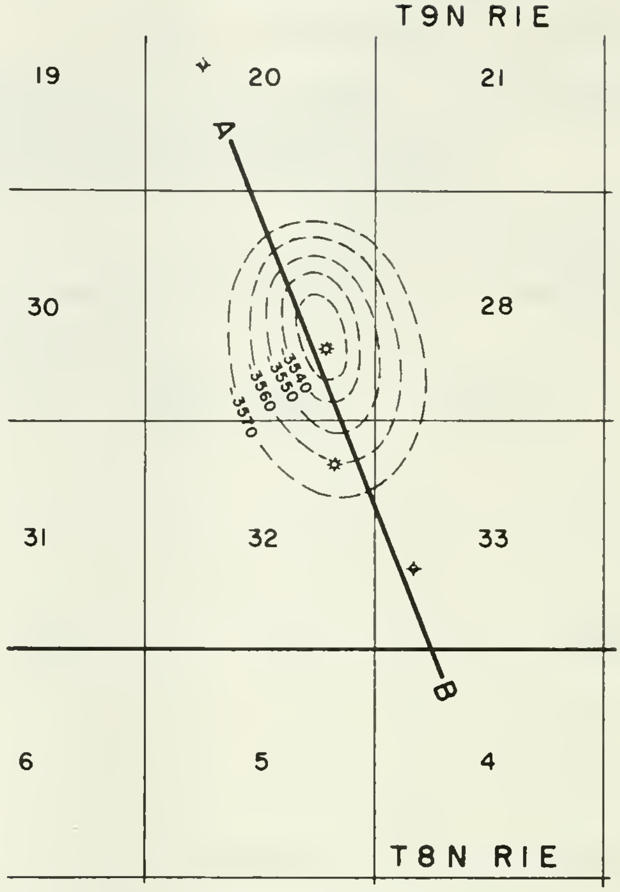
BOP EQUIPMENT Required

MISCELLANEOUS -

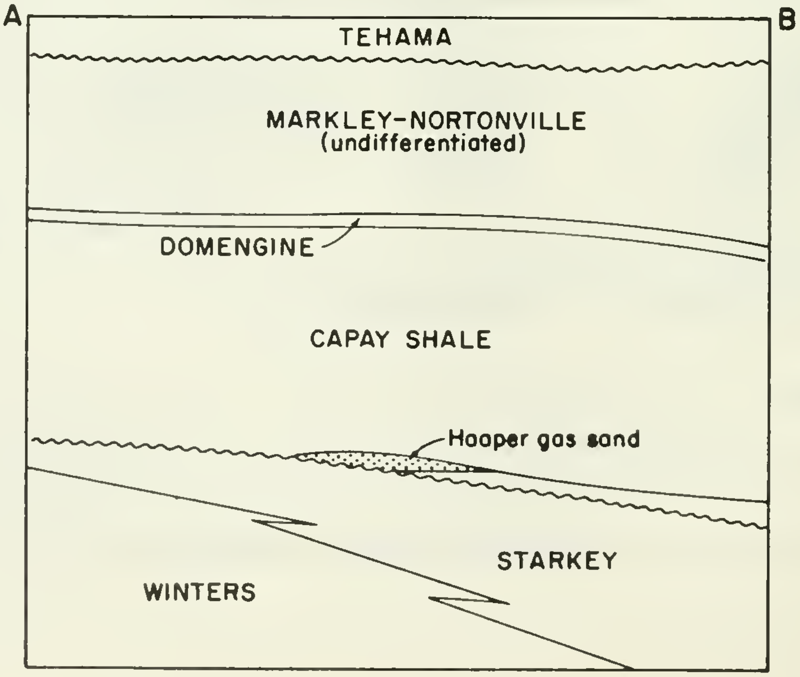
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 38, No. 2 (1952)

FAIRFIELD KNOLLS GAS FIELD
(Abandoned)

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium	300
	Tehama	2200
EOCENE	Markley-Nortonville (undifferentiated)	450
	Domengine	30
	Capay Hooper gas sand	680
UPPER CRETACEOUS	Starkey	410
	Winters	980 (drilled)



CONTOURS ON TOP OF HOOPER GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

FAIRFIELD KNOLLS GAS FIELD
(Abandoned)
Yolo County

LOCATION 8 miles southwest of Woodland.

DISCOVERY DATA Standard Oil Co. of California well No. "E.E. Hooper" 1, Sec. 32, T. 9 N., R. 1 E., M.D.B.& M. Completed November 6, 1937, flowing gas from the interval 3,674-3,699 at the average rate of 13,000 Mcf/d.

STRUCTURE Dome.

ELEVATION 110 BASE OF FRESH WATERS 2,500 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Hooper	3,550	25	Eocene	Capay shale	-	-

DEEPEST WELL DATA The discovery well. T.D. 5,181 in Winters (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	2
Cumulative Gas (Mcf.)	2,521,805	Total Wells Completed	2
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	240
Peak Production (1951) (Mcf.)	357,826		

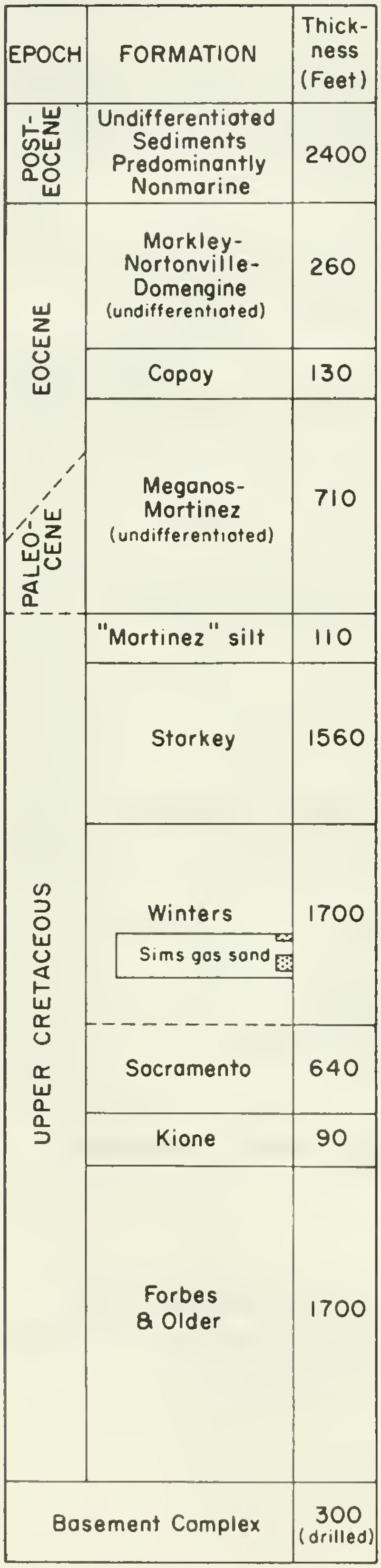
USUAL CASING PROGRAM
13-3/4" cem. 580
6-5/8" cem. above gas sands
4-3/4" liner landed through gas zone

BOP EQUIPMENT Required

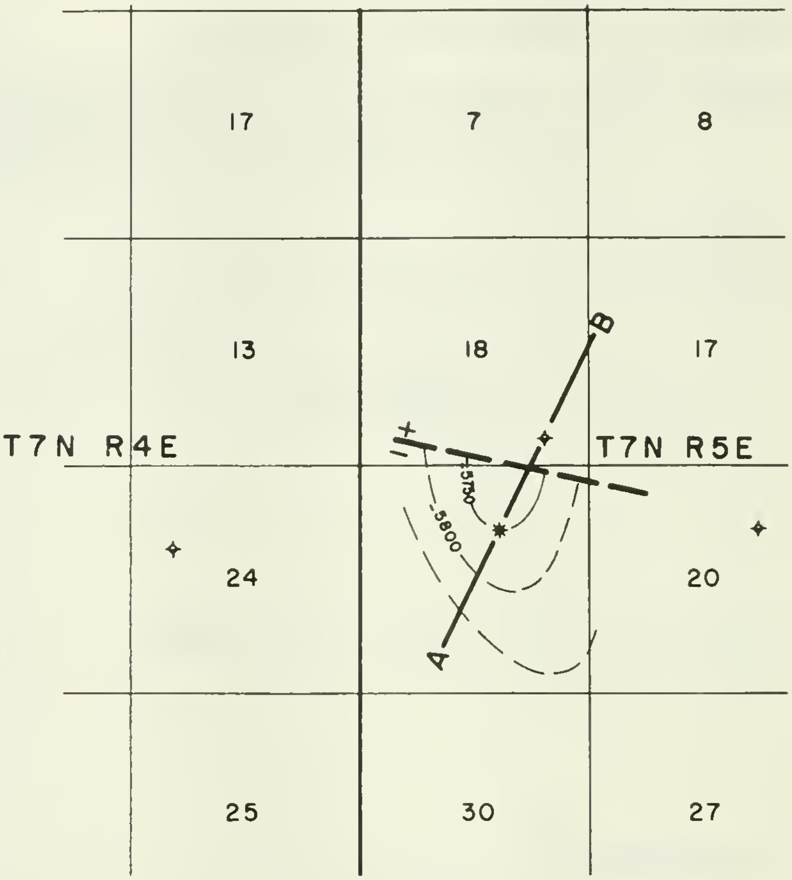
MISCELLANEOUS Formerly known as Plainfield Ridge Gas field. Commercial gas deliveries began in September 1943. The field was abandoned in 1954.

REFERENCES Calif. Div. of Mines Bull. 118 (1943)

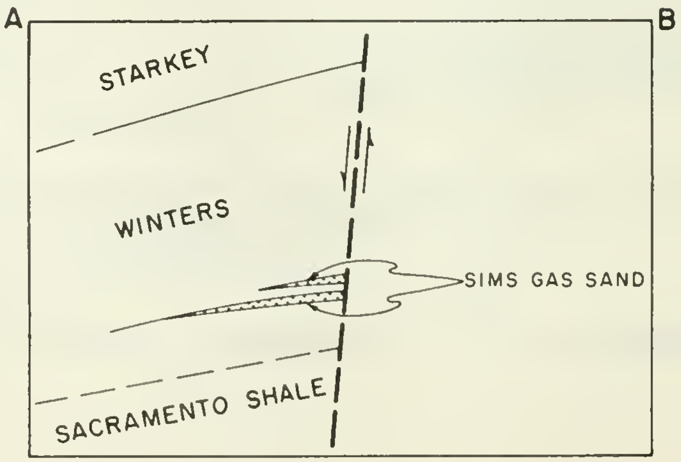
FREEPORT GAS FIELD



EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments Predominantly Nonmarine	2400
EOCENE	Markley-Nortonville-Domengine (undifferentiated)	260
	Capay	130
PALEOCENE	Meganos-Martinez (undifferentiated)	710
UPPER CRETACEOUS	"Martinez" silt	110
	Starkey	1560
	Winters Sims gas sand	1700
	Sacramento	640
	Kione	90
	Forbes & Older	1700
Basement Complex		300 (drilled)



CONTOURS ON TOP OF SIMS GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

FREEPORT GAS FIELD
Sacramento County

LOCATION 9 miles south of Sacramento.

DISCOVERY DATA Standard Oil Co. of California well No. "Sims Community" 1, Sec. 19, T. 7 N., R. 5 E., M.D.B.& M. Completed May 22, 1952, flowing gas from the interval 5,873-5,788 at the average rate of 9,784 Mcf/d through a 1/2-inch bean under a flow pressure of 1,582 psi.

STRUCTURE Faulted nose.

ELEVATION 25 BASE OF FRESH WATERS 750 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Sims	5,780	20	U. Cretaceous	Winters	910	5

DEEPEST WELL DATA Standard Oil Co. of California well No. "Sims Community" 2, Sec. 18, T. 7 N., R. 5 E. T.D. 9,419 in basement complex.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	2
Cumulative Gas (Mcf.)	1,628,721	Total Wells Completed	1
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	293	Maximum Proved Acreage	40
Peak Production (1953) (Mcf.)	614,927		

USUAL CASING PROGRAM
13-3/8" cem. 500
5-1/2" cem. through gas zone and shot-perforated for production

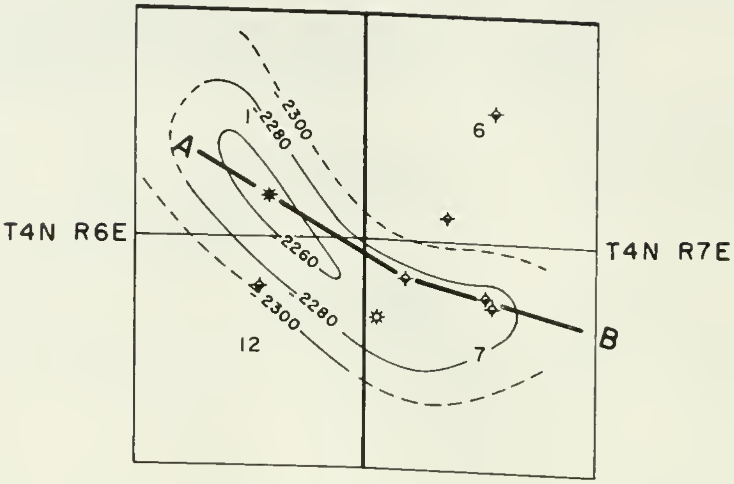
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in January 1953.

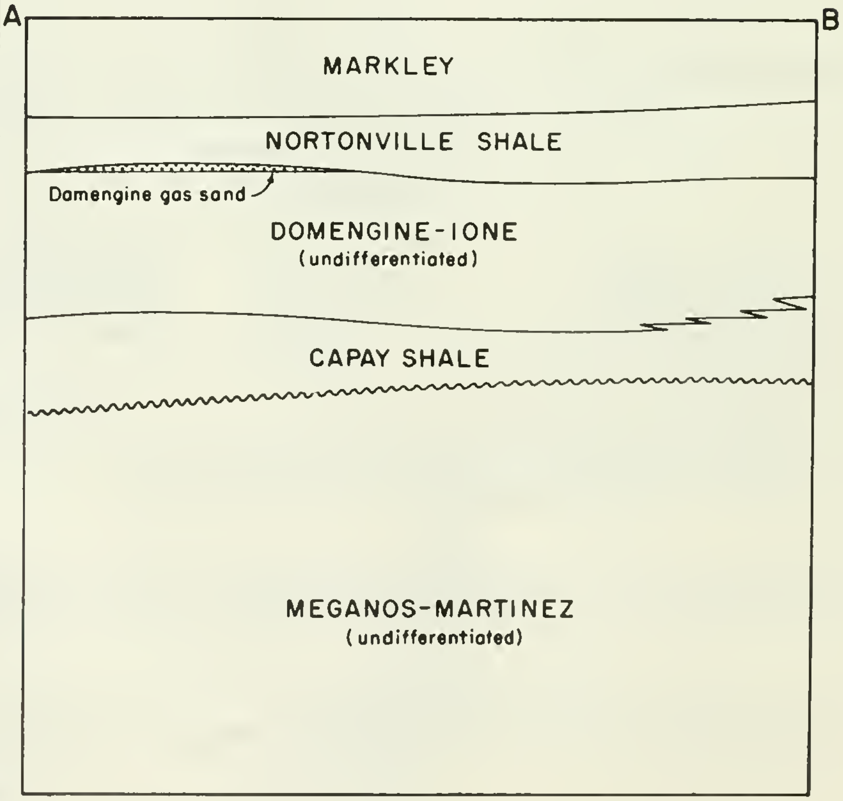
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 38, No. 2 (1952)

GALT GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments, Predominantly Nonmarine	2050
EOCENE	Markley	200
	Nortonville	80
	Domengine Gas Sand ▨	
	Domengine-Ione (undifferentiated)	250
	Capay	160
PALEOCENE	Meganos-Martinez (undifferentiated)	460
UPPER CRETACEOUS	Starkey	1200
	Winters (?)	1300
Basement Complex		40 (drilled)



CONTOURS ON DOMENGINE GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

GALT GAS FIELD
San Joaquin County

LOCATION 5-1/2 miles north of Lodi.

DISCOVERY DATA Bankline Oil Co. well No. "Community 1" 1 (now Amerada Petroleum Corp., Operator, well No. "Community 1" 1), Sec. 1, T. 4 N., R. 6 E., M.D.B.& M. Completed April 29, 1943, flowing gas from intervals between 2,327-2,340 at the average rate of 7,765 Mcf/d through a 3/8-inch bean under a flow pressure of 692 psi.

STRUCTURE Anticline.

ELEVATION 73 BASE OF FRESH WATERS 1,850 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Domengine	2,330	15	Eocene	Domengine	680	230

DEEPEST WELL DATA The discovery well. T.D. 5,765 in basement complex.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	8
Cumulative Gas (Mcf.)	1,899,293	Total Wells Completed	2
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	325	Maximum Proved Acreage	60
Peak Production (1956) (Mcf.)	261,063		

USUAL CASING PROGRAM

9-5/8" cem. 700
5-1/2" cem. through gas sands and shot-perforated for production

BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in October 1946.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 43, No. 1 (1957)

GRAND ISLAND GAS AREA

CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

GRAND ISLAND GAS AREA
Sacramento County

LOCATION 7 miles north of Isleton on Grand Island.

DISCOVERY DATA Amerada Petroleum Corp. well No. "Garin Gas Unit" 1, Sec. 29, T. 5 N., R. 4 E., M.D.B.& M. Completed on August 2, 1960, flowing gas from the interval 4,672 to 4,677 feet at an initial rate of 2,400 Mcf/d through a 1/4-inch bean.

STRUCTURE (?)

ELEVATION 12 BASE OF FRESH WATERS 2,000± SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Garin sand	4,672	5	Paleocene(?)	Meganos-Martinez (undiff.)	-	-

DEEPEST WELL DATA The discovery well. T.D. 6,464 in Upper Cretaceous(?)

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	-	Total Wells Drilled	-
Cumulative Gas (Mcf.)	-	Total Wells Completed	-
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	-
Peak Production	-		

USUAL CASING PROGRAM
11-3/4" cem. 600
5-1/2" cem. through the zone and shot-perforated for production

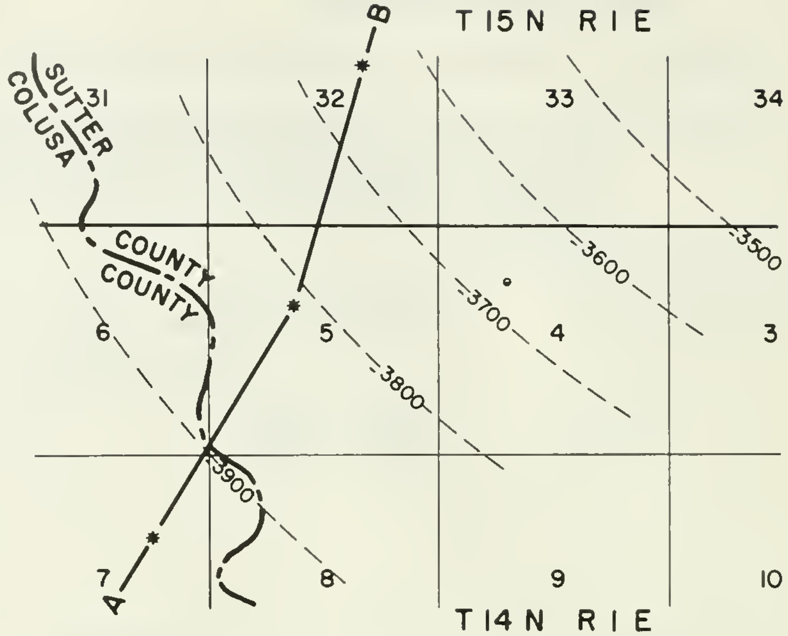
BOP EQUIPMENT Required

MISCELLANEOUS The only producing well is shut-in awaiting an outlet for the gas.

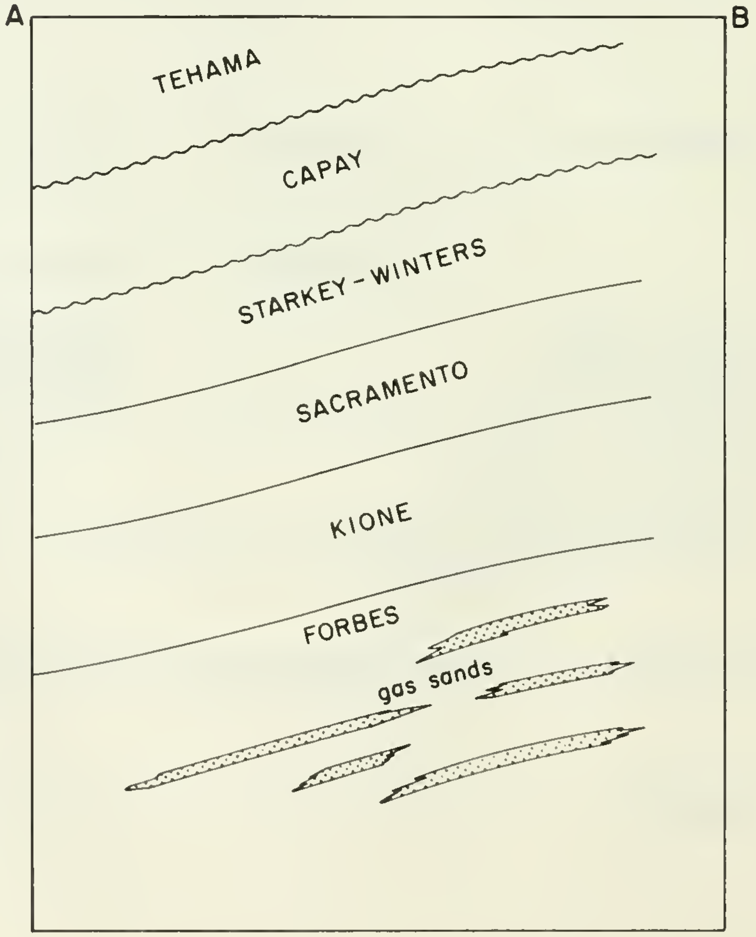
REFERENCES

GRIMES GAS AREA

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium	2800
	Tehama	
EOCENE	Capay	370
UPPER CRETACEOUS	Starkey-Winters	400
	Sacramento	370
	Kione	600
	Forbes	3960 (drilled)



CONTOURS ON BASE OF KIONE FORMATION



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

GRIMES GAS AREA
Colusa and Sutter Counties

LOCATION 10 miles northeast of Arbuckle.

DISCOVERY DATA Cameron Oil Co. well No. "Cameron-Armstrong" 1, Sec. 7, T. 14 N., R. 1 E., M.D.B.& M. Completed January 11, 1960, flowing gas from the interval 6,550-6,590 at an initial rate of 2,820 Mcf/d under a flow pressure of 1,040 psi.

STRUCTURE Homocline with gas accumulations in stratigraphic traps.

ELEVATION 52 BASE OF FRESH WATERS 1,800 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
"F" sands	6,500	100	U. Cretaceous	Forbes	1,000	

DEEPEST WELL DATA Cameron Oil Co. well No. "Helen McLaughlin" 1, Sec. 5, T. 14 N., R. 1 E. T.D. 8,501 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	-	Total Wells Drilled	-
Cumulative Gas (Mcf.)	-	Total Wells Completed	-
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	-
Peak Production	-		

USUAL CASING PROGRAM
13-3/8" cemented at 300
9-5/8" cem. 2,600
5-1/2" cem. through gas zone and shot-perforated for production

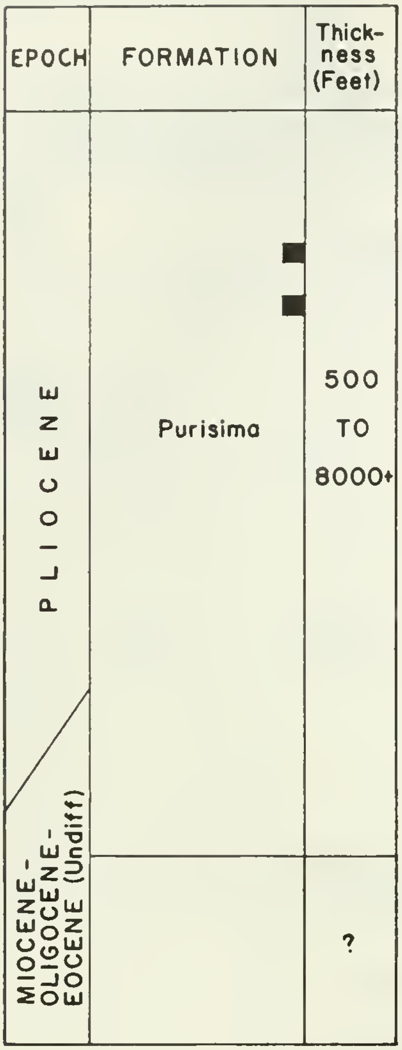
BOP EQUIPMENT Required

MISCELLANEOUS The wells are shut-in awaiting an outlet for the gas.

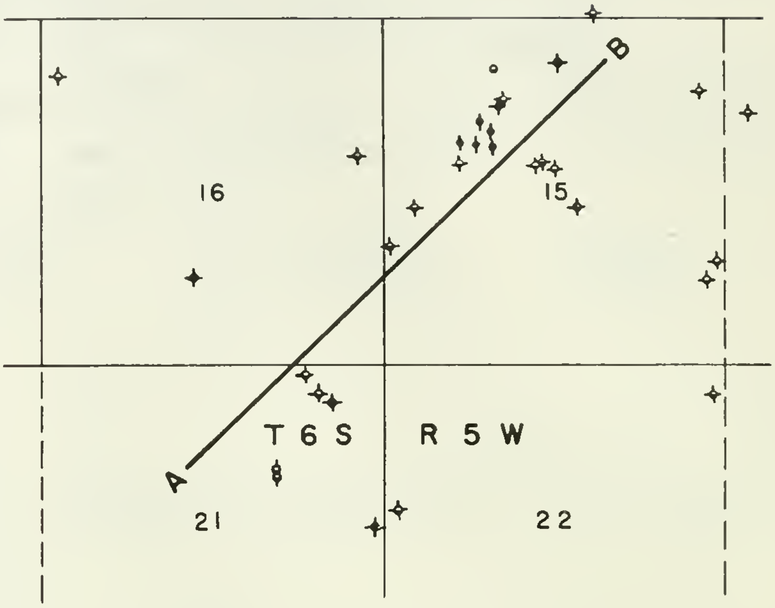
REFERENCES -

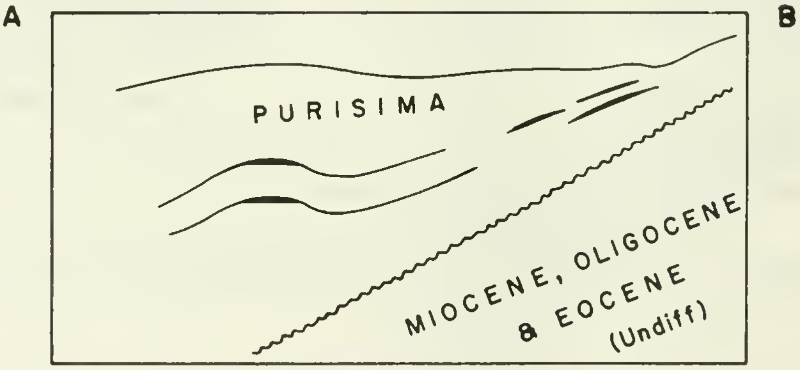
HALFMOON BAY AREA

(Abandoned)



EPOCH	FORMATION	Thickness (Feet)
PLIOCENE	Purisima	500 TO 8000+
MIOCENE-OLIGOCENE-EOCENE (Undiff)		?





CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

HALF MOON BAY AREA
(Abandoned)
San Mateo County

LOCATION 24 miles south of San Francisco.

DISCOVERY DATA Uncertain. Probably one of J. Berger's 5 wells, Sec. 15, T. 6 S., R. 5 W., M.D.B.& M., drilled in the year 1890.

STRUCTURE Anticline and homocline. Gas accumulations in updip lenses.

ELEVATION 200-450 BASE OF FRESH WATERS 100 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
(unnamed)	800 3,100	?	Pliocene	Purisima	45	-

DEEPEST WELL DATA Wilshire Oil Co., Inc., well No. "Cowell" 1, Sec. 21, T. 6 S., R. 5 W. T.D. 7,982 in Purisima (Pliocene-Miocene).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	41,330	Total Wells Drilled	37
Cumulative Gas (Mcf.)	20,000	Total Wells Completed	14
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	150
Peak Production	?		

USUAL CASING PROGRAM
9-5/8" cem. 200
5-1/2" combination string landed through oil zone and cem. through ports above zone with perforations opposite oil sand

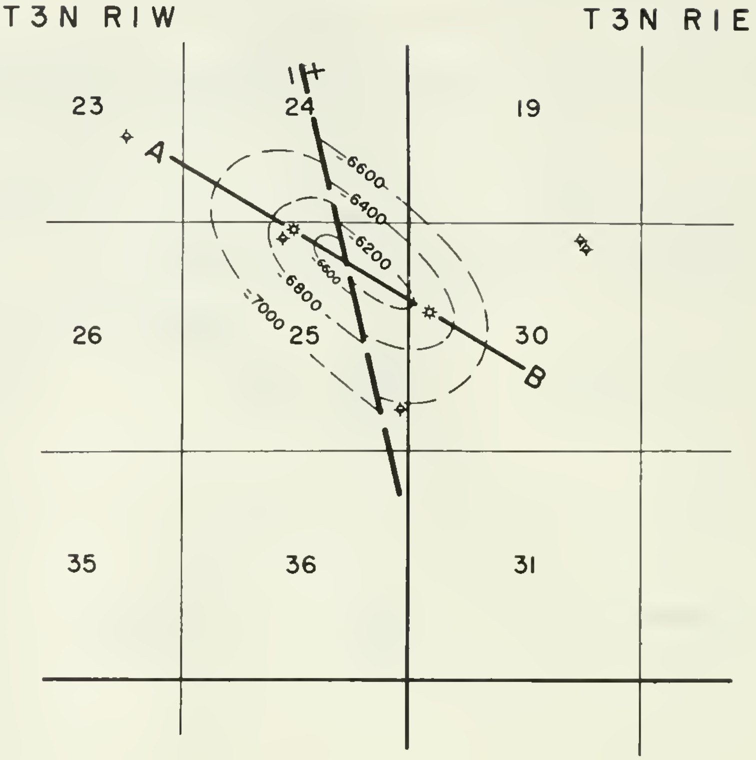
BOP EQUIPMENT Required

MISCELLANEOUS The area includes wells drilled to the south along Tunitas Creek. The area was abandoned in 1938.

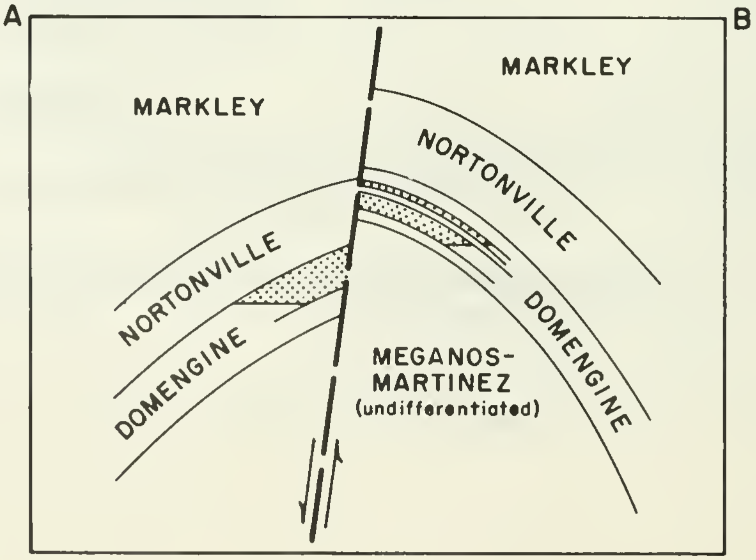
REFERENCES Calif. Div. of Mines, Bull. 118 (1943)

HONKER GAS AREA
(Abandoned)

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments Predominantly Nonmarine	3100
EOCENE	Markley	3000
	Nortonville	400
	Domengine	400
PALEOCENE	Meganos-Martinez (undifferentiated)	400
UPPER CRETACEOUS	Undifferentiated Marine Sediments	1100 (drilled)



CONTOURS ON TOP OF DOMENGINE SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

HONKER GAS AREA
(Abandoned)
Solano County

LOCATION 3 miles northwest of Pittsburg on northeast shore of Honker Bay.

DISCOVERY DATA Standard Oil Co. of California well No. "Honker Community" 1-A, Sec. 25, T. 3 N., R. 1 W., M.D.B.& M. Completed April 9, 1944, flowing gas from the interval 7,190-7,220 at the average rate of 3,200 Mcf/d.

STRUCTURE Faulted anticline.

ELEVATION 10-21 BASE OF FRESH WATERS 150 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Domengine	6,520	200	Eocene	Domengine	-	720

DEEPEST WELL DATA Standard Oil Co. of California well No. "A. O. Stewart" 1, Sec. 25, T. 3 N., R. 1 W. T.D. 8,728 in Upper Cretaceous.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	4
Cumulative Gas (Mcf.)	300,788	Total Wells Completed	2
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	20
Peak Production (1947) (Mcf.)	277,436		

USUAL CASING PROGRAM BOP EQUIPMENT Required

11-3/4" cem. 1,000
5-1/2" cem. through gas zone and shot-perforated for production

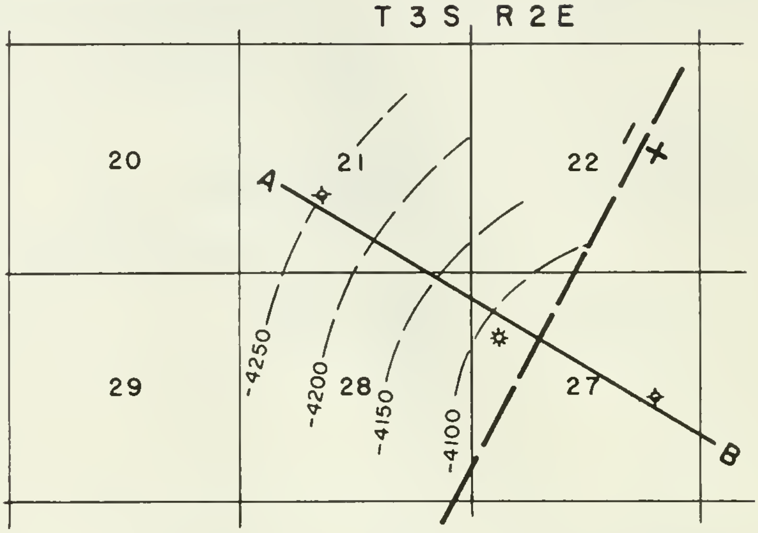
MISCELLANEOUS Commercial gas deliveries began in January 1947. The area was abandoned in 1949.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 30, No. 2 (1944)

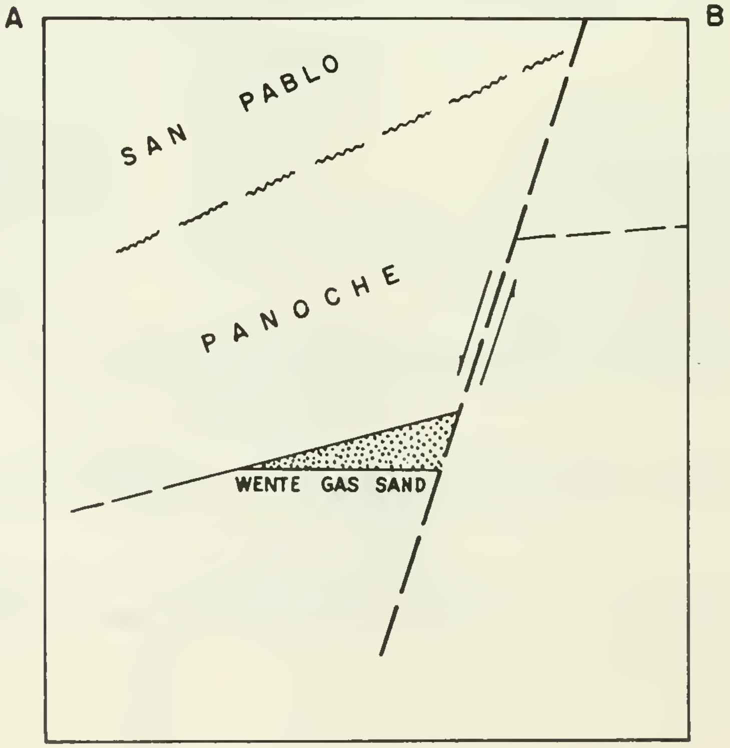
HOSPITAL NOSE GAS AREA

(Abondoned)

EPOCH	FORMATION	Thickness (Feet)
PLEISTOCENE	Livermore Gravel	900
PLIOCENE MIOCENE	Orinda	1850
MIOCENE	San Pablo	600
UPPER CRETACEOUS	Panoche Wente gas sand	3700 (drilled)



CONTOURS ON TOP OF WENTE GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

HOSPITAL NOSE GAS AREA
(Abandoned)
Alameda County

LOCATION 3 miles south of Livermore.

DISCOVERY DATA Texaco Inc. well No. "Hancock-Signal (NCT-1) Wente" 1, Sec. 27, T. 3 S., R. 2 E., M.D.B.& M. Completed April 10, 1952, flowing gas from the intervals 5,057-5,180 and 5,210-5,280 at the average rate of 150 Mcf/d.

STRUCTURE Faulted nose.

ELEVATION 893 BASE OF FRESH WATERS 1,550 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Wente	5,070	200	U. Cretaceous	Panoche	-	-

DEEPEST WELL DATA The discovery well. T.D. 7,062 in Panoche (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	3
Cumulative Gas (Mcf.)	14,183	Total Wells Completed	1
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	40
Peak Production (1954) (Mcf.)	9,424		

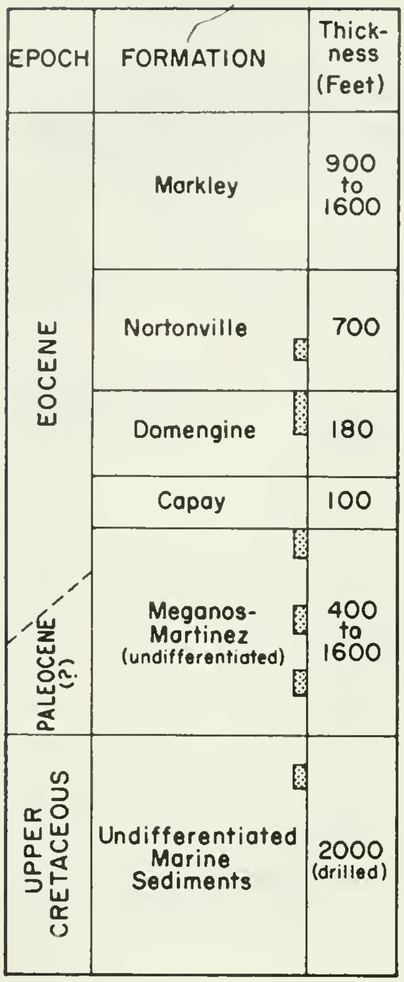
USUAL CASING PROGRAM
11-3/4" cem. 500
5-1/2" cem. through gas zone and shot-perforated for production

BOP EQUIPMENT Required

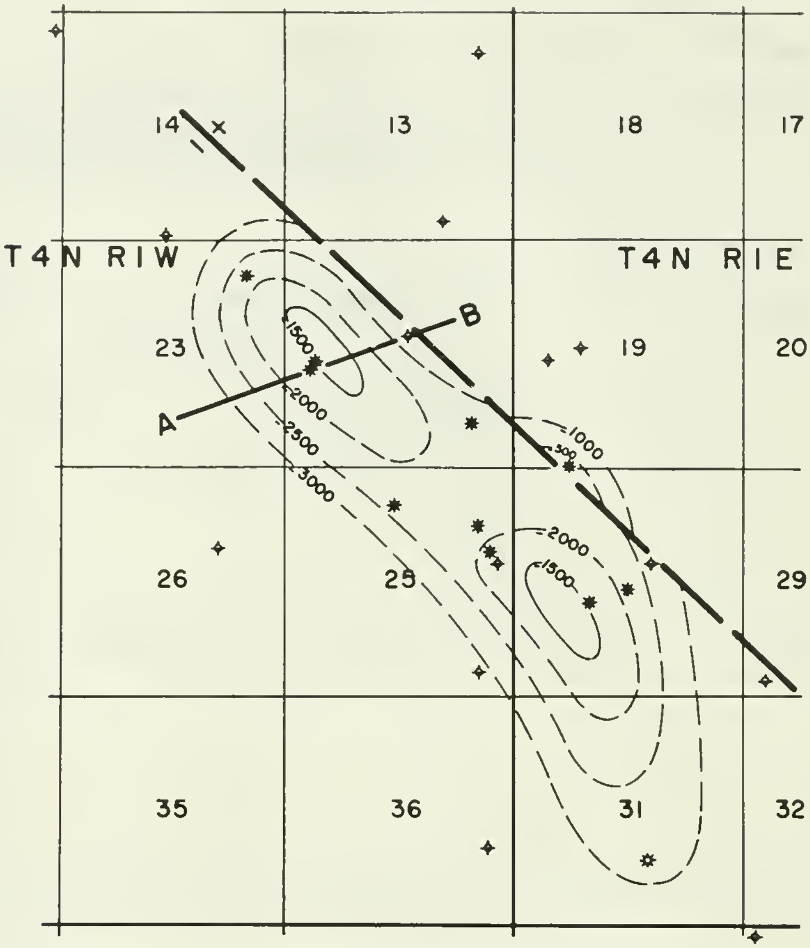
MISCELLANEOUS The area was abandoned in 1956.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 38, No. 2 (1952)
Calif. Div. of Mines Bull. 140 (1948)

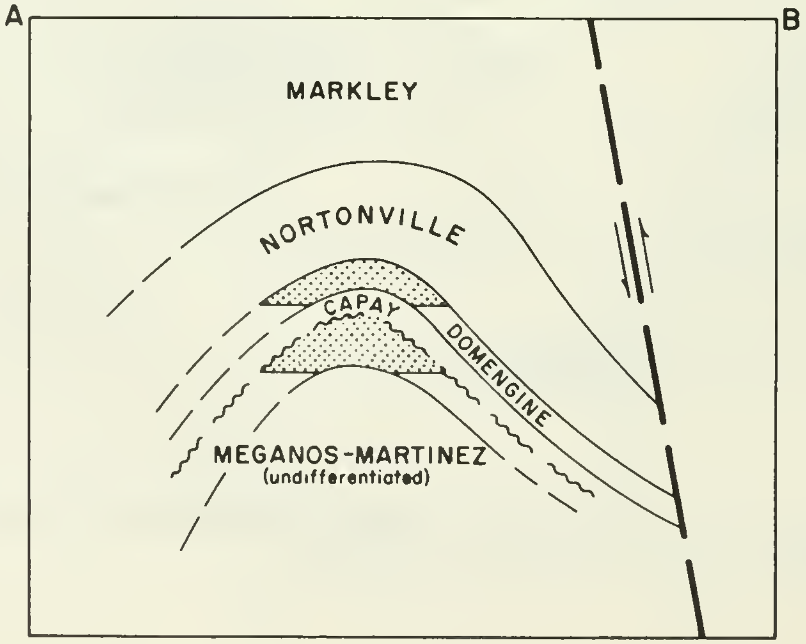
KIRBY HILL GAS FIELD



EPOCH	FORMATION	Thickness (Feet)
EOCENE	Markley	900 to 1600
	Nortonville	700
	Domengine	180
	Capay	100
PALEOCENE (?)	Meganos-Martinez (undifferentiated)	400 to 1600
UPPER CRETACEOUS	Undifferentiated Marine Sediments	2000 (drilled)



CONTOURS ON TOP OF DOMENGINE GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

KIRBY HILL GAS FIELD
Solano County

LOCATION 8 miles southeast of Fairfield.

DISCOVERY DATA Shell Oil Company well No. "Lambie" 1-A, Sec. 25, T. 4 N., R. 1 W., M.D.B.& M. Completed January 10, 1945, flowing gas from the interval 2,289-2,317 at the average rate of 3,980 Mcf/d through a 32/64-inch bean under a flow pressure of 650 psi.

STRUCTURE Faulted anticline.

ELEVATION 2-311 BASE OF FRESH WATERS 250-1,800 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Nortonville	2,250	20	Eocene	Nortonville	990	20 to 540
Domengine	1,550 2,850	10-260	Eocene	Domengine	990	
Eocene	2,850 5,400	10-290	Eocene-Paleocene (?)	Meganos-Martinez (undiff.)	990	
U. Cretaceous	5,540	60	U. Cretaceous	-	990	

DEEPEST WELL DATA Shell Oil Company well No. "Lambie" 6, Sec. 30, T. 4 N., R. 1 E. T.D. 7,897 in Upper Cretaceous.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	22
Cumulative Gas (Mcf.)	34,277,954	Total Wells Completed	11
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	5
1959 Average Gas (Mcf/d)	4,976	Maximum Proved Acreage	770
Peak Production (1949) (Mcf.)	3,715,880		

USUAL CASING PROGRAM
11-3/4" or 13-3/8" cem. 500
5-1/2" or 7" cem. through gas sands and shot-perforated for production

BOP EQUIPMENT Required

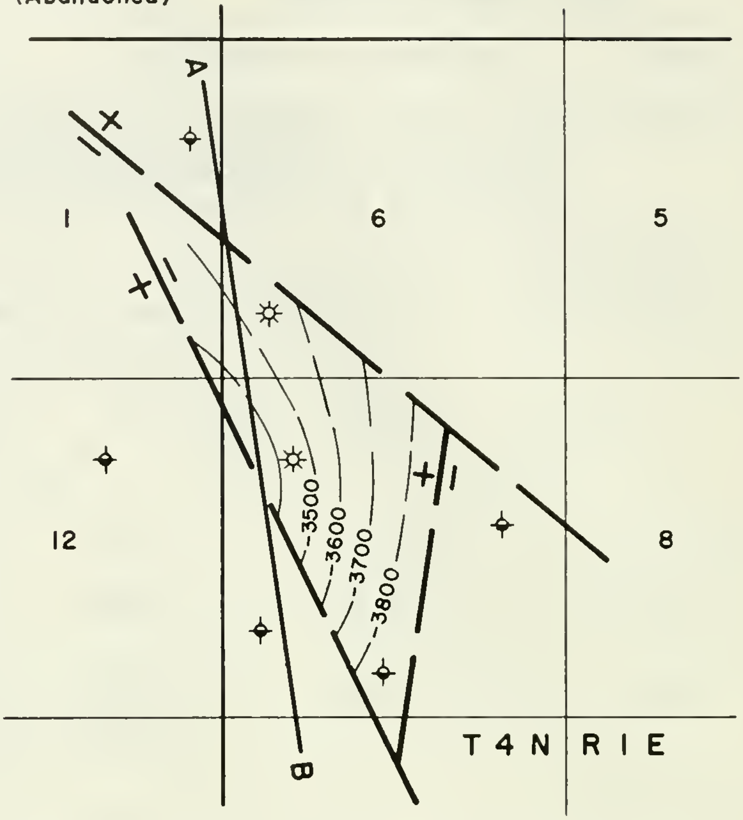
MISCELLANEOUS Abnormally high pressures were encountered at depth. Commercial gas deliveries began in November 1946.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 35, No. 1 (1949)

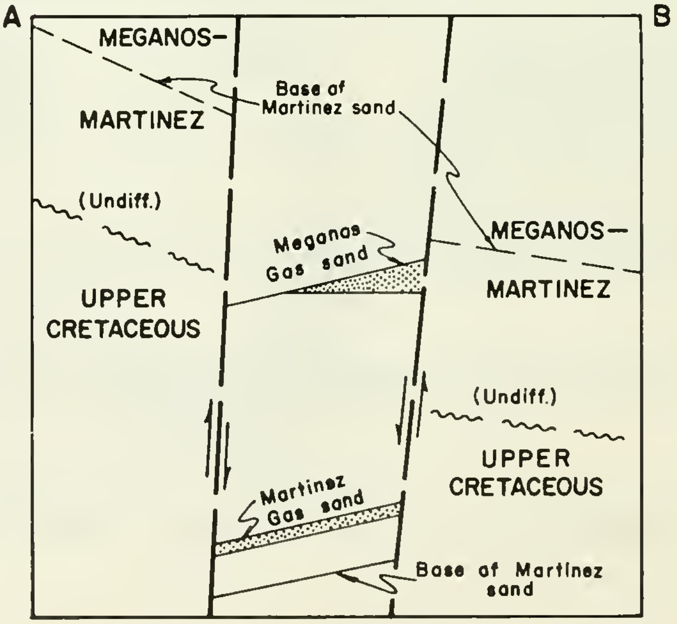
KIRBY HILL, NORTH, GAS FIELD

(Abandoned)

EPOCH	FORMATION	Thickness (Feet)
RECENT	Alluvium	100 to 2200
EOCENE	Markley – Nortonville (undifferentiated)	
	Domengine	220
	Capay	1200
PALEOCENE	Meganos sand Meganos – Martinez (undifferentiated) Martinez sand	1400
UPPER CRETACEOUS	Undifferentiated Marine Sediments	400 (drilled)



CONTOURS ON TOP OF MEGANOS GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

KIRBY HILL, NORTH, GAS FIELD
(Abandoned)
Solano County

LOCATION 7-1/2 miles southeast of Fairfield.

DISCOVERY DATA Shell Oil Company well No. "Unit B" 1, Sec. 7, T. 4 N., R. 1 E., M.D.B.& M. Completed July 29, 1953, flowing gas from the interval 3,515-3,555 at the average rate of 3,500 Mcf/d.

STRUCTURE Faulted nose.

ELEVATION 16 BASE OF FRESH WATERS None SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Meganos	3,510	40	Eocene	Meganos-Martinez (undiff.)	-	-
Martinez	4,260	20	Paleocene	Meganos-Martinez (undiff.)	-	-

DEEPEST WELL DATA Shell Oil Company well No. "Unit A" 1, Sec. 6, T. 4 N., R. 1 E. T.D. 5,150 in Upper Cretaceous.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	5
Cumulative Gas (Mcf.)	187,461	Total Wells Completed	2
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	100
Peak Production (1956) (Mcf.)	184,294		

USUAL CASING PROGRAM
10-3/4" cem. 500
5-1/2" cem. through gas sand and shot-perforated for production

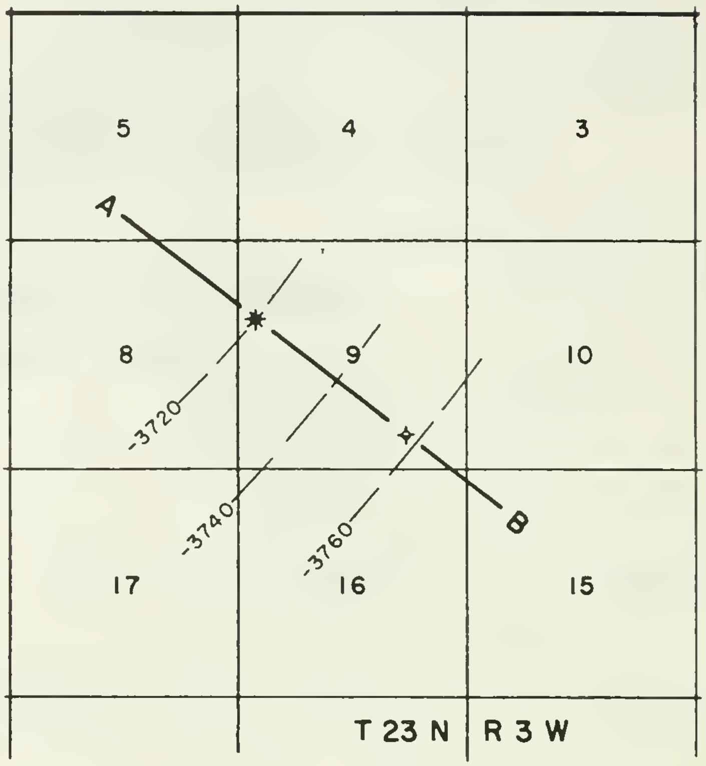
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in March 1956. The field was abandoned in 1957.

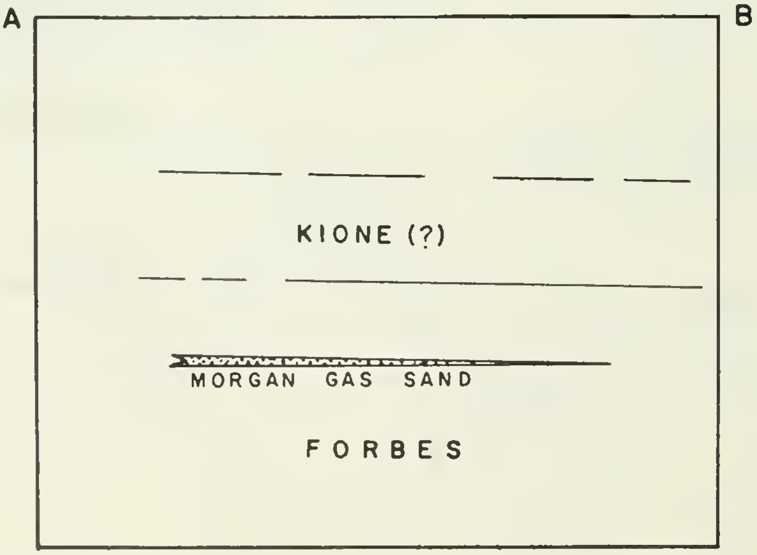
REFERENCES -

KIRKWOOD GAS AREA

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments Predominantly Nonmarine	2000
EOCENE	Undifferentiated Nonmarine	400
UPPER CRETACEOUS	Kione (?)	1100
	Morgan gas sand Forbes	1850
	Dobbins	50 (drilled)



CONTOURS ON TOP OF MORGAN GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

KIRKWOOD GAS AREA
Tehama County

LOCATION 8 miles north of Orland.

DISCOVERY DATA Humble Oil & Refining Co. well No. "James W. Morgan et al" 1 (now James W. Morgan et al well No. "James W. Morgan et al" 1), Sec. 9, T. 23 N., R. 3 W., M.D.B.& M. Comp. December 24, 1958, flowing gas from interval 4,022-4,053 at average rate of 1,118 Mcf/d through a 1/2-inch bean under a flow pressure of 750 psi.

STRUCTURE Possible nose. Gas accumulation in updip lens.

ELEVATION 300 BASE OF FRESH WATERS 2,000 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Morgan	4,020	30	U. Cretaceous	Forbes	-	-

DEEPEST WELL DATA Humble Oil & Refining Co. well No. "Elizabeth J. Roberts et al" 1, Sec. 9, T. 23 N., R. 3 W. T.D. 5,500 in Dobbins (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	2
Cumulative Gas (Mcf.)	0	Total Wells Completed	1
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	40
Peak Production	-		

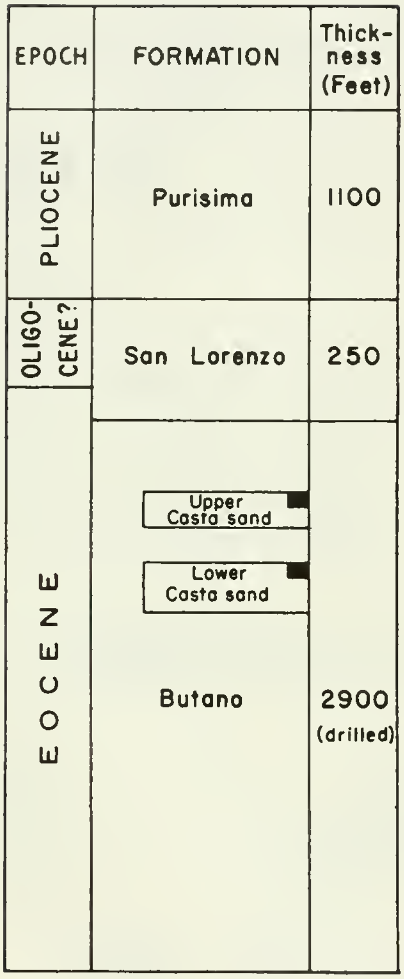
USUAL CASING PROGRAM
7" cem. 1,000
4-1/2" cem. through gas zone and shot-perforated for production

BOP EQUIPMENT Required

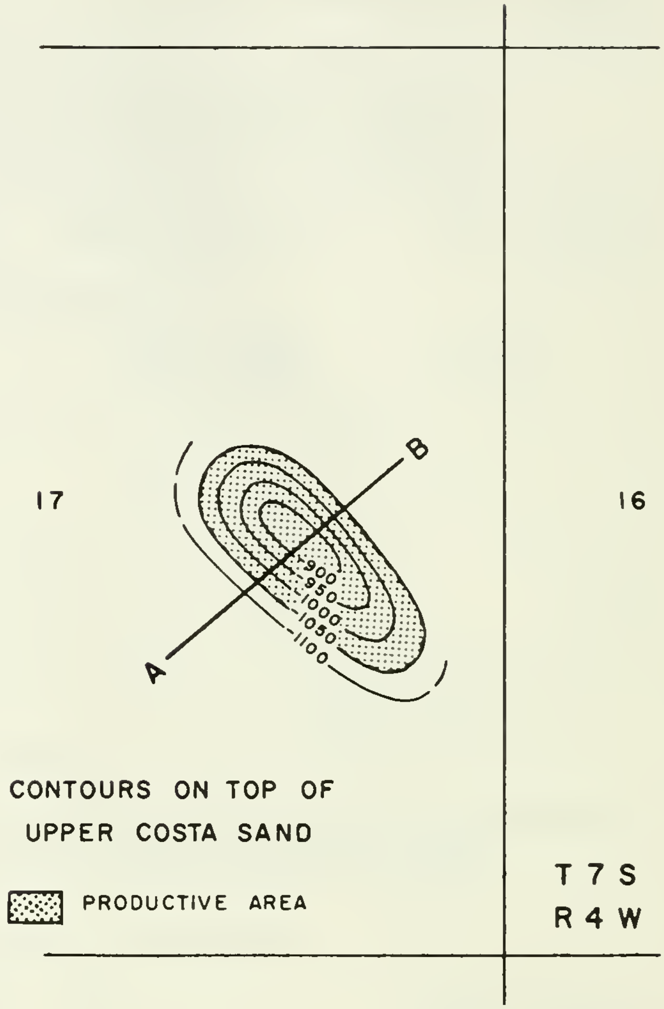
MISCELLANEOUS The well is shut-in pending an outlet for the gas.

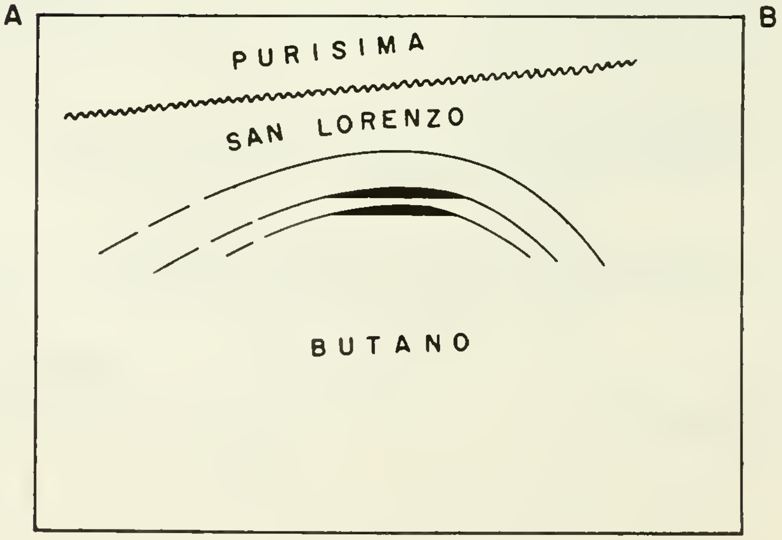
REFERENCES

LA HONDA OIL FIELD
MAIN AREA



EPOCH	FORMATION	Thickness (Feet)
PLIOCENE	Purisima	1100
OLIGOCENE?	San Lorenzo	250
EOCENE	Upper Costa sand Lower Costa sand Butano	2900 (drilled)





CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

LA HONDA OIL FIELD
Main Area
San Mateo County

LOCATION 12 miles southwest of Redwood City and 27 miles southeast of San Francisco.

DISCOVERY DATA Neaves Petroleum Developments well No. "Neaves-Union Oil-Lane" 3 (now Lee & Smith well No. "Carter Lane" 2), Sec. 17, T. 7 S., R. 4 W., M.D.B.& M. Completed December 28, 1956. I.P. 100 b/d 32-degree gravity oil from the interval 1,772-1,793.

STRUCTURE Anticline.

ELEVATION 200-840 BASE OF FRESH WATERS 150 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Upper Costa	1,660	45	Eocene	Butano	40	1,150
Lower Costa	1,800	30	Eocene	Butano	40	1,150

DEEPEST WELL DATA Neaves Petroleum Developments well No. "Neaves-Union Oil Co.-Lane" 1, Sec. 16, T. 7 S., R. 4 W. T.D. 4,271 in Eocene.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	385,041	Total Wells Drilled	25
Cumulative Gas (Mcf.)	58,826	Total Wells Completed	8
1959 Average Oil (b/d)	244	Producing Wells (1959 Aver.)	6
1959 Average Gas (Mcf/d)	37	Maximum Proved Acreage	60
Peak Production (1957) (bbl.)	178,184		

USUAL CASING PROGRAM
10-3/4" cem. 500
5-1/2" combination string landed through oil zone and cem. through ports above the zone with perfs. opposite the oil sand

BOP EQUIPMENT Required

MISCELLANEOUS -

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 42, No. 2 (1956) and Vol. 43, No. 2 (1957)

LA HONDA, SOUTH AREA

EPOCH	FORMATION	Thickness (Feet)
PLIOCENE	Purisima	1350
MIOCENE	Burns sand	400
	Vaqueros	400
OLIGOCENE ?	San Lorenzo	600
EOCENE	Butano	850 (drilled)

CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

LA HONDA OIL FIELD
South Area
San Mateo County

LOCATION 13 miles southwest of Redwood City.

DISCOVERY DATA Neaves Petroleum Developments well No. "Neaves-Union-Burns" 1, Sec. 21, T. 7 S., R. 4 W., M.D.B.& M. Completed July 4, 1959. I.P. 25 b/d 16.4-degree gravity oil from the interval 1,375-1,451.

STRUCTURE Nose (?)

ELEVATION 567-815 BASE OF FRESH WATERS 150 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Burns	1,400	60-180	Miocene	-	17	2,400

DEEPEST WELL DATA Neaves Petroleum Developments well No. "Neaves-Union-Burns" 3, Sec. 21, T. 7 S., R. 4 W. T.D. 3,543 in Eocene.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	12,272	Total Wells Drilled	7
Cumulative Gas (Mcf.)	1,535	Total Wells Completed	6
1959 Average Oil (b/d)	34	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	4	Maximum Proved Acreage	30
Peak Production	-		

USUAL CASING PROGRAM
5-1/2" combination string landed through the oil zone and cemented through ports above the zone with perforations opposite oil sand

BOP EQUIPMENT None

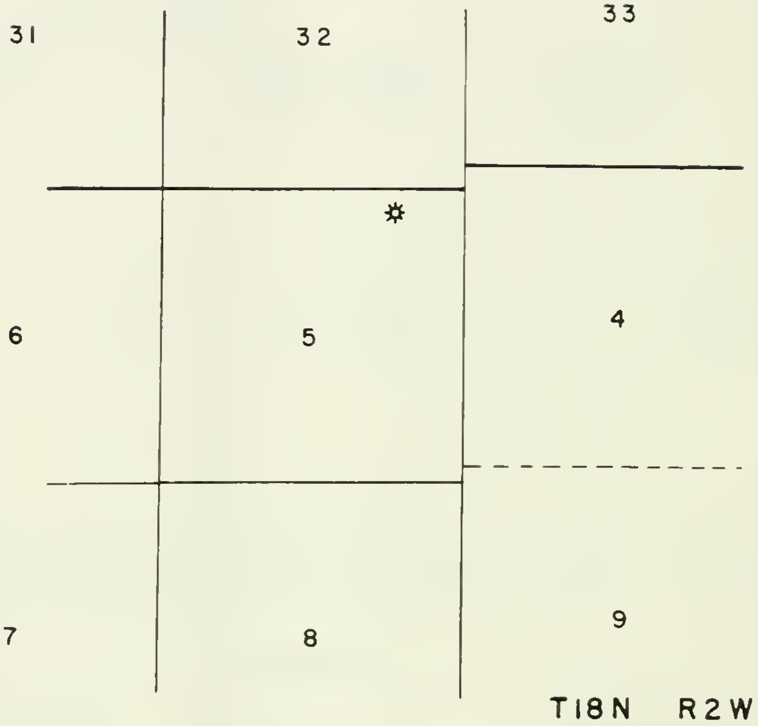
MISCELLANEOUS -

REFERENCES -

LARKIN, WEST, GAS AREA

(Abandoned)

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium Continental Deposits & Tehama	1800
EOCENE	Capay	120
UPPER CRETACEOUS	Kione	600
	Forbes ▨	3800 (drilled)



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

LARKIN, WEST, GAS AREA
(Abandoned)
Glenn County

LOCATION 5-1/2 miles northwest of Princeton.

DISCOVERY DATA Gene Reid Drilling, Inc., well No. "Capital" 1 (now Western Gulf Oil Company well No. "Capital" 1), Sec. 5, T. 18 N., R. 2 W., M.D.B.& M. Completed December 9, 1955, flowing gas from the interval 5,933-5,985 at a sub-commercial rate.

STRUCTURE Possible nose.

ELEVATION 97 **BASE OF FRESH WATERS** 1,600 **SPACING ACT APPLIES** Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Unnamed	5,933	18	U. Cretaceous	Forbes	-	-

DEEPEST WELL DATA The discovery well. T.D. 5,993 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	1
Cumulative Gas (Mcf.)	3,340	Total Wells Completed	1
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	40
Peak Production (1957) (Mcf.)	3,340		

USUAL CASING PROGRAM **BOP EQUIPMENT** Required

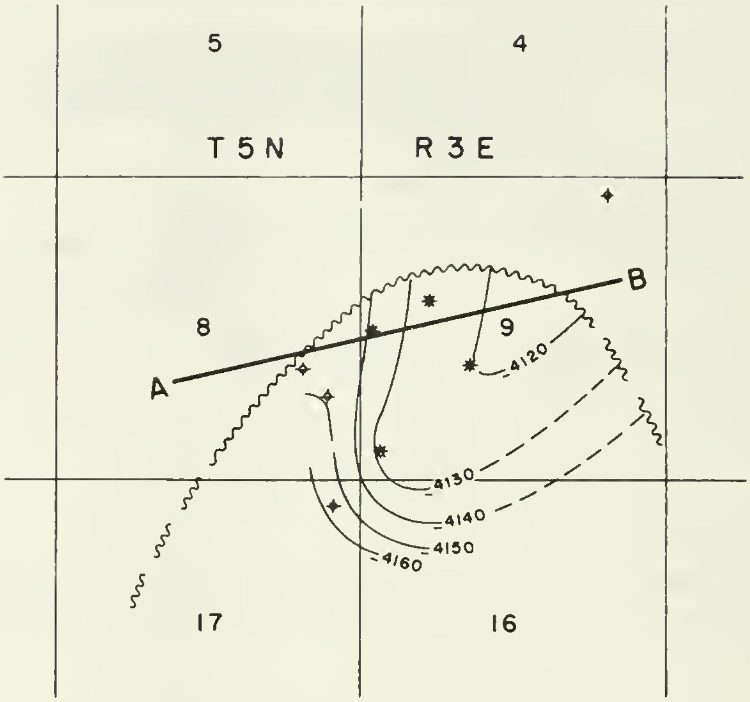
9-5/8" cem. 1,200
5-1/2" cem. through gas zone and shot-perforated for production

MISCELLANEOUS Originally named Willow Creek Gas area. The area was abandoned in 1958.

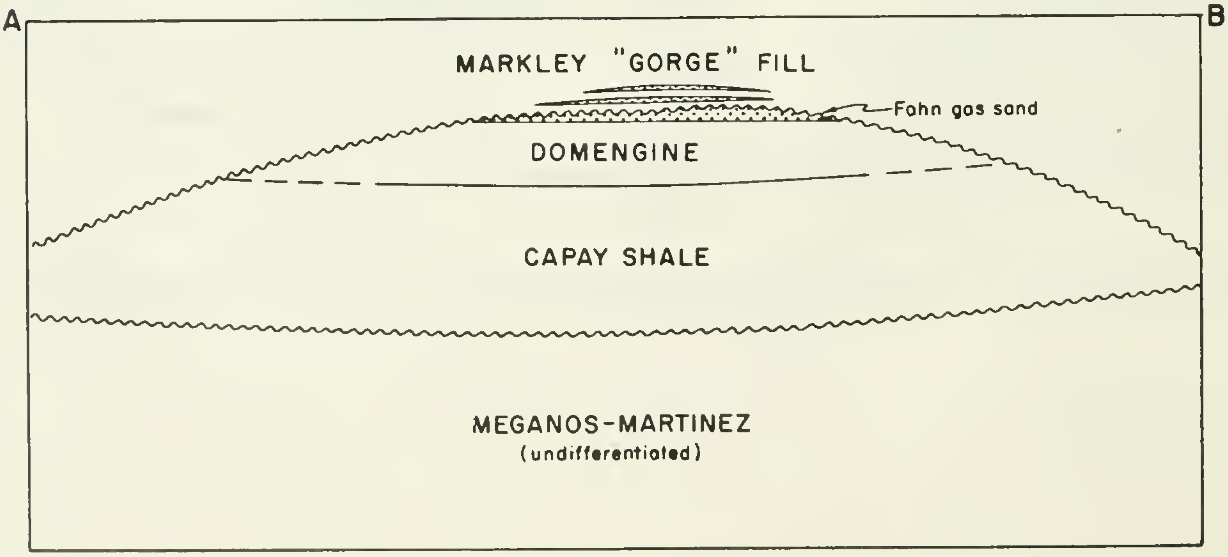
REFERENCES -

LIBERTY CUT GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments, Predominantly Nonmarine	3500
EOCENE	Markley "Gorge" Fill	540 to 1010
	Fahn Gas Sand Domengine	0 to 220
	Copay	100 to 440
PALEOCENE	Meganos-Martinez (undifferentiated)	1400
UPPER CRETACEOUS	"Martinez" silt	80
	Starkey	220 (drilled)



CONTOURS ON BASE OF FAHN GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

LIBERTY CUT GAS FIELD
Solano County

LOCATION 22 miles southwest of Sacramento.

DISCOVERY DATA Arcady Oil Co. well No. "Fahn" 1, Sec. 9, T. 5 N., R. 3 E., M.D.B.& M. Completed November 18, 1953, flowing gas from interval 4,128-4,138 at the average rate of 2,000 Mcf/d through a 12/64-inch bean under a flow pressure of 1,500 psi.

STRUCTURE Truncated nose and sand lenses.

ELEVATION 14 BASE OF FRESH WATERS 2,600 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
(un-named)	4,070	10	Eocene	"Gorge" fill	996	580
Fahn	4,199	40	Eocene	Domengine	996	580

DEEPEST WELL DATA Arcady Oil Co. well No. "Fahn" 5, Sec. 8, T. 5 N., R. 3 E., M.D.B.& M. T.D. 6,463 in Starkey (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	7
Cumulative Gas (Mcf.)	170,024	Total Wells Completed	4
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	2
1959 Average Gas (Mcf/d)	58	Maximum Proved Acreage	190
Peak Production (1957) (Mcf.)	114,677		

USUAL CASING PROGRAM
10-3/4" cem. 500
5-1/2" cem. through gas sands and shot-perforated for production

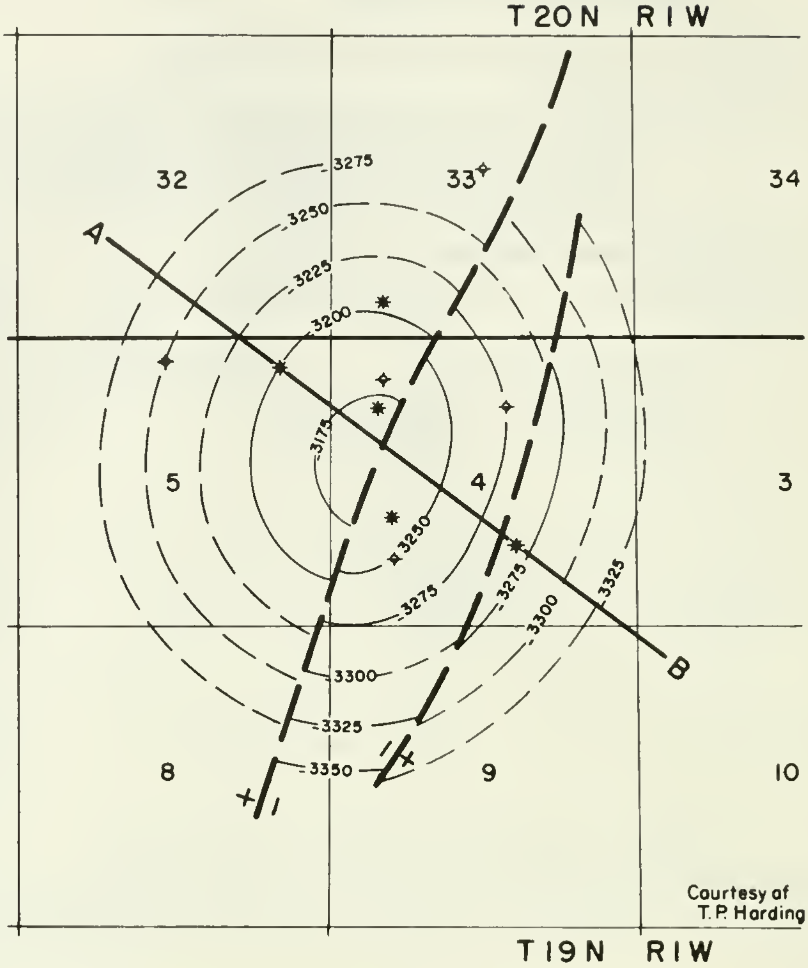
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in June 1957.

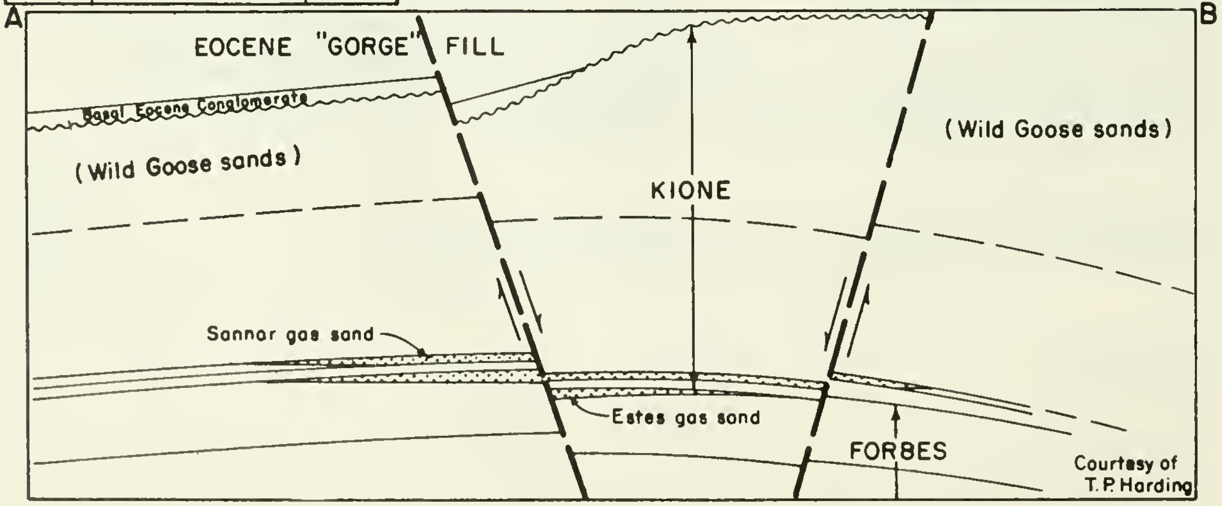
REFERENCES -

LLANO SECO GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT -PLIOCENE	Alluvium & Victor	150
	Tehama	1350
EOCENE	"Gorge" Fill	400 to 1000
	Basal Conglomerate	0-40
UPPER CRETACEOUS	Wild Goose sands Kione Sannar gas sand ▨	350 to 1400
	Estes gas sand ▨ Forbes	1750
	Dobbins	300
	Guinda	450
	Funks	300
	Sites	800 (drilled)



CONTOURS ON TOP OF ESTES GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

LLANO SECO GAS FIELD
Butte and Glenn Counties

LOCATION 11 miles east of Willows.

DISCOVERY DATA Humble Oil & Refining Co. well No. "Parrott Investment Company" 2, Sec. 4, T. 19 N., R. 1 W., M.D.B.& M. Completed November 6, 1954, flowing gas from the intervals 3,225-3,238 and 3,280-3,300 at the average rate of 4,000 Mcf/d.

STRUCTURE Faulted dome.

ELEVATION 110 BASE OF FRESH WATERS 1,300 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Sannar	3,260	12	U. Cretaceous	Kione	960	240
Estes	3,300	5	U. Cretaceous	Forbes	960	240

DEEPEST WELL DATA Socony Mobil Oil Co., Inc., well No. "Llano Seco" 1, Sec. 33, T. 20 N., R. 1 W. T.D. 8,306 in Sites (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	10
Cumulative Gas (Mcf.)	2,241,763	Total Wells Completed	5
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	5
1959 Average Gas (Mcf/d)	1,119	Maximum Proved Acreage	215
Peak Production (1957) (Mcf.)	1,207,199		

USUAL CASING PROGRAM
9-5/8" cem. 600
5-1/2" cem. through gas zone and shot-perforated for production

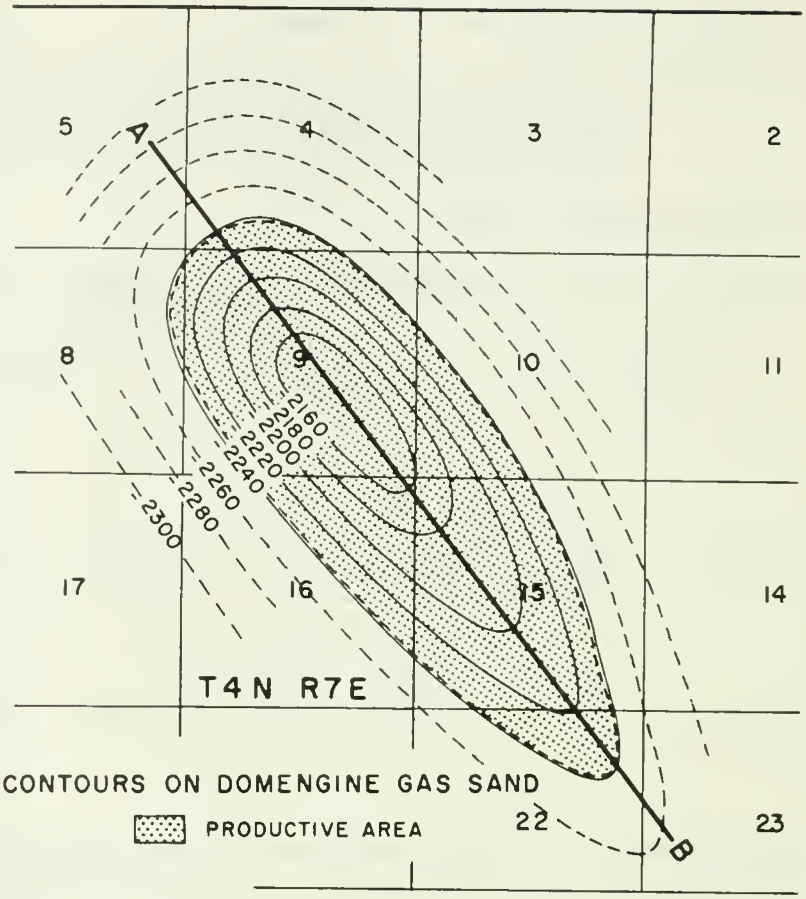
BOP EQUIPMENT Required

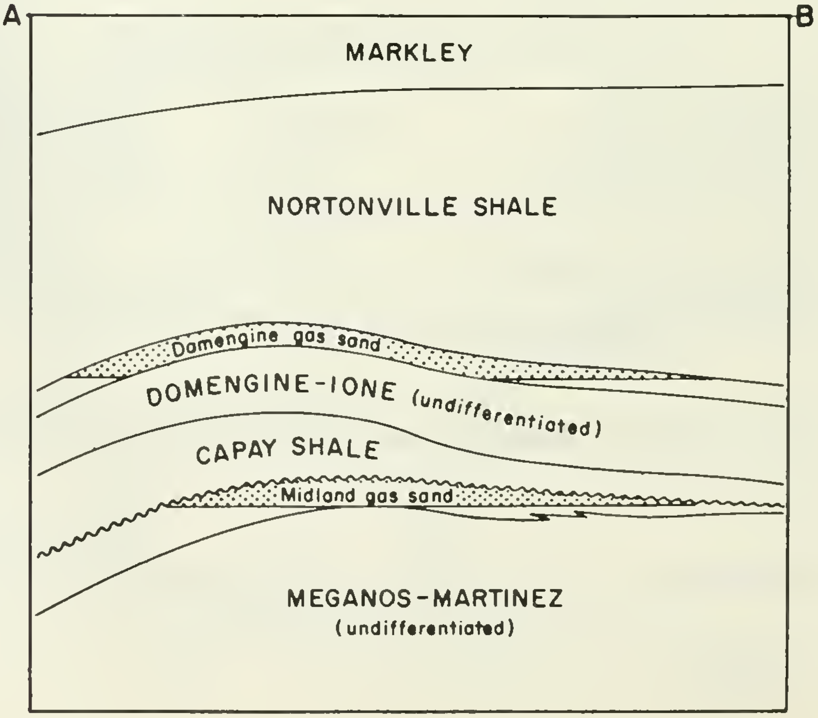
MISCELLANEOUS Commercial gas deliveries began in July 1957.

REFERENCES -

LODI GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments, Predominantly Nonmarine	1870
EOCENE	Markley	190
	Nortonville	240
	Domengine Gas Sand ▨	
	Domengine-Ione (undifferentiated)	160
	Capay	110
	Midland Gas Sand ▨	
EOCENE / PALEOCENE	Meganos-Martinez (undifferentiated)	600
UPPER CRETACEOUS	Starkey	800
	Winters (?)	570
Basement Complex		20 (drilled)





CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

LODI GAS FIELD
San Joaquin County

LOCATION 5 miles northeast of Lodi.

DISCOVERY DATA Amerada Petroleum Corp. well No. "Community 9" 1, Sec. 9, T. 4 N., R. 7 E., M.D.B.& M. Completed April 3, 1943, flowing gas from intervals between 2,240-2,270 at the average rate of 7,222 Mcf/d through a 1/2-inch bean under a flow pressure of 355 psi.

STRUCTURE Anticline.

ELEVATION 80-100 BASE OF FRESH WATERS 1,700 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Domengine	2,280	25	Eocene	Domengine	750	110
Midland	2,515	35	Eocene-Paleocene	Meganos-Martinez (undiff.)	700	200

DEEPEST WELL DATA D.D. Dunlap Oil Co. well No. "Community One" 18-5, Sec. 5, T. 4 N., R. 7 E. T.D. 4,747 in basement complex.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	11
Cumulative Gas (Mcf.)	12,103,557	Total Wells Completed	6
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	6
1959 Average Gas (Mcf/d)	2,746	Maximum Proved Acreage	1,450
Peak Production (1947) (Mcf.)	1,301,472		

USUAL CASING PROGRAM

9-5/8" cem. 700
5-1/2" cem. through gas sands and shot-perforated for production

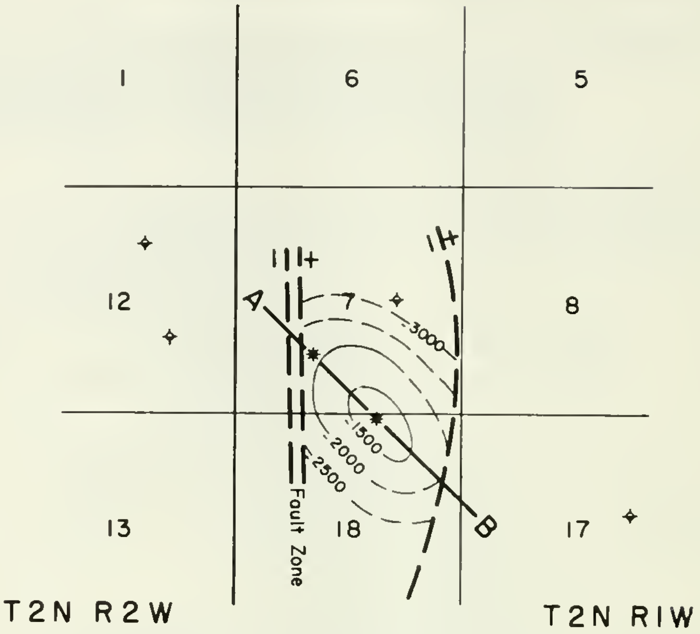
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in October 1946.

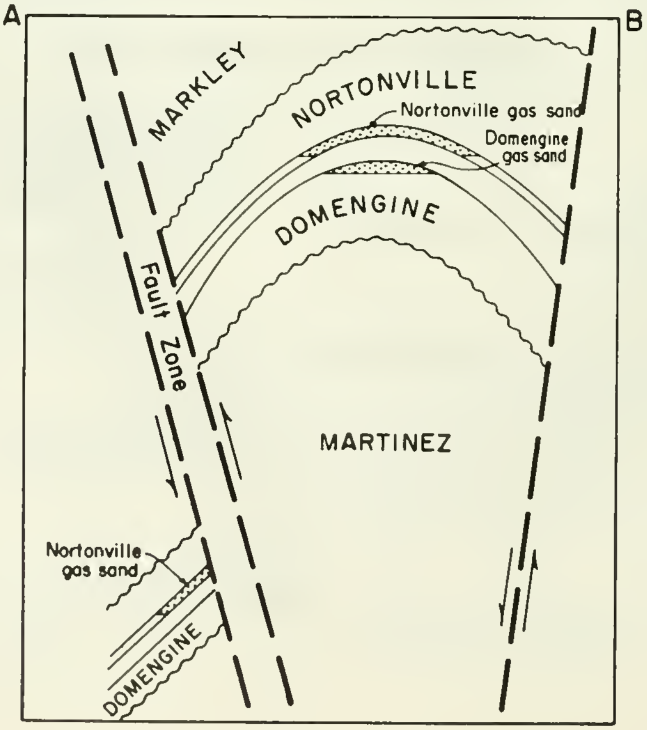
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 43, No. 1 (1957)

LOS MEDANOS GAS AREA

EPOCH	FORMATION	Thickness (Feet)
EOCENE	Markley	1100
	Nortonville	700
	Domengine	400
PALEOCENE	Martinez	1000 (drilled)



CONTOURS ON TOP OF DOMENGINE GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

LOS MEDANOS GAS AREA
Contra Costa County

LOCATION 1 mile south of Port Chicago.

DISCOVERY DATA McCulloch Oil Exploration Co. of California, Inc., well No. "McCulloch-Macson-Ginochio" 1 (now "McCulloch-Ginochio" 1), Sec. 18, T. 2 N., R. 1 W., M.D.B.& M. Completed April 30, 1958, flowing gas at the rate of 1,590 Mcf/d through a 24/64-inch bean under a flow pressure of 425 psi. from the interval 1,872-1,908.

STRUCTURE Faulted anticline.

ELEVATION 217-573 BASE OF FRESH WATERS 150-600 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Nortonville	1,660 & 4,310	40	Eocene	Nortonville	1,020	20
Domengine	1,870	25	Eocene	Domengine	1,020	630

DEEPEST WELL DATA Len Owens and John DeWitt Exploration Co. well No. "Danno" 1, Sec. 18, T. 2 N., R. 1 W. T.D. 5,000 in Martinez (Paleocene).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	3
Cumulative Gas (Mcf.)	139,984	Total Wells Completed	2
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	310	Maximum Proved Acreage	60
Peak Production (1959) (Mcf.)	113,040		

USUAL CASING PROGRAM BOP EQUIPMENT Required

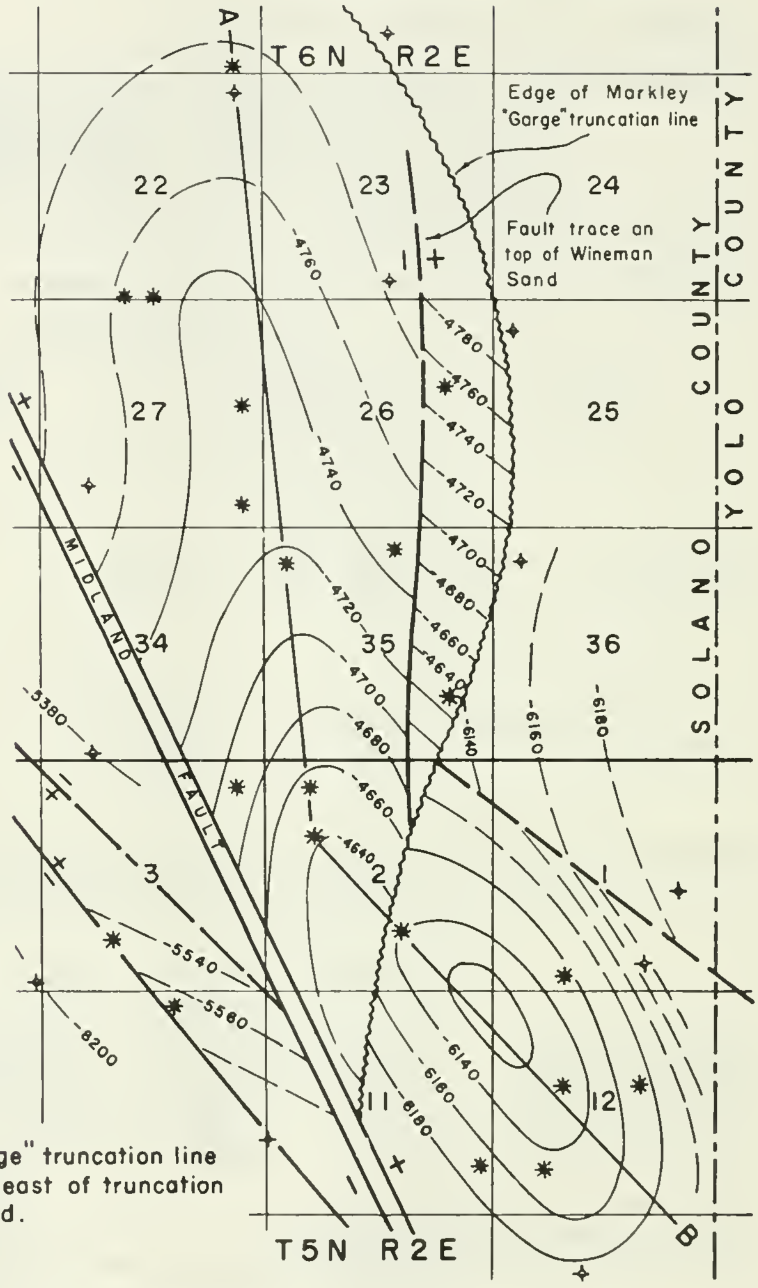
10-3/4" surface casing cem. 500
5-1/2" casing cem. through gas zones and shot-perforated for production

MISCELLANEOUS Commercial gas deliveries began in November 1958.

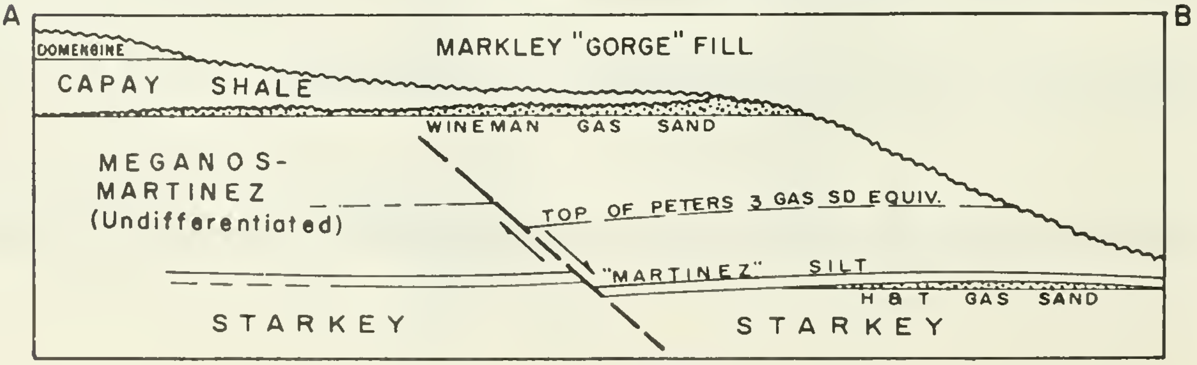
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 44, No. 2 (1958)

MAINE PRAIRIE GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium	300
	Continental Deposits & Tehama	3000
EOCENE	Markley "Gorge" Fill	850 TO 2460
	Domengine	0-200
	Capay	0-450
PALEOCENE	Wineman gas sd. Meganos-Martinez (Undiff) Peters 3 gas sand	250 TO 1350
UPPER CRETACEOUS	"Martinez" Silt	100
	H and T gas sand Storkey	190 (drilled)



Contours west of the "Gorge" truncation line on top of Wineman sand; east of truncation line, on top of H and T sand.



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

MAINE PRAIRIE GAS FIELD
Solano County

LOCATION 20 miles southwest of Sacramento.

DISCOVERY DATA Amerada Petroleum Corp. well No. "I. & L. Wineman" 1, Sec. 26, T. 6 N., R. 2 E., M.D.B.& M. Completed March 2, 1945, flowing gas from the interval 4,769-4,789 at the average rate of 18,997 Mcf/d through a 3/4-inch bean under a flow pressure of 1,758 psi.

STRUCTURE Faulted anticline.

ELEVATION 20 BASE OF FRESH WATERS 2,700 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Wineman	4,740	40	Eocene-Paleocene	Meganos-Martinez (undiff.)	1,020	350
Peters 3	6,440	92	Eocene-Paleocene	Meganos-Martinez (undiff.)	1,060	1,000
H & T	6,160	15	U. Cretaceous	Starkey	1,060	1,000

DEEPEST WELL DATA Amerada Petroleum Corp. well No. "Peters" 1, Sec. 10, T. 5 N., R. 2 E. T.D. 7,381 in Starkey (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	33
Cumulative Gas (Mcf.)	28,939,563	Total Wells Completed	20
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	12
1959 Average Gas (Mcf/d)	10,121	Maximum Proved Acreage	2,040
Peak Production (1959) (Mcf.)	3,694,243		

USUAL CASING PROGRAM
9-5/8" or 10-3/4" cem. 500
5-1/2" cem. through gas sands and shot-perforated for production

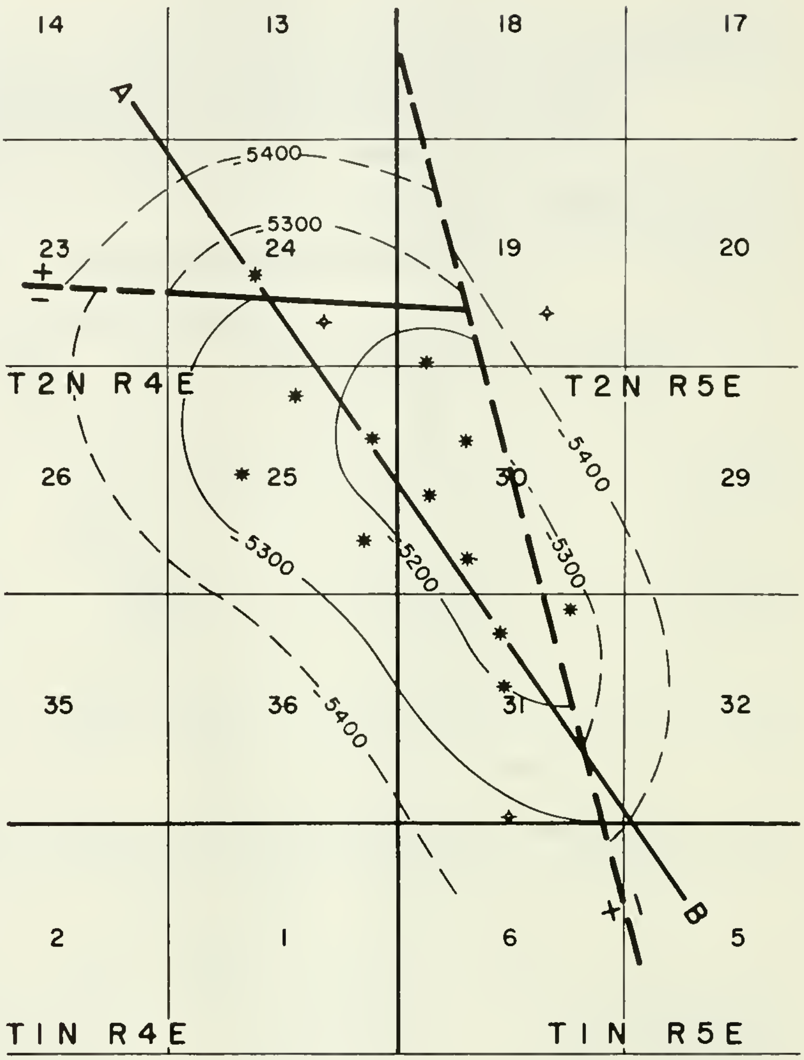
BOP EQUIPMENT Required

MISCELLANEOUS Formerly known as Duck Slough Gas area. Commercial gas deliveries began in July 1947.

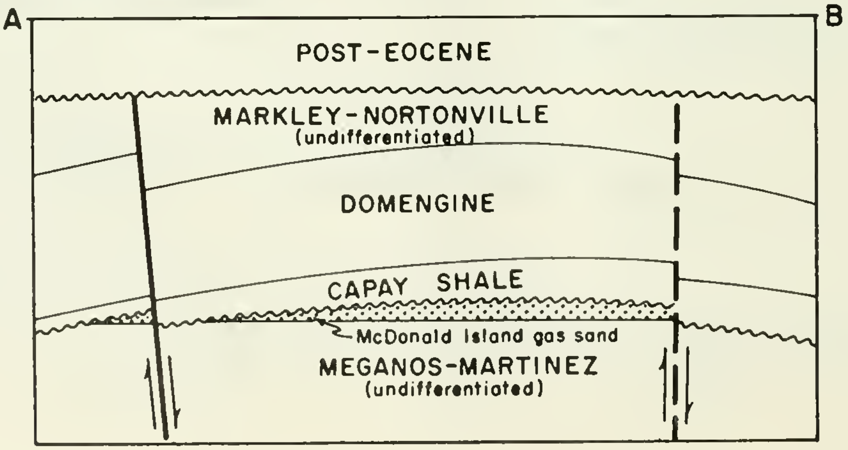
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 31, No. 2 (1945) and Vol. 33, No. 2 (1947)

McDONALD ISLAND GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments, Predominantly Nonmarine	3940
EOCENE	Markley-Nortonville (undifferentiated)	280
	Domengine	800
	Capay	150
	McDonald Island gas sand	
EOCENE PALEOCENE	Meganos-Martinez (undifferentiated)	1590
UPPER CRETACEOUS	Moreno	530
	Panoche	1450 (drilled)



CONTOURS ON TOP OF McDONALD ISLAND GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

McDONALD ISLAND GAS FIELD
San Joaquin County

LOCATION 11 miles west of Stockton.

DISCOVERY DATA Standard Oil Co. of California well No. "McDonald Island Farms" 1 (now Pacific Gas and Electric Company well No. "McDonald Island Farms" 1), Sec. 25, T. 2 N., R. 4 E., M.D.B.& M. Completed May 29, 1936, flowing gas from the interval 5,144-5,225 at the average rate of 26,647 Mcf/d through a 3/4-inch bean under a flow pressure of 2,080 psi.

STRUCTURE Faulted anticline.

ELEVATION 2 BASE OF FRESH WATERS 50-100 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
McDonald Island	5,220	90	Eocene	Meganos	962	690

DEEPEST WELL DATA Standard Oil Co. of California well No. "Weyl-Zuckerman" 2 (now Pacific Gas and Electric Company well No. "Weyl-Zuckerman" 2), Sec. 25, T. 2 N., R. 4 E. T.D. 8,810 in Panoche (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	17
Cumulative Gas (Mcf.)	151,402,407	Total Wells Completed	12
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	82	Maximum Proved Acreage	1,130
Peak Production (1956) (Mcf.)	13,045,665		

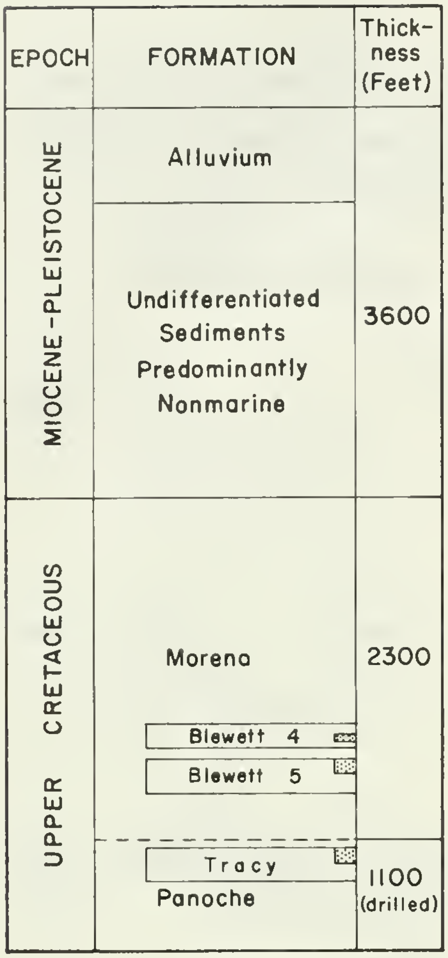
USUAL CASING PROGRAM
11-3/4" cem. 500
7" cem. above gas sand
5-1/2" liner landed through gas zone

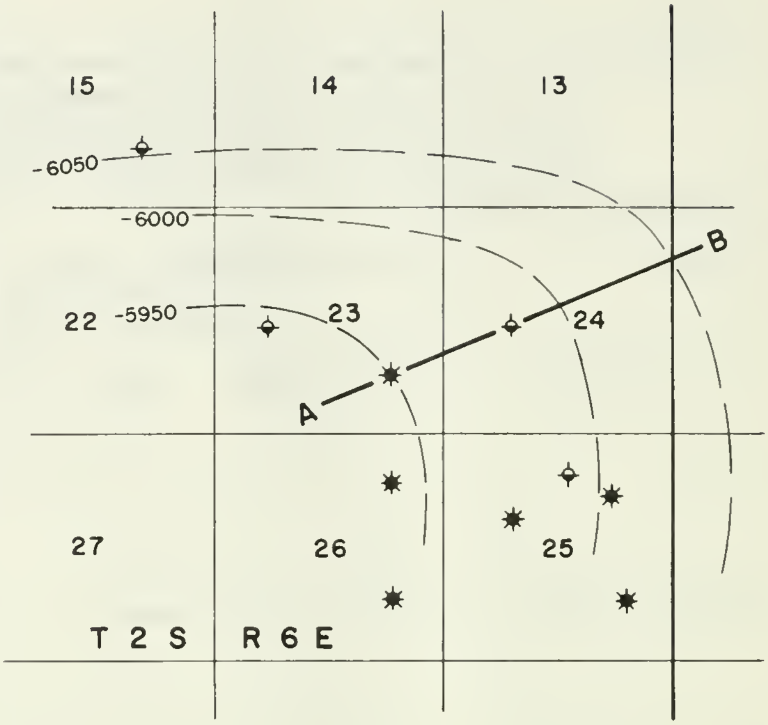
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in April 1937. Pacific Gas and Electric Company acquired the entire field in December 1958 and converted the field to gas storage in August 1959.

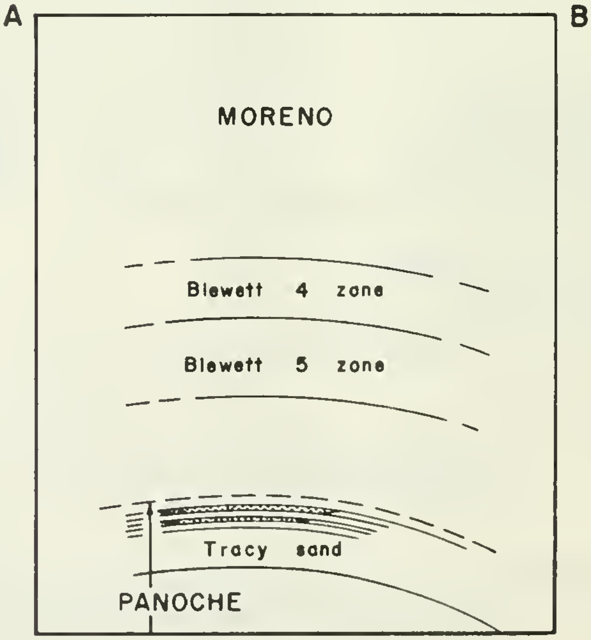
REFERENCES Calif. Div. of Mines Bull. 118 (1943)
Calif. Railroad Comm. and Calif. Div. of Oil and Gas, Estimate of the Natural Gas Reserves of the State of California (1946)
AAPG Pacific Section, Correlation Sections--Central San Joaquin Valley (1958)

McMULLIN RANCH GAS AREA





CONTOURS ON TOP OF TRACY SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

McMULLIN RANCH GAS AREA
San Joaquin County

LOCATION 15-1/2 miles south of Stockton.

DISCOVERY DATA Great Basins Petroleum Co. well No. "Signet-Whiting" 66-23, Sec. 23, T. 2 S., R. 6 E., M.D.B.& M. Completed May 4, 1960, flowing gas from the intervals 5,925-5,945 and 5,957-5,970 at the rate of 2,740 Mcf/d through a 3/8-inch bean under a flow pressure of 775 psi.

STRUCTURE Updip lensing on anticlinal nose(?).

ELEVATION 30 BASE OF FRESH WATERS above 500 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Blewett 4	5,265	31	U. Cretaceous	Moreno	-	-
Blewett 5	5,335	31	U. Cretaceous	Moreno	-	-
Tracy	5,915	36	U. Cretaceous	Panoche	-	-

DEEPEST WELL DATA Signet Operating and Exploration Co. well No. "McMullin" 1, Sec. 23, T. 2 S., R. 6 E. T.D. 6,985 in Panoche (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	-	Total Wells Drilled	-
Cumulative Gas (Mcf.)	-	Total Wells Completed	-
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	-
Peak Production	-		

USUAL CASING PROGRAM
7" cem. 800
4-1/2" cem. through gas zone and shot-perforated for production

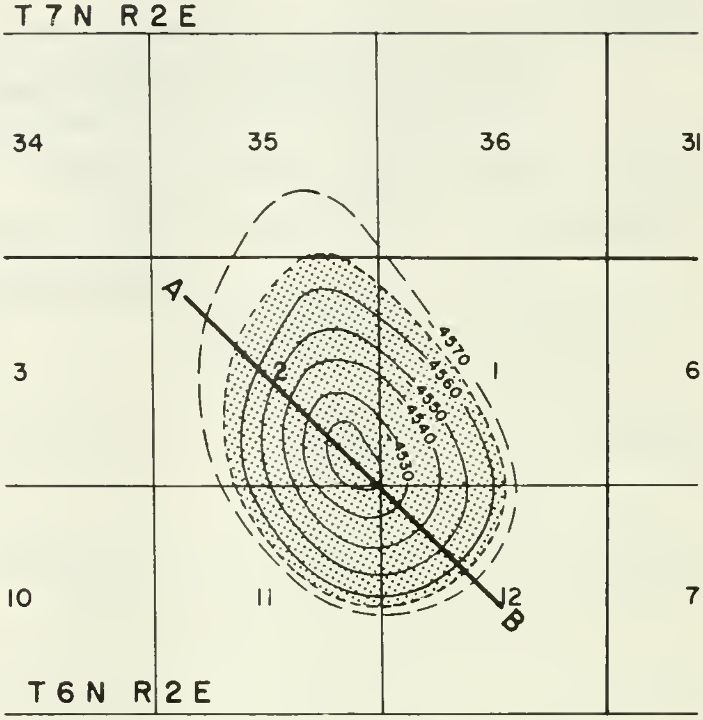
BOP EQUIPMENT Required

MISCELLANEOUS -

REFERENCES -

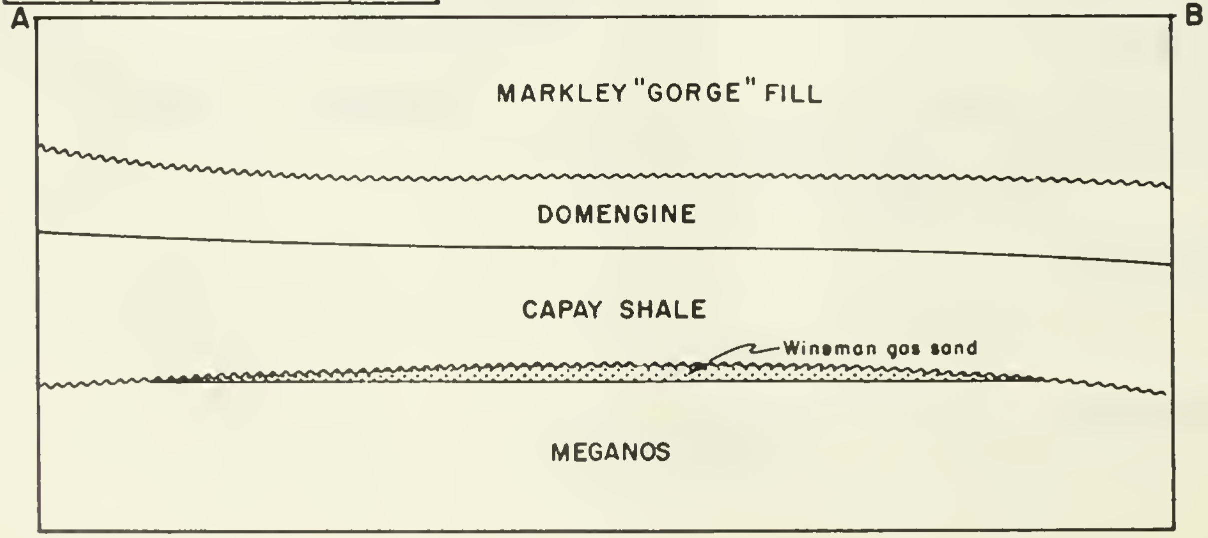
MILLAR GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments, Predominantly Nonmarine	3300
EOCENE	Markley "Gorge" Fill	700
	Domengine	200
	Capay	370
PALEO-CENE	Wineman gas sand ▨ Meganos-Martinez (undifferentiated)	1100
UPPER CRETACEOUS	"Martinez" silt	90
	Starkey	1330
	Winters	2400 (drilled)



CONTOURS ON TOP OF WINEMAN GAS SAND

▨ PRODUCTIVE AREA



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

MILLAR GAS FIELD
Solano County

LOCATION 18 miles southwest of Sacramento.

DISCOVERY DATA Amerada Petroleum Corp. well No. "Starkey Fee" 1 (now "Millar Comm." 1), Sec. 2, T. 6 N., R. 2 E., M.D.B.& M. Completed August 28, 1944, flowing gas from the interval 4,550-4,600 at the average rate of 22,570 Mcf/d.

STRUCTURE Dome.

ELEVATION 30 BASE OF FRESH WATERS 2,600 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Wineman	4,570	48	Eocene	Meganos	980	350

DEEPEST WELL DATA The discovery well. T.D. 9,434 in Winters (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	5
Cumulative Gas (Mcf.)	9,494,766	Total Wells Completed	3
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	104	Maximum Proved Acreage	160
Peak Production (1948) (Mcf.)	2,843,601		

USUAL CASING PROGRAM
9-5/8" cem. at 600
5-1/2" cem. through gas sands and shot-perforated for production

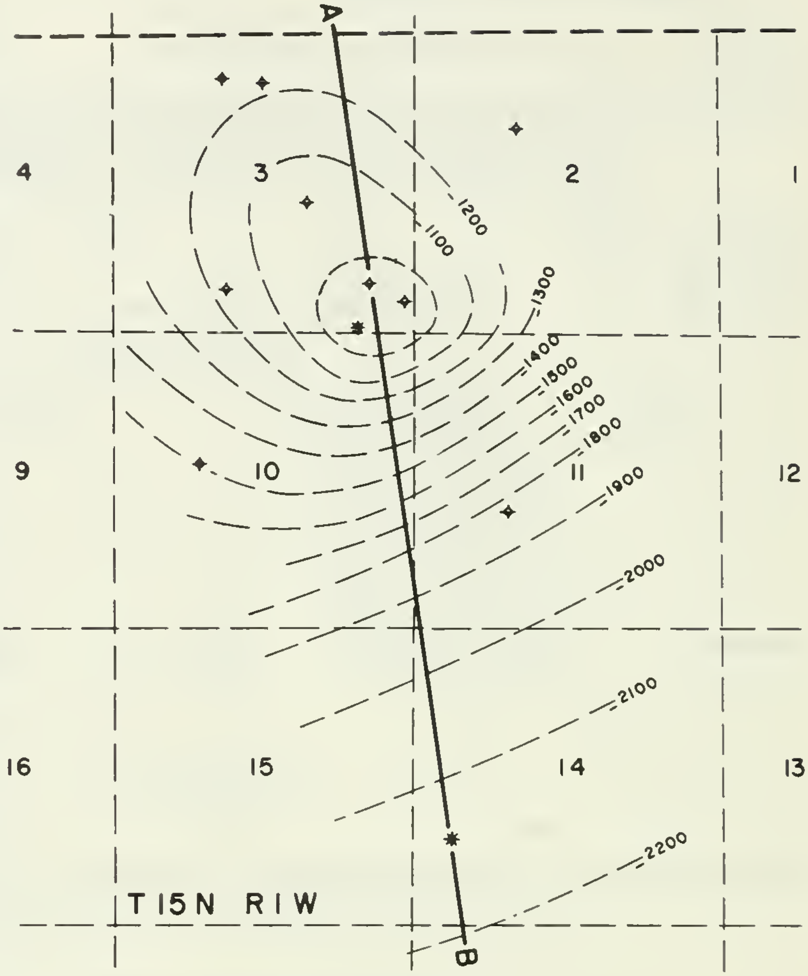
BOP EQUIPMENT Required

MISCELLANEOUS Millar Gas field was originally known as Dixon Gas area. Commercial gas deliveries began in July 1947.

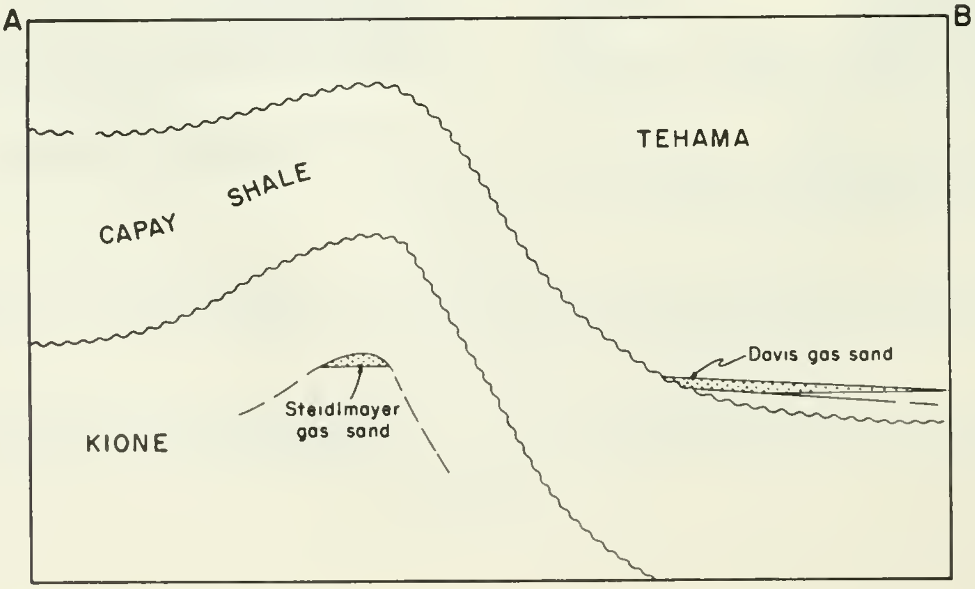
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 33, No. 2 (1947)

MOON BEND GAS AREA

EPOCH	FORMATION	Thickness (Feet)
PLIOCENE-RECENT	Alluvium	500 to 1600
	Tehama Davis sand	
EOCENE	Capay	400 to 600
UPPER CRETACEOUS	Steidlmayer Kione	1200
	Forbes	200 (drilled)



CONTOURS ON TOP OF KIONE



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

MOON BEND GAS AREA
Colusa County

LOCATION 4 miles southeast of Colusa.

DISCOVERY DATA Humble Oil & Refining Co. well No. "Steidlmayer" 3 (now Steidlmayer, et al well No. "Steidlmayer" 3), Sec. 3, T. 15 N., R. 1 W., M.D.B.& M. Completed October 27, 1954, flowing gas from the interval 1,378-1,415 at the average rate of 1,700 Mcf/d through a 1/2-inch bean under a flow pressure of 245 psi.

STRUCTURE Anticline and stratigraphic trap.

ELEVATION 60 BASE OF FRESH WATERS 200-1,300 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Davis	1,480	25	Pliocene	Tehama	-	100
Steidlmayer	1,378	27	U. Cretaceous	Kione	-	-

DEEPEST WELL DATA Humble Oil & Refining Co. well No. "O. P. Davis" B-1, Sec. 14, T. 15 N., R. 1 W. T.D. 3,600 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	11
Cumulative Gas (Mcf.)	0	Total Wells Completed	2
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	80
Peak Production	-		

USUAL CASING PROGRAM BOP EQUIPMENT Required

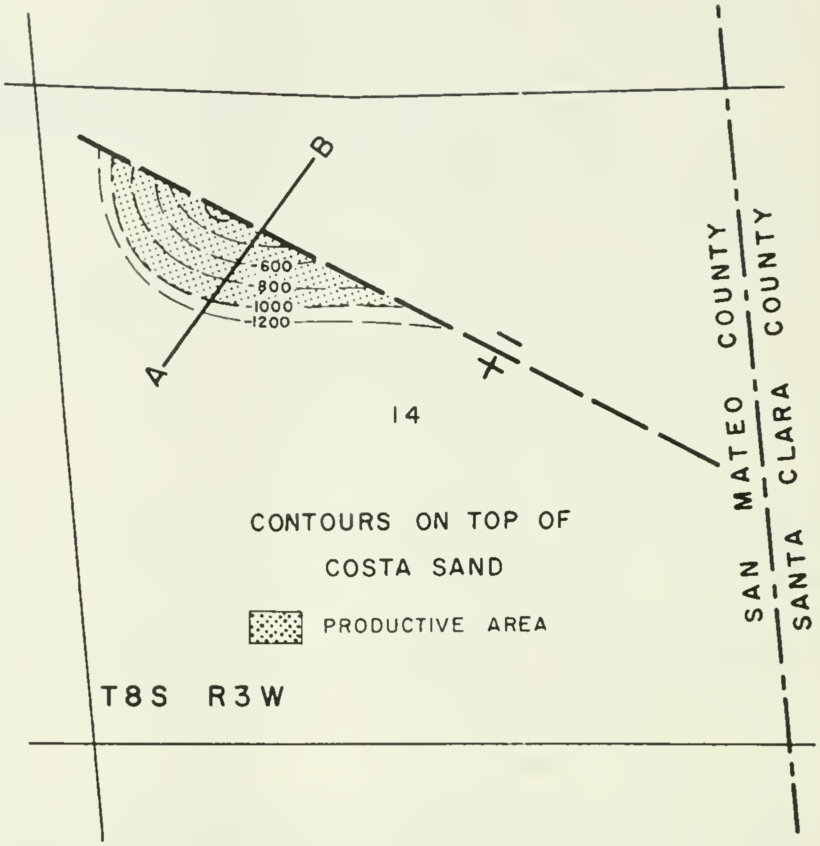
7" cem. 500
5-1/2" cem. through gas zone and shot-perforated for production

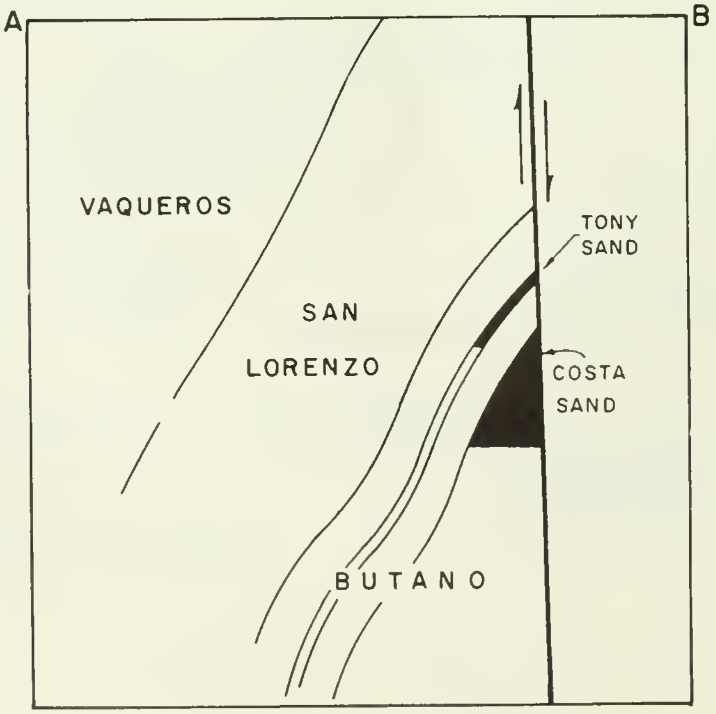
MISCELLANEOUS Wells are shut-in awaiting an outlet for the gas.

REFERENCES

OIL CREEK AREA

EPOCH	FORMATION	Thickness (Feet)
MIOCENE	Vaqueros	0 - ?
	San Lorenzo	1500
OLIGOCENE		
EOCENE	Tony sand Costa sand Butano	3560 (drilled)





CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

OIL CREEK AREA
San Mateo County

LOCATION 20 miles north of Santa Cruz.

DISCOVERY DATA Union Oil Co. of California well No. "Richfield-Costa" 1, Sec. 14, T. 8 S., R. 3 W., M.D.B.& M. Completed October 24, 1955. I.P. 107 b/d 41-degree gravity oil, 17% cut, from the interval 2,060-2,205.

STRUCTURE Faulted nose.

ELEVATION 1,240 BASE OF FRESH WATERS None SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Tony	1,860	55	Eocene	Butano	41	1,480
Costa	2,090	120	Eocene	Butano	41	1,480

DEEPEST WELL DATA Union Oil Co. of California well No. "Richfield-Costa" 4, Sec. 14, T. 8 S., R. 3 W. T.D. 5,112 in Butano (Eocene).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	43,453	Total Wells Drilled	5
Cumulative Gas (Mcf.)	51,660	Total Wells Completed	2
1959 Average Oil (b/d)	16	Producing Wells (1959 Aver.)	2
1959 Average Gas (Mcf/d)	142	Maximum Proved Acreage	20
Peak Production (1956) (bbl.)	14,744		

USUAL CASING PROGRAM
11-3/4" or 10-3/4" cem. 250
7" combination string landed through oil zone and cem. through ports above the zone with perforations opposite oil sand

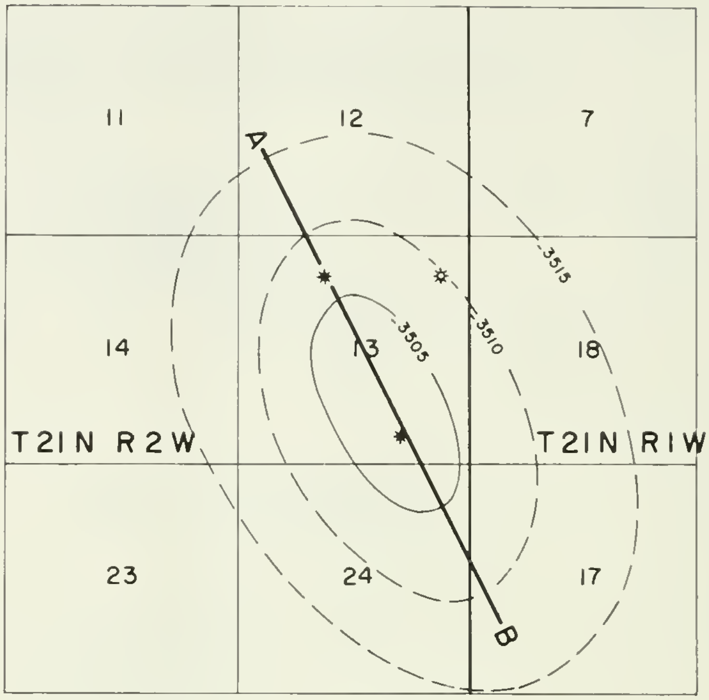
BOP EQUIPMENT Required

MISCELLANEOUS -

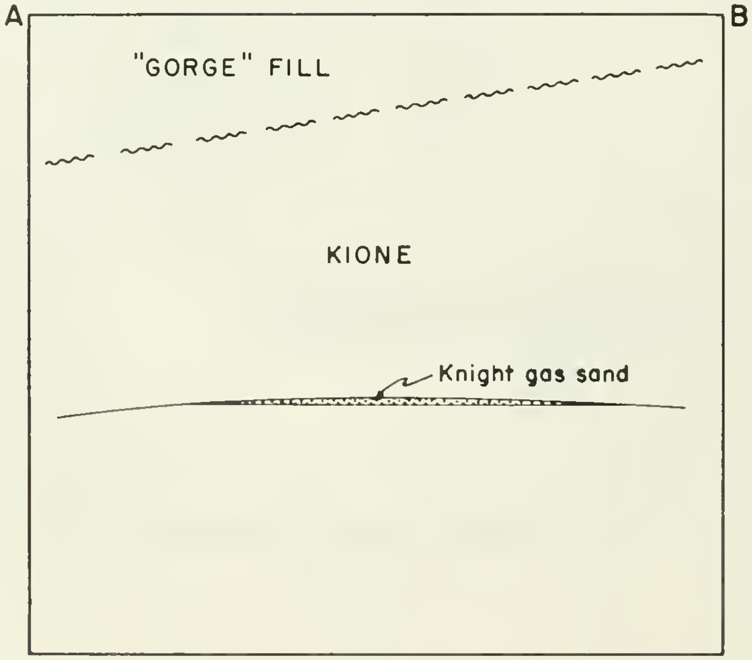
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 41, No. 2 (1955)

ORD BEND GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium	1870
	Tehama	
EOCENE	"Gorge" fill	910
UPPER CRETACEOUS	Kione Knight sand	2050
	Forbes	900
	Dobbins	380
	Guinda	230 (drilled)



CONTOURS ON TOP OF KNIGHT GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

ORD BEND GAS FIELD
Glenn County

LOCATION 11 miles southwest of Chico.

DISCOVERY DATA The Superior Oil Co. well No. "Knight" 1, Sec. 13, T. 21 N., R. 2 W., M.D.B.& M. Completed August 24, 1943, flowing gas from the interval 3,659-3,664 at the average rate of 5,040 Mcf/d through a 24/64-inch bean under a flow pressure of 1,075 psi.

STRUCTURE Dome.

ELEVATION 155 BASE OF FRESH WATERS 1,200 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Knight	3,660	13	U. Cretaceous	Kione	910	900

DEEPEST WELL DATA The discovery well. T.D. 6,346 in Guinda (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	3
Cumulative Gas (Mcf.)	8,088,845	Total Wells Completed	3
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	2
1959 Average Gas (Mcf/d)	890	Maximum Proved Acreage	300
Peak Production (1947) (Mcf.)	1,034,566		

USUAL CASING PROGRAM BOP EQUIPMENT Required

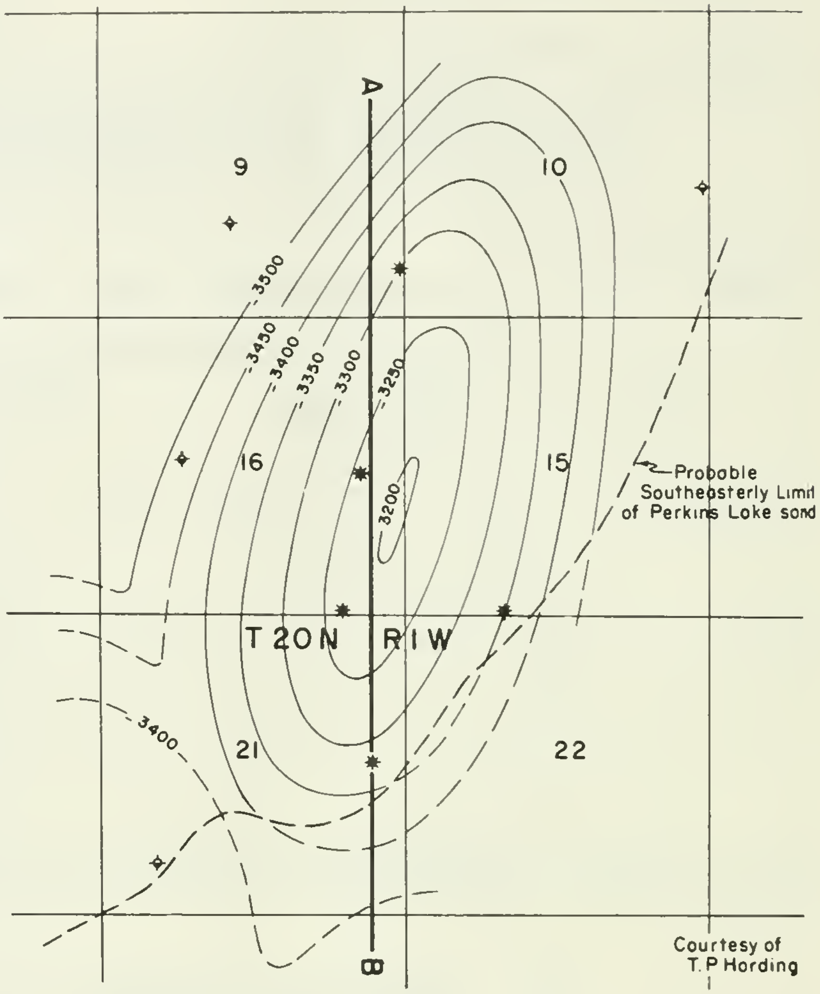
12-3/4" surface casing cem. 500
5-1/2" cem. through gas sand and shot-perforated for production

MISCELLANEOUS Commercial gas deliveries began in January 1945.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 29, No. 2 (1943)

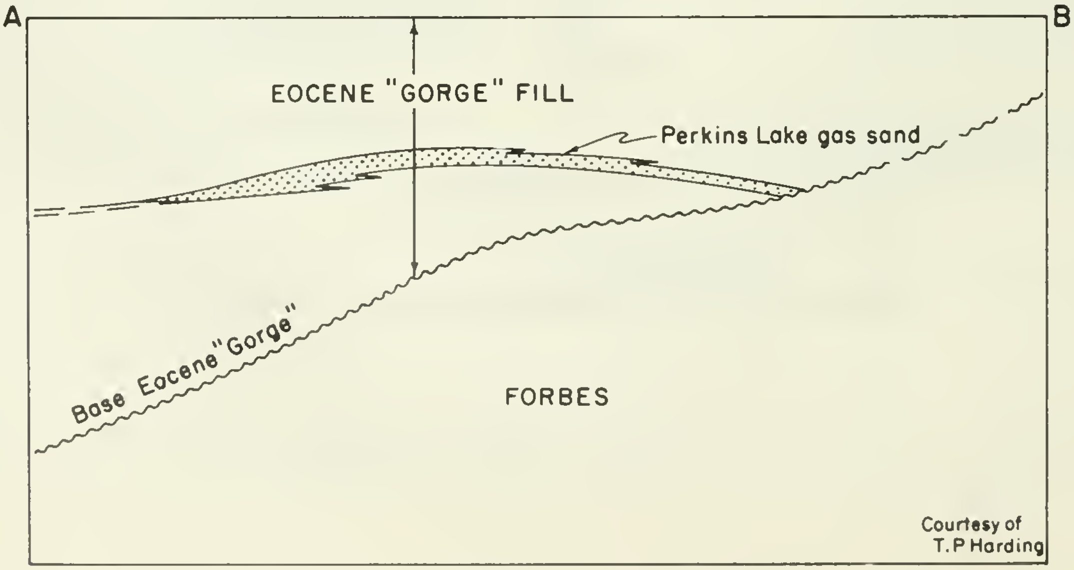
PERKINS LAKE GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT -PLIOCENE	Alluvium & Victor	150±
	Tehama	1880
EOCENE	"Gorge" Fill Perkins Loke gas sond	1000 to 2100
UPPER CRETACEOUS	Forbes	1690
	Dabbins	380
	Guinda	520 (drilled)



Courtesy of T. P Hording

CONTOURS ON TOP OF PERKINS LAKE GAS SAND



Courtesy of T. P Harding

CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

PERKINS LAKE GAS FIELD
Butte County

LOCATION 12 miles northeast of Willows.

DISCOVERY DATA Humble Oil & Refining Co. well No. "Parrott Investment Company" B-1, Sec. 16, T. 20 N., R. 1 W., M.D.B.& M. Completed September 21, 1955, flowing gas from the interval 3,365-3,390 at the average rate of 4,060 Mcf/d through a 3/8-inch bean under a flow pressure of 975 psi.

STRUCTURE Anticline.

ELEVATION 115 BASE OF FRESH WATERS 1,500 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Perkins Lake	3,402	35	Eocene	"Gorge" Fill	950	250

DEEPEST WELL DATA Humble Oil & Refining Co. well No. "Parrott Investment Company" B-6, Sec. 16, T. 20 N., R. 1 W. T.D. 6,500 in Guinda (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	9
Cumulative Gas (Mcf.)	6,764,706	Total Wells Completed	5
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	5
1959 Average Gas (Mcf/d)	6,283	Maximum Proved Acreage	440
Peak Production (1957) (Mcf.)	2,342,016		

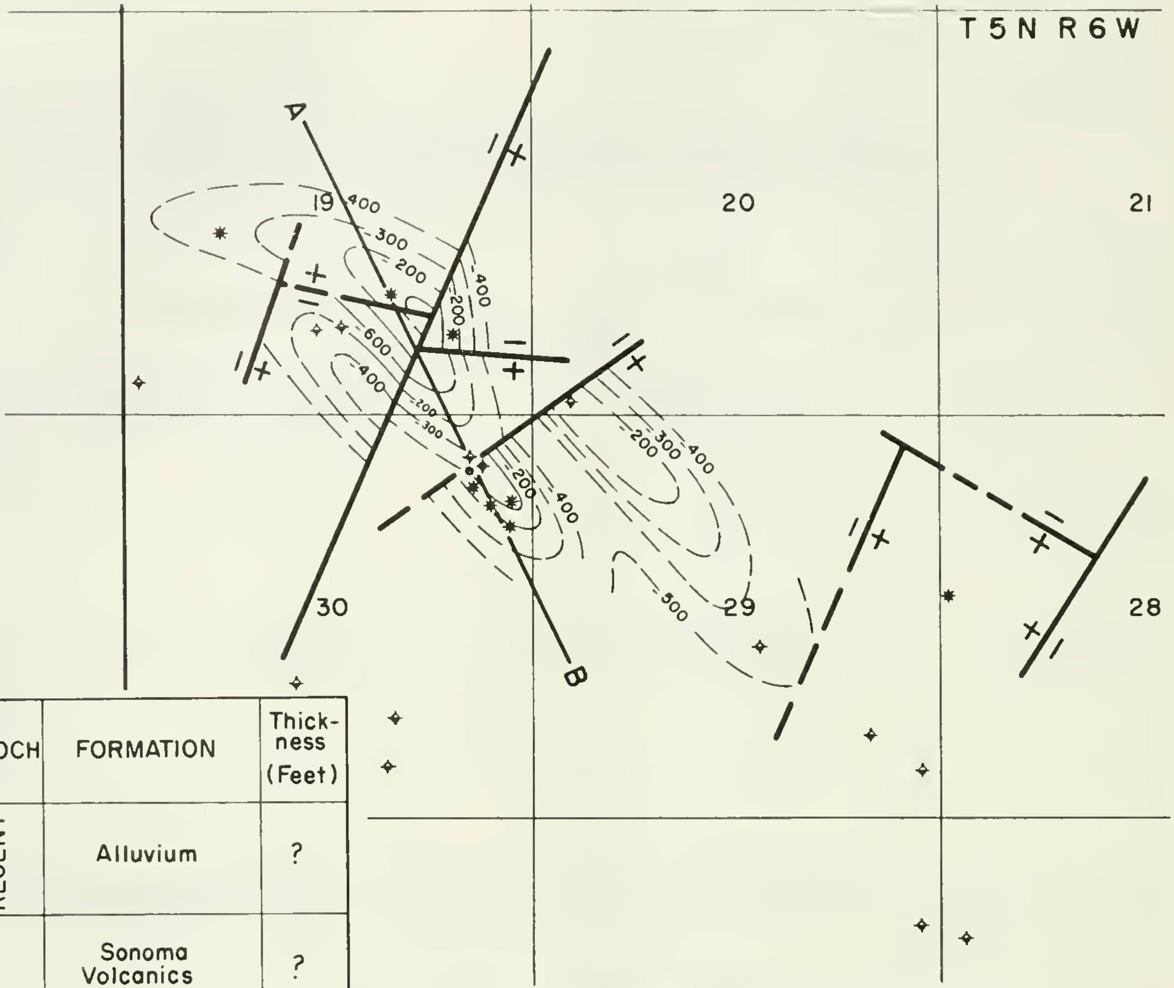
USUAL CASING PROGRAM
7" cem. 600
4-1/2" cem. through gas zone and shot-perforated
for production

BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in December 1956.

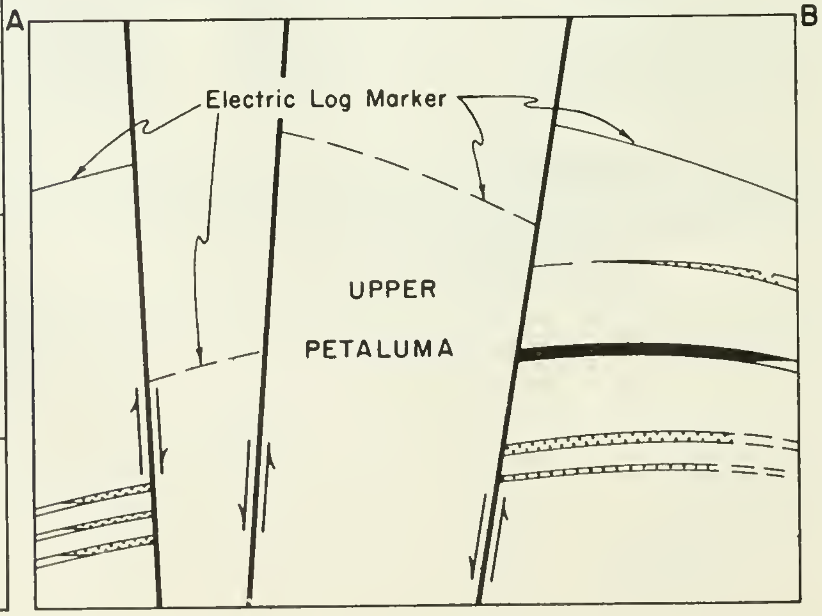
REFERENCES

PETALUMA FIELD



CONTOURS ON ELECTRIC LOG MARKER IN UPPER PETALUMA FORMATION

EPOCH	FORMATION	Thickness (Feet)
RECENT	Alluvium	?
PLIOCENE	Sonoma Volcanics	?
	Upper Petaluma Upper Oil Lower	2200
	Lower Petaluma	
	Tolay	3800 (drilled)
JURASSIC	Franciscan	?



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

PETALUMA FIELD
Sonoma County

LOCATION 4 miles east of Petaluma.

DISCOVERY DATA Hubert N. Witt & Associates, Inc., well No. 2, Sec. 19, T. 5 N., R. 6 W., M.D.B.& M. Completed May 10, 1926. I.P. 12 b/d from the interval 950-1,022.

STRUCTURE Faulted anticline.

ELEVATION 150-360 BASE OF FRESH WATERS 100 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Upper (gas)	670	20	Pliocene	U. Petaluma	1,010	270
Oil	920	25	Pliocene	U. Petaluma	20	-
Lower (gas)	1,240	5-30	Pliocene	U. Petaluma	1,010 1,170	270

DEEPEST WELL DATA Shell Oil Company well No. "Murphy" 1, Sec. 19, T. 5 N., R. 6 W. T.D. 6,385 in igneous rock.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)		13,157
Cumulative Gas (Mcf.)		426,559
1959 Average Oil (b/d)		0
1959 Average Gas (Mcf/d)		164
Peak Production (1951)	(bbl.)	1,508
(1956)	(Mcf.)	136,004

Total Wells Drilled	25
Total Wells Completed	10
Producing Wells (1959 Aver.)	3
Maximum Proved Acreage	135

USUAL CASING PROGRAM
10" cem. 200
4-3/4" cem. through gas zone and shot-perforated for production

BOP EQUIPMENT Required

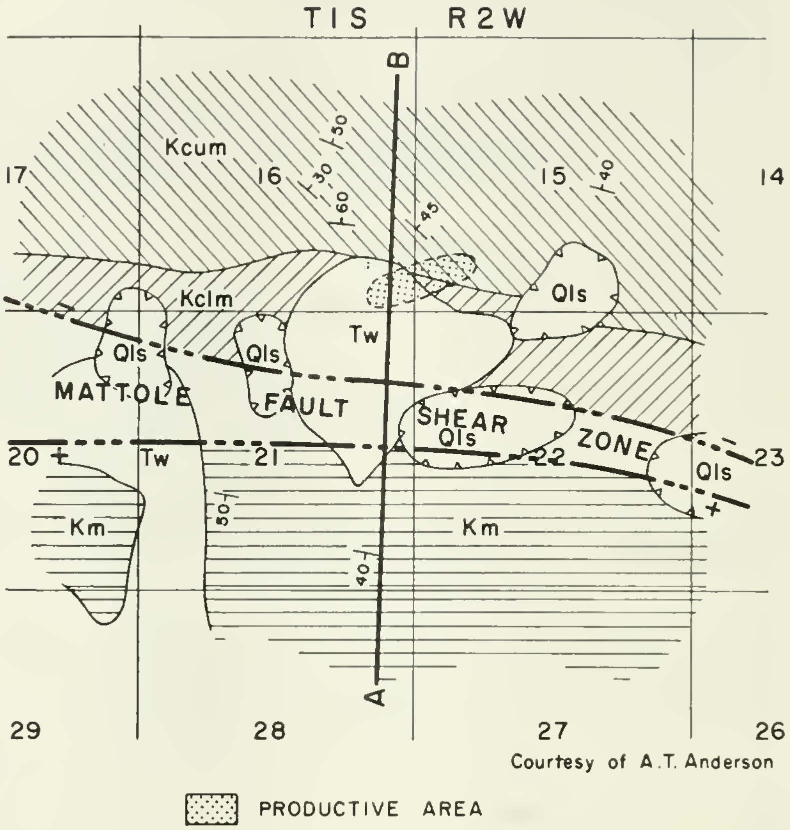
MISCELLANEOUS The field produces mainly dry gas. Only one oil well remains, and it has been shut-in since February 1959. Blu-Cal Oil & Gas Corp. well No. "Petaluma Comm. 5" 2, now producing gas, was originally completed as an oil well.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 27 (1941) and Vol. 34, No. 2 (1948)

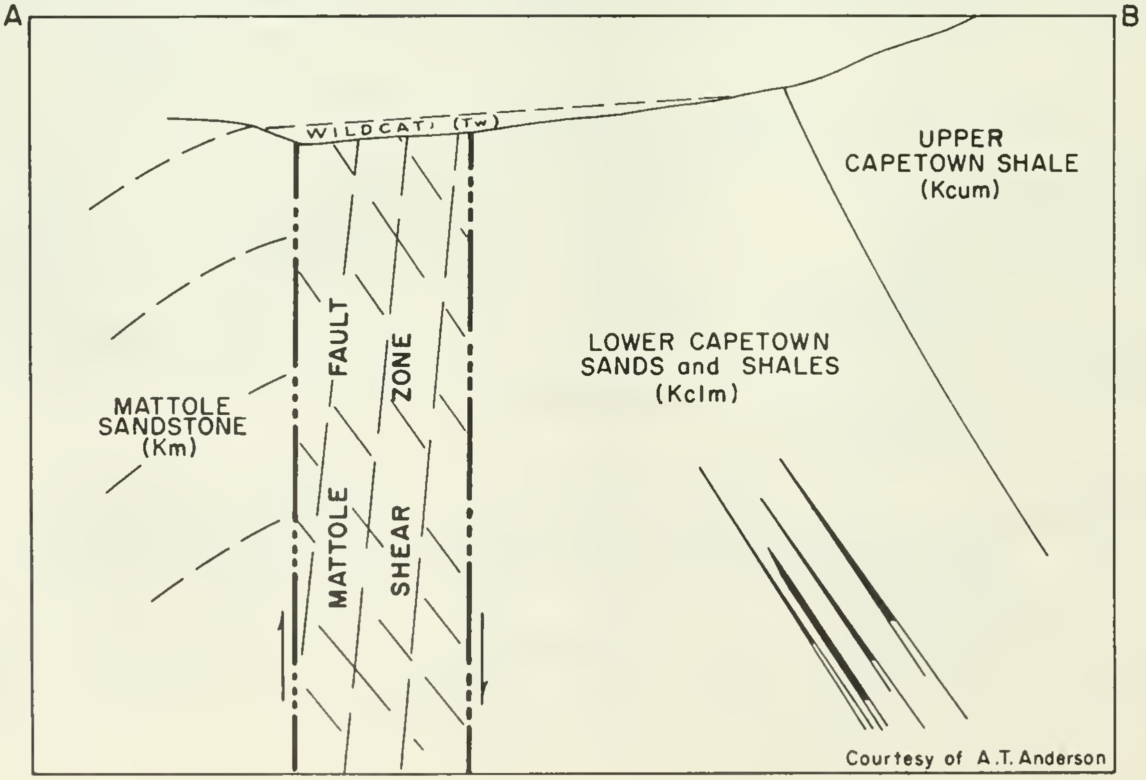
Calif. Div. of Mines Bull. 118 (1943)

PETROLIA AREA

EPOCH	FORMATION	Thickness (Feet)
RECENT	(landslide)	?
PLIOCENE to MIOCENE	Wildcat	50 to 100
UPPER CRETACEOUS	Upper Capetown	7000
	Lower Capetown	
	Mattole	5000



Courtesy of A.T. Anderson



Courtesy of A.T. Anderson

CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

PETROLIA AREA
Humboldt County

LOCATION 30 miles south of Eureka.

DISCOVERY DATA West Coast Oil Corp. well No. "West Coast" 1, Sec. 21, T. 1 S., R. 2 W., H.B.& M. Completed October 7, 1953. I.P. 30 b/d 46-degree gravity oil from the interval 1,580-1,620.

STRUCTURE Stratigraphic trap. Oil accumulation in updip lenses.

ELEVATION 800-1,400 BASE OF FRESH WATERS 40 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
(unnamed)	1,570	90	L. Cretaceous	L. Capetown	46	-

DEEPEST WELL DATA Richfield Oil Corp. well No. "Walker" 1, Sec. 17, T. 1 S., R. 2 W. T.D. 3,499 in Lower Cretaceous.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	350	Total Wells Drilled	17
Cumulative Gas (Mcf.)	0	Total Wells Completed	2
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	10
Peak Production (1954) (bbl.)	140		

USUAL CASING PROGRAM BOP EQUIPMENT Required

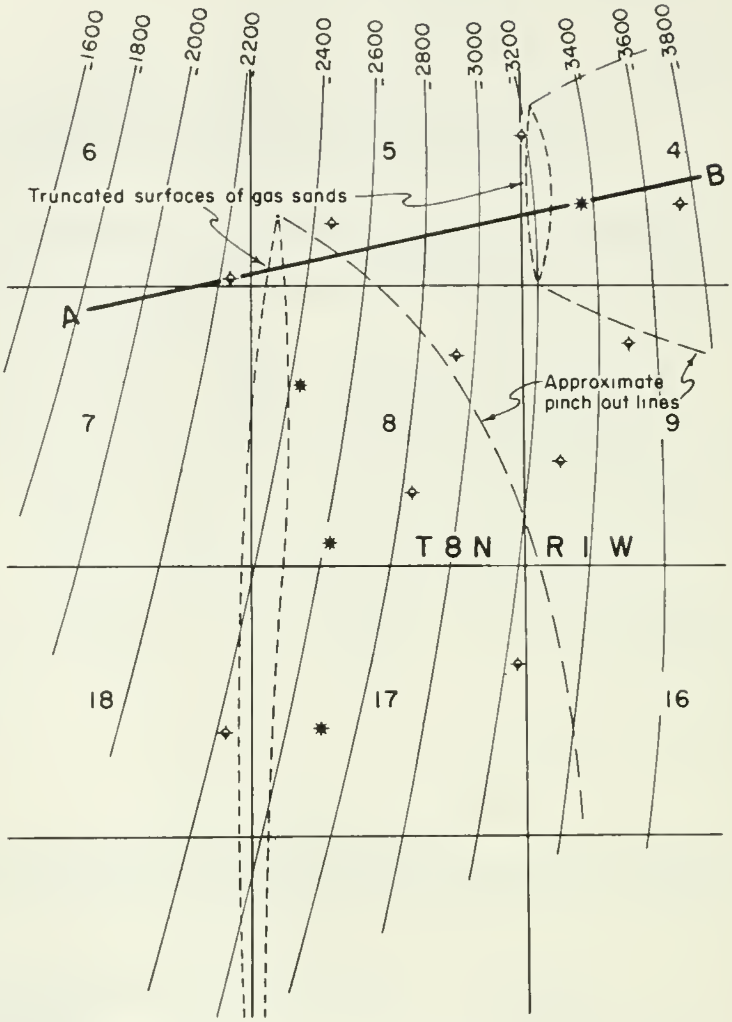
13-3/8" cem. 300
5-1/2" combination string landed through oil zone and cem. through ports above the zone with perforations opposite oil sand

MISCELLANEOUS -

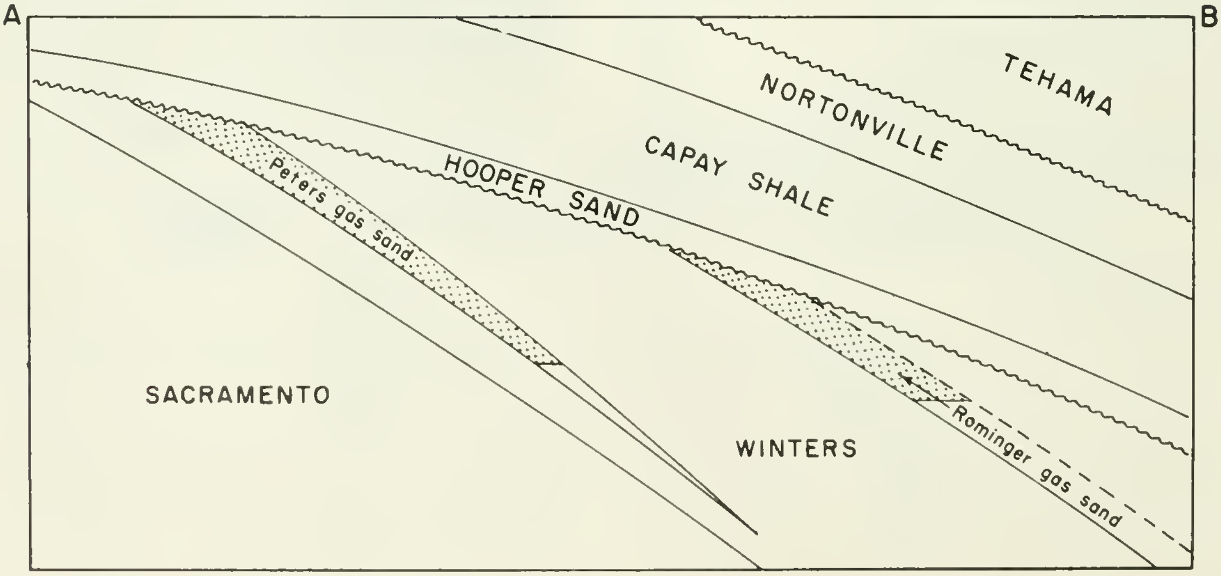
REFERENCES -

PLEASANT CREEK GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
PLIOCENE	Tehama	1700 to 2700
EOCENE	Nortonville	420
	Domengine	10
	Capay	670
	Hooper sand	70
UPPER CRETACEOUS	Winters Rominger sand ▨ Peters sand ▨	0 to 300
	Sacramento	740 (drilled)



CONTOURS ON TOP OF UPPER CRETACEOUS



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

PLEASANT CREEK GAS FIELD
Yolo County

LOCATION 11 miles southwest of Woodland and 1 mile northwest of Winters.

DISCOVERY DATA Shell Oil Co. well No. "Pleasant Creek Unit 3" 1 (now Pacific Gas & Electric Co. well No. "Pleasant Creek Unit 3" 1), Sec. 8, T. 8 N., R. 1 W., M.D.B.& M. Completed December 22, 1948, flowing gas at a rate of 9,550 Mcf/d from the interval 2,783-2,818 through a 1-inch bean under a flow pressure of 508 psi.

STRUCTURE Truncated homocline.

ELEVATION 170-200 BASE OF FRESH WATERS 1,700-2,700 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Rominger	3,700	25	U. Cretaceous	Winters	990	
Peters	2,800	30	U. Cretaceous	Winters	990	-

DEEPEST WELL DATA The Divide Ridge Oil Co. well No. 1, Sec. 8, T. 8 N., R. 1 W. T.D. 5,003 in Upper Cretaceous.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	14
Cumulative Gas (Mcf.)	3,579,429	Total Wells Completed	4
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	200
Peak Production (1952) (Mcf.)	1,021,466		

USUAL CASING PROGRAM
8-5/8" to 11-3/4" cem. at 500
7" or 4-1/2" cem. through gas sands and shot-perforated for production

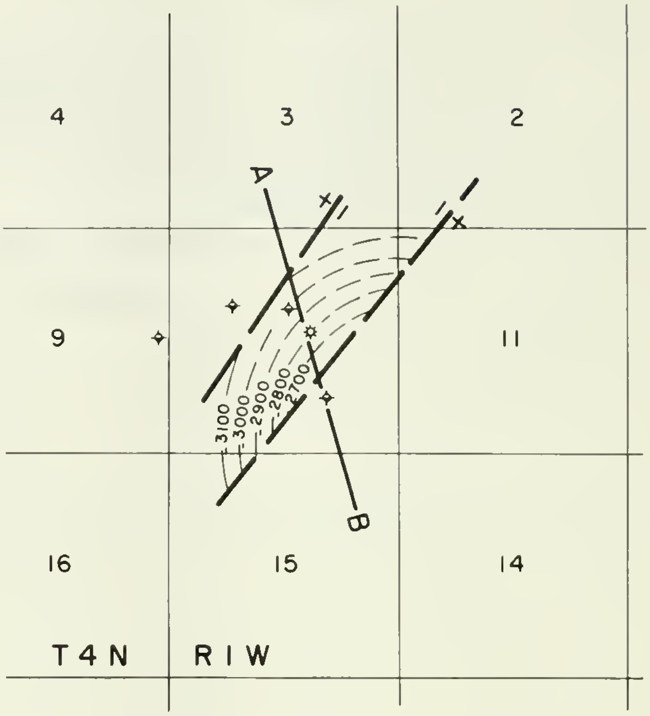
BOP EQUIPMENT Required

MISCELLANEOUS Northeast portion of Pleasant Creek Gas field was also known as Chickahominy Gas field. Pacific Gas and Electric Company acquired the producing wells in December 1958 and converted the field to gas storage in April 1960.

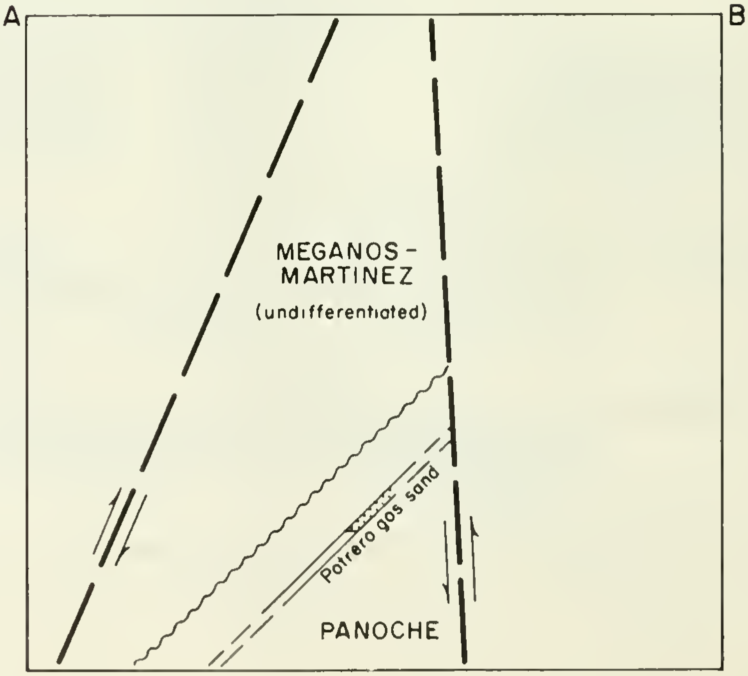
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 41, No. 1 (1955)

POTRERO HILLS GAS AREA
(Abandoned)

EPOCH	FORMATION	Thickness (Feet)
EOCENE	Capay	1800
EOCENE PALEOCENE	Meganos-Martinez (undifferentiated)	1250
UPPER CRETACEOUS	Potrero sand	
	Panoche	5700 (drilled)



CONTOURS ON TOP OF PANOCHE



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

POTRERO HILLS GAS AREA
Solano County
(Abandoned)

LOCATION 5 miles southeast of Fairfield.

DISCOVERY DATA Richfield Oil Corp. well No. "Potrero Hills" 1, Sec. 10, T. 4 N., R. 1 W., M.D.B.& M. Completed December 12, 1938, flowing gas from the interval 3,235-3,265 at the average rate of 1,500 Mcf/d.

STRUCTURE Faulted nose.

ELEVATION 100-360 BASE OF FRESH WATERS 1,100 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Potrero	3,245	6	U. Cretaceous	Panoche	-	-

DEEPEST WELL DATA McCulloch Oil Exploration Co. of Calif., Inc., well No. "McCulloch-Macson Scally Unit" 1, Sec. 10, T. 4 N., R. 1 W. T.D. 9,020 in Panoche (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	4
Cumulative Gas (Mcf.)	21,542	Total Wells Completed	1
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	20
Peak Production (1942) (Mcf.)	20,042		

USUAL CASING PROGRAM

13-3/8" cem. 1,000
5-1/2" cem. through gas zone and shot-perforated for production

BOP EQUIPMENT Required

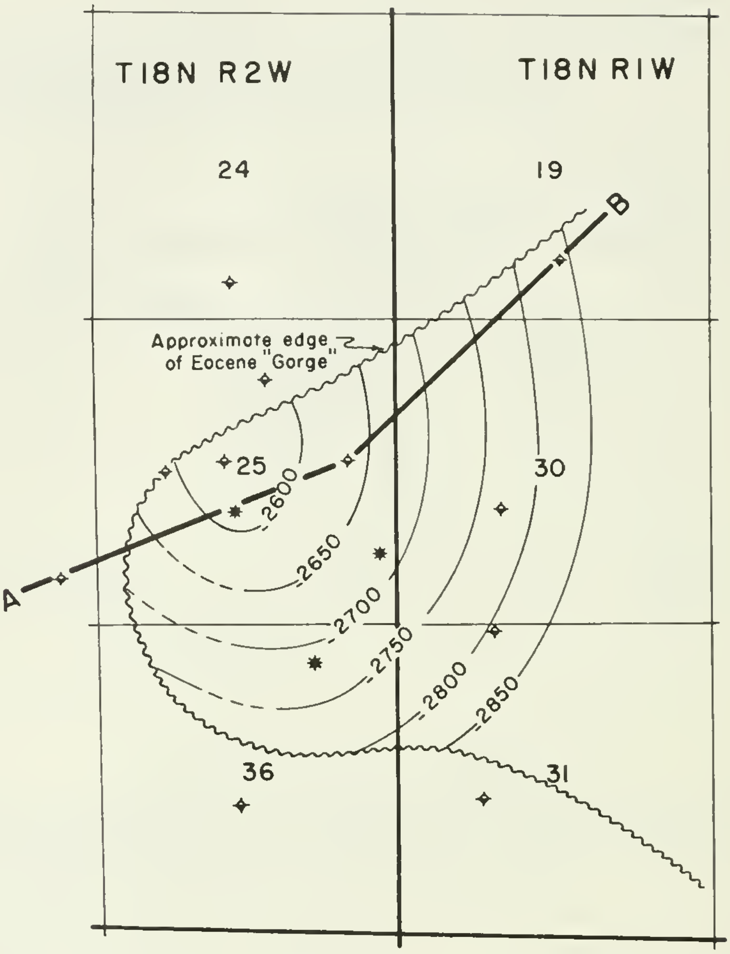
MISCELLANEOUS Commercial gas deliveries began in October 1942. The well produced for 3 months only before abandonment in 1943.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 24, No. 3 (1938) and Vol. 26 (1940)

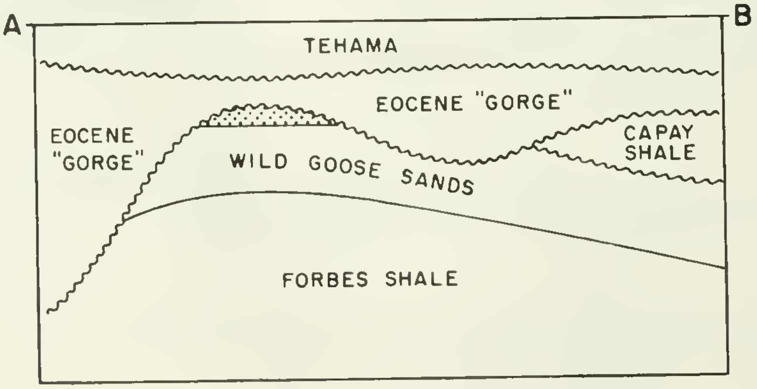
Calif. Div. of Mines Bull. 118 (1943)

PRINCETON GAS FIELD

EPOCH	FORMATION		Thickness (Feet)
RECENT	Alluvium		100
PLIOCENE	Tehoma		1800
EOCENE	"Gorge" Fill		250 to 2000
	Capay		0 to 175
UPPER CRETACEOUS	Kione	Wild Goose sands ▨	0 to 500
	Forbes		2400 (drilled)



CONTOURS ON BASE OF WILD GOOSE SANDS



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

PRINCETON GAS FIELD
Colusa County

LOCATION 12 miles north of Colusa.

DISCOVERY DATA Richard S. Rheem, Operator, well No. "Southam" 1 (now D & R Oil Company well No. "Southam" 1), Sec. 25, T. 18 N., R. 2 W., M.D.B.& M. Completed December 18, 1953, flowing gas at the rate of 2,850 Mcf/d through a 3/8-inch bean from the interval 2,215-2,230.

STRUCTURE Truncated anticline.

ELEVATION 70 BASE OF FRESH WATERS 1,800 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Wild Goose	2,170	110	U. Cretaceous	Kione	980	-

DEEPEST WELL DATA Humble Oil & Refining Co. well No. "Joe Gomes et ux" 1, Sec. 25, T. 18 N., R. 2 W. T.D. 7,631 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	11
Cumulative Gas (Mcf.)	2,637,690	Total Wells Completed	3
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	2
1959 Average Gas (Mcf/d)	1,391	Maximum Proved Acreage	320
Peak Production (1956) (Mcf.)	881,744		

USUAL CASING PROGRAM
10-3/4" cem. 650
5-1/2" cem. through gas zone and shot-perforated for production

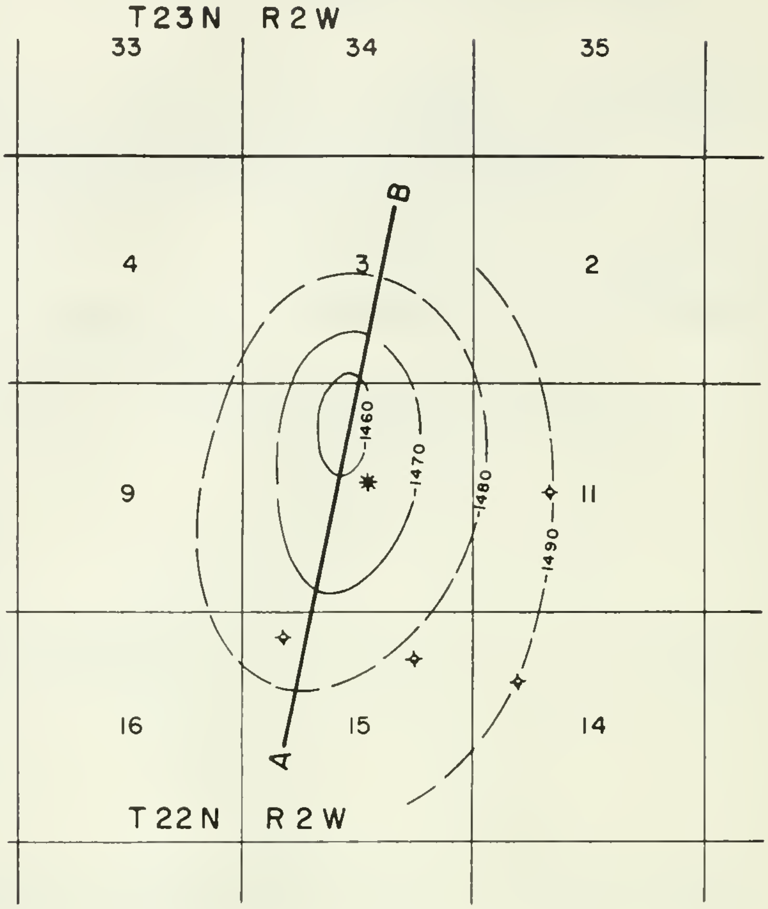
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in August 1955.

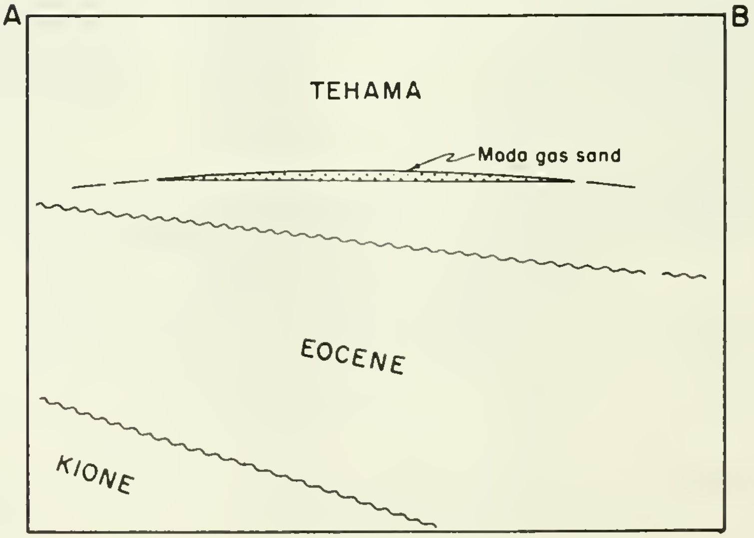
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 45, No. 1 (1959)

RANCHO CAPAY GAS AREA

EPOCH	FORMATION	Thickness (Feet)
PLIOCENE - RECENT	Alluvium & Tehomo Moda gas sd	1850
EOCENE	Eocene (undifferentiated)	800
UPPER CRETACEOUS	Kione	1350
	Forbes	1600
	Dobbins	300 (drilled)



CONTOURS ON MODA SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

RANCHO CAPAY GAS AREA
Glenn County

LOCATION 7 miles northeast of Orland.

DISCOVERY DATA Socony Mobil Oil Co., Inc., well No. "Moda A" 54-10 (now G.E. Kadane and Son well No. "Moda A" 54-10), Sec. 10, T. 22 N., R. 2 W., M.D.B.& M. Completed August 21, 1959, flowing gas from the interval 1,710 to 1,735 at the average rate of 5,800 Mcf/d through a 56/64-inch bean under a flow pressure of 390 psi.

STRUCTURE Dome.

ELEVATION 198 BASE OF FRESH WATERS 1,200 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Moda	1,710	25	Pliocene	Tehama	860	-

DEEPEST WELL DATA The discovery well. T.D. 5,898 in Dobbins (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	5
Cumulative Gas (Mcf.)	0	Total Wells Completed	1
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	40
Peak Production	-		

USUAL CASING PROGRAM
7" cem. 400
4-3/4" cem. through gas zone and shot-perforated for production

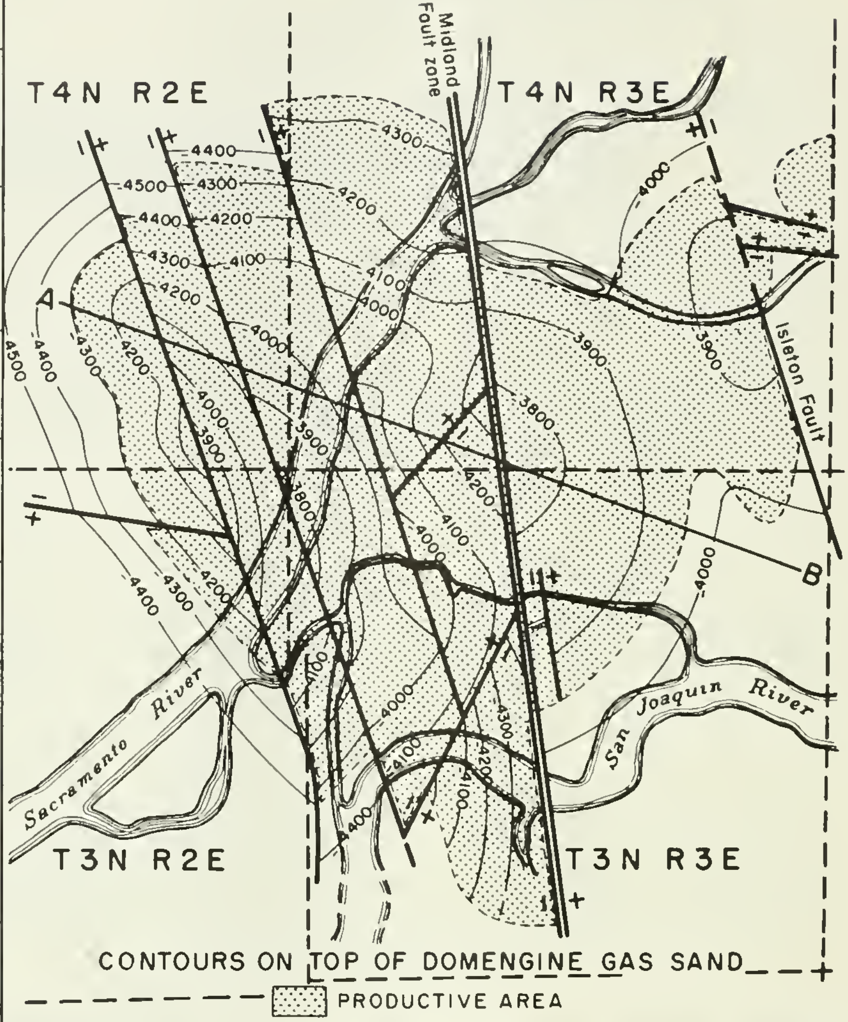
BOP EQUIPMENT Required

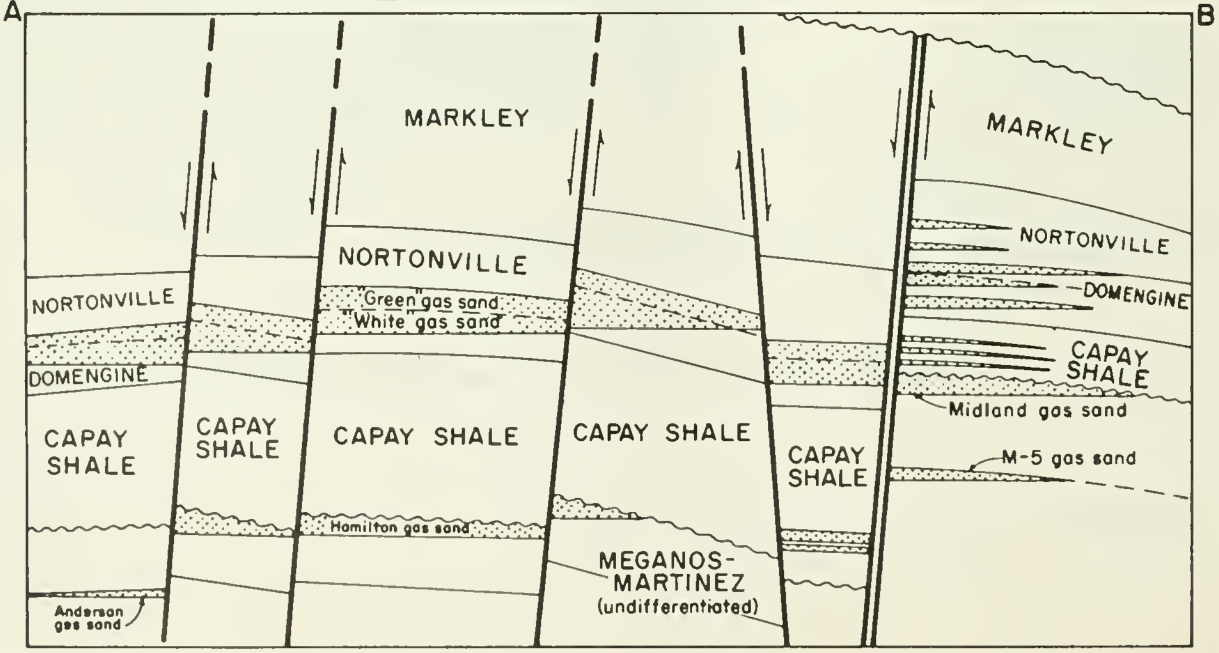
MISCELLANEOUS The well is shut-in pending the completion of pipeline connections.

REFERENCES -

EPOCH	FORMATION		Thickness (Feet)
RECENT-MIOCENE	Undifferentiated Sediments Predominantly Nonmarine		1900 to 2900
EOCENE	Markley		700 to 2200
	Nortonville (Emigh shale)		300
	Domengine	"Green" sand	400
		"White" sand	
	Capay		200 to 1000
	Meganos-	Hamilton or Midland sand	3500
		Andersan or M-5 sand	
PALEOCENE	Martinez (undifferentiated)		
UPPER CRETACEOUS			2120 (drilled)

RIO VISTA GAS FIELD





CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

RIO VISTA GAS FIELD
Sacramento, Contra Costa
& Solano Counties

LOCATION 45 miles northeast of San Francisco and 30 miles southwest of Sacramento.

DISCOVERY DATA Amerada Petroleum Corp. well No. "Emigh" 1, Sec. 26, T. 4 N., R. 2 E., M.D.B.& M. Completed June 19, 1936, flowing gas from the interval 4,278-4,484 at the average rate of 8,750 Mcf/d through a 1/2-inch bean under a flow pressure of 1,375 psi.

STRUCTURE Faulted dome.

ELEVATION 55 BASE OF FRESH WATERS 1,900-2,900 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
WEST OF MIDLAND FAULT:						
Nortonville	4,200	25	Eocene	Nortonville	-	-
West Emigh-Green sd.)	4,300	(70-150	Eocene	Domengine	1,030	360
West Emigh-White sd.)		(200-315	Eocene	Domengine	1,030	550
Capay	5,100	60	Eocene	Capay	)1,070)	910
Hamilton	5,300	145	Eocene-Paleo.	Meganos-Martinez	)1,070)	to
Anderson	5,750	45	Eocene-Paleo.	Meganos-Martinez	)1,070)	1,100
EAST OF MIDLAND FAULT:						
Nortonville	3,700	15	Eocene	Nortonville	))	370
East Emigh-					)1,000)	to
Green & White(?)sds.	3,800	40-100	Eocene	Domengine	) to)	500
Capay	4,400	20	Eocene	Capay	)1,050)	500
Midland	4,500	40-140	Eocene-Paleo.	Meganos-Martinez	))	810
M-5	5,000	10	Eocene-Paleo.	Meganos-Martinez	990	660

DEEPEST WELL DATA Amerada Petroleum Corp. well No. "McCormick" 4, Sec. 36, T. 4 N., R. 2 E. T.D. 11,051 in Upper Cretaceous.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	214
Cumulative Gas (Mcf.)	1,960,068,574	Total Wells Completed	186
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	150
1959 Average Gas (Mcf/d)	159,369	Maximum Proved Acreage	23,690
Peak Production (1945) (Mcf.)	159,577,428		

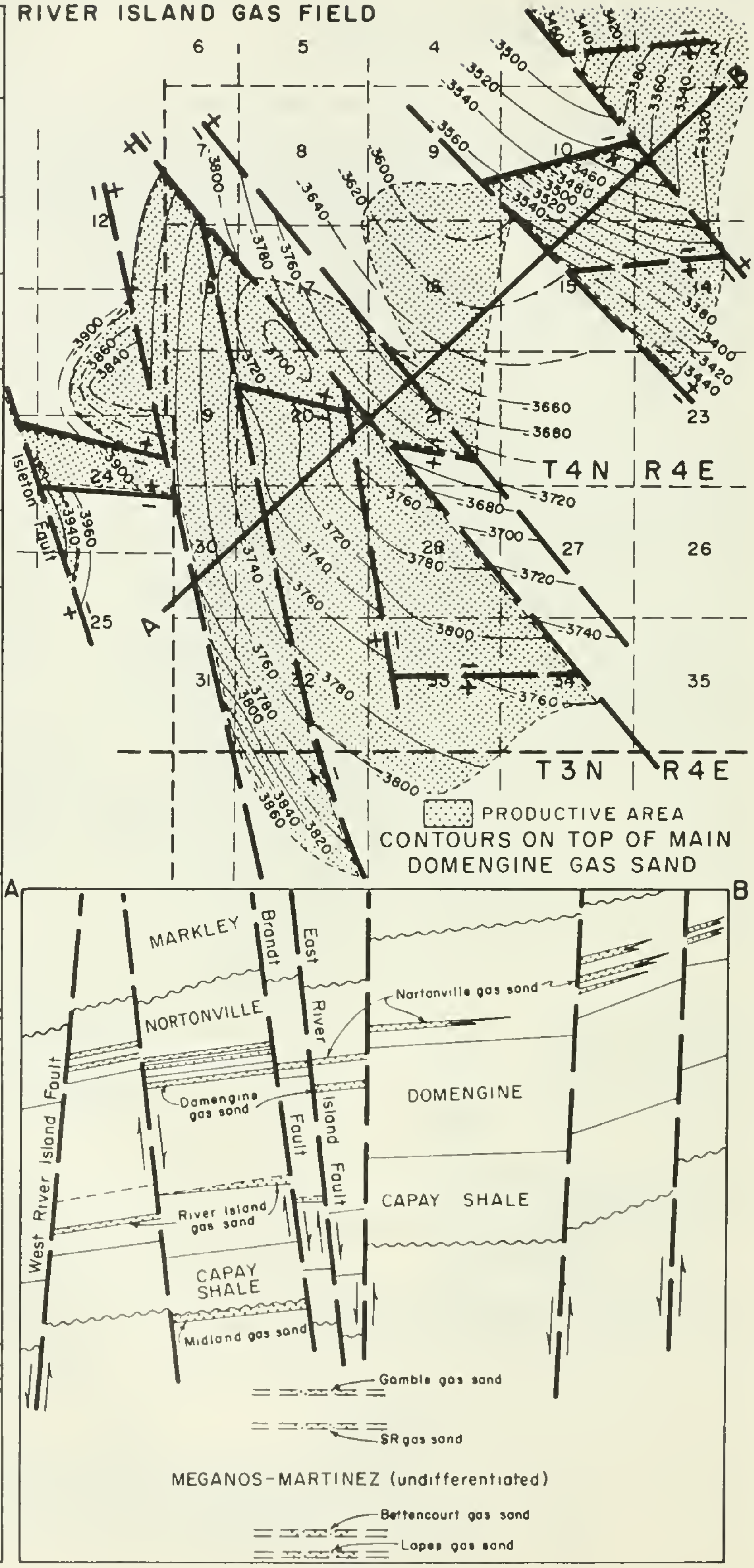
USUAL CASING PROGRAM
9-5/8" cem. 600
5-1/2" cem. through gas zone and shot-perforated for production

BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in September 1937.

REFERENCES
Calif. Div. of Mines Bull. 118 (1943)
Calif. Div. of Oil and Gas "Summary of Operations" Vol. 30, No. 1 (1944); Vol. 34, No. 1 (1948) and Vol. 39, No. 1 (1953)
Calif. Railroad Comm. and Calif. Div. of Oil and Gas Estimate of the Natural Gas Reserves of the State of California (1946)

EPOCH	FORMATION		Thickness (Feet)
RECENT-MIOCENE	Undifferentiated Sediments Predominantly Nonmarine		3100
EOCENE	Markley		300
	Nortonville		300
	Domengine	Domengine sand River Island sand	400
	Capay		280
PALEOCENE	Meganos-Martinez (undifferentiated)	Midland sand Gamble sand SR sand Bettencourt Lopes sand	1700
UPPER CRETACEOUS	Starkey		1400
	Winters		3500
	Sacramento (?)		900 (drilled)



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

RIVER ISLAND GAS FIELD
Sacramento County

LOCATION 30 miles south of Sacramento, adjacent to Rio Vista Gas field.

DISCOVERY DATA Brazos Oil and Gas Co. well No. "River Island Land Company" 1, Sec. 29, T. 4 N., R. 4 E., M.D.B.& M. Completed June 5, 1950, flowing gas from the interval 4,160-4,170 at the average rate of 4,100 Mcf/d through a 3/8-inch bean under a flow pressure of 1,050 psi.

STRUCTURE Faulted anticlinal nose.

ELEVATION 3 BASE OF FRESH WATERS 2,000 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Nortonville	3,600	5)	Eocene	(Nortonville	1,010	100-400
Domengine	3,730	20)		(Domengine	1,000	250-410
River Island	4,130	7)		(Domengine	1,010	100-250
Capay	4,230	20)		(Capay shale	1,010	265-450
Midland	4,350	40)	Eocene-Paleocene	(Meganos-Martinez (undiff.)	970	550
Gamble	4,750	8)		(	980	-
SR	4,910	20)		(	980	10
Bettencourt	5,360	10)		(	990	-
Lopes	5,450	25)		(	990	5

DEEPEST WELL DATA Brazos Oil and Gas Company, Operator, well No. "S.R. Unit No. 1" 1, Sec. 17, T. 4 N., R. 4 E. T.D. 10,902 in Sacramento shale (?) (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	71
Cumulative Gas (Mcf.)	37,167,418	Total Wells Completed	48
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	24
1959 Average Gas (Mcf/d)	8,553	Maximum Proved Acreage	3,250
Peak Production (1955) (Mcf.)	5,123,698		

USUAL CASING PROGRAM
9-5/8" cem. 600
5-1/2" cem. through gas zone and shot-perforated for production

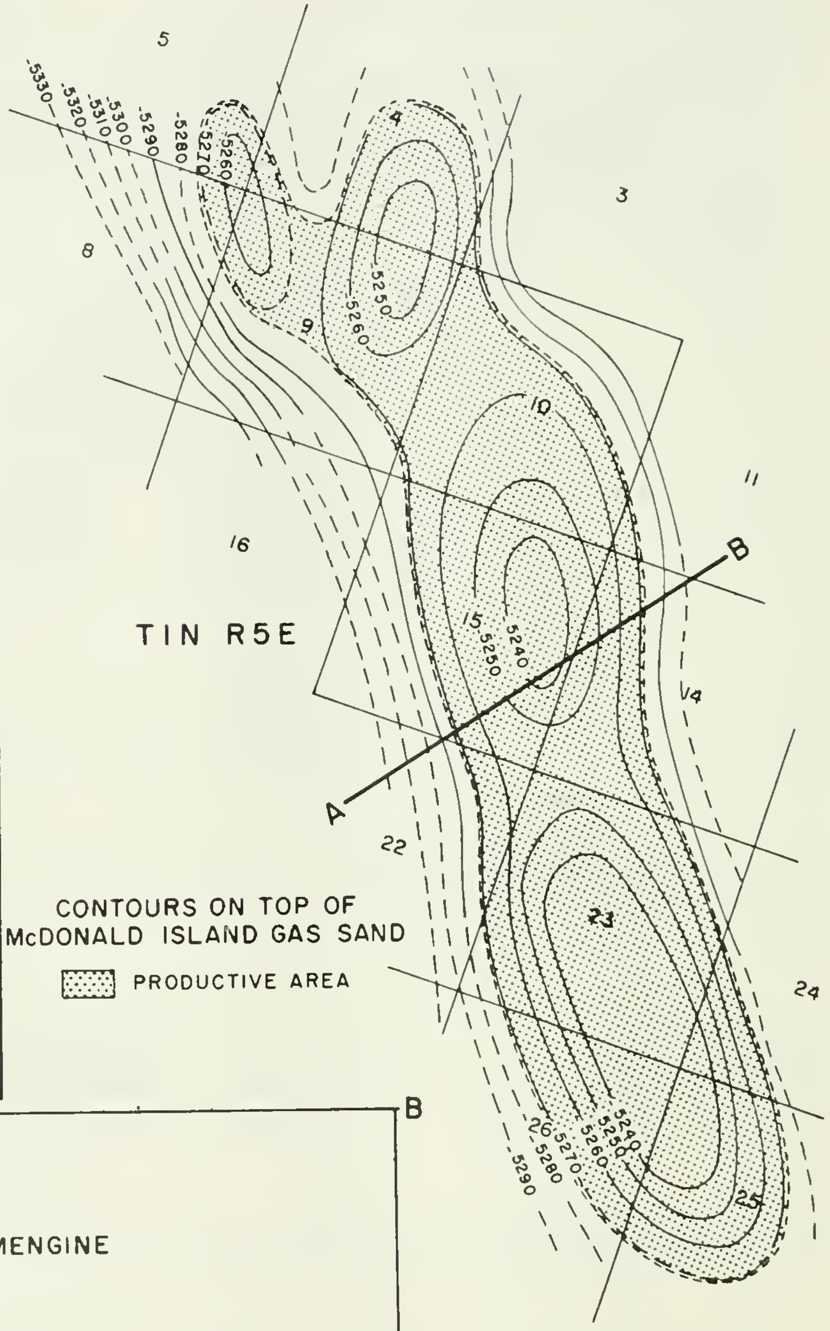
BOP EQUIPMENT Required

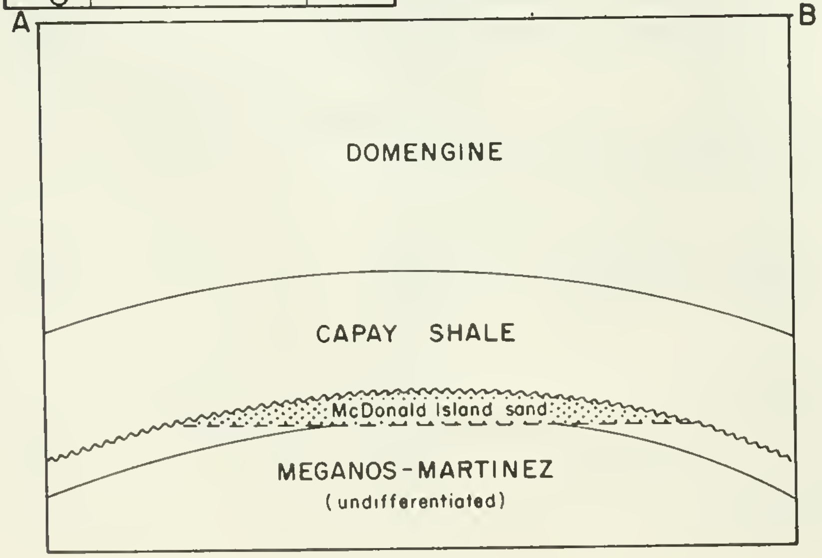
MISCELLANEOUS Commercial gas deliveries began in May 1949.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 39, No. 1 (1953)

ROBERTS ISLAND GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments, Predominantly Nonmarine	4150
EOCENE	Markley and Nortonville (undifferentiated)	260
	Domengine	670
	Capay	180
PALEOCENE	McDonald Island sand Meganos-Martinez (undifferentiated)	1050±
UPPER CRETACEOUS		703 (drilled)





CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

ROBERTS ISLAND GAS FIELD
San Joaquin County

LOCATION 6 miles southwest of Stockton.

DISCOVERY DATA Standard Oil Co. of California well No. "Woods Community 2" 1, Sec. 23, T. 1 N., R. 5 E., M.D.B.& M. Completed August 16, 1942, flowing gas at the rate of 5,613 Mcf/d through a 3/8-inch bean under a flow pressure of 1,766 psi.

STRUCTURE Elongated anticline.

ELEVATION Sea level BASE OF FRESH WATERS 75 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
McDonald Island	5,250	10	Eocene-Paleocene	Meganos-Martinez (undiff.)	955	300-700

DEEPEST WELL DATA Standard Oil Co. of California well No. "Woods Comm." 1, Sec. 24, T. 1 N., R. 5 E. T.D. 7,014 in Upper Cretaceous.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	24
Cumulative Gas (Mcf.)	11,592,895	Total Wells Completed	14
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	13
1959 Average Gas (Mcf/d)	8,096	Maximum Proved Acreage	1,400
Peak Production (1959) (Mcf.)	2,955,221		

USUAL CASING PROGRAM
9-5/8" cem. 500
5-1/2" cem. through gas sands and shot-perforated for production

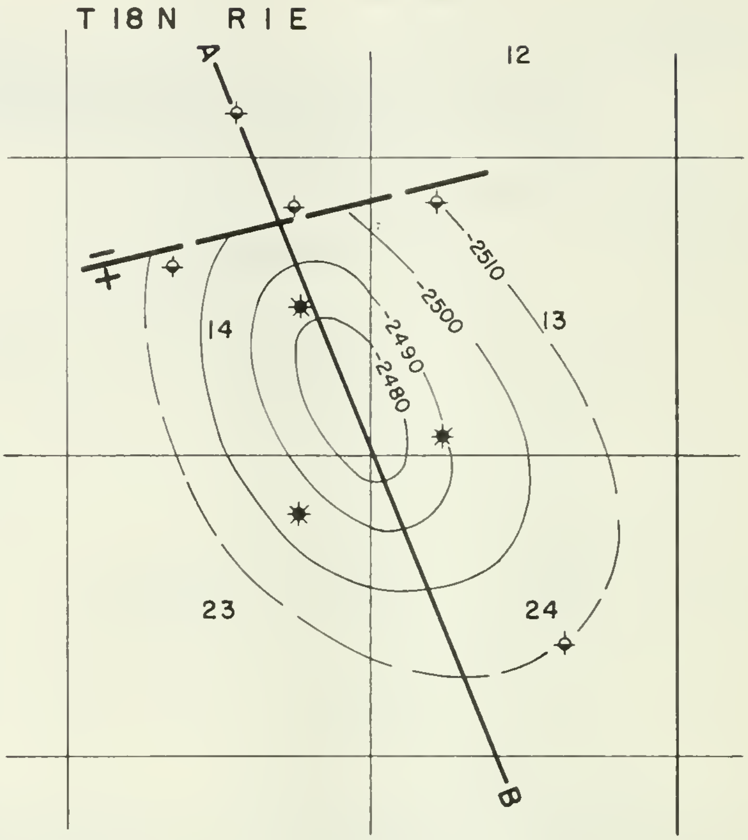
BOP EQUIPMENT Required

MISCELLANEOUS Field includes area to the northwest formerly known as Whisky Slough area. Commercial gas deliveries began in October 1942.

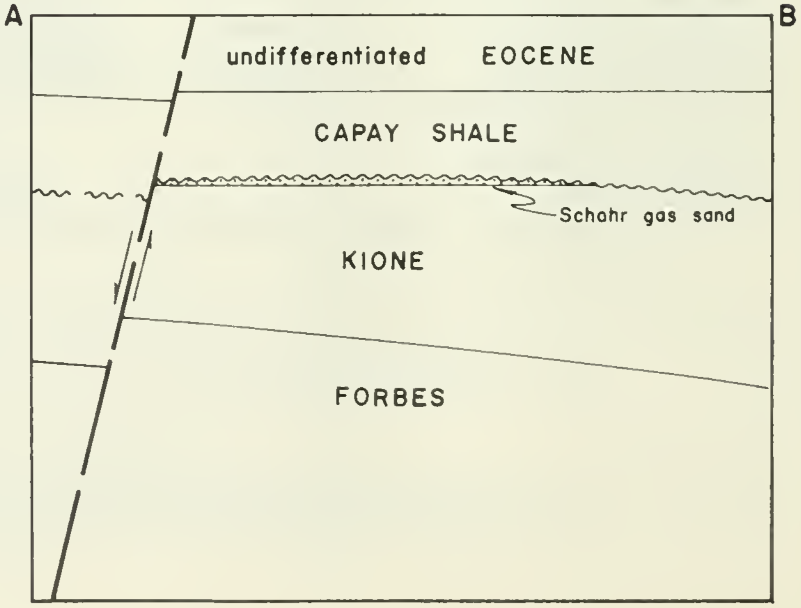
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 44, No. 1 (1958)
Munger Oilogram Calif. Oil and Gas Exploration (1958)

SCHOHR RANCH GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium Continental Deposits & Tehama	1600
EOCENE	Eocene (undifferentiated)	700
	Capay	270
UPPER CRETACEOUS	Schohr gas sand ▨	
	Kione	440
	Forbes	2350
	Dobbins	80
	Guinda	300
Basement Complex		70 (drilled)



CONTOURS ON SCHOHR GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

SCHOHR RANCH GAS FIELD
Butte County

LOCATION 10 miles east of Princeton.

DISCOVERY DATA Humble Oil & Refining Co. "Elna B. Schohr" 1, Sec. 23, T. 18 N., R. 1 E., M.D.B.& M. Completed March 20, 1957, flowing gas from the interval 2,572-2,587 at the average rate of 5,073 Mcf/d through a 1/2-inch bean under a flow pressure of 800 psi.

STRUCTURE Faulted anticline.

ELEVATION 85 BASE OF FRESH WATERS 1,200 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Schohr	2,570	16	U. Cretaceous	Kione	840	250

DEEPEST WELL DATA The discovery well. T.D. 5,830 in basement complex.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	7
Cumulative Gas (Mcf.)	37,600	Total Wells Completed	3
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	82	Maximum Proved Acreage	120
Peak Production (1959) (Mcf.)	29,800		

USUAL CASING PROGRAM

7" cem. 500
4-1/2" cem. through gas sand and shot-perforated for production

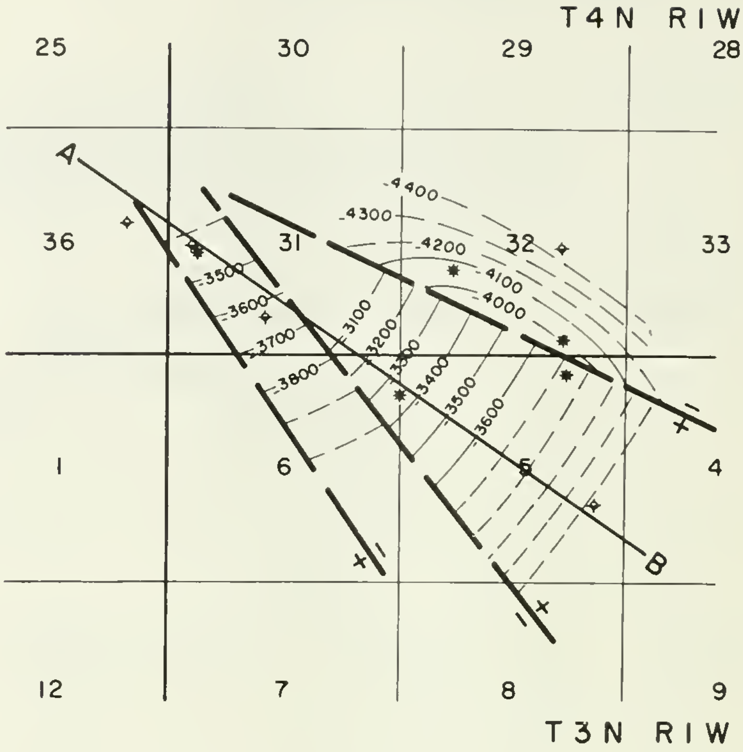
BOP EQUIPMENT Required

MISCELLANEOUS Formerly known as West Biggs area. Commercial gas deliveries began in December 1959.

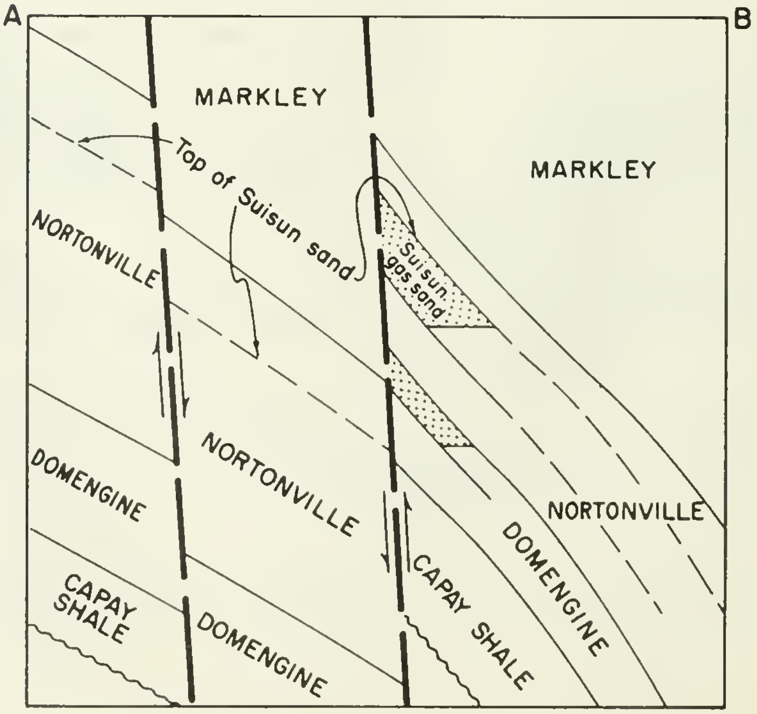
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 43, No. 2 (1957)

SUISUN BAY GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Tehama ▨	1300
EOCENE	Markley	2240
	Nortonville Suisun gas sand ▨	800
	▨ Domengine	300
	Capay	250
EOCENE PALEOCENE	Meganos-Martinez (undifferentiated)	1750 (drilled)



CONTOURS ON TOP OF SUISUN SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

SUISUN BAY GAS FIELD
Solano County

LOCATION 14 miles east of Vallejo.

DISCOVERY DATA Standard Oil Co. of California well No. "Fontana Farms" 2, Sec. 32, T. 4 N., R. 1 W., M.D.B.& M. Completed December 11, 1944, flowing gas from the interval 4,017-4,089 at the average rate of 4,755 Mcf/d through a 3/8-inch bean under a flow pressure of 1,509 psi.

STRUCTURE Faulted anticline (?)

ELEVATION 15 BASE OF FRESH WATERS None SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic		Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
			Age	Formation		
Tehama	650	10	Pliocene	Tehama	1,020	-
Suisun	3,410	210	Eocene	Nortonville	1,040	250-960
Domengine	4,385	65	Eocene	Domengine	1,040	390-990

DEEPEST WELL DATA Standard Oil Co. of California well No. "Suisun Community" 4, Sec. 5, T. 3 N., R. 1 W. T.D. 6,947 in Meganos-Martinez, undiff. (Eocene-Paleocene).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	10
Cumulative Gas (Mcf.)	30,394,762	Total Wells Completed	5
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	4
1959 Average Gas (Mcf/d)	7,331	Maximum Proved Acreage	100
Peak Production (1950) (Mcf.)	3,026,641		

USUAL CASING PROGRAM BOP EQUIPMENT Required

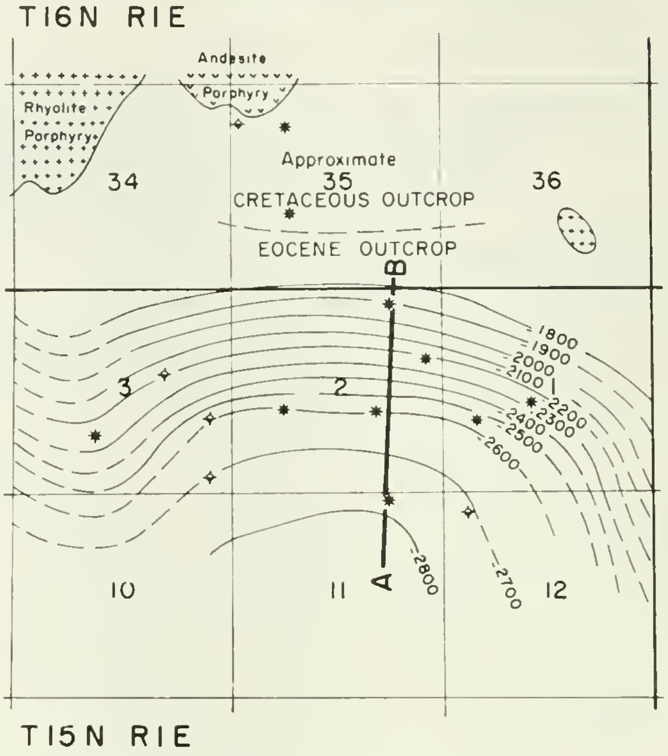
13-3/8" cem. 500
9-5/9" cem. at 1,000 and shot-perforated for production
from shallow gas sands
5-1/2" cem. through deeper gas zone and shot-perforated for production

MISCELLANEOUS Commercial gas deliveries began in February 1947.

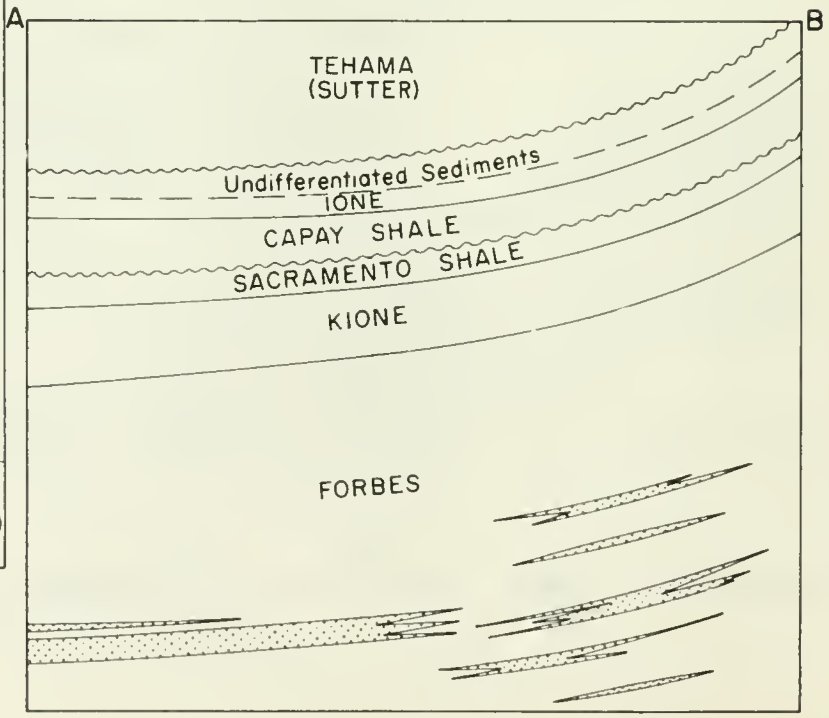
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 33, No. 2 (1947)

SUTTER (MARYSVILLE) BUTTES GAS FIELD
MAIN AREA

EPOCH	FORMATION	Thickness (Feet)
PLIOCENE	Tehama (Sutter)	1000
EOCENE	Undifferentiated Sediments	250
	Ione	170
	Capay	450
UPPER CRETACEOUS	Sacramento	250
	Kione	675
	Forbes lenticular gas sands	4740
	Guinda (?)	
Basement Complex		4 (drilled)



CONTOURS ON TOP OF KIONE



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

SUTTER (MARYSVILLE) BUTTES GAS FIELD
Main Area
Sutter County

LOCATION 11 miles northwest of Yuba City.

DISCOVERY DATA The Buttes Oilfields, Inc. (now Buttes Gas & Oil Co.) well No. "Buttes" 1, Sec. 35, T. 16 N., R. 1 E., M.D.B.& M. Completed February 9, 1933, flowing gas from the interval 2,100-2,727 at the average rate of 3,062 Mcf/d.

STRUCTURE Stratigraphic trap. Gas accumulation in updip lenses adjacent to volcanic plug.

ELEVATION 65-635 BASE OF FRESH WATERS 2,000 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or ° B.t.u	Salinity of Zone Water Gr./Gal.
Cretaceous	5,500	60	U. Cretaceous	Forbes-Guinda	1,000	900 1,830

DEEPEST WELL DATA Richfield Oil Corp. well No. "Buttes Community C" 2, Sec. 35, T. 16 N., R. 1 E. T.D. 7,768 in basement (Jurassic?).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	15
Cumulative Gas (Mcf.)	15,109,901	Total Wells Completed	10
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	8
1959 Average Gas (Mcf/d)	1,285	Maximum Proved Acreage	840
Peak Production (1941) (Mcf.)	1,497,894		

USUAL CASING PROGRAM
9-5/8" cem. 500 to 1,000
5-1/2" combination string landed through gas zone and cem. through ports above the zone with perforations opposite gas sands

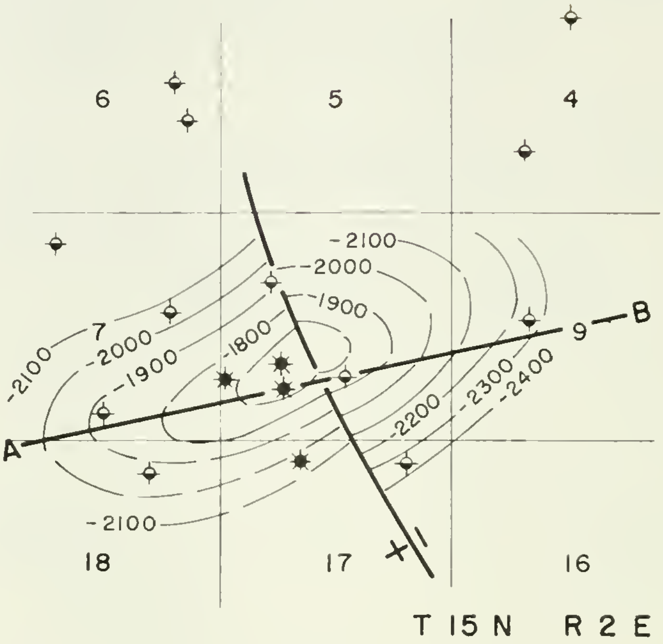
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in November 1938.

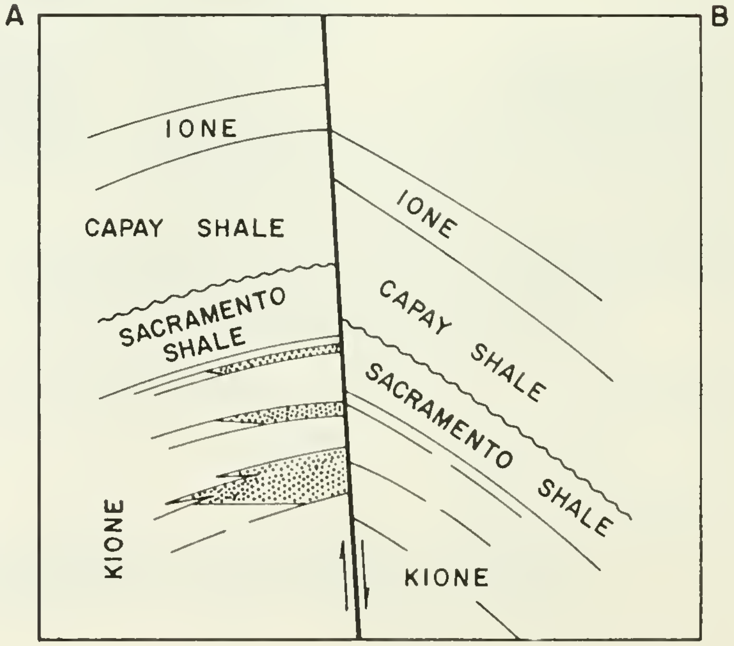
REFERENCES Calif. Div. of Mines Bull. 118 (1943)
Calif. Div. of Oil and Gas "Summary of Operations" Vol. 41, No. 1 (1955)

SUTTER (MARYSVILLE) BUTTES GAS FIELD
SUTTER CITY AREA

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Alluvium	700
	Tehama & Continental Deposits	
EOCENE	Undifferentiated Eocene Sediments	250
	Ione	150
	Capay	350
UPPER CRETACEOUS	Sacramento	200
	Kione Upper Middle Lower	600
	Forbes	2750
	Guinda (?)	
Rhyolite		30 (drilled)



CONTOURS ON TOP OF KIONE



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

SUTTER (MARYSVILLE) BUTTES GAS FIELD
Sutter City Area
Sutter County

LOCATION 9 miles northwest of Yuba City.

DISCOVERY DATA Richfield Oil Corp. well No. "Sutter Community A" 1 (now Buttes Gas & Oil Co. well No. "Sutter Community A" 1), Sec. 8, T. 15 N., R. 2 E., M.D.B.& M. Completed August 24, 1952, flowing gas from the interval 2,065-2,145 at the rate of 281 Mcf/d under a flow pressure of 900 psi.

STRUCTURE Faulted anticline.

ELEVATION 60-90 BASE OF FRESH WATERS 1,200 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Upper	1,700	25	U. Cretaceous	Kione	900	110
Middle	1,900	30	U. Cretaceous	Kione	900	110
Lower	2,000	85	U. Cretaceous	Kione	900	110

DEEPEST WELL DATA Richfield Oil Corp. well No. "Butte Community B" 6, Sec. 7, T. 15 N., R. 2 E. T.D. 5,084 in basement (?).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	13
Cumulative Gas (Mcf.)	6,688,718	Total Wells Completed	4
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	3
1959 Average Gas (Mcf/d)	4,569	Maximum Proved Acreage	120
Peak Production (1958) (Mcf.)	2,062,265		

USUAL CASING PROGRAM
10-3/4" cem. 500
7" cem. through gas zone and shot-perforated for production

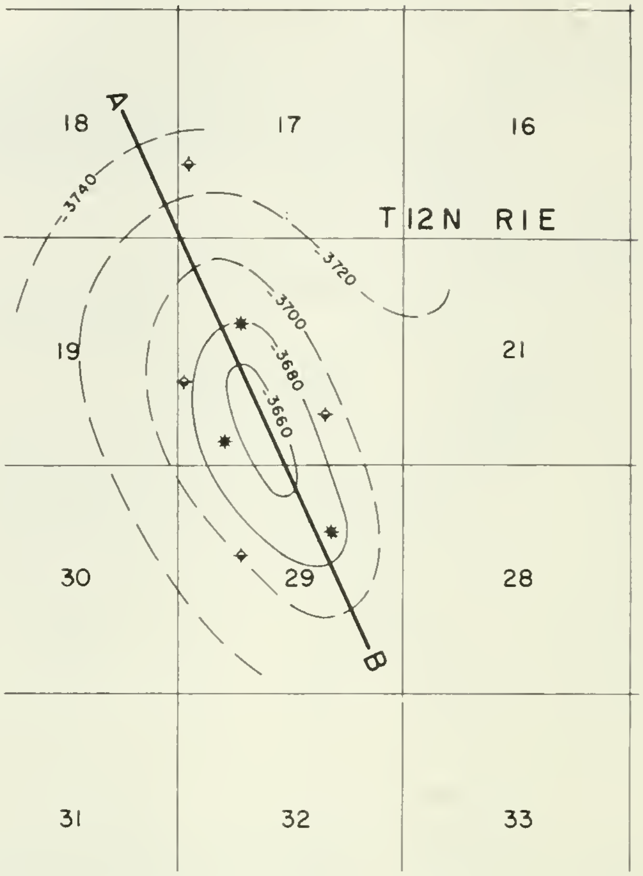
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in June 1953.

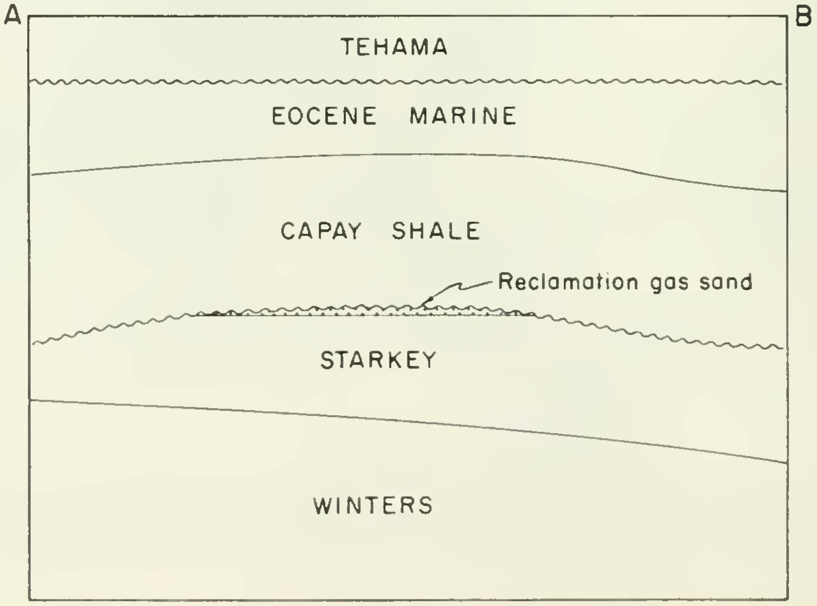
REFERENCES Calif. Div. of Mines Bull. 118 (1943)
Calif. Div. of Oil and Gas "Summary of Operations" Vol. 41, No. 1 (1955)

SYCAMORE SLOUGH GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Alluvium	300
	Tehama	2720
EOCENE	Marine sediments	200
	Capay	440
UPPER CRETACEOUS	Reclamation gas sand ▨ Starkey	330
	Winters	800
	Sacramento	300
	Kione	260
	Forbes	90 (drilled)



CONTOURS ON TOP OF RECLAMATION GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

SYCAMORE SLOUGH GAS FIELD
Yolo County

LOCATION 13 miles northwest of Woodland.

DISCOVERY DATA Signal Oil and Gas Company well No. "Signal-Monterey-Reclamation" 1, Sec. 20, T. 12 N., R. 1 E., M.D.B.& M. Completed October 11, 1953, flowing gas from the interval 3,717-3,724 at the average rate of 4,200 Mcf/d through a 1/2-inch bean under a flow pressure of 1,100 psi.

STRUCTURE Anticline.

ELEVATION 35 BASE OF FRESH WATERS 2,100 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Reclamation	3,720	25	U. Cretaceous	Starkey	-	600

DEEPEST WELL DATA The discovery well. T.D. 5,500 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	5
Cumulative Gas (Mcf.)	517,963	Total Wells Completed	3
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	3
1959 Average Gas (Mcf/d)	305	Maximum Proved Acreage	160
Peak Production (1957) (Mcf.)	181,114		

USUAL CASING PROGRAM
9-5/8" cem. 700
5-1/2" cem. through gas zone and shot-perforated for production

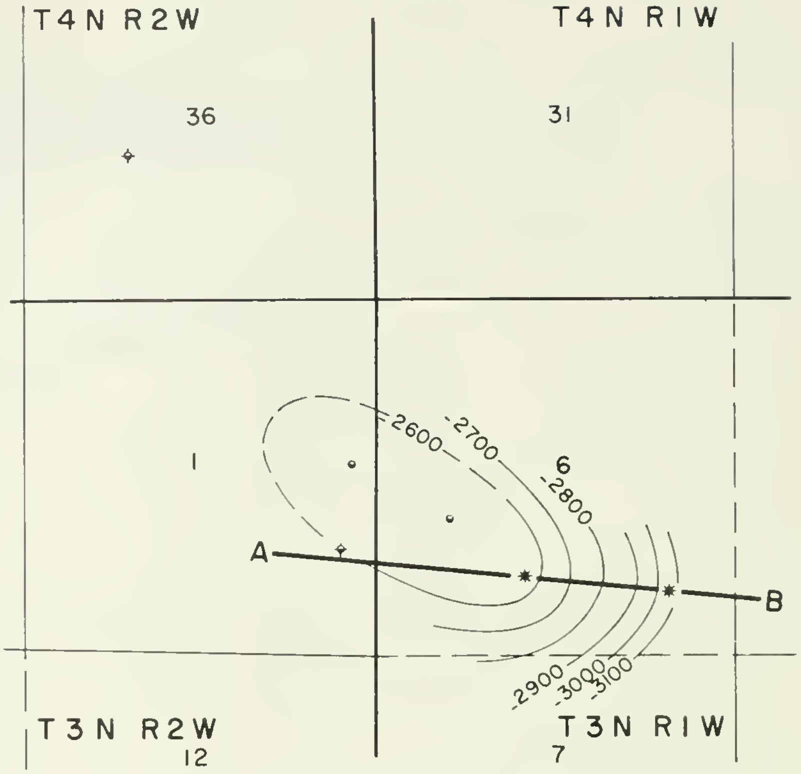
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in August 1956.

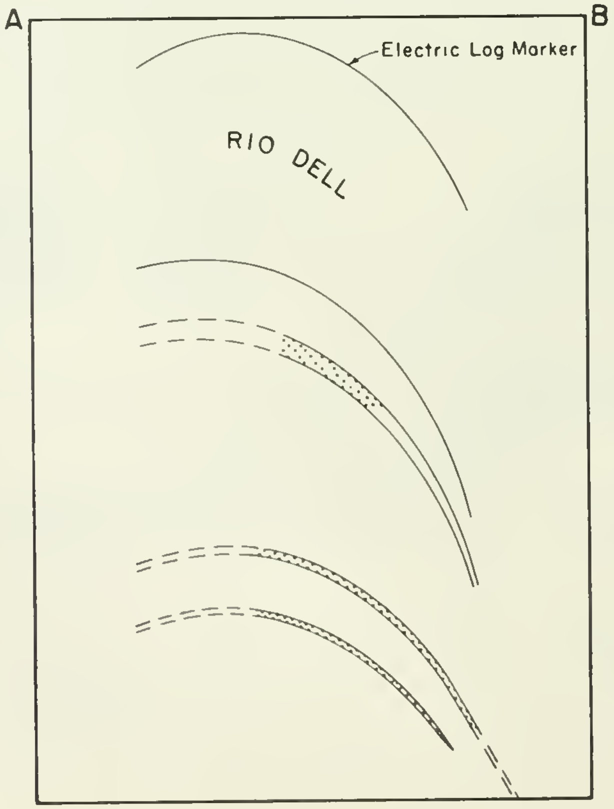
REFERENCES

TABLE BLUFF GAS AREA

EPOCH	FORMATION	Thickness (Feet)
RECENT-PLIOCENE	Hookton	1900
	Carlotta	
	Scotia Bluffs	
PLIOCENE	Rio Dell	2800
	Eel River	1200
LOWER CRETACEOUS	Yager (?)	200 (drilled)



CONTOURS ON ELECTRIC LOG MARKER WITHIN RIO DELL FORMATION



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

TABLE BLUFF GAS AREA
Humboldt County

LOCATION 9-1/2 miles southwest of Eureka and 4 miles northwest of Tompkins Hill gas field.

DISCOVERY DATA Zephyr Oil Company well No. "Leon Oro Blanco" T-1, Sec. 6, T. 3 N., R. 1 W., H.B.& M. Completed June 8, 1960, flowing gas from the interval 4,801-4,805 at the average rate of 800 Mcf/d through an 8/64-inch bean under a flow pressure of 1,600 psi.

STRUCTURE Anticline.

ELEVATION 210-465 BASE OF FRESH WATERS 700-1,000 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
(unnamed)	3,920	60	Pliocene	Rio Dell	-	-
(unnamed)	4,410	15	Pliocene	Rio Dell	-	-
(unnamed)	4,780	10	Pliocene	Rio Dell	1,035	-

DEEPEST WELL DATA The Texas Company (now Texaco Inc.) well No. "Eureka" 1, Sec. 1, T. 3 N., R. 2 W. T.D. 6,133 in Yager (?) (Lower Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	-	Total Wells Drilled	-
Cumulative Gas (Mcf.)	-	Total Wells Completed	-
1959 Average Oil (b/d)	-	Producing Wells (1959 Aver.)	-
1959 Average Gas (Mcf/d)	-	Maximum Proved Acreage	-
Peak Production	-		

USUAL CASING PROGRAM
9-5/8" cem. 600
5-1/2" cem. through gas zone and shot-perforated for production

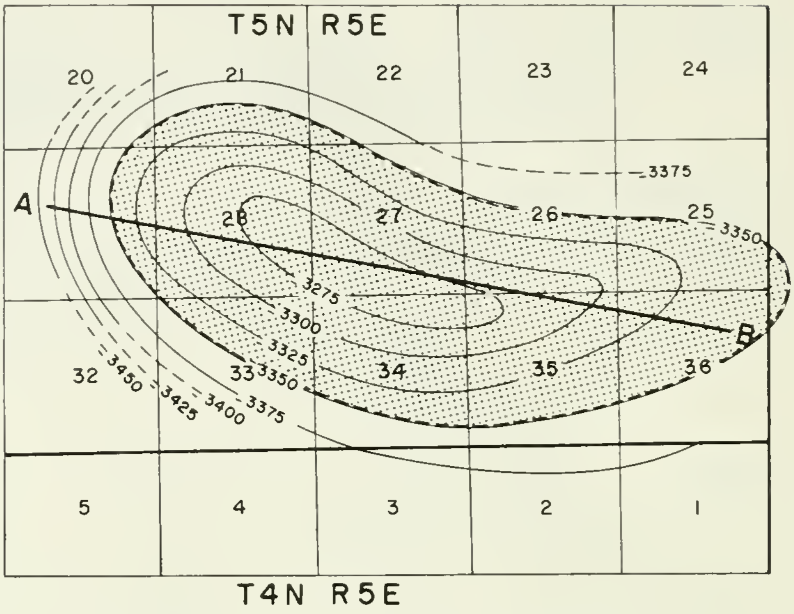
BOP EQUIPMENT Required

MISCELLANEOUS -

REFERENCES Calif. Div. of Mines Bull. 164 (1953)

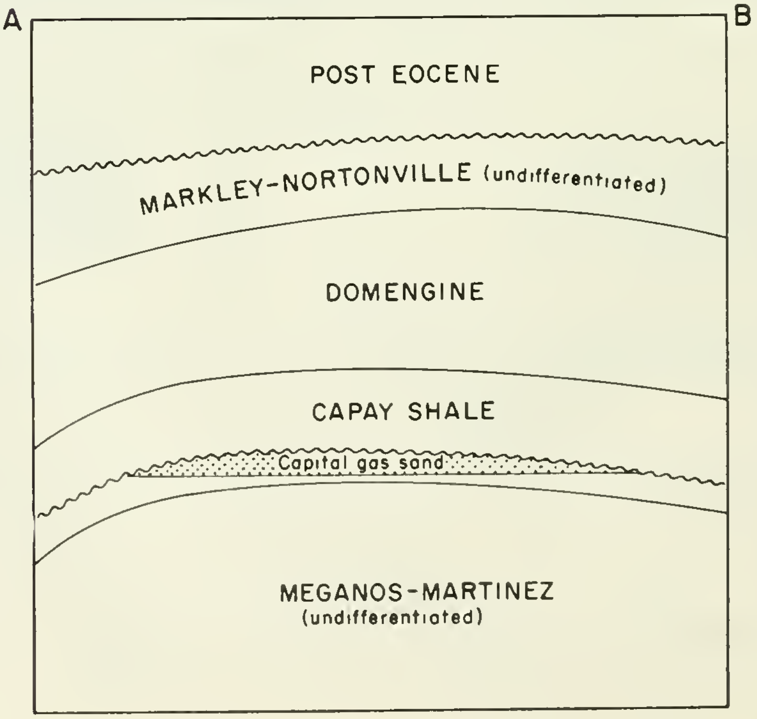
THORNTON GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments, Predominantly Nonmarine	2400
EOCENE	Markley-Nortonville (undifferentiated)	240
	Domengine	450
	Capay	260
	Capital gas sand	
PALEOCENE	Meganos-Martinez (undifferentiated)	1050
UPPER CRETACEOUS	Starkey	2000
	Winters	1400
	Sacramento	570 (drilled)



CONTOURS ON TOP OF CAPITAL GAS SAND

▨ PRODUCTIVE AREA



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

THORNTON GAS FIELD
Sacramento & San Joaquin Counties

LOCATION 23 miles south of Sacramento.

DISCOVERY DATA Amerada Petroleum Corp., Operator, well No. "Capital Company" 1, Sec. 36, T. 5 N., R. 5 E., M.D.B.& M. Completed July 2, 1943, flowing gas from the interval 3,355-3,380 at the rate of 6,897 Mcf/d through a 3/8-inch bean under a flow pressure of 806 psi.

STRUCTURE Anticline.

ELEVATION 15-25 BASE OF FRESH WATERS 600 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Capital	3,300	32	Eocene-Paleocene	Meganos-Martinez (undiff.)	960	550

DEEPEST WELL DATA The discovery well. T.D. 8,367 in Moreno (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	16
Cumulative Gas (Mcf.)	39,646,424	Total Wells Completed	12
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	6
1959 Average Gas (Mcf/d)	6,782	Maximum Proved Acreage	4,960
Peak Production (1957) (Mcf.)	4,063,765		

USUAL CASING PROGRAM BOP EQUIPMENT Required

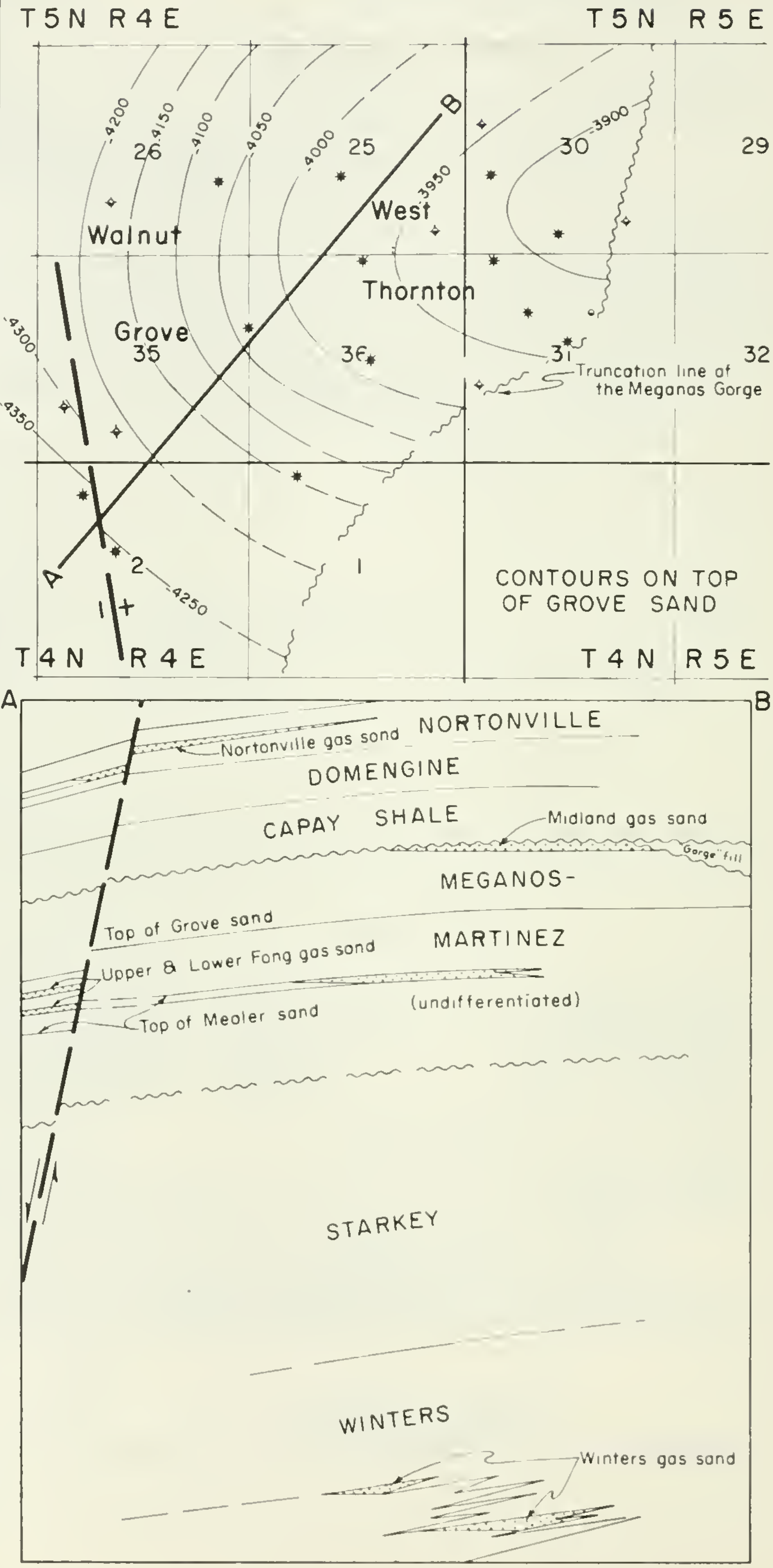
9-7/8" cem. 600
5-1/2" cem. through gas sands and shot-perforated for production
or
combination string cemented above gas zone with perforations opposite gas sands

MISCELLANEOUS Commercial gas deliveries began in December 1946.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 43, No. 1 (1957)

EPOCH	FORMATION	Thickness (Feet)
POST-EOCENE	Undifferentiated Sediments Predominantly Nonmarine	2800
EOCENE	Markley	150
	Nortonville	170
	Domengine	320
	Capay	300
	"Gorge" fill	0 to 300
PALEOCENE	Meganos-Martinez (undiff) Midland sand Fong sands Meoler sand	1400
UPPER CRETACEOUS	Starkey	1900
	Winters	1400
	Sacramenta (?)	1150 (drilled)

WEST THORNTON-WALNUT GROVE GAS AREA



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

THORNTON, WEST-WALNUT GROVE GAS AREA
Sacramento & San Joaquin Counties

LOCATION 22 miles south of Sacramento between River Island and Thornton gas fields.

DISCOVERY DATA Standard Oil Co. of California well No. "McCormack-Williamson" 1, Sec. 30, T. 5 N., R. 5 E., M.D.B.& M. Completed July 20, 1956, flowing gas from the interval 3,541-3,544 at an average rate of 1,754 Mcf/d through a 16/64-inch bean under a flow pressure of 1,135 psi.

STRUCTURE Faulted nose.

ELEVATION 16 BASE OF FRESH WATERS 1,350 SPACING ACT APPLIES **Yes**

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Nortonville	3,000	12	Eocene	Nortonville	970	-
Midland	3,650	8-75	Eocene-Paleo.	Meganos-Martinez (undiff.)	950	670
Mealer	4,400	25	Eocene-Paleo.	Meganos-Martinez (undiff.)	950	-
Upper Fong	4,475	8	Eocene-Paleo.	Meganos-Martinez (undiff.)	975	-
Lower Fong	4,566	7	Eocene-Paleo.	Meganos-Martinez (undiff.)	975	-
Winters	7,900	10-36	U. Cretaceous	Winters	920	-

DEEPEST WELL DATA Brazos Oil and Gas Company (now Brazos Oil and Gas Company, Operator) well No. "Walnut Grove Unit A" 1, Sec. 35, T. 5 N., R. 4 E. T.D. 9,505 in Sacramento (?) (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	16
Cumulative Gas (Mcf.)	598,598	Total Wells Completed	10
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	1
1959 Average Gas (Mcf/d)	1,442	Maximum Proved Acreage	720
Peak Production (1959) (Mcf.)	526,384		

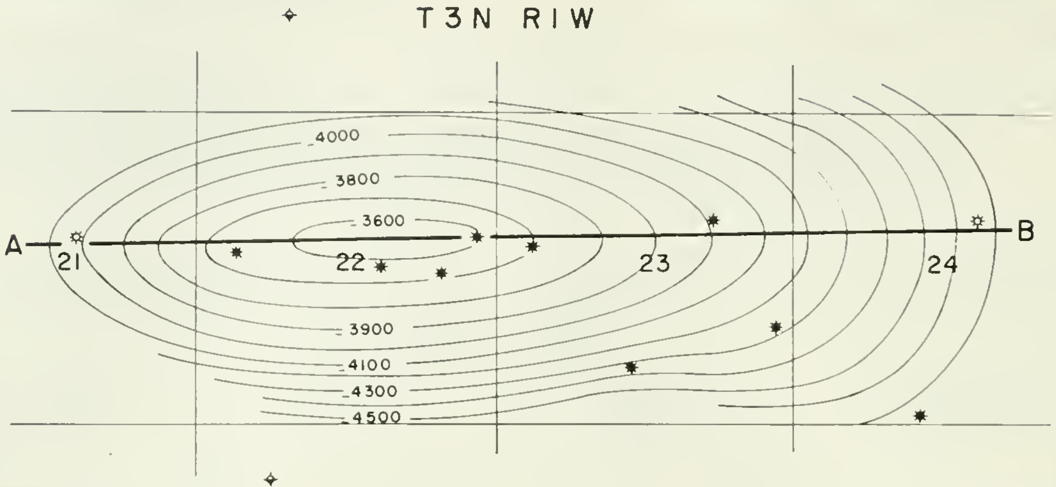
USUAL CASING PROGRAM
7" or 9-5/8" surface casing cem. at 600
4-1/2" or 5-1/2" cem. through gas sands and shot-perforated for production

BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in June 1958.

REFERENCES -

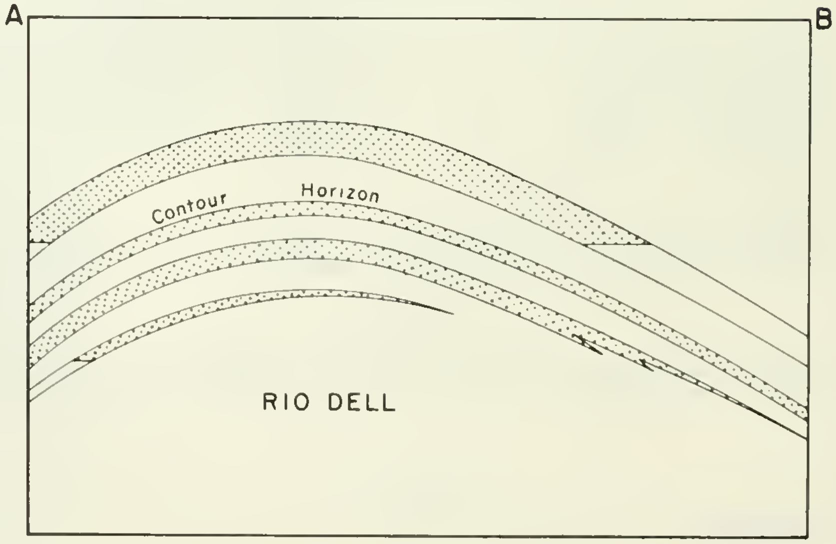
TOMPKINS HILL (EUREKA) GAS FIELD



Courtesy of A S Hawley

CONTOURS ON 2nd GAS SAND

EPOCH	FORMATION	Thickness (Feet)
PLEISTOCEIE to PLIOCENE	Carlotta-Scotia Bluffs	1600
PLIOCENE	Rio Dell	4400
	Eel River	1800
LOWER CRETACEOUS (?) -JURASSIC	Yager	50 (drilled)



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

TOMPKINS HILL (EUREKA) GAS FIELD
Humboldt County

LOCATION 12 miles south of Eureka.

DISCOVERY DATA The Texas Company (now Texaco Inc.) well No. "Eureka (NCT-1)" 2, Sec. 22, T. 3 N., R. 1 W., H.B.& M. Completed September 1, 1937, flowing gas from the intervals 4,010-4,850, 5,110-5,350, 5,500-5,570 and 5,760-5,800 at the average rate of 1,400 Mcf/d.

STRUCTURE Anticline.

ELEVATION 480-950 BASE OF FRESH WATERS 1,600 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Eureka	3,750 5,780	140	Pliocene	Rio Dell	1,030	630 1,320

DEEPEST WELL DATA The Texas Company (now Texaco Inc.) well No. "Holmes-Eureka" 3, Sec. 22, T. 3 N., R. 1 W. T.D. 7,852 in Yager (Lower Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	13
Cumulative Gas (Mcf.)	24,057,012	Total Wells Completed	11
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	7
1959 Average Gas (Mcf/d)	2,735	Maximum Proved Acreage	940
Peak Production (1955) (Mcf.)	2,247,903		

USUAL CASING PROGRAM
9-5/8" cem. 800
5-1/2" cem. through gas sands and shot-perforated for production

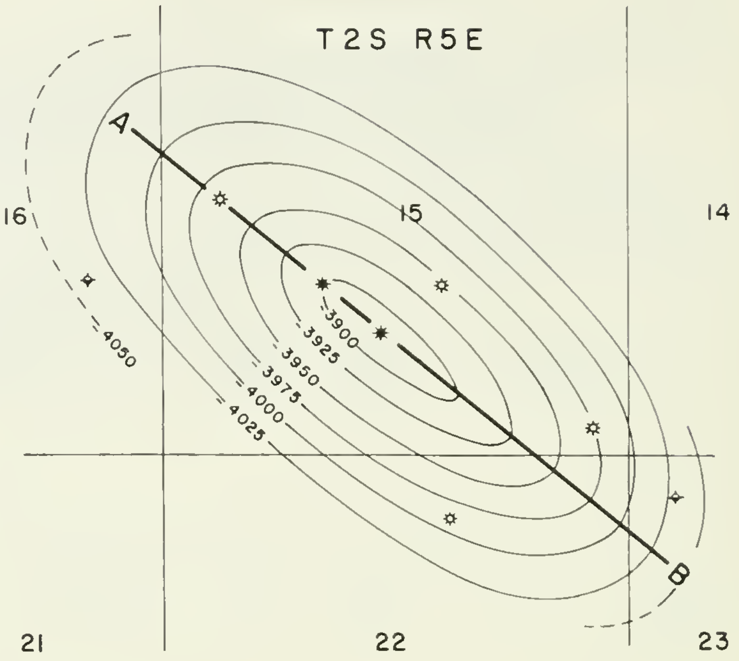
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in November 1938.

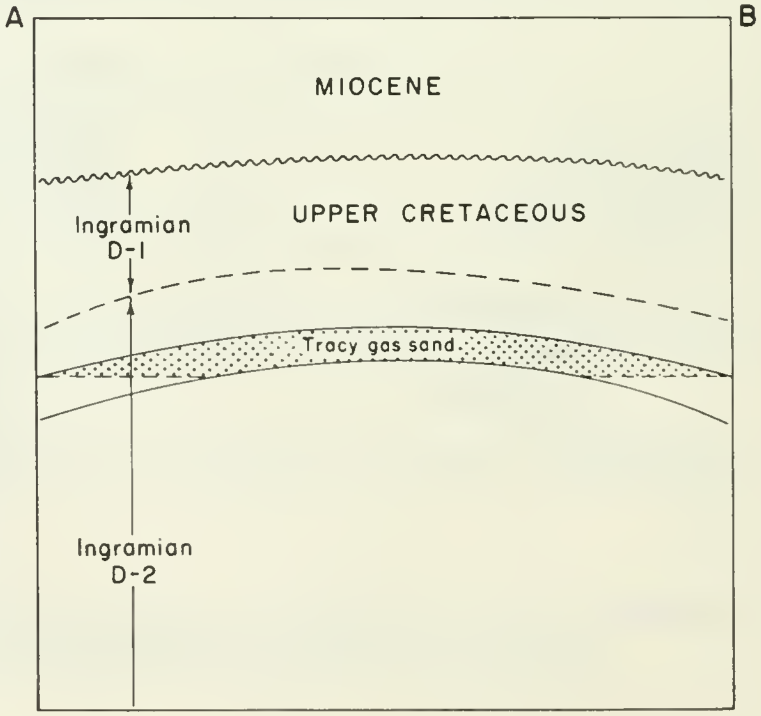
REFERENCES Calif. Railroad Comm. and Calif. Div. of Oil and Gas Estimate of the Natural Gas Reserves of the State of California (1941)
Calif. Div. of Mines Bull. 118 (1943) and Bull. 164 (1953)

TRACY GAS FIELD

EPOCH	STAGE		FORMATION	Thickness (Feet)
PLIOCENE - RECENT			Undifferentiated Sediments, Predominantly Nonmarine	2525
MIOCENE(?)			POSSIBLY ZILCH OR VALLEY SPRINGS (nonmarine)	950
UPPER CRETACEOUS	INGRAMIAN	D-1	Moreno(?)	395
		D-2	Tracy sand Panoche	1845
	TRACIAN	E		1185
	WELDONIAN	F-1		2000
		F-2		535
	?			255 (drilled)



CONTOURS ON TOP OF TRACY GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

TRACY GAS FIELD
San Joaquin County

LOCATION 20 miles southwest of Stockton.

DISCOVERY DATA Amerada Petroleum Corp. well No. "F.D.L." 2, Sec. 15, T. 2 S., R. 5 E., M.D.B.& M. Completed August 11, 1935, flowing gas from intervals between 3,973-4,063 at the average rate of 35,000 Mcf/d through a 1-3/4-inch bean under a flow pressure of 1,400 psi.

STRUCTURE Anticline.

ELEVATION 35 BASE OF FRESH WATERS 1,200 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Tracy	3,900	41	U. Cretaceous	Panoche	930	400-500

DEEPEST WELL DATA Amerada Petroleum Corp. well No. "F.D.L." 1, Sec. 15, T. 2 S., R. 5 E. T.D. 9,690 in Panoche (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	8
Cumulative Gas (Mcf.)	13,775,969	Total Wells Completed	6
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	350
Peak Production (1936) (Mcf.)	3,012,083		

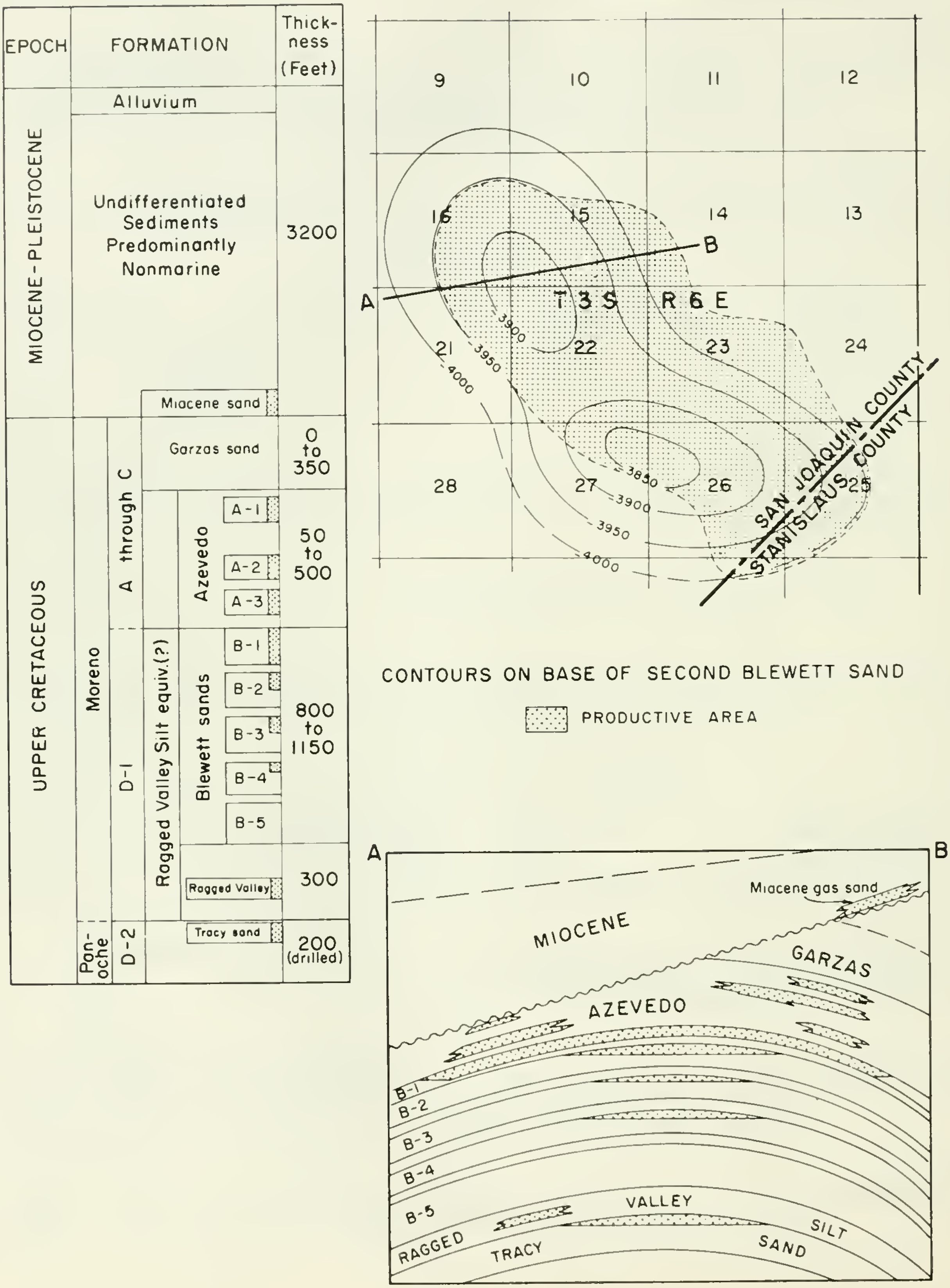
USUAL CASING PROGRAM
13-3/8" cem. at 300
8-5/8" or 9-7/8" cem. above gas sand
6-5/8" liner landed through gas zone

BOP EQUIPMENT Required

MISCELLANEOUS First commercial gas field found in northern part of State and first to produce gas commercially from Cretaceous sediments. Commercial gas deliveries began in September 1935.

REFERENCES Calif. Div. of Mines Bull. 118 (1943)
Calif. Div. of Oil and Gas "Summary of Operations" Vol. 43, No. 1 (1957)

VERNALIS GAS FIELD



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

VERNALIS GAS FIELD
San Joaquin & Stanislaus Counties

LOCATION Approx. 10 miles southeast of Tracy.

DISCOVERY DATA Standard Oil Co. of California well No. "Blewett Community" 1, Sec. 25, T. 3 S., R. 6 E., M.D.B.& M. Completed January 8, 1941, flowing gas from the interval 3,857-3,869 at the average rate of 9,706 Mcf/d through a 5/8-inch bean under a flow pressure of 1,141 psi.

STRUCTURE Anticline.

ELEVATION 48-103 BASE OF FRESH WATERS 800-1,000 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Miocene	3,000	0-50	Miocene	(?)	-	125
Azevedo	3,600	0-75	U. Cretaceous	Moreno	-	-
Blewett 1	3,800	25	U. Cretaceous	Moreno	920	-
Blewett 2	3,900	30	U. Cretaceous	Moreno	-	180
Blewett 3	4,100	20	U. Cretaceous	Moreno	-	215
Blewett 4	4,200	20	U. Cretaceous	Moreno	-	-
Ragged Valley silt	4,750	10	U. Cretaceous	Moreno	-	-
Tracy	4,900	30	U. Cretaceous	Panoche	-	-

DEEPEST WELL DATA Standard Oil Co. of California well No. "Blewett Community" 2, Sec. 25, T. 3 S., R. 6 E. T.D. 5,506 in Panoche (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	20
Cumulative Gas (Mcf.)	10,247,527	Total Wells Completed	15
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	3
1959 Average Gas (Mcf/d)	1,366	Maximum Proved Acreage	2,460
Peak Production (1942) (Mcf.)	1,275,269		

USUAL CASING PROGRAM
9-5/8" cem. 1,000
5-1/2" cem. through gas sands and shot-perforated for production

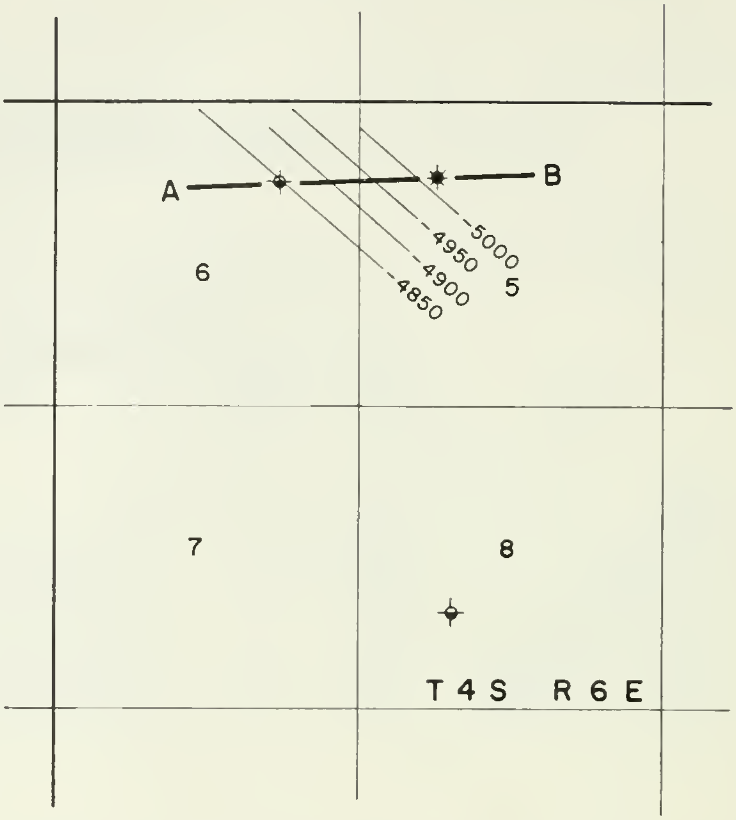
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in May 1942.

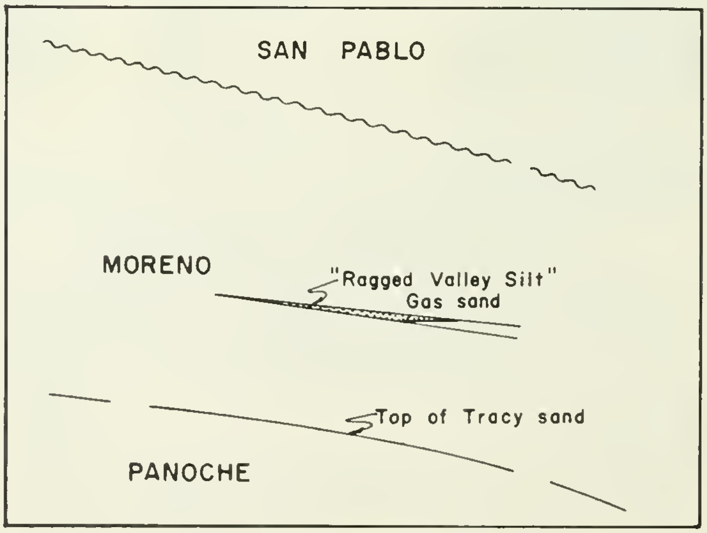
REFERENCES

VERNALIS, SOUTHWEST, GAS AREA

EPOCH	FORMATION	Thickness (Feet)
RECENT	Alluvium	3350
MIOCENE-PLEISTOCENE	Tulare	
	San Pablo	
UPPER CRETACEOUS	Moreno ▨	1850
	Panoche	200 (drilled)



CONTOURS ON TOP OF TRACY SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

VERNALIS, SOUTHWEST, GAS AREA
San Joaquin County

LOCATION 9 miles southeast of Tracy and 3 miles southwest of Vernalis Gas field.

DISCOVERY DATA Porter Sesnon, et al well No. "Sesnon-Vernalis" 22-5, Sec. 5, T. 4 S., R. 6 E., M.D.B.& M. Completed August 18, 1959, flowing gas from the interval 4,560-4,564 at the rate of 530 Mcf/d through a 1/4-inch bean under a flow pressure of 340 psi.

STRUCTURE Updip lensing on homocline(?).

ELEVATION 226 BASE OF FRESH WATERS 2,600 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
"Ragged Valley Silt"	4,560	4	U. Cretaceous	Moreno	870	-

DEEPEST WELL DATA The discovery well. T.D. 5,450 in Panoche (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	1
Cumulative Gas (Mcf.)	0	Total Wells Completed	1
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	20
Peak Production	-		

USUAL CASING PROGRAM
9-5/8" cem. 1,200
5-1/2" cem. through gas sand and shot-perforated for production

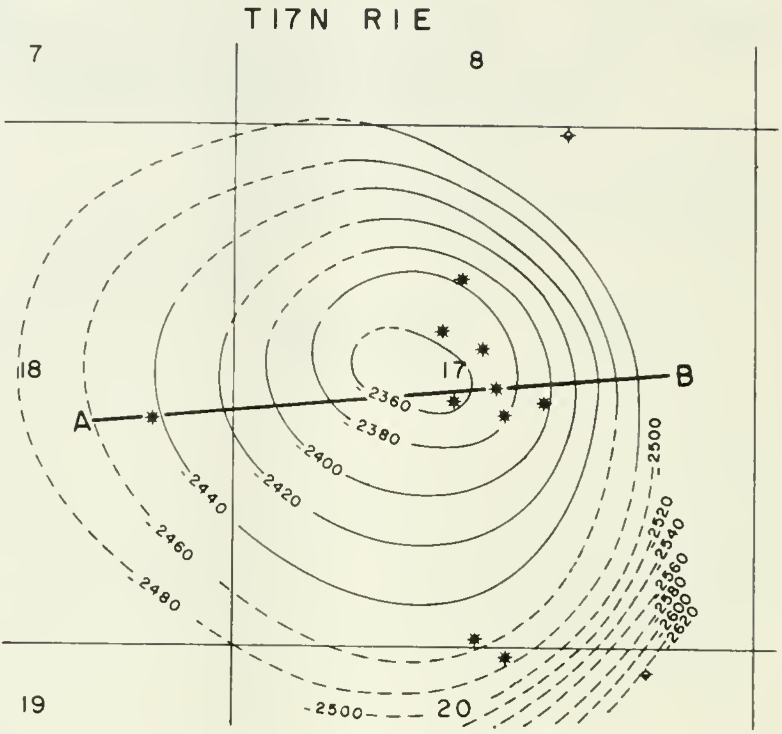
BOP EQUIPMENT Required

MISCELLANEOUS The well is shut-in.

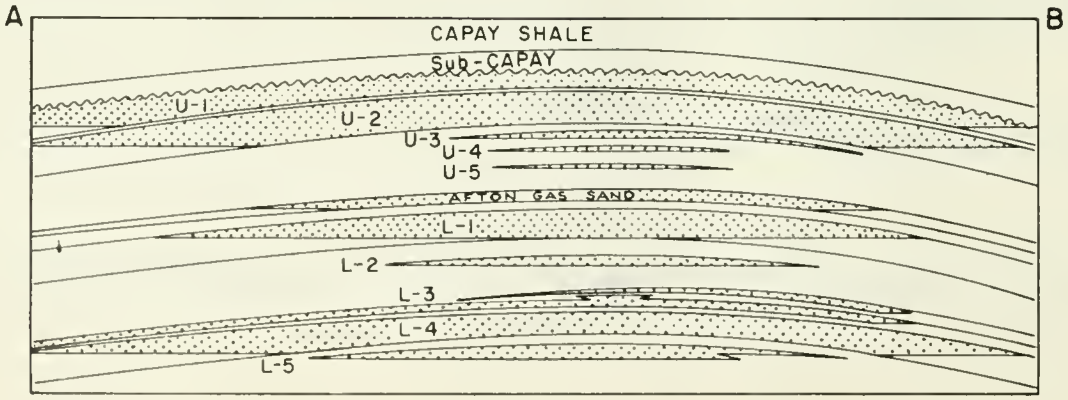
REFERENCES State Div. of Mines "California Journal of Mines and Geology" Vol. 51, No. 1 (Jan. 1955)

WILD GOOSE GAS FIELD

EPOCH	FORMATION			Thickness (Feet)
RECENT-PLIOCENE	Alluvium			1320
	Tehama			
EOCENE	Undifferentiated Nonmarine Sediments			600
	Ione sand			130
	Capay			370
	Sub-Capay			50
UPPER CRETACEOUS	Kione	Upper "Wild Goose" sands	U-1 U-2 U-3 U-4 U-5	950
		Afton sand	▨	
		Lower "Wild Goose" sands	L-1 L-2 L-3 L-4 L-5	
	Forbes			574 (drilled)



CONTOURS ON TOP OF SUB-CAPAY



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

WILD GOOSE GAS FIELD
Butte and Colusa Counties

LOCATION 10 miles northwest of Colusa.

DISCOVERY DATA Honolulu Oil Corp. well No. "Honolulu-Humble Wild Goose" 1, Sec. 17, T. 17 N., R. 1 E., M.D.B.& M. Completed August 10, 1951, flowing gas from the interval 3,192-3,314 at the rate of 4,020 Mcf/d through a 24/64-inch bean under a flow pressure of 1,370 psi.

STRUCTURE Dome.

ELEVATION 65 BASE OF FRESH WATERS 800 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Upper Wild Goose	2,600	200	U. Cretaceous	Kione	810	1,250
Afton	2,900	30	U. Cretaceous	Kione	810	1,250
Lower Wild Goose	3,150	250	U. Cretaceous	Kione	810	1,250

DEEPEST WELL DATA The discovery well. T.D. 4,009 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	13
Cumulative Gas (Mcf.)	33,768,283	Total Wells Completed	10
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	7
1959 Average Gas (Mcf/d)	15,186	Maximum Proved Acreage	360
Peak Production (1959) (Mcf.)	5,543,181		

USUAL CASING PROGRAM
13-3/8" or 9-7/8" cem. 800
7" or 5-1/2" cem. through gas sands and shot-perforated for production

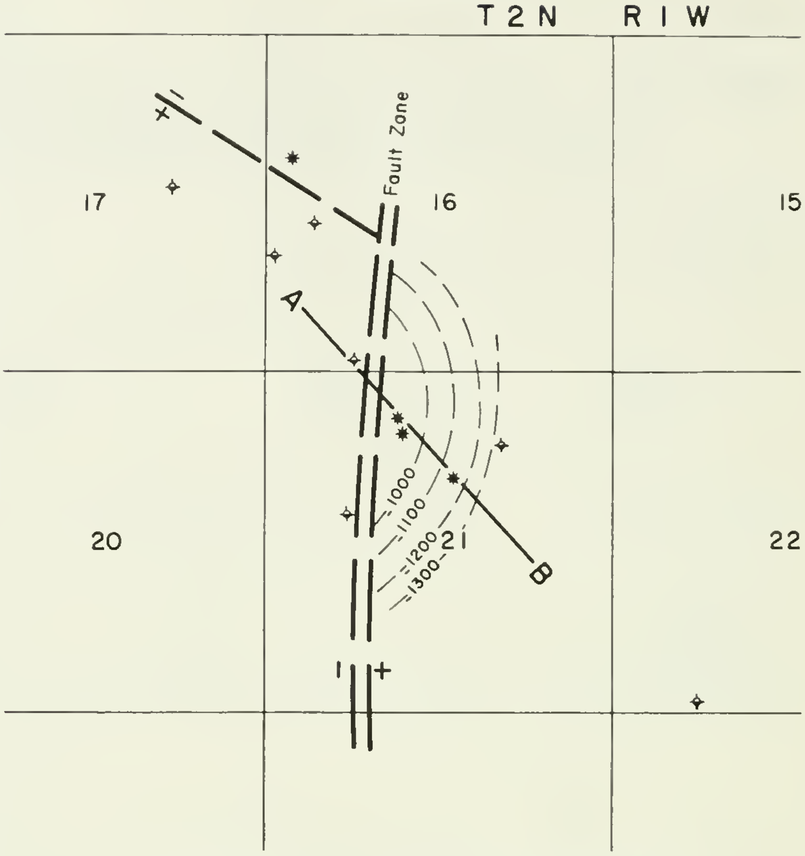
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in November 1951.

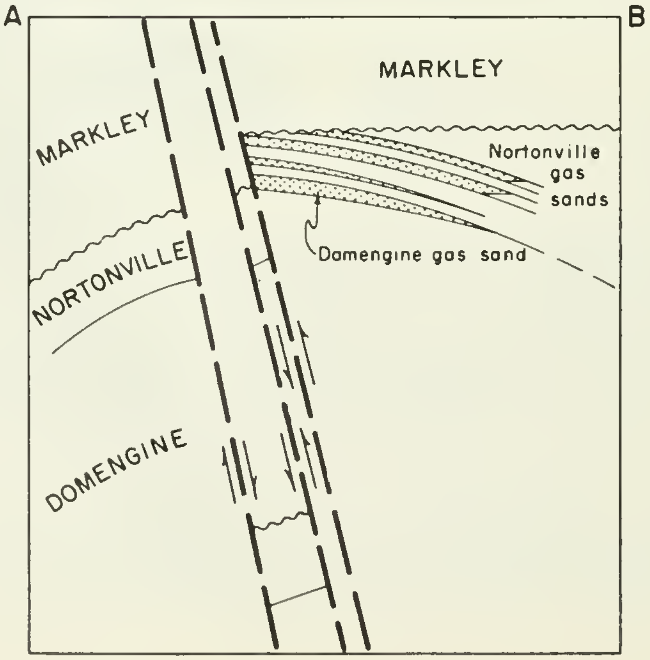
REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 41, No. 1 (1955)

WILLOW PASS GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
EOCENE	Markley	1400
	Nortonville	250 to 510
	Domengine	400±
PALEOCENE	Martinez	1340
UPPER CRETACEOUS		40 (drilled)



CONTOURS ON TOP OF DOMENGINE GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

WILLOW PASS GAS FIELD
Contra Costa County

LOCATION 8-1/2 milea east of Martinez.

DISCOVERY DATA Trico Oil and Gas Co. well No. "Faria Unit" 1, Sec. 21, T. 2 N., R. 1 W., M.D.B.& M. Completed May 31, 1959, flowing gas from the interval 1,714-1,777 at an average rate of 4,300 Mcf/d through a 3/4-inch bean under a flow pressure of 290 psi.

STRUCTURE Faulted anticline (?)

ELEVATION 527-777 BASE OF FRESH WATERS 150 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Nortonville	1,500 3,100	35	Eocene	Nortonville	1,000	-
Domengine	1,800	50	Eocene	Domengine	1,020	-

DEEPEST WELL DATA John Baldwin, Operator, well No. "Baldwin-Soite" 1, Sec. 17, T. 2 N., R. 1 W. T.D. 5,493 in Upper Cretaceous (?).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	8
Cumulative Gas (Mcf.)	0	Total Wells Completed	4
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	0
1959 Average Gas (Mcf/d)	0	Maximum Proved Acreage	60
Peak Production	-		

USUAL CASING PROGRAM
9-5/8" cem. 500
5-1/2" cem. through gas zones and shot-perforated for production

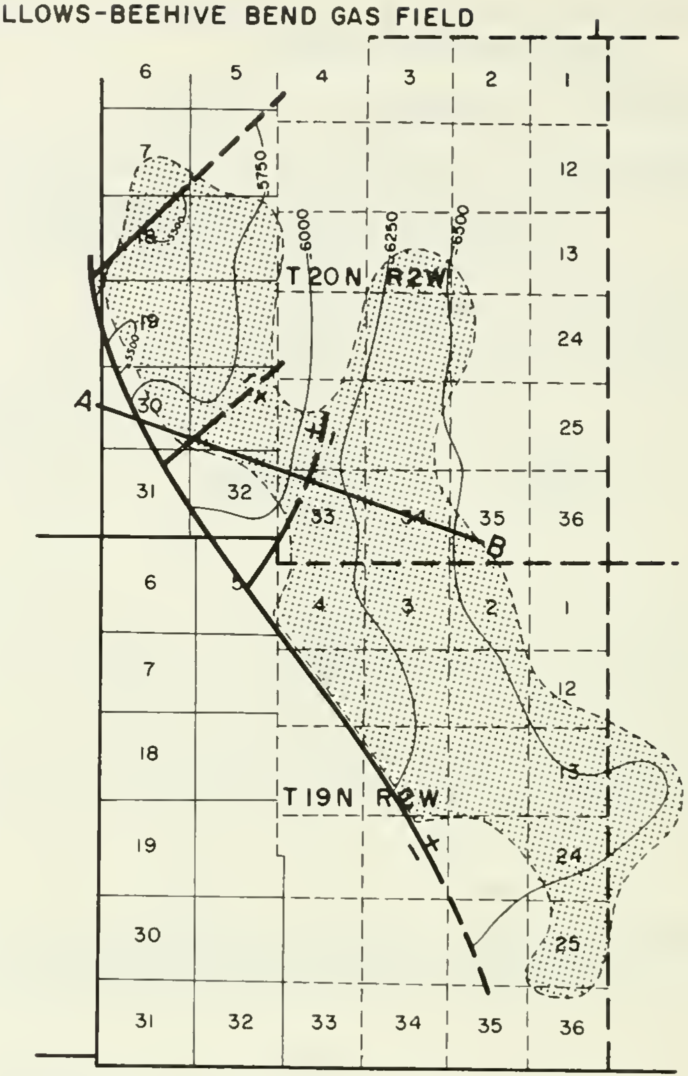
BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in April 1960.

REFERENCES -

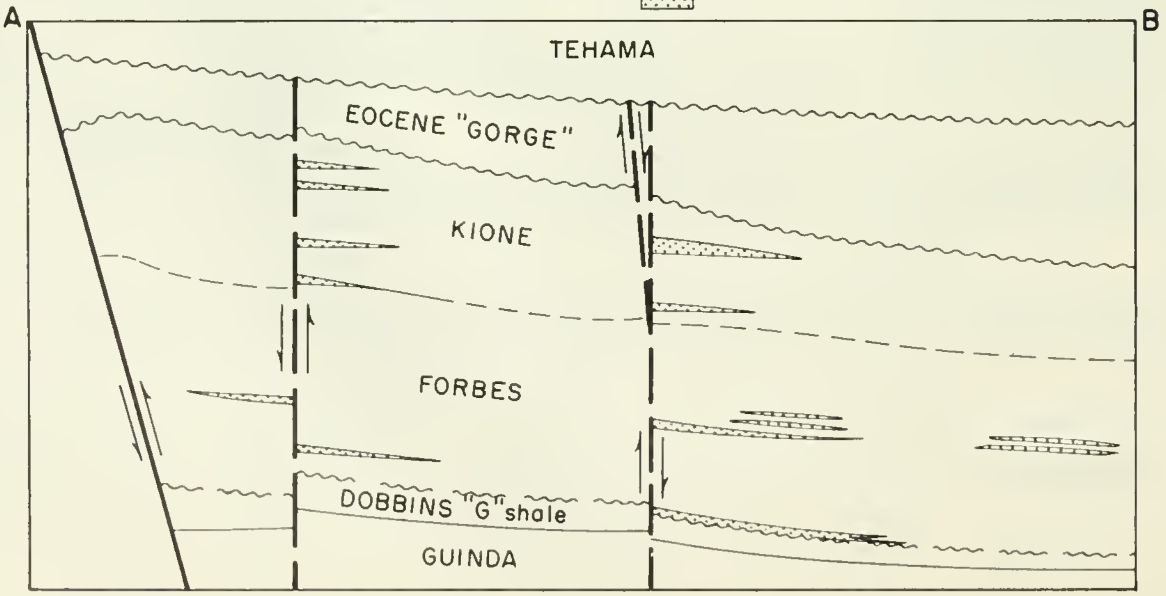
EPOCH	FORAM ZONE	FORMATION		Thickness (Feet)
POST-PLIO-CENE		Continental deposits		1300
PLIO-CENE		Tehama		
EOCENE	B-2 to B-4	"Gorge" fill		1000
UPPER CRETACEOUS	E	Kione	Afton Lower Wild Goose Estes Willard	1500
	F-1 & F-2	Forbes	Friesen Zumwalt Capital Sprague-Lewis	2700
	G-1	Dobbins ("G" shale)		300
		Guinda	Walcott	800
		Funks		500
	G-2	Sites		1300
		Yolo		120
	H	Venado		1150
Basement Complex				45 (drilled)

WILLOWS-BEEHIVE BEND GAS FIELD



CONTOURS ON TOP OF DOBBINS ("G" SHALE)

▨ PRODUCTIVE AREA



CALIFORNIA DIVISION OF OIL AND GAS
FIELD DATA SHEET

WILLOWS-BEEHIVE BEND GAS FIELD
Glenn County

LOCATION 7 miles east of Willows.

DISCOVERY DATA The Ohio Oil Company well No. "E. E. Willard" 1-A (now Capital Company well No. "71-18"), Sec. 18, T. 20 N., R. 2 W., M.D.B.& M. Completed August 23, 1938, flowing gas from the interval 2,237-2,245 at the average rate of 5,356 Mcf/d through a 21/32-inch bean under a flow pressure of 515 psi.

STRUCTURE Faulted anticline. Gas accumulations are in lenticular sands.

ELEVATION 95-145 BASE OF FRESH WATERS 850-1,500 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
Afton	1,860	20	U. Cretaceous	Kione	993	-
Lower Wild Goose	1,930	25	U. Cretaceous	Kione	-	410
Estes	3,650	80	U. Cretaceous	Kione	992	290
Willard	2,250	25	U. Cretaceous	Kione	-	1,075
Friesen	4,420	15	U. Cretaceous	Forbes	991	70
Zumwalt	6,000	30	U. Cretaceous	Forbes	979	1,000
Capital	5,650	30	U. Cretaceous	Forbes	986	825
Sprague Lewis	6,400	60	U. Cretaceous	Forbes	973	710
(Unnamed)	6,700	12	U. Cretaceous	Dobbins	-	-
Wolcott	7,275	70	U. Cretaceous	Guinda	-	-

DEEPEST WELL DATA Sunray Mid-Continent Oil Co. well No. "Sunray-General Petroleum Whyler-Wolcott Unit" 1, Sec. 11, T. 19 N., R. 2 W. T.D. 10,807 in basement complex.

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	129
Cumulative Gas (Mcf.)	73,191,757	Total Wells Completed	82
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	60
1959 Average Gas (Mcf/d)	80,006	Maximum Proved Acreage	7,100
Peak Production (1959) (Mcf.)	29,202,019		

USUAL CASING PROGRAM
9-5/8" cem. 1,500
5-1/2" cem. through gas zone and shot-perforated for production

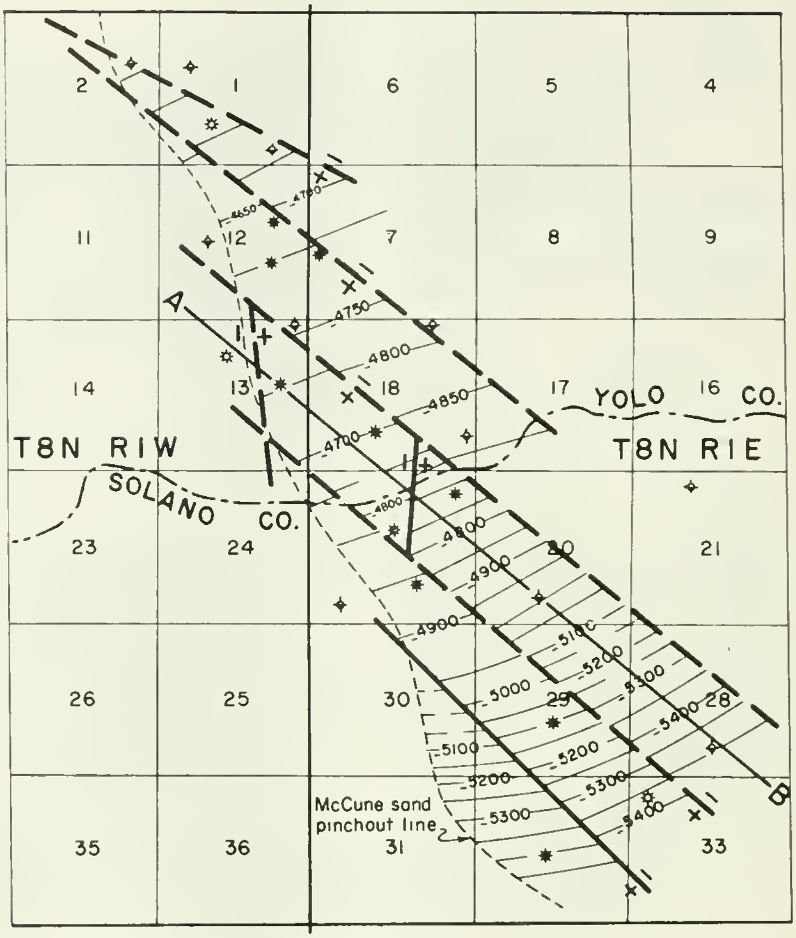
BOP EQUIPMENT Required

MISCELLANEOUS The Ohio Oil Company well No. "E. E. Willard" 1 (now Capital Company well No. "E. E. Willard" 1) may be considered the discovery well. The well blew out in January 1938 while drill pipe was being removed after reaching depth of 4,505. A large crater formed in which the derrick and equipment were lost.

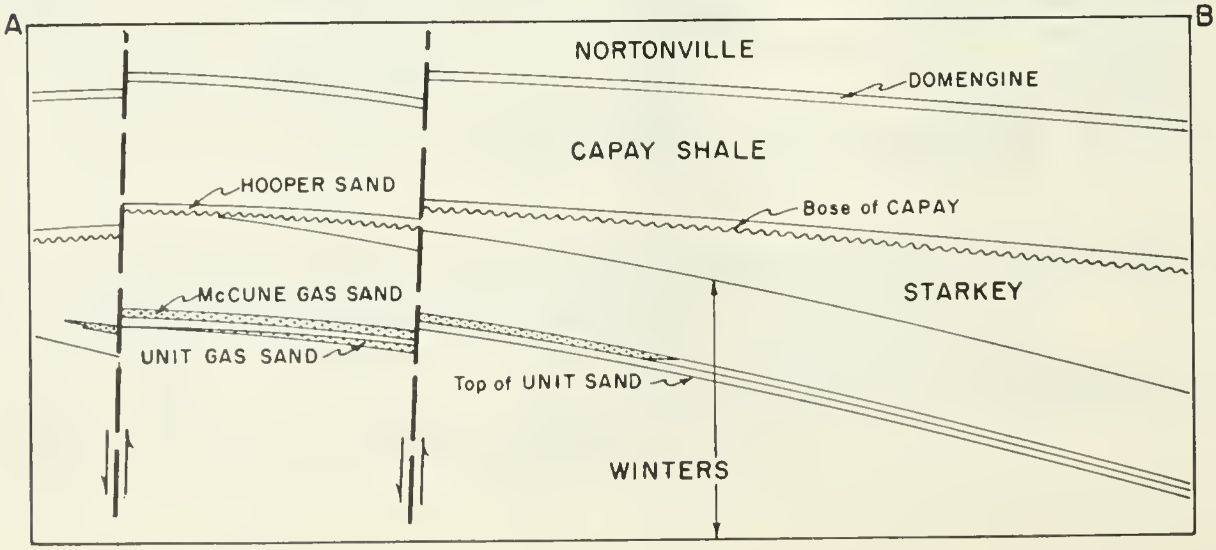
REFERENCES Calif. Div. of Mines Bull. 118 (1943)
Calif. Div. of Oil and Gas "Summary of Operations" Vol. 43, No. 2 (1957)

WINTERS GAS FIELD

EPOCH	FORMATION	Thickness (Feet)
RECENT TO PLIOCENE	Tehama	2650
EOCENE	Nortonville	860
	Domengine	15
	Capay	730
	Hooper sand	65
UPPER CRETACEOUS	Starkey	230
	McCune gas sand ▨ Unit gas sand ▨ Winters	1800
	Sacramento	850
	Forbes	1330 (drilled)



CONTOURS ON TOP OF McCUNE GAS SAND



CALIFORNIA DIVISION OF OIL AND GAS

FIELD DATA SHEET

WINTERS GAS FIELD
Solano and Yolo Counties

LOCATION 23 miles west of Sacramento and 3 miles east of Winters.

DISCOVERY DATA Shell Oil Co. well No. "McCune" 1, Sec. 29, T. 8 N., R. 1 E., M.D.B.& M. Completed February 7, 1946, flowing gas from interval 5,209-5,239 at the average rate of 12,500 Mcf/d through a 1/2-inch bean under a flow pressure of 1,626 psi.

STRUCTURE Faulted homocline with sands pinching out to the west.

ELEVATION 111 BASE OF FRESH WATERS 2,400 SPACING ACT APPLIES Yes

PRODUCING ZONES

Name of Zone or E. Log Marker	Average Depth (feet)	Average Thickness (feet)	Geologic Age	Geologic Formation	Gravity or B.t.u.	Salinity of Zone Water Gr./Gal.
McCune	4,850	20	U. Cretaceous	Winters	900	820
Unit	4,920	5	U. Cretaceous	Winters	900	540

DEEPEST WELL DATA Shell Oil Co. well No. "Winters Unit 2" 1, Sec. 18, T. 8 N., R. 1 E. T.D. 8,493 in Forbes (Upper Cretaceous).

PRODUCTION DATA—JANUARY 1, 1960

Cumulative Oil (bbl.)	0	Total Wells Drilled	23
Cumulative Gas (Mcf.)	18,276,853	Total Wells Completed	12
1959 Average Oil (b/d)	0	Producing Wells (1959 Aver.)	6
1959 Average Gas (Mcf/d)	4,542	Maximum Proved Acreage	740
Peak Production (1956) (Mcf.)	2,092,238		

USUAL CASING PROGRAM

10-3/4" or 9-5/8" cem. 500
5-1/2" cem. through gas sands and shot-perforated for production

BOP EQUIPMENT Required

MISCELLANEOUS Commercial gas deliveries began in January 1949.

REFERENCES Calif. Div. of Oil and Gas "Summary of Operations" Vol. 42, No. 2 (1956)

PART IV

FIELD TRIP GUIDES

CONTENTS

FIELD TRIP 1: SACRAMENTO VALLEY

By BRUCE D. BROOKS
Brazos Oil and Gas Company
Division of the Dow Chemical Company

DONALD ROGERS
Humble Oil and Refining Company

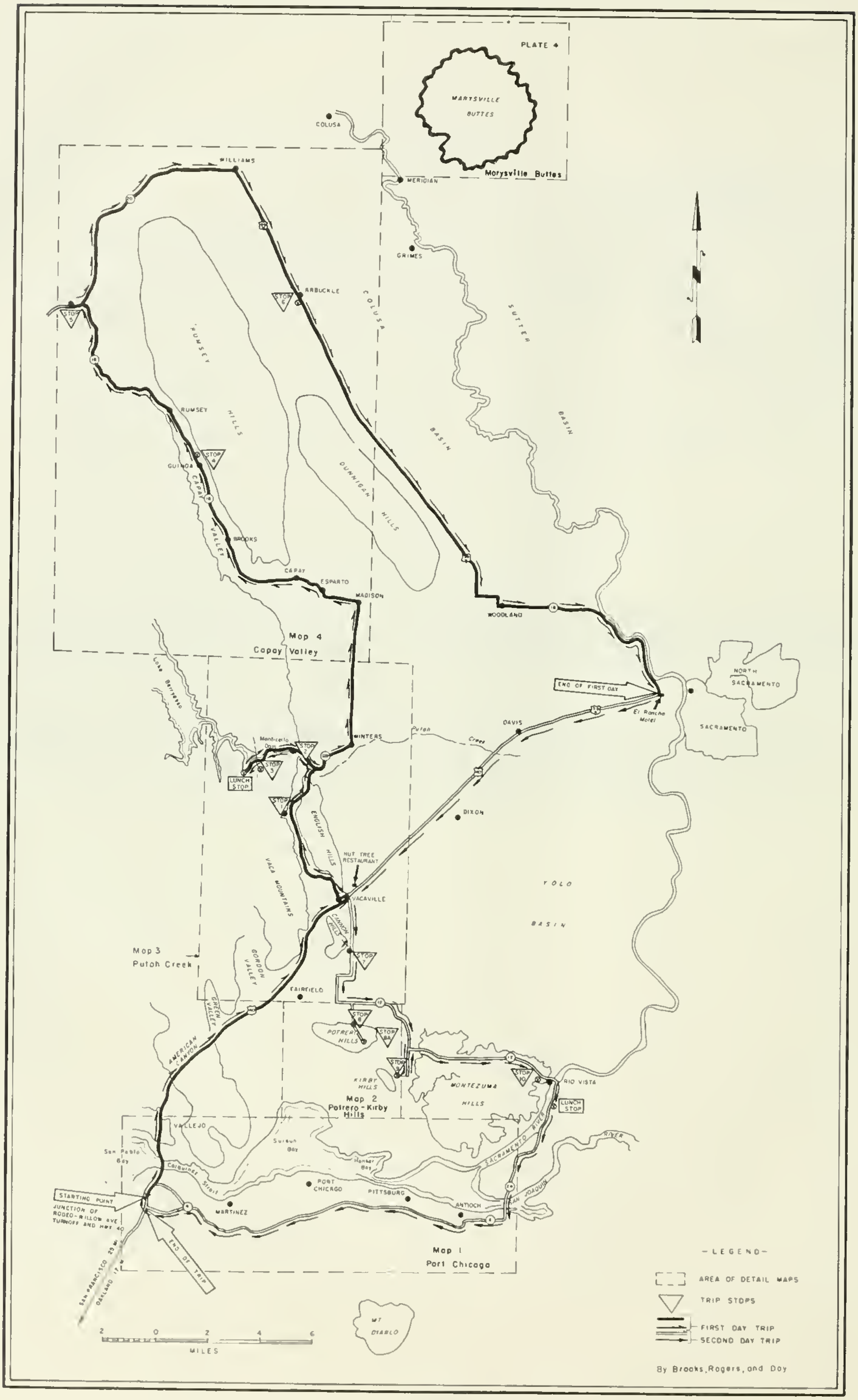
PAUL DAY
Gulf Oil Corporation of California

and TOM WOOTTON
Shell Oil Company

First day, March 24, 1962: Carquinez Strait—Gordon Valley—Pleasant Valley—Putah Canyon—Capay Valley—Bear Valley—Mountain House—Arbuckle Gas Field—Dunnigan Hills—Sacramento. Total driving distance 205.3 miles.

Second day, March 25, 1962: Sacramento—Vacaville—Cannon Anticline—Potrero Hills—Kirby Hills—Rio Vista—Antioch—Martinez. Total driving distance 121.8 miles.

Map 1, *Geologic map of Port Chicago area;* Map 2, *Geologic map of Potrero-Kirby Hills area;* Map 3, *Geologic map of Putah Creek area;* Map 4, *Geologic map of Capay Valley and vicinity;* and Plate 25, *Geologic cross section, Putah Creek to Winters,* accompany this paper.



By Brooks, Rogers, and Day

Figure 1. Index map showing trip routes and orientation of reference geologic maps for the Sacramento Valley field trips. The geologic maps (Maps 1-4) are folded in box.

FIRST DAY

The first day's trip will introduce the field trip participants to many of the Upper Cretaceous units mapped along the west side of the Sacramento Valley as well as most of the Tertiary section. The road log begins at the junction of Rodeo-Willow Avenue and U. S. Highway 40, approximately 3 miles southwest of Carquinez Bridge,* and ends at El Rancho Motel in West Sacramento. Please refer to master road map (fig. 1) for location of starting point, route of field trip, and coverage of detail maps.

Distance	*Total mileage*	
0	0	Starting point: North side of junction of Rodeo-Willow Avenue turnoff and U. S. Highway 40. Parking space available for those wishing to board busses at this point rather than in San Francisco.
0.5	0.5	Gently dipping Miocene San Pablo group sand and shale on either side of road. Westerly limb of San Pablo syncline.
0.3	0.8	California Street overcrossing.
0.2	1.0	Union Oil Company Oleum refinery can be observed on the north side of the highway at 10 o'clock (direction).
0.1	1.4	At 3 o'clock, near-vertical upper Miocene Cierbo sandstone member of San Pablo group.
0.6	2.0	Approximate contact of Cierbo sandstone with Monterey shale.
0.05	2.05	Cummings Skyway turnoff.
0.25	2.3	Road cut through dark gray to black-weathering Miocene Monterey shale.
0.6	2.9	At 9 o'clock, possible trace of Franklin fault.
0.1	3.0	Southwest approach to Carquinez Bridge.
0.05	3.05	At 3 o'clock, Upper Cretaceous outcrops in hills.
0.55	3.6	Solano County line and center of Carquinez Bridge. At 9 o'clock, San Pablo Bay.
0.45	4.05	Undifferentiated Upper Cretaceous sandstone and shale crop out on both sides of highway. Road approximately parallels Vallejo syncline at this point.
0.05	4.1	Vallejo city limit.
0.25	4.35	Toll gates for Carquinez Bridge. From this point through the town of Vallejo, the road traverses poorly exposed Upper Cretaceous rocks.
4.5	8.85	At 10 o'clock, Solano County fair ground.
0.05	8.9	At 1 o'clock, bold outcrops of red chert of Upper Jurassic Franciscan formation in probable fault contact with Upper Cretaceous rocks.
0.4	9.3	Napa turnoff. Sulfur Springs Mountain visible at approximately 3 o'clock.
0.4	9.7	At 2 o'clock, Franciscan cherts again visible. Sulfur Springs fault probably passes between this point and the Franciscan outcrops.
0.8	10.5	Fault contact of Upper Cretaceous shale with Franciscan chert and sandstone. This area structurally complicated by numerous faults.
0.2	10.7	Serpentine outcrop on left side of highway, of probable Jurassic age.
0.9	11.6	Highly contorted Cretaceous contact with serpentine body.
0.25	11.85	Solano County line. Outcrops west of Jurassic Franciscan were mapped as Lower Cretaceous by Weaver.
0.35	12.2	At 11 o'clock, Eocene sandstone resting uncomformably on Lower Cretaceous shale.
0.9	13.1	Road passing through American Canyon. Eocene rocks crop out on left side of road.
1.3	14.4	Road traverses Eocene Markley sandstone on both sides. of road. Note west-dipping outcrops at 9 o'clock.
0.4	14.8	View of Green Valley at 3 o'clock.
0.6	15.4	Red-weathering Sonoma volcanic rocks at 11 o'clock, resting unconformably on upper Eocene Markley sand.
0.5	15.9	Railroad overcrossing, junction with California Highway 12.
0.6	16.5	Hills at 1 o'clock and 10 o'clock are underlain by Sonoma volcanic rocks.
1.5	18.0	Cliff-forming Sonoma volcanic rocks approximately 2 miles away, at 9 o'clock.
0.7	18.7	Crossing alluvial plain of Gordon Valley.
0.8	19.5	Distant hills at 10 o'clock are underlain by rocks of Lower Cretaceous age.
1.3	20.8	At 3 o'clock, on a clear day, Mount Diablo is visible. At 2 o'clock are the low hills of the Potrero Hills anticline.
0.5	21.3	Fairfield turnoff.
1.9	23.2	Travis A.F.B. turnoff.
0.6	23.8	Low hills on either side of road are underlain by Upper Cretaceous rocks.
0.6	24.4	At 2 o'clock, Cement Hill, where travertine deposits were quarried for cement by Pacific Portland Cement Co. during the period 1903-1927.
0.7	25.1	Upper Cretaceous shales crop out in road cut.
1.8	26.9	At 2 o'clock, Lagoon Valley. Lagoon Valley thrust-fault passes along east side of valley at base of hills in distance, repeating the Upper Cretaceous section.
0.4	27.3	Pleasants Valley road.
1.1	28.4	Old Rancho Los Putos, on right side of road. Site of 10-square-league land grant (1845) to Juan Pena and Manuel Cabeza de Vaca, for whom the town of Vacaville is named.
0.3	28.7	Lagoon Valley fault in road cut on right.
0.5	29.2	In road cut on left, east-dipping Forbes formation, sand and shale.
0.3	29.5	Vacaville turnoff.
0.9	30.4	Railroad crossing.
0.1	30.5	At 9 o'clock, east-dipping upper Eocene Markley sand.
0.2	30.7	At 3 o'clock, gently dipping Miocene Basalt capping hills in distance.
0.3	31.0	Ulatis Creek.
0.4	31.4	Contact of Miocene San Pablo sandstone with Pliocene Tehama formation.
0.4	31.8	Keep to left.
0.5	32.3	Left turn into Nut Tree. Rest stop. Limited to 10 minutes.
0.3	32.6	Return to Hwy. 40, heading west toward Vacaville.

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* Three miles west of Carquinez Bridge to Capay logged by B. D. Brooks, Brazos Oil and Gas Division of the Dow Chemical Company.

Photo 1. Roncho Los Putos. Photo by Mory Hill.

Distance	*Total mileage*	
0.4	33.0	Take Vacaville turnoff to right.
0.2	33.2	Vacaville city limit.
0.3	33.5	Gently east-dipping Pliocene Tehama formation sands and gravels in contact with tuffaceous sands of Miocene San Pablo formation.
0.5	34.0	Railroad crossing.
0.1	34.1	Continue straight ahead. Do not turn.
0.1	34.2	Turn right on Vine Street.
0.4	34.6	At 12 o'clock, Miocene basalt resting unconformably upon upper Eocene Markley sands.
0.7	35.3	At 2 o'clock, better view of basalt outcrop. Road lined with English walnut trees.
0.4	35.7	Road turn sharply left.
0.1	35.8	At 12 o'clock, Pleasants Valley with Vaca Mountains on horizon. At 3 o'clock, Markley sands dipping east.
0.1	35.9	Turn right.
0.2	36.1	Take road to left across Pleasants Valley.
0.3	36.4	Bridge. Dangerous intersection. Continue straight ahead on Pleasants Valley road.
0.2	36.6	At 2 o'clock, Domengine sands of middle Eocene age overlying Capay shale. Road continues over Capay shale covered by Recent alluvium. Domengine sand poorly developed in area.
1.2	37.8	Turn right toward Winters.
0.1	37.9	Road runs parallel to Paleocene Martinez contact with Upper Cretaceous Forbes formation, approximately 150 yards west of highway.
1.0	38.9	At 3 o'clock, small white outcrop of Domengine sand on east side of valley. At 9 o'clock, steep hills in background comprised of Upper Cretaceous sand and shale.
0.9	39.8	Ulatis Creek bridge.
0.3	40.1	Road slowly rises over Paleocene Martinez sand and shale.
0.3	40.4	Approximate contact of Paleocene Martinez formation with Capay shale.

Distance	*Total mileage*	
0.3	40.7	At 3 o'clock, note brown and tan-weathering poorly developed Domengine sands capping ridge and resting on Capay shale.
0.5	41.2	Road to right goes up Cantaloupe grade. Continue straight.
0.3	41.5	At 2 o'clock, Putnam Peak, capped by Miocene basalt.
0.6	42.1	**STOP 1.** Busses turn left through T. J. Cunningham Ranch gate and park along road. Disembark from busses and walk through gate and across road to exposure of Capay shale in gully.
0.3	42.4	Return to Pleasants Valley road. Continue northward.
0.4	42.8	Mix Canyon at 9 o'clock, Putnam Peak at 3 o'clock.
0.5	43.3	Road makes sharp S-curve.
0.2	43.5	Narrow bridge. Approximate top Cretaceous contact.
0.8	44.3	Road goes back and forth across Capay-Cretaceous contact.
0.5	44.8	Road curves sharply to right.
0.1	44.9	Bridge across Pleasant Creek. At 3 o'clock, Domengine sand.
0.4	45.3	At 11 o'clock, good outcrop of Markley sandstone across creek.
0.4	45.7	At 8 o'clock, Markley sand, dipping east. At 12 o'clock, contact of Pliocene Tehama with Eocene Markley sand near top of hill.
0.8	46.5	Markley sand in road cut at left side of road. At 3 o'clock, Tehama conglomerate resting unconformably on Markley sand.
0.3	46.8	Winters turnoff. Continue straight ahead.
0.1	46.9	Contact of basal Tehama conglomerate with Markley sand.
0.4	47.3	Nomlaki tuff member of Tehama formation in cuts along right side of road.
0.2	47.5	Road cut exposing Nomlaki tuff.
0.2	47.7	Putah Creek.
0.1	47.8	Intersection with Winters-Napa road. Turn left.
0.2	48.0	Nomlaki tuff in road cuts on right.
0.4	48.4	Basal Tehama gravel and conglomerate in road cut on right.
0.8	49.2	Small hill at 2 o'clock is slumped block of Tehama formation.
0.5	49.7	At 12 o'clock, sands and shales of Forbes formation, Capay shale poorly exposed in slopes at 3 o'clock with Tehama formation at top of hill.
0.5	50.2	**STOP 2.** Black rocks point at mouth of Putah Canyon. At this point, there will be a discussion of the relationships of the Eocene, Pliocene, and Cretaceous rocks in the area, as well as Upper Cretaceous rocks to be seen as busses continue up Putah Canyon. There are no convenient stopping places along the canyon to view the rocks and contacts closely. Return to busses and continue up Putah Canyon. Road for next half mile crosses Forbes sand and shale of Goudkoff's F_1- and F_2-zone age. Sandstone content increases in lower portion.
1.1	51.3	Approximate contact of Dobbins shale.
0.2	51.5	At 9 o'clock. Guinda sand in outcrop across creek. Note the painted cannonball concretion.
0.1	51.6	Top of Funks shale.
0.2	51.8	Approximate contact of Funks shale with Sites sandstone. Top of Goudkoff G_2 zone.
0.6	52.4	Recreation beach.
0.2	52.6	Approximate top of Yolo shale, base Sites sand (under bridge).
0.2	52.8	Yolo shale in roadcut on left.
0.3	53.1	Approximate top of Venado formation, on left side of road.
0.1	53.2	At 2 o'clock, steeply dipping Venado sand.
0.2	53.4	**STOP 3.** Monticello Dam. At this point a discussion of the Venado formation with basal conglomerate, and underlying Antelope shale. Discussion of Monticello Dam. Persons wishing to view lower portion of Venado formation will have to walk approximately 150 yards from parking facility.
0.05	53.45	Napa County line.
0.15	53.6	Basal conglomerate in Venado formation.
0.2	53.8	Approximate top of Lower Cretaceous. Beautiful view at 3 o'clock of Lake Berryessa.
1.8	55.6	**LUNCH STOP.** Markley Canyon resort.
0.1	55.7	Return to Highway 128, turn left out of Markley Canyon resort back toward Monticello Dam.
2.2	57.9	Monticello Dam.
3.1	61.0	Black Rocks Point.
0.7	61.7	At 11 o'clock, note gap in ridge formed by slumped block of Tehama formation.
1.75	63.45	Intersection with Pleasants Valley road. Continue straight ahead toward Winters.
0.25	63.7	At 2 o'clock, low hills consist of Tehama sand and conglomerate.
1.2	64.9	Road turns right onto the alluvial plain of the Sacramento Valley. Numerous apricot orchards on either side of the highway leading into Winters.
2.1	67.0	Winters city limit.

Photo 2. Closeup of Monticello Dam on Putah Creek. Abutments are in sandstone and shale of the Upper Cretaceous Venado formation.

Distance	*Total mileage*	
0.7	67.7	Turn left on Winters-Madison road.
1.7	69.4	At 10 o'clock, the Pleasant Creek gas field is located approximately 2 miles away in gently rolling hills formed by Tehama formation. At 3 o'clock, approximately 3 miles distant, is the Winters field, which contains the only producing oil well in the Sacramento Valley.
2.9	72.3	At 11 o'clock, the Rumsey Hills.
6.15	78.45	Madison city limits.
0.35	78.8	Junction with Highway 16. Turn left toward Esparto.
2.7	81.5	Turn right toward Esparto.
0.1	81.6	Esparto city limit.
0.35	81.95	Turn left toward Capay.
1.65	83.6	Rumsey Hills at 2 o'clock.
0.45	84.05	Capay city limit.
0.15	84.2	Capay.* Northeast of the town of Capay are the Dunnigan Hills in which the Dunnigan gas field is located. Although this field trip does not extend into that area, it is of interest in that it is the closest producing gas field to the Capay-Wilbur Springs area. The Dunnigan Hills gas field was discovered in 1946 by The Texas Company as a result of a reflection seismograph survey.
7.4	91.6	Brooks. From Capay to Brooks the route of travel passes through the Tehama formation of upper Pliocene-Pleistocene age. The Tehama formation consists of nonmarine sandstone, gravel, and gray and yellowish-gray siltstone; thin freshwater limestone is found locally near the base. The basal part is also characterized in

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* Capay to Williams logged by Don Rogers, Humble Oil and Refining Co.

Photo 3. Monticello Dam, on Putah Creek 9 miles west of Winters, Solano County. It is a concrete, thin-arch dam 304 feet high and 1,023 feet long, storing 1,600,000 acre feet of water over an area of 20,700 acres.

Distance	*Total mileage*	
		many places by a thin white volcanic ash member (Nomlaki tuff). This tuff crops out on the east flank of the hills north of the town of Capay near the Cretaceous-Tehama contact. Capay Valley is a topographic feature of synclinal origin bounded on the east by the Rumsey Hills and on the west by the Blue Ridge of the Vaca Mountains.
1.6	93.2	Junction, road 70 and Highway 16. Smith canyon, 1½ miles west of this intersection, is the type locality of the lower Eocene Capay formation. The structure in the canyon is essentially homoclinal and beds dip east rather steeply (50°+). The Capay formation extends continuously north for more than 10 miles. It grades from purely channel conglomerate in the north to presumably estuarine deposits in the south, bearing a fauna identical with that in the Butte gravels of Marysville Buttes on the south. These deposits reach a maximum thickness of at least 2400 feet and there is evidence that much of the material was locally derived.
		The lower 600 feet contain at least four conglomerate beds; near the top of these is a 10-foot gritty mudstone with many pebbles and small gastropods. The mudstone rests upon sandstone that contains a few poorly preserved Eocene fossils, and is overlain by a coarse conglomerate with micaceous quartz sand matrix. *Turritella merriami* has been found only in the conglomerate, along with many other forms, many of which are worn and generally larger than those in the mudstone.
4.9	98.1	Guinda.
3.7	101.8	**STOP 4.** This point in Capay Valley provides a good view of the Blue Slides and the Rumsey Hills. The conspicuous blue color of the slides is attributable to ferrous-iron-bearing minerals in the sandstone of the Tehama formation.
		The Rumsey Hills—a distinct topographic unit lying between the Sacramento Valley on the east and Capay Valley on the west—is an anticlinal flexture, striking northwest, about 22 miles long. The prominent escarpment on the western front of the Rumsey Hills marks the trace of the Sweitzer fault. This reverse fault dips eastward at the surface at an angle of about 45 degrees. In all probability the fault steepens at depth. The displacement rarely exceeds the actual height of the escarpment—probably less than 450 feet in most cases, although the amount differs from place to place.
		The crumpled crestal zone of the Rumsey Hills anticline lies to the west of the Sweitzer fault and has been broken in many places by secondary faults. Between Guinda and Rumsey the crestal zone is further complicated by the development of the Eisner thrust fault. Here gently dipping Cretaceous beds have been thrust westward across nearly vertical younger Cretaceous beds and Tehama gravel.
		Typical exposures of the Guinda formation are present along the faulted western escarpment of the Rumsey Hills. The Guinda formation consists of massive- to well-bedded, fine- to medium-grained, concretionary sandstone which weathers to a gray or buff color.
		Higher up in the Rumsey Hills is the Forbes shale, resting stratigraphically above the Guinda formation. The Forbes formation is primarily soft, well-bedded to massive, greenish-gray to gray siltstone and shale, but contains a few beds of sandstone.
		The presence of natural gas in springs throughout the Rumsey Hills called attention early to the area as prospective oil or gas territory. The earliest wells to search for soil and gas date back to 1900-03 when four wells were drilled by Gorrell and Smith in the bottom of Sand Creek. The deepest of these wells was 2100 feet, and—although gas was encountered in three of the wells—none proved to be economic. One well drilled in 1930, by the Nigger Heaven Dome Oil and Gas Company, encountered gas and salt water under considerable pressure in the interval 5,240 to 6,763 feet in Cretaceuos beds. The well was never completed as a producer but today continues to flow hot salt water. In 1957 Humble Oil and Refining Company drilled a deep test on the crest of this structure. The well was abandoned at a total depth of 15,298 feet.
1.0	102.8	Rumsey.
2.8	105.6	A good exposure of Sites sand (Upper Cretaceous) may be seen on the east bank of Cache Creek. In this same outcrop a prominent fault cuts these beds and tilts them to a nearly vertical position. This fault is probably the northern end of the Sweitzer fault, which appears to die out gradually as a bedding-plane fault in the Sites sand about half a mile upstream.
0.9	106.5	Contact between the Sites sand and the underlying Yolo shale. The Yolo shale is approximately 800 feet thick; this site is taken as its type locality. A good fossil locality is present on the opposite (north) bank of the river, a short distance downstream from the bridge. Here forams are abundant and ammonities have been recovered.
1.0	107.5	Base of the Venado sandstone (Upper Cretaceous). There is a prominent fault in the outcrop.
1.0	108.5	Here Road 40 (to town of Knoxville) crosses Cache Creek over a low-water bridge. Both up- and down-stream from the bridge good microfossils can be collected in the weathered shale.
		About 1½ miles south on Road 40 the Salt Creek conglomerate is faulted out (in NW¼ sec. 16). At present there are no data proving its presence farther south.
0.4	108.9	Prominent landslide and vertical to overturned west-dipping "Antelope shale" can be seen in west bank of Cache Creek. These features reflect the proximity of a steep fault which thrusts lower members of Antelope shale, Salt Creek conglomerate, and uppermost Paskenta sandstone northeast over Antelope shale.
1.4	110.3 to 110.7	In this stretch the Antelope shale can be seen in the cut bank. It steepens progressively from 50° NE until it overturns to a 65° SW dip, as fault is approached.
0.8	111.1	Highway 16 leaves Cache Creek and begins to follow Bear Creek. For more than 7 miles to the northwest, Cache Creek winds obliquely across the southern limb of a broad, faulted, and cross-folded syncline of Knoxville and Paskenta beds.

Distance	*Total mileage*	
1.0	112.1	Overturned Salt Creek conglomerate crops out out on a hilltop a quarter of a mile west of Bear Creek. From here northward, conglomerate can be followed almost continuously into the Wilbur Springs quadrangle. Pebbles in this thin, persistent bed, reworked from underlying Paskenta beds, are chiefly clay-ironstone concretions or well-rounded, very durable rocks. The Salt Creek conglomerate is a stratigraphic marker which indicates a possible unconformity.
0.6	112.7	Roadcut exposes basal sandstone of Antelope shale. Note distinctive bed with brown concretions.
0.3	113.0	Salt Creek conglomerate at mouth of Brophy Canyon.
2.5	115.5	Road cuts across Salt Creek conglomerate and upper Paskenta sandstone and enters area of shale and detrital serpentine.
1.4	116.9	Exposure of detrital serpentine 5000 feet thick, on left (west) side of highway.
1.1	118.0	Junction, Highway 16 and Highway 20. Detrital serpentine is exposed in the road cut. For 2 miles west, both Highway 20 and the Wilbur Springs road pass through 5000 to 7500 feet of Lower Cretaceous breccia. This breccia is made up almost entirely of serpentine detritus with some pebbles of shale, limestone, and chert. Work in this area has indicated that Upper Jurassic serpentine was elevated above sea level to form headlands here during Lower Cretaceous time. As a result, huge slides moved eastward into an adjacent sea. These slides continued intermittently during a large part of the time when Lower Cretaceous sandstone and shale were being deposited, so that the slide breccia is interbedded with them. Ocean currents and wave action reworked and spread the serpentine breccia to the north and south, drawing out breccia beds which interfinger with the other sediments. The road to Wilbur Springs crosses detrital serpentine, as well as Cretaceous and Franciscan sediments. About 3 miles upstream is the site where a number of wells were bored in search of petroleum during the years 1864-65. Wilbur Springs lies approximately 5 miles from the junction of Highways 20 and 16. It is the site of sulphurous hot springs popular for over half a century for their curative effects. Here also lie the remains of the old quicksilver mining camps. Old mine adits, tailings, and foundations of old mills are still visible. Quicksilver production dates back to about the 1870's. The two most important mines were the Manzanita and Wide-Awake. A few flasks of quicksilver were produced as late as 1943. Old mining reports (Irelan, 1888) mention a gas well on the south side of Sulphur Creek near Wilbur Springs, which burned for years with a flame 8 inches to 2 feet long. Turn left at junction onto Highway 20 and proceed 1 mile.
1.0	119.0	**STOP 5.** Oil seep in detrital serpentine visible on west side of Bear Creek in open pit dug by Mr. J. P. Rathburn of Williams during the late 1800's.
1.0	120.0	Back at intersection of Highway 20 and Highway 16, proceed toward town of Williams.
3.6	123.6	View of Salt Creek conglomerate on west side of highway; conjectural base of Upper Cretaceous.
3.3	126.9	This locality is of particular interest because of the presence of oil seeps and of the so-called medicinal oil wells on the left (north) side of the highway. The oil seeps occur along with springs of brackish or salt water in Upper Cretaceous beds. Half a dozen wells each produce from half a barrel to 2 barrels per day. Gas bubbles can be observed in Salt Creek at many places in in this area.
0.5	127.4	Base of Venado formation.
11.3	138.7	Center of Williams.* Proceed south on U.S. Highway 99 W. Between Williams and Arbuckle the Marysville Buttes can be seen about 12 miles distance to the east on a clear day.
9.5	148.2	North limit of Arbuckle gas field.
1.1	149.3	North end of Arbuckle freeway.
1.3	150.6	Exit off U.S. 99W freeway (marked College City).
1.9	152.5	**STOP 6.** Gulf Arbuckle field office. Exhibit of typical Cretaceous cores. Discussion of Arbuckle gas field, Marysville Buttes, and intervening fields.
1.6	154.1	High school. Turn right (east) on road immediately south of high school.
0.2	154.3	U.S. 99W—Turn right (south) onto highway.
0.7	155.0	Carl's Cafe and Truck Stop. Possible rest stop.
9.6	164.6	Dunnigan. South of Dunnigan and more or less continuously to Yolo, the Dunnigan Hills can be seen to the west, about 5 miles away.
1.6	166.2	Sands & Trapps.
1.2	167.4	Winters cutoff. Keep straight ahead on Highway 99W.
5.5	172.9	Zamora.
6.0	178.9	Yolo.
3.5	182.4	Kentucky Avenue. Divider here—turn left onto Kentucky Avenue.
2.1	184.5	East Street (just over railroad tracks and by rice-drying plant). Turn right (south) on Highway 24.
1.1	185.6	Junction California Highway 24 (East Street) and California Highway 16 (River Road). Turn left (east).
7.5	193.1	Elkhorn Ferry. Highway follows banks of Sacramento River south of here.
8.0	201.1	Narrow causeway (north end).
1.4	202.5	Harbor Boulevard. A short distance after coming off levee, highway 16 turns right. Harbor Boulevard is straight ahead, up short rise and across railroad tracks.
1.2	203.7	Corner Harbor Boulevard and West Capitol Avenue. Turn left (east).
1.6	205.3	El Rancho Motel, West Sacramento.

End of First Day's Trip

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* Williams to West Sacramento logged by Paul Day of Gulf Oil Corporation of California.

SECOND DAY

The second day's trip is primarily concerned with the Rio Vista portion of the Sacramento Valley. Whereas most of the first day's trip was concerned with Cretaceous rocks and production therefrom, emphasis will now be placed with the Tertiary section from which the majority of gas has been produced in the valley.*

Distance	*Total mileage*	
0.0	0.0	Start at El Rancho Hotel in West Sacramento at 6:30 a.m., if we breakfast in the field. Start at 8:00 a.m. if we breakfast at the motel. Proceed west on West Capitol Avenue to first intersection, turn left and proceed to highway entry-road, turn right to U. S. Highway 40-99W.
0.4	0.4	Turn right onto four-lane highway and travel west toward Davis. The proposed site of the Sacramento deep-water port and turning basin is located a short distance to the south (left) side of the highway. This port will provide loading and unloading facilities for ocean-going vessels which will navigate the Sacramento River from San Francisco Bay.
3.2	3.6	Entering the Yolo Causeway. This highway structure is 3.2 miles in length and spans the Yolo Bypass, a flood-control device which relieves the main Sacramento River channel under high-water conditions. During the dry season the bed of the bypass is extensively farmed.
		Breakfast stop. During clear weather the Marysville Buttes may be seen directly to the right at a distance of approximately 40 miles.
8.9	12.5	Davis exit. Site of the Davis campus of the University of California. The campus and many of the experimental farming areas may be seen to the north (right) of the highway west of the city of Davis.
4.0	16.5	Directly to the west (about 45° to the right of the highway) Putah Creek Canyon may be seen as a notch in the range of mountains.
		The flat valley floor in this area is ideally suited to the diversified irrigated farming seen along both sides of the highway.
12.5	29.0	The low range of grass-covered hills extending northward (to the right) are the English Hills, which were seen from the other side on the previous day's trip.
1.2	30.2	On the right is the Nut Tree restaurant and gift shop. A rather widely known stopping place for tourists and natives alike.
0.8	31.0	Roadcut in which gently east-dipping continental Pliocene Tehama beds are expossed.
0.8	31.8	Elmira junction interchange. Ahead 0.2 mile, in a highway roadcut and in large industrial plant yard, is an exposure of east-dipping upper Eocene Markley rocks. Turn right off highway at this junction and continue right under highway overpass onto Elmira highway.
0.3	32.1	Road intersection. Turn right toward Cannon Hills onto Travis A. F. B. road. This road follows the east flank of the Cannon Hills.
1.9	34.0	To the right is the California Medical Facility, an institution for medical treatment and observation of convicted felons. This has been the site of many important medical experiments and developments.
1.1	35.1	Entering area of outcrop of east- and southeast-dipping Upper Cretaceous sand and shale beds of E-zone age.
0.7	35.8	**STOP 7.** Traffic conditions may not allow us to leave the buses. Roadcut exposure. Notice the sandstone dikes cutting steeply across the gently

Photo 4. Sandstone dike at Stop 7.
Photo by Mary Hill.

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* Logged by Tom Wootton, Shell Oil Company, Sacramento, California.

Distance	*Total mileage*	
		southeast-dipping Upper Cretaceous E-zone shale beds. The E-zone sand and shale exposed in this area overlie the older and more resistant F-zone sandstone and shale of the Cannon Hills, which are immediately to the west.
2.2	38.0	Turn right toward Fairfield on Air Base Parkway. At this point the buildings of Travis Air Force Base may be seen to the southeast. This air base is the major port of aerial embarkation on the West Coast.
1.1	39.1	Turn left onto the Walters road, which runs due south from this intersection.
2.0	41.1	Turn right onto Scandia road. Continue west to well-marked intersection with State Highway 12.
0.4	41.5	Turn left onto Highway 12 and continue southeast toward Rio Vista. To the south (right) are the east-trending Potrero Hills, a faulted anticlinal structure with Eocene Markley and Domengine beds exposed along the flanks, and Paleocene strata exposed in the axial portion.
1.8	43.3	Turn right (south) onto Scally Road.
0.5	43.8	Upper contact of poorly exposed Pliocene Tehama beds.
0.2	44.0	Upper contact of underlying Eocene Markley rocks.
0.1	44.1	Left turn at end of Scally Road.
0.2	44.2	Upper contact of undifferentiated Eocene Nortonville-Domengine rocks.
0.3	55.5	**STOP 8.** Sand pit on either side of road. The beds exposed in these pits are of Domengine white sand. A few pieces of petrified wood and concentrations of megafossils may be found at this location.
0.3	44.8	Upper contact of Paleocene beds.
0.6	45.4	Upper contact of Paleocene beds on south flank of the anticline.
0.5	45.9	**STOP 8A.** Stop on poorly exposed Eocene Domengine. Walk up to the crest of the adjacent hill for a good view of the surrounding country. The large body of water to the southwest is Suisun Bay. To the south is the very prominent Mount Diablo, the point of origin of the local Base and Meridian. Between Mount Diablo and Suisun Bay and on the far side of the river complex is a range of low-lying, east-trending hills, Los Medanos Hills, on which are located Los Medanos and Willow Pass gas fields. To the southeast may be seen isolated Kirby Hill which will be visited later. A great number of sloughs and marshes stretch throughout this area. The wet ground is composed mostly of peat, which makes seismic operations very difficult. To the east are the low-lying, rolling, Montezuma Hills. In the north foreground is the large area covered by Travis Air Force Base. In the north and northwest background are the hills and mountains of resistant Upper and Lower Cretaceous beds. Return to Highway 12.
2.6	48.5	Turn right onto Highway 12 and continue toward Rio Vista.
4.8	53.3	Turn right (south) onto Bird's Landing road. Scattered exposures in small road cuts for the next 1.8 miles are of continental Neroly blue sand of the upper Miocene San Pablo group.
4.1	57.4	Turn right (west) onto road leading to Kirby Hill. Take right branch of "Y" after passing through gate.
0.6	58.0	**STOP 9.** Sand and gravel pit. On the north wall of the pit is a fault contact between the steeply dipping San Pablo sand and gravel beds and upper Eocene Markley beds. A number of gas-well locations on the faulted domal Kirby Hill gas field may be seen on and around the hill.
0.3	58.3	Location of Shell Oil Company, Lambie No. 6 gas well. Return to Bird's Landing road.
0.9	59.2	Turn left onto Bird's Landing road and continue north.
1.6	60.8	Right turn onto county road opposite Little Honker Bay Resort sign. Entering Montezuma Hills. Dry-land grain farming and stock grazing predominate in this area.
2.6	63.4	Stop sign at intersection with Highway 12. Continue straight ahead toward Rio Vista.
2.0	65.4	Dixon road intersection. Continue straight ahead on Highway 12. Exposures in small road cuts along highway are of the Quaternary terrace deposits which form the Montezuma Hills.
5.2	70.6	Approaching the western edge of the Rio Vista gas field. A compressor plant may be seen to the right and gas-well locations are scattered over the area. The Rio Vista field is a faulted, broad, gentle domal structure producing from Eocene and Paleocene sands. This is the largest single gas field in California.
0.7	71.3	Turn right off Highway 12, follow road to Amerada Petroleum Corporation field office.
1.6	72.9	**STOP 10.** Amerada Petroleum Corporation field office yard. Stop for discussion of completion practices, examination of Tertiary cores, and brief discussion of Rio Vista gas field. Return to Highway 12.
1.6	74.5	Right turn onto Highway 12, continue toward Rio Vista.
0.1	74.6	Rio Vista city limits. Follow Highway 12 through Rio Vista, over bridge spanning the Sacramento River to intersection with State Highway 24.
2.5	77.1	Turn right at stop onto Highway 24 and continue southwest.
3.4	80.5	**LUNCH STOP.** Brannon Island State Park. This stop is located near the southwestern limit of the Rio Vista gas field.
1.1	81.6	U. S. Army's Rio Vista floating-stock depot. The farms in this area are at, or below, water level, and water removal is the main problem.
5.6	87.2	Antioch Bridge. This bridge crosses the San Joaquin River about 6 miles east of its confluence with the Sacramento River. To the left, near the south shore of the river may be seen the levees of a submerged island.

Photo 5. American Smelting & Refining Company smelter at Selby, Contra Costa County, as seen from old Highway 40 west of Carquinez Bridge. Photo by Mary Hill.

Distance	*Total mileage*	
1.7	88.9	Turn right on road opposite E. I. DuPont de Nemours Corporation plant and continue west to Antioch.
0.5	89.4	Along the north (right) side of the road is an industrial complex consisting of a Pacific Gas and Electric Company steam-generating plant, a Fiberboard Products plant, a paper mill and a gypsum-products plant.
2.7	92.1	Turn left onto A Street in Antioch and continue south to intersection with Highway 24-4.
0.3	92.4	Continue straight ahead (south) onto Highway 24-4, which turns to the west at the south edge of Antioch. Continue west on Highway 24-4. To the north along the edge of the river is a strip of diversified industrial plants that runs for several miles.
3.0	95.4	To the left is a portion of the storage tanks located along the northern part of the San Joaquin oil pipelines which bring oil from the southern part of the San Joaquin Valley to refineries in the San Francisco Bay area. In the distance are upturned beds of Miocene, Eocene, and Cretaceous rocks along the north flank of Mt. Diablo.
1.0	96.4	To the left is all that remains of Camp Stoneman, a major staging base during World War II.
6.0	102.4	Entering the Willow Pass area. The Willow Pass gas field is to the south (left) of the highway and is hidden from view by the hills. The first outcrops observed in the road cuts are of Miocene Neroly beds.
0.2	102.6	Upper contact of upper Eocene Markley (?) formation underlying the upper Miocene Neroly formation.
2.3	104.9	To the north (right) is located Los Medanos gas field. The thickest continuous section of gas-sands in the Sacramento Valley area (320′) has been penetrated here.
1.7	106.6	Intersection of Highways 4 and 24. Continue straight ahead on Highway 4.
1.1	107.7	To the north is one of the first oil refineries to be established in this area; the Tidewater Oil Company Avon refinery.
1.3	109.0	Intersection of Highways 4 and 21. Continue straight ahead (west) on Highway 4. The exposures encountered from this point westward are increasingly younger formations across the east flank of a northwest-trending syncline. The formations encountered over the next 1.3 miles are Eocene Domengine, Oligocene San Ramon, middle Miocene Sobrante, and upper Miocene Briones.
1.3	110.3	Axis of syncline. The beds crossed from this point for 1.6 miles are successively older in reverse order from the sequence just traversed.
1.6	111.9	Contact between Eocene Domengine and Paleocene Martinez formations.
0.9	112.8	Fault contact between Paleocene Martinez formation and undifferentiated Upper Cretaceous rocks.
3.5	116.3	Axis of general synclinal structure. Notice the change in dip in outcrops from west to east.
0.9	117.2	Fault contact between Upper Cretaceous rocks and the Hercules shale member of the upper Miocene Briones formation.
0.6	117.8	Upper contact of middle Miocene Rodeo shale of the Monterey group.
0.8	118.6	Contact between middle Miocene Rodeo shale and overlying Briones formation. Remainder of trip is over beds of the upper Miocene Briones formation.
3.2	121.8	Junction of Highway 4 and U.S. Highway 40. Continue left on Highway 40 to San Francisco, or right to Sacramento.

FIELD TRIP 2: SAN FRANCISCO TO MONTEREY VIA CALIFORNIA HIGHWAYS 1, 5, 17 AND CONNECTING ROUTES

MARCH 26, 1962

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PART I: Santa Cruz Mountains, from San Francisco to Sea Cliff State Park, by Earl E. Brabb

PART II: Sea Cliff Beach to Point Lobos via State Highway 1, by Oliver E. Bowen, Jr., and Earl W. Hart

PART I

The Santa Cruz Mountains are part of the Coast Ranges physiographic province of California that extends many miles north and south of the San Francisco Bay area. The principal pre-Tertiary basement rocks of the Santa Cruz Mountains are granitic and intruded metamorphic rocks and the Franciscan formation. The Franciscan formation consists of a thick sequence of graywacke, shale, volcanic rocks, radiolarian chert, limestone, and metamorphic rocks. These have been intruded by ultramafic rocks, chiefly serpentine. Fossils indicate that the Franciscan formation ranges in age from Late Jurassic to Late Cretaceous. The granitic and metamorphic rocks consist predominantly of quartz diorite and associated roof pendants of schist and gneiss, all different from rocks now seen in the Franciscan formation. Radiometric dating indicates that the quartz diorite is approximately 90 million years old, hence is early Late Cretaceous.

The granitic and associated metamorphic rocks lie between two large areas of Franciscan rocks and are separated from them by the San Andreas and Pilarcitos faults on the northeast and the Nacimiento fault, 125 miles southeast of San Francisco, on the southwest. The structural relations between these blocks ramains one of the challenging problems of California geology.

The granitic and metamorphic rocks crop out locally in the Santa Cruz Mountains and form the basement floor of a former sedimentary marine basin. This basin contains a thick sequence of Upper Cretaceous and Tertiary marine strata, predominantly sandstone and shale, that vary in thickness and lithology within a small area. These variations, poor surface exposures, complex structure, and lithologic similarity of formations require that geologic mapping be accompanied by closely spaced paleontologic control.

The geologic history recorded in the rocks of La Honda basin is discontinuous and complex. The strata were probably folded, faulted, uplifted, and eroded near the end of the Cretaceous, Paleocene, Oligocene, lower and middle Miocene, and during the Pleistocene. Some folds were accentuated by successive disastrophisms and others are hidden by a cover of relatively undisturbed strata. Volcanism occurred in early Miocene time and resulted in the interstratification of basaltic lava and pyroclastic material with sand and mud on the basin floor.

Exploration for oil and gas in the Santa Cruz Mountains has been in progress since 1864. By the end of 1960, two small commercial oil fields and several subcommercial oil fields had been discovered. Most of the production is from the Butano sandstone of Eocene (Narizian) age and from sandstone of Oligocene (Zemorrian) age. The oil is trapped in relatively small northwestward-trending anticlines and is further restricted by "pinch-outs" and unconformities.

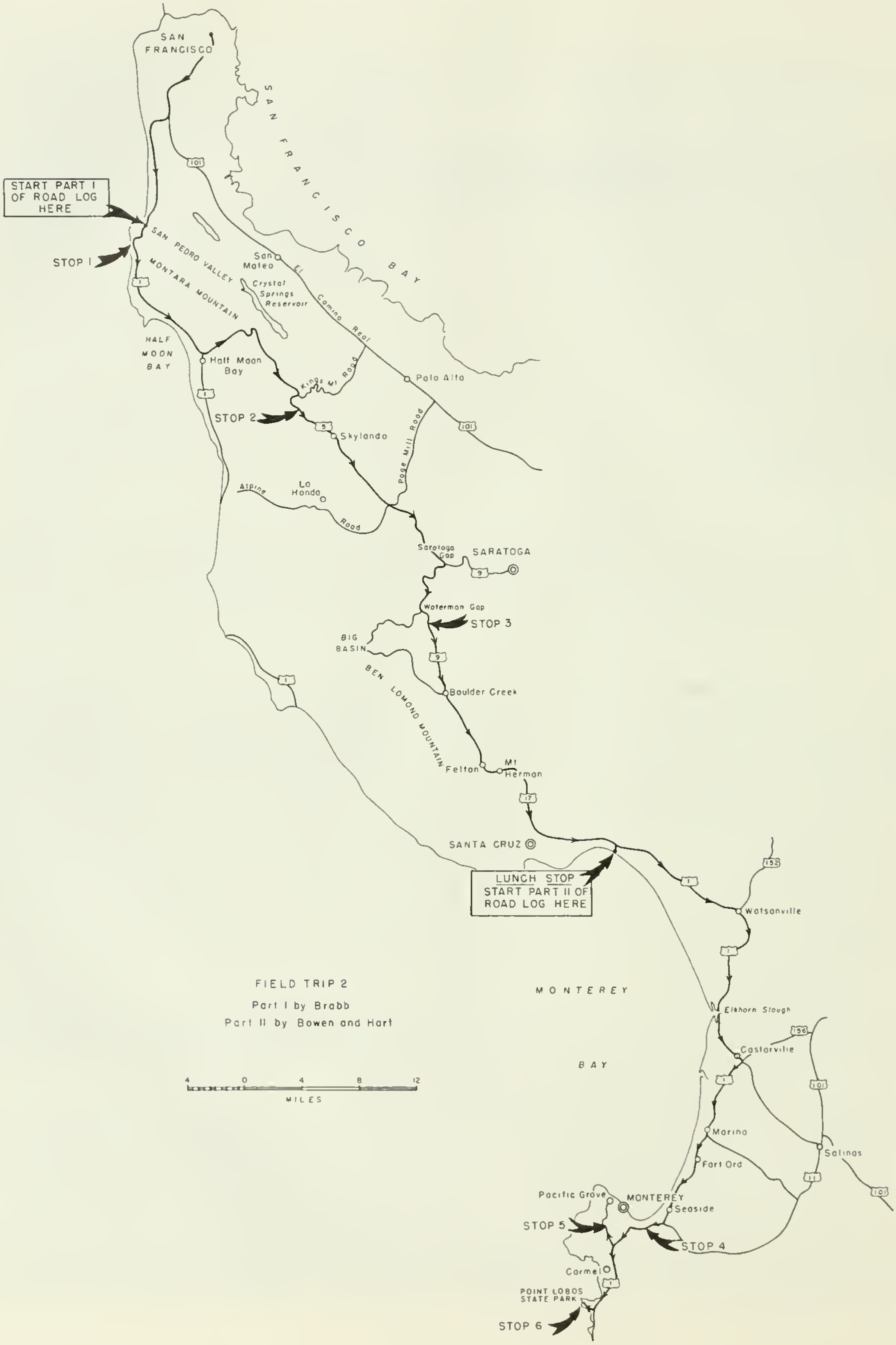


Figure 1. Index map showing route and stops for the Santa Cruz Mountains-Monterey field trip.

Mileage

0 Set mileage at the intersection of State Highway 1 and Linda Mar Boulevard, about 1 mile south of the town of Rockaway Beach. Proceed south along Highway 1.

The Pilarcitos fault trends southeastward along San Pedro Valley to the left (east) and marks the contact between Franciscan basement rocks to the northeast and granitic basement rocks to the southwest. South of San Pedro Valley, Highway 1 winds up the west flank of Montara Mountain. The first outcrops along the road are thin-bedded sandstone and shale of Late Cretaceous(?) age. Unconformably overlying these rocks are conglomerate, sandstone, and shale of Paleocene age. Note the large granitic boulders in the basal conglomerate of Paleocene age along the right (west) side of the highway.

1.8 **STOP 1.** Devil's Slide area. Excellent exposures of sandstone and shale of Paleocene age and infaulted slivers of shale of Late Cretaceous(?) age. Note the sedimentary structures and the tightly folded beds. To the south, the granitic basement is seen between the highway and the Pacific Ocean. To the north, a well-bedded Upper Cretaceous(?) sequence is seen at San Pedro Point.

2.2 Devil's Slide is an active landslide area. On several occasions, slides have destroyed the highway.

6.0 The Cretaceous(?) and Paleocene rocks were eroded from the southwest flank of Montara Mountain before the deposition of the Purisima formation of Pliocene age. The Purisima formation is not well exposed along the highway, but it can be seen at Moss Beach and Seal Cove where it rests unconformably on granitic rocks.

Highway 1 south of Montara is built on a warped marine terrace. The terrace is extensively cultivated for artichokes, Brussells sprouts, and other vegetables. In 1769, the area was a camp site for the Portola expedition.

6.9 The scarp west of the airfield on the right (west) side of the highway is along the Seal Cove fault. The upraised strata west of the fault are Purisima formation.

12.7 Turn left (east) on Half Moon Bay road towards San Mateo. Half Moon Bay is the northern limit of an area of active oil seeps. Exploration in the vicinity of these seeps began in 1867 and resulted in the discovery of several subcommercial wells. Nearly all of these wells produced high-gravity oil from sandstone and fractured shale of the Purisima formation.

The road winds eastward to the crest of the Santa Cruz Mountains which separate San Francisco Bay and the Santa Clara Valley from the Pacific Ocean. The first exposures along the road are sandstone of the Purisima formation.

Unconformably underlying the Purisima formation and exposed on the left (north) side of the road is a predominantly shale unit which at this locality is middle Miocene (Luisian) in age. This unit has a basal sandstone that rests nonconformably on granitic basement rocks. The basal sandstone forms hogbacks opposite (north of) the California Farm Laboratory and is exposed in a quarry on the north side of the road.

15.3 Granitic rocks crop out along the left (north) side of the road for the next mile. To the southeast they are buried beneath a cover of Cenozoic strata, but they reappear again along the core of Ben Lomond Mountain in the central Santa Cruz Mountains, 25 miles to the south.

16.6 Conglomerate, sandstone, shale, and volcanic rocks of late Oligocene (Zemorrian) age crop out along the highway. In a distance of 15 miles, therefore, four formations ranging in age from Cretaceous to Pliocene are in proximity to or rest on the granitic basement.

17.5 The road turns sharply to the left and crosses the Pilarcitos fault. The first exposures beyond the fault are conglomerate and graywacke that have been mapped as the Franciscan formation. Rudistids of Cretaceous age have been collected from these rocks.

Mileage

18.2 Turn right (southeast) on Skyline Boulevard (State Highway 5). San Francisco Bay, Santa Clara Valley, and the Diablo Range can be seen to the east. The lake in the foreground, Crystal Springs Reservoir, lies along the San Andreas fault zone. At least two major faults are thought to be concealed beneath alluvium in the central part of the Santa Clara Valley; the Hayward and related faults trend northwest near the east side of the valley. The abrupt change in the geological sequence across most of these faults led geologists to the belief that the faults formed the boundaries of blocks that moved up and down and horizontally during the Cenozoic and perhaps during the Mesozoic era.

20.2 Sandstone and shale of Paleocene or Eocene age crop out along the road and apparently rest unconformably on the Franciscan formation.

25.5 Kings Mountain Road intersection. A few hundred feet south of this intersection, Skyline Boulevard crosses the Pilarcitos fault. Mudstone of possible early Miocene (Saucesian) age crops out southwest of this fault.

27.3 **STOP 2.** Skeggs Point. View of San Francisco Bay, Santa Clara Valley, and the Diablo Range. Siltstone and shale at Skeggs Point and part of the upper Oligocene and lower Miocene sequence. They grade laterally as well as vertically downward into the Vaqueros sandstone of late Oligocene (Zemorrian) age. This facies relationship is complicated at many localities by intercalated basalt flows and tuffaceous sedimentary rocks.

27.9 Giant redwood tree on left (east) side of the road. The tree is more than 17 feet in diameter and has been estimated to be 1,500 years old.

28.9 Vaqueros sandstone is well exposed along the road. It is a fairly good reservoir rock but has been eroded from most of the anticlines in the Santa Cruz Mountains.

29.3 Butano sandstone of Eocene age crops out along the road.

31.4 Sky Londa. Ten-minute rest stop.

Sky Londa is near the crest of the Sky Londa anticline, one of the northwestward-trending folds that are common in the Santa Cruz Mountains. Sandstone exposed along the core of this anticline was formerly mapped as Vaqueros sandstone, but Eocene (Narizian) foraminifers in the interbedded shales indicate that it is a part of the Butano sandstone. The Butano and Vaqueros sandstones are similar mineraligocally and texturally and can only be distinguished by means of fossils. The Butano sandstone is the principal petroleum reservoir rock in the Santa Cruz Mountains, but only the uppermost 500 feet of this 9,000-foot-thick formation is porous and productive. Butano sandstone and its interbedded shale are poorly exposed along Skyline Boulevard for 2 miles south of Sky Londa.

33.4 The change in vegetation from redwood-covered hills to grassland marks the contact between the Butano sandstone and San Lorenzo formation. The San Lorenzo formation is predominantly shale and mudstone that creeps and slides on steep slopes and impedes the growth of large trees. The unit was the first formation in California to be referred to the Oligocene, but this age assignment is still in doubt. The type San Lorenzo is Narizian (late Eocene), Refugian (early Oligocene), and Zemorrian (late Oligocene) in microfossil stage terminology. The upper part of the San Lorenzo formation grades laterally as well as vertically upward into the Vaqueros sandstone; the lower part grades into the Butano sandstone.

33.6 Diabase sills that intrude the San Lorenzo formation are exposed along the road. Sandstone, siltstone, basalt, and tuffaceous rocks of late Oligocene and early Miocene age crop out along Skyline Boulevard for the next 6.5 miles. The volcanic rocks presumably emanated from submarine vents in the vicinity of Langley and Mindego Hills, a mile or two southwest of Skyline Boulevard.

Photo 1. Steeply dipping Cretaceous strata at Point San Pedro, San Mateo County, consisting of alternating black shale and buff sandstone which display in detail many sedimentary structures formed by turbidity currents. Photo by C. W. Jennings and R. W. Strand.

Mileage

39.1 Alpine and Page Mill Roads intersection. Continue south on Skyline Boulevard.

39.8 Vaqueros sandstone is exposed along the highway for the next 1.4 miles. The valley east of and parallel to the highway is the topographic expression of the San Andreas fault.

41.6 Diabase sill.

42.7 Several unsuccessful exploratory wells have been drilled in this area. The structure is anticlinal, and like many of the folds in the Santa Cruz Mountains, the anticline is small, tightly folded, and faulted. Butano sandstone, the objective in this structure, yields more than 200 barrels of 32° gravity oil daily from wells on similar anticlines near La Honda, 8 miles west of this area.

The San Lorenzo formation, Vaqueros sandstone and Mindego formation of late Oligocene (Zemorrian) and early Miocene (Saucesian) age crop out along the highway for the next 4 miles.

45.9 Saratoga Gap. Turn right (west) on State Highway 9.

46.4 Shale and siltstone of the Mindego formation are well exposed along the left (south) side of the highway.

47.5 Woodhams shale member of the Monterey formation of middle Miocene (Relizian and Luisian) age crops out on the left (south) side of the highway. Shale in the Woodhams shale is more siliceous and better laminated than shale in the underlying Mindego formation. Highway 9 winds back and forth across the contact between these units for the next 2.4 miles.

49.4 The dirt road barred by a metal gate leads to the Oil Creek field. The discovery of this field in 1955 revived interest in the petroleum possibilities of the Santa Cruz Mountains. By January 1, 1961, a production of 45,000 barrels of 43° gravity oil had been obtained from the single producing well. The reservoir rock is the Butano sandstone; the trap is a tightly folded and faulted anticline.

Woodhams shale, Vaqueros sandstone, San Lorenzo formation, and Mindego formation crop out along the highway for the next 3 miles. Several high-angle faults trend across the highway in the same stretch.

51.0 View to the south of flat-topped Ben Lomond Mountain. This anticlinal ridge has granitic basement rocks exposed along the crest.

52.2 Waterman Gap. Keep left on Highway 9 toward Santa Cruz. Waterman Gap was the terminus of a railroad that originated in Santa Cruz. This railroad was used in the late 1800's and early 1900's to haul tanbark and oak, redwood, and other timber from the once extensive forests in this area. The road extending southwest from Waterman Gap leads to Big Basin Redwoods State Park where the primordial beauty of the redwood forest is preserved. Grizzly bears once frequented this area but they were exterminated by 1890.

The first exposures on Highway 9 south of Waterman Gap are Vaqueros sandstone. Further along the highway the underlying San Lorenzo formation crops out. A few hundred feet south of the highway bridge across the San Lorenzo River, Butano sandstone can be seen on the left (east) side of the highway.

54.5 **STOP 3.** San Lorenzo River area. The San Lorenzo formation dips steeply toward the southwest along the river but near the road the beds have been disturbed by slumping and sliding. A glauconitic sandstone exposed near a culvert on the east side of the highway marks the contact between the shale member of late Eocene (Narizian) age of the San Lorenzo formation, and the mudstone member of Oligocene (Refugian and Zemorrian) age. The lower member produced more than 80,000 barrels of high gravity oil at the Moody Gulch field 8 miles east of Stop 3.

The highway south of Stop 3 cuts across the axes of several folds. All of the anticlines have been tested for petroleum. One interesting feature of exploration is that holes that have penetrated the Butano sandstone show an increase in the dip of the beds with increasing depth. The dip is nearly vertical at the bottom of the hole. This feature makes it difficult to locate the crest of an anticline at depth. Other factors that have caused most oil companies to suspend exploration in the Santa Cruz Mountains are: (1) complex stratigraphy and structure and poor surface exposures make it difficult to accurately delimit structures and to estimate the depth of a potential petroleum reservoir; (2) adequate porosity and permeability are only locally developed; and (3) oil pools already discovered are relatively small. On the other hand, the density of drilling is much lower than in other sedimentary basins of comparable size, and a few promising anticlines have not been tested. Moreover, fault traps and stratigraphic traps have been largely ignored in previous exploration, and conditions may be favorable for petroleum accumulation in these traps if the details can be worked out.

Mileage

The San Lorenzo formation, Butano sandstone, and Vaqueros sandstone crop out along the highway for the next 7.8 miles.

60.4 Town of Boulder Creek.

61.3 Sandstone is exposed along the right (west) side of Highway 9. The sandstone is not fossiliferous but is probably of middle Miocene age because it grades upward into shale of middle Miocene (Luisian) age. The sandstone rests nonformably on quartz diorite indicating that 15,000 feet of Eocene, Oligocene, and lower Miocene strata were either removed by erosion prior to the deposition of the sandstone, or that lower and middle Tertiary strata never extended to this locality.

Shale and sandstone of middle Miocene (Luisian) age are exposed along Highway 9 for the next 3.8 miles. Granitic and metamorphic rocks that form the core of Ben Lomond Mountain are exposed a few hundred feet west of the highway, but are not visible from the bus. At a few localities the shale and sandstone rest unconformably on rocks of Paleocene (Ynezian) age. The stratigraphic sequence, therefore, is generally similar to that at Montara Mountain.

65.2 The white hills east of the highway are sandstone of early Pliocene age. The sandstone contains a curious mixture of marine and terrestrial fossils including whales, sea cows, sand dollars, shark teeth, snails, clams, horses, and camels.

67.5 Felton. Turn left (east) towards Los Gatos.

68.1 Shale and sandstone of middle Miocene age crop out along the highway for the next 1.2 miles.

68.4 Mount Hermon, one of the many religious settlements in the Santa Cruz Mountains.

69.1 The contact between middle Miocene strata and overlying white sandstone of early Pliocene age is exposed along the right (south) side of the highway.

71.0 Stop sign and road intersection. Turn right (south) on State Highway 17 toward Santa Cruz.

71.3 The contact between white sandstone of early Pliocene age and underlying granitic rocks can be seen on the right (west) side of the highway. This locality is only 2 miles from the Mount Hermon area where the sandstone is underlain by a thick sequence of siliceous shale of middle Miocene age.

74.9 Take State Highway 1 to Watsonville and Monterey. The town of Santa Cruz can be seen on the right (south) side of the road where the overpass crosses Highway 17. Oil seeps and bituminous sandstone in the vicinity of Santa Cruz stimulated petroleum exploration in the early 1900's but no oil fields were discovered. Husky Oil Company recently experimented with an adaptation of the Lins process which was designed to recover petroleum from this sandstone. Thus far no commercial application has been started.

81.9 Turn right (west) towards Sea Cliff State Park. Lunch stop!

PART II

The second half of the field trip arcs around Monterey Bay, crossing the Salinas Valley and terminating on the northwest margin of the Santa Lucia Range in the vicinity of Pt. Lobos. The oldest rocks exposed along the route are prophyritic granodiorites of Cretaceous age. Resting on this crystalline basement at various points are marine sediments of Paleocene, Miocene, and Pliocene age; continental sediments of Miocene, Pliocene, and Quaternary age; and basaltic volcanic rocks of middle Miocene age. A complex diastrophic history since Miocene time, plus deep erosion, have resulted in removal of much of the prism of marine sediments originally present. The chances of finding oil along the northern margin of the Santa Lucia Range consequently are poorer than in the Santa Cruz Mountains and environs.

Northeast of Carmel Valley and southeast of the Salinas River the marine Tertiary section is no more than 5500 feet thick and the entire sedimentary mantle does not exceed 7100 feet. The deepest part of the deltaic portion of Salinas River basin lies just north of Elkhorn Slough where Bayside Development Company's Vierra No. 1 wildcat well bottomed in probable middle miocene beds at 7916 feet. A generalized correlation chart of sections exposed or penetrated by exploratory wells in the Monterey Bay area may be seen in figure 2 and a structure section, drawn from the Point Lobos vicinity to Seaside, in figure 3.

Mileage

0.0 Sea Cliff Beach road junction. Highway 1 crosses a deeply dissected, alluviated marine terrace. Greenish-gray marine Pliocene deposits containing an abundant pelecypod-gastropod fauna are exposed in the cliffs of Sea Cliff Beach and in some of the adjacent gulches. Overlying these deposits is the Aromas red sand, a torrentially bedded, reddish-orange gravelly sand of middle (?) Pleistocene age (named by J. E. Allen in 1946 for typical exposures near Aromas town). This is the principal formation seen in roadcuts between this point and Watsonville. Locally the Aromas beds are overlain by less colorful later Pleistocene river-terrace deposits.

10.2 Junction of Highways 1 and 132 (Hecker Pass road) in Watsonville. Town first laid out in 1852 by Judge John H. Watson on part of the former Spanish land grant Rancho Bolsa del Pájaro. The vicinity is noted for its apple orchards and truck gardens.

10.8 Pájaro River bridge. The Pájaro (Bird) River drains the Hollister, San Benito, and Santa Clara Valleys.

12.3 Junction of Highway 1 and Elkhorn Road. Badlands to be seen on both sides of the highway are eroded in the Aromas red sand. Here the formation is partly fluviatile, partly lagoonal and partly eolian. It reaches a thickness of nearly 200 feet.

13.9 Extensive road cuts in Aromas red sand.

16.4 East of the highway are the colorful crystallizing ponds of the Monterey Bay Salt Works. The plant utilizes sea water from Elkhorn Slough, to produce crude salt for industrial use. Red algae are responsible for the unusual water color.

16.6 Elkhorn Slough bridge. Prior to 1906 the Salinas River debouched into this lagoon. Lurch effects from the 1906 quake resulted in shifting of the outlet south to its present location. A number of unsuccessful wells were drilled in this vicinity. One, the Bayside Development Company Vierra No. 1, abandoned in 1946, reached a depth of 7916 feet and bottomed in Miocene rocks. The Texas Company Pieri No. 1 well, drilled only 2 miles due south of the Vierra well, bottomed in granitic rock, the granite being penetrated at 3,255 feet. Either the basement is downfaulted in the vicinity of Elkhorn Slough or else the submarine canyon present opposite Elkhorn Slough extends landward beneath the Tertiary and Quaternary fill of Salinas Valley.

16.9 The prominent installation east of the highway is the gas-fueled, steam-driven electric power plant of Pacific Gas and Electric Company. The gas comes from Texas and New Mexico. West of the highway are the Moss Landing seaport facilities where a number of deepdraft vessels can be accommodated. The port was established in 1862 as a whaling, fishing, and cargo-shipping center.

Mileage

17.2 The extensive industrial plant east of the highway is the Moss Landing plant of Kaiser Aluminum and Chemical Corporation. The plant utilizes sea water, calcined dolomite, and Philippine chrome ore to produce magnesia and Chrome-magnesia refractory products. Initially erected in 1942 to produce magnesium oxide for use in the company's Permanente, California, metallic magnesium factory, the plant was enlarged in 1948 to give the United States its first fully integrated basic refractory industry.

20.2 Castroville. Founded in 1864 by Juan Castro on part of the Mexican grant Bolsa Nuevo y Moro Cojo. The center of a vast truck-gardening area specializing in artichokes.

20.7 Junction of Highways 1 and 156. Turn right toward Monterey on Highway 1.

23.3 Salinas River Bridge.

25.2 To the east is the beginning of an extensive rolling terrain of stabilized, grass-covered, late Pleistocene sand dunes. Note the depressions among the vegetated hummocks. Vernal pools are common in season.

26.2 Entrance to Monterey Sand Company's Marina pit and processing plant. Many millions of dollars worth of Modern beach and Recent dune sands have been produced during the past 40 years along the perimeter of Monterey Bay. One plant utilizes older, possibly Pleistocene strand-line deposits. At present six sand plants are operated—three at Marina and three at Seaside. In order to get desirable sand-size grading, most of the plants dredge very coarse sand from the beach and surf zones during times of the year when surf action is greatest. For some uses this material is blended with the finer dune sand. The sand is used in concrete, asphalt paving, stucco, filter beds, sandblasting, foundry work, and numerous specialty products.

28.5 Marina.

33.3 Prattco railroad siding. West of road are sand stockpiles of Pacific Cement and Aggregates, Inc., and Granite Construction Company.

33.5 Y-junction of Highways 1 and the Monterey cutoff. Keep to the left.

33.6 Large sand stockpiles of Monterey Sand Company west of the road.

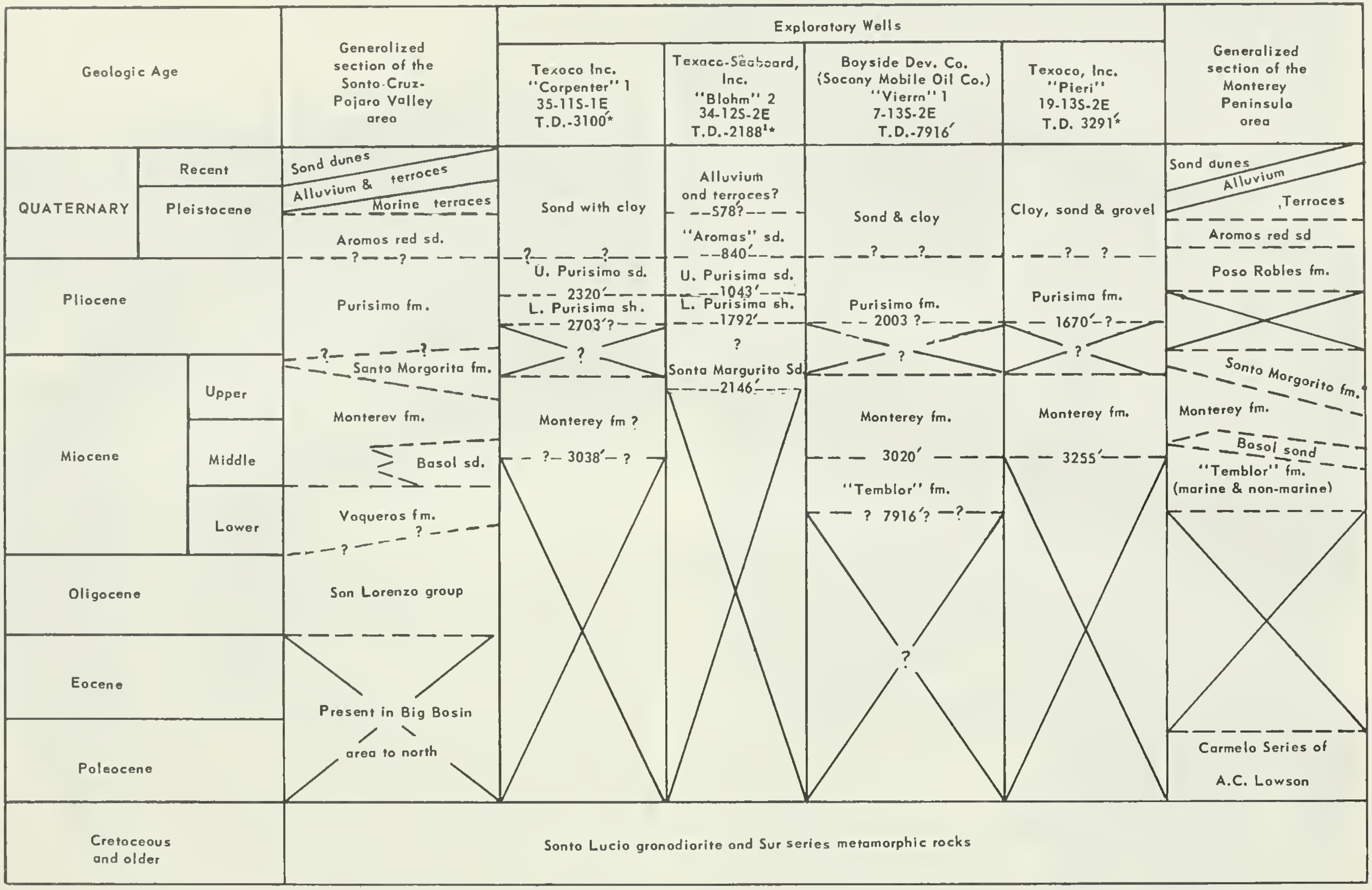
34.3 Del Rey Theatre in Seaside.

35.1 Junction of Highways 1 and 117, the Canyon del Rey road.

36.1 Junction of Highway 1 and the Monterey Airport-Canyon del Rey road (first stop signal). Turn left onto Monterey Airport road.

Photo 2. The bell tower of Carmel Mission (San Carlos Borroméo) at Carmel. Photo by Mary Hill.

Photo 3. Adobe wall at San Carlos Borroméo. Bell tower (photo opposite) is of native "Carmel stone." Photo by Mary Hill.



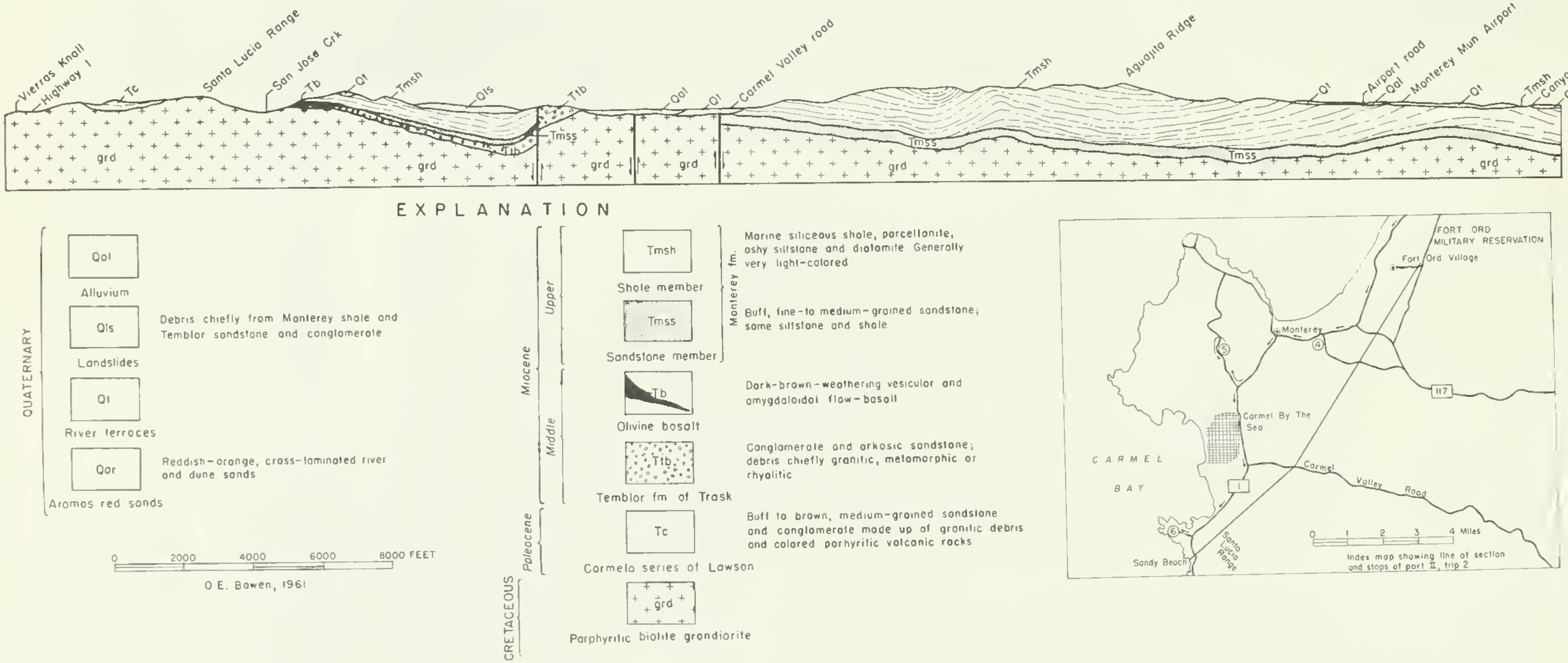
*Bottomed in basement complex.

Depth in feet shown to bottom of formations where known.

☒ Formations missing.

Figure 2 (above). Generalized correlation chart and sections penetrated by wells.

Figure 3 (below). Structure section SW-NE across Monterey and Seaside quadrangles, from Vierros Knoll, Pt. Lobos State Park, to Seaside, through the east end of Monterey Municipal Airport.



Mileage

36.4 **STOP 1.** Junction of Monterey Airport-Canyon del Rey road and entrance to Santa Catalina School. Roadcuts both sides of the highway expose typical upper Miocene Monterey "shale" containing a Mohnian (probably lower Mohnian) fauna consisting of:

1. *Pulvinulinella gyroidinaformis* (Cushman and Goudkoff)
2. *Nonion costiferum* (Cushman)
3. *Buliminella curta* (Cushman)
4. *Nonion* cf *montereyanum*
5. *Bulimina* cf *ovata*
6. *Bolivina* sp

The "shale" is an opaline rock commonly rich in diatoms and foraminifera as well as volcanic ash and silt. The rock has been described variously as siliceous shale, porcellanite, opalite, opaline chert, opaline shale, and cherty shale—take your pick! Much of the opal has been dissolved and reprecipitated during lithifaction. Sandstone, siltstone, claystone, ash and pumicite are interbedded with the porcellanite in some places, particularly to the east in Calera Canyon of Spreckels quadrangle. Brown, non-swelling bentonite beds a few inches thick, such as those seen in the westside roadcuts of this locality, are typical of the porcellanite part of the Monterey formation. Three more or less mapable members are present in the formation in the Monterey vicinity—a basal sandstone a few tens to as much as 200 feet thick; a middle porcellanite, possibly as much as 2500 feet thick; and an upper diatomite 200 to 800 feet thick. The basal sand member in the type area 1 to 3 miles (west) of this locality lies largely in the Luisian faunal stage of Kleinpell; to the southeast the basal beds are no lower than Mohnian and some are possibly Delmontian. The older, deeper parts of the basin clearly lie toward the Pacific side of the basin and the basal beds are progressively younger toward the east. The middle porcellanite member lies largely in the Mohnian and the upper diatomite member lies mainly in the Delmontian stage. Here we are well down in the porcellanite member, possibly 2,000 feet above granitic bedrock. The H. L. Norris and Associates Saucito well, located 1 mile south of this locality, bottomed in granite at a depth of 1917 feet. This well was drilled and abandoned in 1949.

Make a U-turn; go back to Highway 1 and turn left.

36.9 Back at junction point of Highway 1 and Monterey Airport-Canyon del Rey road, westbound on Highway 1.

37.4 Stop signal, Sloat Ave. junction; continue west.

37.7 Stop signal, Aguajito Road; continue west.

38.3 Intersection Abrego and Fremont Streets in Monterey; turn left, following Highway 1.

39.2 Highway 1 crosses dissected Pleistocene terrace.

40.0 Junction of Highway 1 and the 17-Mile Drive and Pacific Grove roads. Turn right on Pacific Grove road (farthest to right). Roadcuts in Luisian Monterey shale and sandstone.

40.4 California Division of Forestry Station.

41.7 **STOP 2.** Huckleberry Hill underpass.

Basal sands of the Monterey formation may be seen lying on porphyritic granodiorite. A Luisian fauna containing 15 species of Foraminifera has been collected in shaly beds at this locality by Galliher, Kleinpell, and others. The list:

Mileage

1. *Baggina californica* Cushman
2. *Bolivina advena* var. *ornata* Cushman
3. *Bolivina advena* var. *striatella* Cushman
4. *Bolivina imbricata* Cushman
5. *Hemicristellaria beali* (Cushman)
6. *Nonion costiferum* (Cushman)
7. *Robulus smileyi* Kleinpell
8. *Siphogenerina Collomi* Cushman
9. *Siphogenerina nuciformis* Kleinpell
10. *Siphogenerina reedi* Cushman
11. *Uvigerinella nudocostata* Cushman
12. *Valvulineria californica* Cushman
13. *Valvulineria californica* var. *appressa* Cushman
14. *Valvulineria californica* var. *obesa* Cushman
15. *Valvulineria miocenica* Cushman

42.1 Del Monte Properties Company decomposed granite quarry (operated by Monterey County). Make U-turn. Note the basal yellowish sands of the Monterey formation lying on granodiorite in the east face of the quarry. Return to Highway 1.

43.8 Back on Highway 1. Proceed south toward Carmel Valley. Road cuts are in Monterey "shale".

44.1 Stop signal. North entrance to Carmel Village. Continue south on Highway 1.

45.0 Stop signal. Main entrance to Carmel Village opposite Carmel High School.

45.4 River terrace gravels may be seen lying unconformably on Monterey porcellanite on east side of highway.

45.9 Junction of Highway 1 and the Carmel Valley road. Porphyritic granodiorite forms the cliff to the right of the junction; overlain by terrace gravels. Note the remains of several terrace levels on the north side of the valley; also the gently north-dipping Monterey porcellanite beds across Carmel Valley to the south.

46.2 Junction point of road to Mission San Carlos Borromeo (El Carmelo) founded by Junipero Serra in 1770.

48.6 East-trending fault contact between basement granodiorite and conglomeratic beds of the Monterey formation.

49.9 **STOP 3** (optional). Entrance to Point Lobos State Park. A fee of $1.00 per car is collected per private automobile. On the beach three-quarters of a mile from the park entrance the Paleocene Carmelo series of Lawson is well exposed. Conglomerates containing strongly colored volcanic porphyries, from an unknown source, are characteristic of the Carmelo series. Sandstone and silty shale are also abundant in the series. The beds have yielded one *Turritella pachecoensis* and fragments of one genus of arenaceous forams—*Bathysiphon* sp. Similar beds at Pebble Beach, across Carmelo Bay, have yielded one species of *Anomalina* and a single specimen of *Lucina* cf. *comiltha*. The specimens of *Anomalina* are similar to those of lower Eocene or Paleocene age found in well cores in the Rio Vista area (C. C. Church, personal communication, 1959). There can be little doubt that the age of the Carmelo series is Paleocene rather than Cretaceous or Eocene. Lawson originally described the beds as Eocene (?).

FIELD TRIP 3: POINT REYES PENINSULA AND SAN ANDREAS FAULT ZONE

MARCH 28, 1962

By ALAN J. GALLOWAY
California Academy of Sciences

San Francisco—Golden Gate Bridge—Stinson Beach—Olema—Bear Valley Ranch—Inverness—Drakes Beach County Park—Point Reyes Lighthouse—Samuel Taylor State Park—Greenbrae—San Francisco

Plate 26, *Geologic map of Point Reyes Peninsula and San Andreas fault zone* (with structure sections) accompanies this paper.

Sketch of Geology. The trip will start from the Fairmont Hotel and proceed north across the Golden Gate Bridge. The country immediately north of San Francisco consists of Franciscan rocks of Jurassic to Cretaceous age, including sandstone, shale, radiolarian chert, pillow lava and pyroclastic rocks and serpentine intrusives, a typical eugeosynclinal assemblage. We will see these rocks immediately after we cross the Golden Gate Bridge, and will travel on them all the way to our encounter with the San Andreas fault near Bolinas. We will see them again on our way home on the Sir Francis Drake Highway between Olema and San Francisco. The structure of these rocks is complex and in places they have been altered hydrothermally.

From the Bolinas road junction to Inverness we will follow the course of the San Andreas fault along the Olema Valley. Most of the way the road lies 1,000 to 2,000 feet east of the rupture produced at the time of the 1906 earthquake, but all the way the road is within the overall zone of faulting. Along the fault zone will be seen striking examples of fault topography, and reminders of the large lateral displacement which took place at the time of the San Francisco earthquake of April 18, 1906.

To the west of the fault the rocks consist of relatively undisturbed Tertiary beds lying on the quartz diorite basement. They form a sharp contrast with the Franciscan rocks to the east.

On reaching Inverness the route turns west and then south across the quartz diorite and Tertiary rocks of the peninsula. Box lunches will be served at Drakes Beach County Park. Thence the route goes to Point Reyes lighthouse, where an interesting Paleocene conglomerate is exposed.

On the return trip the same route will be travelled back as far as Olema, at which point we will strike eastward through the Franciscan terrain back to San Francisco.

There will be no extensive walking side-trips and ordinary sports or business clothing will be adequate.

The general course of the route can be followed on the enclosed geological map.

History. Historically the Point Reyes Peninsula is of considerable interest, since most historians believe it was here that Sir Francis Drake, the Elizabethan freebooter, spent 6 weeks in the summer of 1579 in the course of his circumnavigation of the globe, and claimed the land for Queen Elizabeth I of England. (The Pilgrims did not land in Massachusetts until 1620, and the first successful settlement in Virginia was in 1607.) But Drake did not stay to settle the land (he didn't like the cold foggy summer weather!); the Spanish did not settle the area until the last part of the 18th century and early part of the 19th century.

Following California's joining the Union in 1846 and the rise of San Francisco, the Point Reyes area was divided into large dairy and cattle ranches, and it has stayed almost in that condition until now, although it is close to the expanding three million population of the Bay Region. This lack of real estate development is due to its inaccessibility over hilly, winding roads, and its generally foggy and cool summer climate. The real estate subdivider is gradually moving in, however; and in an effort to preserve the area in its relatively untouched condition a proposal has been made to make it into a National Seashore, part of the National Park system.

Oil. Bolinas, at the south end of the Point Reyes Peninsula (see pl. 26), had an oil boom as long ago as 1865, and it was enthusiastic enough to result in the building of a Petroleum Hotel, although no commercial oil has ever been found.

Photo 1. The Golden Gate Bridge. View northeast toward Marin County. Photo by Sarah A. Davis.

Early stories tell of a live gas seep at Duxbury Point, a mile west of Bolinas, and there are oil-filled joints and asphaltic clastic dikes in the Miocene shale in this vicinity. Farther north up the coast are massive tar sands and oil sands, in middle Miocene beds.

One of the wells drilled in 1865 was located near the oil indications at Duxbury Point; but no oil was found. Another was drilled near the wharf in Bolinas. The next serious attempt to find oil was during the years 1901-06; three wells were drilled near Duxbury Point. Production of a barrel a day was reported from one of these wells, but whether this report was reliable is not known. It seems authentic that two of the three wells had oil showings.

A third cycle of wildcat drilling started in 1947, in the course of which one well was drilled in the vicinity of Double Point, 6 miles northwest of Bolinas, one on the south extension of Inverness Ridge, one near Point Reyes and one near Duxbury Point. The last of these wells was completed in 1952. No commercial production was obtained, although some showings of gas and oil were reported. At the time of writing (October 1961) there was no drilling activity in the area.

Acknowledgments. The writer wishes to acknowledge the assistance of many helpers in the preparation of this manuscript and road log. Much of the material on the Franciscan has been drawn from the California Division of Mines Bulletin 154, and from U. S. Geological Survey Map 272; thanks are due to these two organizations for permission to incorporate their work. In addition the writer is indebted to Park Snavely and J. E. Schoellhamer of the U. S. Geological Survey, to Oliver E. Bowen of the California Division of Mines and Geology, to W. F. Barbat and J. H. Kinser of the Standard Oil Company of California, and to Gerry Burton and Ward Abbott of Shell Oil Company.

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ROAD LOG

Mileage

00.0 Fairmont Hotel, San Francisco. Here on the summit of Nob Hill the great town houses of the early California millionaires were built. The only one to survive the earthquake and fire was the Flood Mansion immediately west of us: it is now the Pacific Union Club.

Proceed westward on California Street. The cable cars, a feature of old-time San Francisco, are well suited to the steep hills; San Franciscans have refused to allow them to be abolished in favor of more modern transportation.

00.1 On our right, Grace Cathedral (Episcopal) still being built after 50 years of gradual construction. On our left, the marble Masonic Temple, built in 1956-58.

00.6 Intersection of California Street and Van Ness Avenue. Turn right (north) on Van Ness Avenue. This avenue formed the western edge of the great fire which destroyed central San Francisco after the earthquake of April 18, 1906. Practically the entire city between Van Ness Avenue and San Francisco Bay to the east was burned to the ground. Van Ness Avenue is now the automobile row of San Francisco. It also harbors some modern luxury motels.

01.4 Intersection of Van Ness Avenue and Lombard Street; turn left (west) on Lombard Street, a street lined with motels and restaurants.

02.8 The pink plaster structure on the right is the old Palace of Fine Arts, built for the Panama-Pacific Exposition of 1915.

03.3 Approach to Golden Gate Bridge. On right Crissy Field (Army): on left Presidio Military Reservation, first occupied by Spain in 1776.

Mileage

04.6 Golden Gate Bridge toll gate. Across the bridge to the north can be seen Fort Baker Military Reservation, and to the west the Golden Gate and Point Bonita. To the east is Alcatraz Island. The south pier of the bridge rests on Franciscan serpentine of relatively low strength: the north pier on stronger basalt, chert, and sandstone of the same series. The length of the main span is 4200 feet, the longest in the world (the closest competitor, Mackinac bridge main span, is 3800 feet). The Golden Gate itself is a drowned river valley eroded by the ancestral Sacramento-San Joaquin River. Depth of the present channel at the bridge is more than 300 feet.

06.6 Turn off at Vista Point; view of San Francisco to south.

06.7 **STOP 1.** Vista Point. Looking north we see Franciscan beds dipping southwest. To the tight (east) of the highway tunnel the rocks are mainly volcanic: the prominent hills to the left (west) of the tunnel are mainly radiolarian chert and graywacke sandstone. These beds form the west limb of an anticline whose axis is in Richardson's Bay to the east. Our route will remain in Franciscan rocks until we meet the San Andreas fault at Bolinas, 21 miles from here.

07.1 Franciscan sandstone in road cut.

07.6 Radiolarian chert at entrance to tunnel.

08.1 Well-developed blackish-green pillow basalt full of calcite veinlets. Pillow basalt is common in the Franciscan and is often associated with chert, which can be seen just ahead on both sides of the road.

San Andreas fault

Photo 2 (opposite). Aerial view of the Marin Peninsula northwest toward the San Andreas fault and Point Reyes. The dissected hills in the foreground, which culminate in Mt. Tamalpais in the right middle ground, are composed of graywacke, shale, radiolarian chert, greenstone, and serpentine of the Jurassic and Cretaceous Franciscan formation. The pronounced trench of the San Andreas fault separates the Franciscan formation from Mesozoic granitic rocks and Tertiary sedimentary rocks on the Point Reyes Peninsula. The field trip follows Highway 101 (left foreground of picture) passes through Waldo Tunnel and above Sausalito (settlement in central foreground). The terraced road cuts are on Highway 101. At the base of Mount Tamalpais (right upper ground), on the Bay shoreline above Richardson Bay overpass, nestles Mill Valley. "Tam Valley Junction," between Sausalito and Mill Valley, marks the turnoff for Highway 1, the route up Tamalpais Valley and over the ridge to the Coast. Photo by Aero Photographers, Sausalito.

Mileage

10.6 Fork right onto State Highway 1, the Coast Highway. To the north can be seen Mt. Tamalpais, elevation 2604 feet. Our trip today will take us westward across the southern slope of Mt. Tamalpais in the morning, and eastward on the northern side in the afternoon, so that we will see the mountain from all angles.

11.6 Turn left on Highway 1.

14.3 Junction with Panoramic Highway which leads to Muir Woods and Mt. Tamalpais.

16.1 Green Gulch ranch on left (south).

16.5 On right (east) prominent outcrop of grayish-green chert; Muir Beach on left.

17.0 Intersection with road to Muir Woods via Frank Valley. Turn left up ridge.

18.4 **STOP 2.** Tamalpais and Frank Valley on right (northeast). Green chert outcrop in Franciscan to right.

To the left (west) on a clear day may be seen the Farallon Islands, composed of quartz diorite similar to that of Point Reyes.

19.2 To the left, the Slide Ranch—situated on a large landslide. There are many such slides along this strip of coast.

20.1 To the left, good views of Slide Ranch landslide.

21.6 To the right, outcrop of serpentine in Franciscan beds.

22.1 To the left, Steep Ravine resort and landslide.

22.5 Old quarry in red manganiferous chert to right.

23.0 **STOP 3.** View of Stinson Beach sandspit, Bolinas Lagoon, and on a good clear day, Point Reyes. Sedimentation by streams will eventually fill Bolinas Lagoon to form first a marsh, and finally a coastal plain. Topographically the lagoon is an expression of the San Andreas fault, which here emerges from the sea on its way north. Leaving Bolinas Lagoon the fault occupies a long straight valley, the Olema Valley, for 12 miles, and then the narrow Tomales Bay which is 15 miles long, before submerging below the Pacific Ocean again. Up to now our whole trip has been in Franciscan (Jurassic-Cretaceous) terrain. But from this point we can look westward across the fault and see the yellow cliffs of Bolinas which are soft siltstone and fine sandstone of the marine Pliocene (Merced). Farther west, we can see Duxbury Reef which is made up of southwest dipping hard Miocene siliceous shale. At Duxbury Reef there are oil-filled joints in the cliffs and a reported gas-seep.

Mileage

23.2 Junction with Panoramic Highway from Mt. Tamalpais. Village of Stinson Beach.

27.9 Coarse talus breccia—probably Quaternary, tilted east.

28.1 Intersection with road to Bolinas.

28.7 Intersection with Horseshoe Hill Road. Trace of 1906 earthquake crack immediately to left. Beds are the Merced formation of Pliocene age—here is a small sliver of Pliocene east of the 1906 fault trace: elsewhere on the east side of 1906 trace the rocks are nearly all Franciscan.

29.1 On the right is Coppermine Canyon where a copper mine was opened in 1863 in Franciscan rocks. It was never commercial, but a little ore was shipped from it during the first World War. On the left is a grove of eucalyptus trees; in this grove can be found a line of trees which was offset 13½ feet by right lateral movement of the 1906 earthquake.

29.7 Texeira Ranch—the fault traverses the meadow to our left (west).

31.7 On the left the old Biesler Ranch: Mr. Biesler was milking a cow when the earthquake hit, and the crack developed within 6 feet of where he was. Would that he had been a geologist and could have told us just how the movement on the fault proceeded.

At this point the topography is so affected by the San Andreas fault that there are two streams, about 1000 feet apart and parallel to one another, the eastern one flowing north and emptying into Tomales Bay and the western one flowing south and emptying into Bolinas Lagoon. Each of these streams is actively eroding along an old fault trace. The whole faulted zone is about half a mile wide.

33.2 On the left at the bottom of the creek are some old lime kilns, built to burn limestone from an outcrop of Calera (Franciscan) limestone in the side of the canyon. For many years it was thought that these lime kilns were built by the Russians, who were established 50 miles north of here in 1812. But it is now known that they were built by American settlers in 1850.

34.0 The lumber mill to the left (west) stands directly on the 1906 earthquake fault trace.

35.6 On the right (east) of the road is a prominent sag pond, typical of many along the fault zone. This one is not on the 1906 fault trace, but on a well-marked older trace lying 1400 feet east of it, near the east edge of the faulted zone.

37.7 Village of Olema—junction with Sir Francis Drake Highway from San Rafael.

37.8 Turn left on Bear Valley Ranch road.

38.3 **STOP 4.** Bear Valley Ranch. Here the road is right on top of the 1906 fault trace. Survey markers were established here in 1907 to assist in measuring the next movement on the trace; two are visible from the road. Here the path leading up to the old house (no longer standing) was offset 15 feet laterally. At the next ranch south, the Shafter place, a cow fell headfirst into a fault crevice. "The closure which immediately followed left only the tail visible" (G. K. Gilbert).

39.5 Turn left. The crack caused by the 1906 earthquake is on the hillside immediately to the east of us.

Photo 3. Aerial oblique view of western Marin County and Point Reyes, showing San Andreas fault. Observer facing northwest. Photo by courtesy of Clyde Sunderland Aerial Photographs, Oakland.

Mileage

40.1 Junction with Highway 1. On the road to the right (east), occurred the greatest lateral displacement of the 1906 movement, amounting to 20 feet. The road has been straightened, but the eye of the faithful can still, with a little imagination, see the bend caused by the earthquake.

On the west the rocks are mostly quartz diorite, but up the canyon to the left lies one of several roof-pendants of crystalline limestone enclosed in the quartz diorite. The limestone contains scheelite (calcium tungstate).

40.3 White House Pool. Fifty to a hundred years ago this was a loading point for schooners which took the lumber and dairy products of the area to San Francisco. They also took lime, obtained from another roof-pendant of crystalline limestone well exposed up the road to our left.

41.5 Adams real estate office. Behind this building is an exposure of mica schist included in the quartz diorite.

42.6 Willow Point. Up the canyon to the left (west) is another pendant of metamorphosed crystalline limestone containing scheelite.

43.4 Village of Inverness.

44.7 Road turns west over Inverness Ridge. Exposure of schist in quartz diorite on left.

Mileage

45.4 In the roadcut, to the right—basal Miocene sand resting on quartz diorite.

46.0 Take left fork to Point Reyes: right fork goes to Tomales Point.

46.4 In roadcut to right—basal Miocene sands (inlier).

46.8 Quarry on right in quartz diorite.

47.4 Quarry on right in typical rhythmically bedded white-weathering Monterey shale.

49.1 Left (south): head of Drake's Estero, a drowned valley occupying the Point Reyes syncline. Its outlet is at Drakes Bay to the south.

49.9 R.C.A. trans-Pacific receiving station and A.T. & T. receiving station.

53.9 Fork left to Drakes Beach County Park.

55.6 **STOP 5.** Drakes Beach County Park. Box lunches will be served. The white cliffs, which Drake likened to the chalk cliffs of England, are composed of fine sandstone, siltstone and a subordinate amount of siliceous shale of upper Miocene age. These beds fill the gentle syncline of Point Reyes Peninsula, lying unconformably on the Paleocene and quartz diorite of Point Reyes to the west, and on the

Photo 4 (above). The San Andreas fault just north of Bear Valley Ranch headquarters, Highway 1, Marin County. Erosion since 1906 has exposed this portion of the fault, along which large surface displacement took place in 1906. Photo by Mary Hill.

Photo 5 (below). Marin County Franciscan chert. Photo by Mary Hill.

Mileage

middle Miocene chert to the east. At the base of these upper Miocene beds are glauconite-bearing "greensands" often rich in bones of whales and other marine fossils. The unconformity between the upper Miocene and the underlying middle Miocene is exposed at low tide on the beach to the east of us. The middle Miocene cherty beds are steeply folded, indicating a period of folding and possible emergence before the upper Miocene beds were laid down unconformably on top of them. Drake is supposed to have careened his ship, the *Golden Hinde*, close to this spot. The exact place will not be known until archeologists turn up the site of the fort which he built here.

57.3 Return to Sir Francis Drake Highway, turn left (south) toward Point Reyes.

57.6 Glimpse of Point Reyes Beach and sand dunes to right west.

58.4 Sand dune across highway.

61.6 Nunes Ranch.

62.2 Radio relay station is located on quartz diorite.

63.1 **STOP 6.** Parking lot, Point Reyes Lighthouse. Here we will walk down to the top of the lighthouse steps. On the way are fine exposures of the coarse Paleocene conglomerate which here overlies the quartz diorite. This conglomerate dips at a high angle to the northwest, and is found in three separate faulted blocks on the point. Interesting sedimentary structures, including channeling, are to be seen. The glauconite-bearing basal sand of the upper Miocene lies unconformably on both quartz diorite and conglomerate at the east end of the point; the contact is obscured by blown sand at this end of the point.

To the north lies the 12-mile-long Point Reyes Beach, a spectacular sight on a clear day.

88.5 Retrace our road to Olema—junction of Coast Highway 1 and Sir Francis Drake Highway. Turn left (east) on Sir Francis Drake Highway. The remainder of the trip will be in Franciscan rocks. In the roadcut ahead Franciscan sandstone is well exposed.

93.4 Samuel Taylor State Park, a fine grove of second-growth redwoods. The stumps of the original trees, cut in the 1850's, are still there and measure up to 16 feet in diameter.

95.7 **STOP 7.** Confluence of Lagunitas and San Geronimo Creeks. Pillow lava exposed in roadcut to south contains numerous glassy feldspar crystals. Pillow structure is well demonstrated; it is believed to indicate rapid cooling of the molten rock in a very wet medium.

98.0 Lagunitas District School: on the north side of the road can be seen yellowish-brown silica-carbonate rock, an alteration product of serpentine, along with green serpentine and Franciscan sandstone and chert.

101.4 Whites' Hill. A fine section of interbedded Franciscan sandstone and shale is exposed in roadcuts at the summit.

109.4 Greenbrae. Turn right (south) on Highway 101. These marshlands, typical of drowned valleys, now are nearly filled by Recent sediments (and subdivisions). The San Francisco-Marin fault block on which we have been traveling since we left the San Andreas fault is tilted eastward, producing these drowned valleys extending into San Francisco Bay.

In the hills north of Greenbrae was found in 1956 the "plate of brasse" which Sir Francis Drake affixed to a point at Drakes Bay in 1579, claiming the land of "New Albion" for Queen Elizabeth. The plate has passed all tests for genuineness—presumably it was brought from Drake's Bay to Greenbrae by the Indians.

118.1 Golden Gate Bridge. On the right can be seen Mile Rock Lighthouse. And so back to the Fairmont Hotel, located on a knob of Franciscan shale, surrounded by sand dunes blown in from the Pacific.

Photo 6. Olema lime kiln, built around 1850 for burning limestone from an outcrop of Calera (Franciscan) limestone. Photo by Mary Hill.

FIELD TRIP 4: SAN FRANCISCO PENINSULA

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Geology of San Francisco Peninsula with emphasis on rocks of the Franciscan formation, on the route via Telegraph Hill—Point Lobos and Cliff House—Half Moon Bay—Pilarcitos Creek—San Andreas fault—Twin Peaks

This field trip affords glimpses of the rocks on which a large city and its suburbs are built. San Francisco is also the type area of the Franciscan formation, the most extensive and controversial formation in California. Though small oil seeps have been found in the Franciscan formation of the northern Coast Ranges and hydrocarbons are associated with mercury deposits in serpentine, the Franciscan formation is generally considered to be unfavorable for oil prospecting. Some reasons for this belief are: (1) Porosity and permeability of the sandstone beds are exceedingly low; and (2) possible traps have been modified by pervasive fracturing and shearing which, combined with mild metamorphism, served to release the fluid hydrocarbons to the atmosphere. No indications of oil or gas have been found in the Franciscan formation of the San Francisco Peninsula. High-gravity oil has been produced from Pliocene deposits in the Half Moon Bay area, but the total production since 1867 has only been about 50,000 barrels.

The Franciscan formation is found throughout the Coast Ranges of California and ranges in age from Late Jurassic to Late Cretaceous. It consists mostly of sandstone (graywacke type), shale, and volcanic rocks and minor amounts of ferruginous chert, conglomerate, limestone, and metamorphic rocks. Accumulation of the sediments was probably in a deep-sea eugeosynclinal environment. The metamorphic rocks resulted from deep burial, local high shear stress, and mineralogic changes. Some of the metamorphic rocks have been moved by faulting and diapir intrusion and are now found as isolated bodies surrounded by unmetamorphosed rock or rock of lower or higher metamorphic grade. Others formed in the spatial relationship now seen. All were intruded by serpentine either during or following Franciscan time.

For many years the Franciscan formation was considered to be limited in age to the latest Jurassic (Taliaferro, 1943, p. 195). Recent discoveries of Early and Late Cretaceous fossils in the Franciscan formation in its type area and elsewhere have forced geologists to assign a younger age to parts of it (Irwin, 1957, p. 2289). Lack of marker beds, scarcity of fossils, and pervasive structural complexities prevent geologists from devising a standard stratigraphic section or accurately determining the thickness of the formation. Petrologic methods of characterizing the Franciscan formation and other upper Mesozoic sedimentary rocks have been tried with moderate success in solving local as well as regional stratigraphic and structural problems. For example, by using a simple stain technique in studying a thick, conformable sequence of fossiliferous, shelf and slope facies sandstones of Late Jurassic to Late Cretaceous age along the west side of the Sacramento Valley, Bailey and Irwin (1959, p. 2806) found that the amount of detrital potassium feldspar increases progressively with decreasing age. This stain technique, when applied to sandstones of the Franciscan formation, showed that most contain no potassium feldspar, though locally, significant amounts are present, especially in the western part of the Coast Ranges. Bailey and Irwin (1961, personal communication) suggests that sandstones of the Franciscan formation that contain appreciable amounts of potassium feldspar, say 5 percent or more, are probably Cretaceous in age, but that sandstones of the Franciscan formation that contain little or no potassium feldspar may be either Cretaceous or Jurassic in age.

Another petrologic method, specific gravity determination, was tried on approximately 1,000 sandstone specimens from the Sacramento Valley sequence mentioned above (Irwin, in press). The study showed an increase in median specific gravity with increasing age of deposition: 2.55 for sandstones of Late Cretaceous age; 2.57 for sandstones of Early Cretaceous age; 2.59 for sandstones of Late Jurassic age. Eugeosynclinal-type sandstones from the Franciscan formation have a median value of 2.65.

In the type area of the Franciscan formation, eugeosynclinal-type sandstones contain little or no detrital potassium feldspar. The sandstones of San Bruno Mountain, south of San Francisco, however, which were included by Lawson in his Franciscan group (1914), were found to consistently contain potassium feldspar, in large amounts in some places. This mineralogical difference, as well as other features thought to be atypical of sandstone of the eugeosynclinal environment, such as persistent bedding, general lack of pervasive fracturing and shearing, and general absence of volcanic rocks and radiolarian chert, casts doubt on the correlation of the sedimentary rocks of San Bruno Mountain with the eugeosynclinal assemblage of rocks of the Franciscan formation in the City of San Francisco.

On this field trip most of the rock types of the Franciscan formation will be seen, as well as the ultramafics which intrude it and the Pliocene and Quaternary rocks which cover it. The route follows the edge of San Francisco Peninsula from Telegraph Hill on the northeast to Point Lobos and the Cliff House on the west, then south along the Pacific Ocean to Half Moon Bay. The Santa Cruz Range is then crossed along Pilarcitos Creek and the famous San Andreas fault is followed northwestward for more than 10 miles. On returning to San Francisco, the Peninsula is crossed and the San Francisco Bay side is followed for several miles before climbing to a central high point, Twin Peaks, to get an overall view of San Francisco and its environs.

The geologic structure of San Francisco Peninsula is poorly known. Franciscan rocks north of the Fort Point-Hunters Point shear zone, and sandstone and shale of San Bruno Mountain south of the City College-Lands End shear zone are folded along northwest-trending axes. The block bounded by these shear zones consists of rocks of the Franciscan formation, mostly radiolarian chert and volcanic rocks, folded on east-west and north-south axes. The marine Merced formation of Pliocene and Pleistocene(?) age lies on the Franciscan formation west and south of San Bruno Mountain. It appears to be folded into a large northwest-trending syncline upon which minor folds have been superimposed. Franciscan rocks, mostly pyroclastics, make up the block between the San Andreas and Pilarcitos faults. South of the Pilarcitos fault granitic rocks are covered by Mesozoic and Cenozoic deposits. The crustal segment between the San Andreas and Hayward faults may be a structural block tilted down on the northeast. The granitic rocks of Montara Mountain may be a part of an adjoining structural block also tilted down on the northeast.

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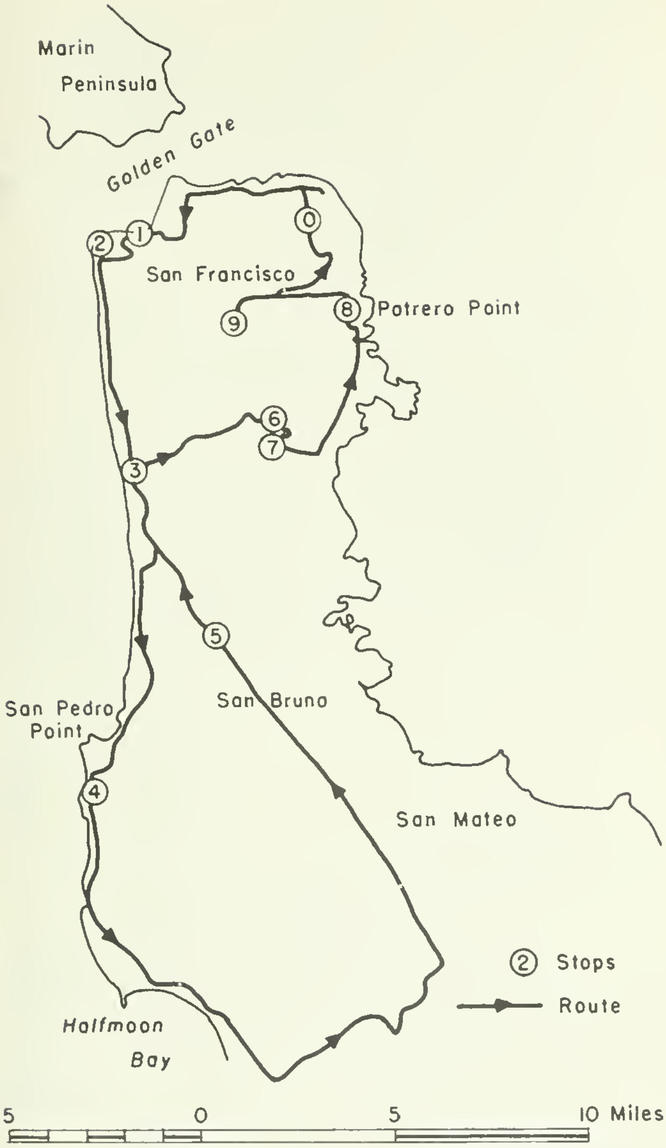
ROAD LOG

Mileage	
0.0	Start mileage count at Sacramento and Taylor Streets, 1 block west of Fairmont Hotel. Go north on Taylor Street.
0.4	Taylor Street crosses Broadway twin-bore vehicular tunnel. Massive sandstone and sheared, thin-bedded sandstone and shale of the Franciscan formation were encountered in excavating the tunnels. No potassium feldspar is found in the sandstone.
0.5	Vallejo Street, Coolbrith Park. Potassium-feldspar-free sandstone and shale of the Franciscan formation on both sides of street. Rocks are sheared, fractured, thrust-faulted and overturned. View of Alcatraz and Angel Islands.
0.6	Telegraph Hill on right.
0.8	Cross Columbus Avenue.
0.9	Turn right (east) onto Bay Street.
1.4	Turn right onto Kearney Street and go 1 block south.
1.5	Massive sandstone of the Franciscan formation in quarry face. No potassium feldspar in this rock. Southwest dip shown by thin shale beds. Thin-bedded sandstone and shale form the west side of Telegraph Hill. Rocks of Telegraph Hill and Russian Hill are part of northwest-plunging syncline (Schlocker, Bonilla, and Radbruch, 1958).
1.6	Retrace route and turn left (west) onto Bay Street.
3.1	Turn right (north) onto Laguna Street. East edge of large area of beach sand and land reclaimed from bay.
3.2	Turn left (west) onto Marina Boulevard.
3.9	Yacht Harbor and view of Golden Gate Bridge.
4.2	Site of Pan-Pacific Exposition, 1914-15. Enter Golden Gate Bridge approach.
4.3	Presidio military reservation. Set aside in 1776 by Spanish Government for military purposes. Still held for military use as headquarters of U. S. Sixth Army.
5.4	Turn right where sign points to Funston Avenue-Nineteenth Avenue. Route crosses Hunters Point-Fort Point shear zone. Serpentine and sheared rocks of the Franciscan are exposed in cuts.
6.7	Mountain Lake on left. Juan Bautista de Anza camped on its shores in 1776 when he founded San Francisco.
6.9	Turn right onto Lake Street which is built on dune sands.
7.5	Turn right on 25th Avenue. Sea Cliff district.
7.7	Turn left on El Camino del Mar.



FIELD TRIP 4

Figure 1. Index map showing route and field stops.

Mileage

8.2 **STOP 1.** East edge of Lincoln Park Golf Course. Walk north on path along former street car line. About 75 feet from El Camino del Mar, path is on landslide. From north to south are seen: Golden Gate Bridge; landslides in serpentine along the shore on the west edge of the Presidio; Bakers Beach; Phelan Beach State Park. The narrow spur north of the stop is a fossil locality in sandstone of the Franciscan formation with 2 percent potassium feldspar, where a Cretaceous ammonite, *Douvilleiceras*, was found. The Franicscan here consists mostly of eastward-dipping sandstone and shale and small amounts of radiolarian chert and greenstone that are locally disturbed by faulting and landsliding. Serpentine is found in a shear zone cutting the formation at Phelan Beach, 1,000 feet east of the stop. The large rock, about 10 feet high, lying on the west edge of Phelan Beach, is altered volcanic rock (greenstone) of the Franciscan formation. It is probably a tectonic inclusion in the shear zone. The cliffs on the north side of the Golden Gate show a section of radiolarian chert, greenstone, and sandstone, dipping mostly southwest. Pillow lava dips eastward at Point Bonita, the site of the lighthouse at the north portal of the Golden Gate. Mile Rock Lighthouse, west of stop 1 and about one-half mile offshore, is on greenstone that is probably a tectonic inclusion in the shear zone that can be seen on shore at Lands End.

Mileage

8.7 Continue west on El Camino del Mar to Legion of Honor Art Gallery. Turn left in front of Art Gallery. Landslides have closed El Camino del Mar to the west despite efforts to control them.

9.1 Turn right onto Clement Street and go 12 blocks to 48th Avenue.

9.9 Turn right onto 48th Avenue to parking area at Point Lobos.

10.1 **STOP 2.** Point Lobos. Walk eastward along roadcut south of parking area. Massive sandstone is exposed below marine lookout. Eastward the rock at the base of the cut is laminated shale and sandstone dipping steeply northeastward. Sandstone here contains substantial amounts of potassium feldspar and is believed to correlate with sandstone in San Bruno Mountain rather than with the potassium feldspar-free sandstone of the Franciscan formation at Telegraph Hill and vicinity. Hydrothermal alteration, probably by acid waters, affected most of the bedrock in the Point Lobos area. A wide shear zone and landslide lie about 100 feet east of parking area. Retrace route and turn west on Point Lobos Avenue which becomes the Esplanade south of the Cliff House.

10.6 Cliff House. Massive, fractured sandstone exposed in cliffs east of road. The simulated rock face is a concrete coating placed to stabilize cliff. Sandstone contains more than 5 percent potassium feldspar.

10.7 North end of Ocean Beach. Seal Rocks to north and sea cliffs below Cliff House are mostly sandstone. Sandstone at the contact with the Colma formation is hydrothermally altered but is fresh about 100 feet north of the contact. East of the Esplanade, at the north end of the amusement park, the Colma formation, probably of late Pleistocene age, lies on sandstone and is overlain by dune sand. The base of the Colma here consists of steeply dipping rubble beds derived from the underlying massive sandstone. The upper part of the formation, orange, clayey sand, dips about 8 degrees to the south. At this locality, the clayey sand of the Colma formation is probably marine, though the rubble beds may be nonmarine. The beach extends southward for about 7 miles. Sand on the San Francisco part of the beach comes from the south by the action of currents moving parallel with the shore. The arcuate sandy shoals that extend as far as 5 miles offshore, opposite the Golden Gate, may be a result of the north-drifting sand being deflected from shore by the ebb tide from San Francisco Bay.

11.0 Amundsen's ship *Gjoa* on the left was the first to make the Northwest Passage.

11.5 Cross Lincoln Avenue. Enter north end of Great Highway. Dune sand blown eastward from Ocean Beach covers much of northern San Francisco. The sand was also blown over the 700-foot-high ridge 2 miles to the left (east), and is more than 30 feet thick on the lee side. Most of the fill material used to reclaim land from the Bay east of Montgomery Street in downtown San Francisco was obtained from sand dunes in that area. Movement of sand is now mostly confined to the area west of the Great Highway, though sand persistently enters tunnels under the Great Highway.

Mileage

13.5 Fleishhacker Zoo. Cross Sloat Boulevard and continue south on Park Road and Skyline Boulevard.

14.3 Lake Merced. The earthquake of March 1957 caused large sections of road along the shores to slide into the lake. Lake Merced is a drowned stream valley separated from the ocean by beach- and dune-sand.

16.0 Landslide on right.

16.4 **STOP 3.** Alemany Boulevard at Thornton Beach. Walk one block west. Flat-lying sand of the Colma formation, exposed along east side of abandoned highway, overlies the Pleistocene(?) part of the Merced formation with slight discordance. Half a mile to the south, the Pliocene part of the Merced dips as much as 70 degrees. Large landslides are found here and for 1 mile to the north. Highway to south has been abandoned because of landslides.

16.8 Continue south on routes 1 and 5, Skyline Boulevard. Houses on right (west) were moderately damaged by earthquakes of March 1957.

17.6 Cross Westmoor Avenue. Merced formation underlies this general area.

18.7 Turn right on State Highway 1 where sign points to Santa Cruz.

22.1 Sharp Park Golf Course. The lagoon to the right (west) is on the drowned south edge of a tilted marine terrace, correlated with the Half Moon Bay terrace.

22.4 Hills to the south are sandstone and altered pyroclastic rock (greenstone) of the Franciscan formation.

22.9 Entering Calera Valley, type locality of the Calera limestone member of the Franciscan.

23.1 The Calera limestone member is exposed in Rockaway quarry on the right. This is the northernmost exposure of the Calera limestone member in the type locality. The limestone is interbedded with sandstone which Lawson (1914) designated the oldest formation of his Franciscan group. The limestone, however, contains Cenomanian (Late Cretaceous) Foraminifera, which suggest it is the upper part of the Franciscan formation.

23.9 Dark gray limestone of the Calera in road cut on left.

24.0 Road cut in shear zone exposes a confused mixture of several rock types of the Franciscan formation. Shear zone may be part of Pilarcitos fault discussed below.

24.5 Portola expedition marker. From a camp near this point scouts of the expedition discovered San Francisco Bay in 1769.

24.8 Intersection with road to Pedro Valley section of the City of Pacifica. The southeast-trending Pilarcitos fault lies in Pedro Valley. The fault is the boundary between the Franciscan formation to the northeast and granitic rocks to the southwest. Some geologists believe that the Pilarcitos fault is more active than the part of the San Andreas fault northeast of it. The western projection of the coastline, on the south side of Pedro Valley, has been cited as evidence for Quaternary right-lateral movements. In contrast the coastline is only slightly irregular where it is cut by the San Andreas fault, 5 miles north of Pedro Valley.

25.1 Thin-bedded, fine-grained sandstone and shale, possibly of Late Cretaceous age, dip southward in the road cuts.

25.9 In road cut on right, granitic boulder conglomerate of probable Paleocene age lies unconformably on Upper Cretaceous(?) beds.

26.3 Paleocene beds dip northward on south limb of syncline.

26.5 **STOP 4.** Devils Slide area. Road cut, several hundred feet high, exposes tightly folded thin-bedded sandstone and shale of Paleocene age. Slivers, mostly of gray shale of Late Cretaceous(?) age, are exposed in a large landslide visible in the roadcut. San Pedro Rock, the small island to the north with conspicuous bedding, consists of Upper Cretaceous(?) rocks. Granitic rocks are exposed along the highway for more than a mile south of Devils Slide.

Mileage

27.0 Road crosses large landslide on left in sheared and shattered granitic and sedimentary rocks. Crown of landslide is more than 600 feet above the road. The highway has been completely blocked many times by movement of this slide, especially following long periods of heavy rainfall. Control of the slide movement or relocation of the highway both present difficult problems.

28.8 Town of Montara. The highway is on Half Moon Bay marine terrace developed during a Pleistocene interglacial stage and subsequently warped.

30.0 Road cut in continental terrace sediments which overlie marine sediments that in turn lie on the wave-cut terrace surface.

30.5 Moss Beach on southwestern flank of Montara Mountain. The granitic rocks of Montara Mountain are exposed over an area of more than 30 square miles. They have not been mapped in detail, but are known to range from granite to quartz diorite. A sample collected 5 miles to the east gave a potassium-argon date of 91.6 million years (Curtis, and others, 1958, p. 9). Cretaceous and Paleocene deposits evidently were stripped from this area before the deposition of the marine Pliocene sediments which lie on granitic rocks and are exposed in small folds along the beach and on the wave-cut bench at low tide.

31.9 Road is on the Half Moon Bay marine terrace. Hill to right is of marine Pliocene beds slightly older than those of the type Merced formation. Northeast face of hill is probably a recent fault scarp formed by movement along the Seal Cove fault.

34.1 El Granada Beach. Structurally low portion of the warped Half Moon Bay marine terrace.

35.0 Rocks exposed about three-fourths of a mile east of highway are sandstone and shale of Miocene age.

37.2 Turn left (east) onto Half Moon Bay road. Sign points to San Mateo. Town of Half Moon Bay is at northern limits of an area of gas and high-gravity oil seepages from Pliocene and Miocene sedimentary rocks. Commercial production of oil has been small. It is mostly from wells on a northwest-trending anticline that intersects the coast about 4 miles south of the town. In the next 9 miles the route crosses part of the Santa Cruz Mountains and drops into the valley eroded along the San Andreas fault. For the first 3 miles the road is in a deep canyon cut by Pilarcitos Creek. Evidence of Quaternary and possibly Tertiary uplift can be inferred from several marine terraces that are higher than the Half Moon Bay terrace and stream terraces that appear as flat benches on the spurs jutting into Pilarcitos Creek Canyon. The Montara Mountain granitic rock mass plunges southeastward beneath a cover of Tertiary and Quaternary rocks.

37.8 Purisima formation exposed in road cut on left. It is marine sandstone deposited during the Pliocene.

38.1 Monterey shale exposed in road cut on left. At this locality the shale contains middle Miocene (Luisian) fossils. It grades downward into sandstone which can be seen at mileages 39.7 and 39.9.

39.7 On left and ahead, view of hogback of basal arkosic sandstone of the Monterey shale dipping westward.

39.9 Same basal sandstone exposed in quarry on left.

40.4 Granitic rock in road cut on left.

41.0 In road cut on left, conglomerate of Pliocene (?) age is thrust over sheared granitic rocks.

Mileage

41.3 In road cut on left sandstone, shale, and basalt of early Miocene (Zemorrian) age are faulted against conglomerate of Pliocene(?) age.

41.7 Good locality for collecting lower Miocene (Zemorrian) Foraminifera in shale in road cut on left.

41.9 The Pilarcitos fault crosses the road. It is the eastern border of the granitic rocks in this area. Beyond the fault the exposure of sandstone and conglomerate, mapped as the Franciscan formation, has yielded Cretaceous Rudistids.

43.0 Intersection with Skyline Boulevard (State Highway 5). Continue eastward on Skyline Boulevard.

43.6 Good view eastward of: The valley of the San Andreas fault; hills east of it truncated by a flat to rolling Pleistocene erosion surface 600 to 800 feet above sea level cut on serpentine and Franciscan formation; San Francisco Bay; and the Berkeley Hills and Diablo Range.

Crystal Springs Lake in the valley of the San Andreas fault supplies water to San Francisco Peninsula towns. Most of the water comes from Hetch Hetchy Valley in the Sierra Nevada. The active Hayward fault lies on or near the west edge of the hills beyond (east of) San Francisco Bay. Recent movement along the San Andreas and Hayward faults has been right lateral or clockwise.

44.4 Causeway on Crystal Springs Lake. Offset of the causeway along the surface trace of the San Andreas fault in 1906 at this point was 8 feet.

44.6 Turn left (north) toward San Francisco.

45.4 Serpentine derived from peridotite in road cut on right. Serpentine here consists of hard blocks, rounded by shearing.

45.5 Serpentine in cuts on both sides of road.

45.6 Intersection with Bunker Hill Drive.

46.1 Skyline Boulevard crosses Crystal Springs Dam which, when completed in 1888, was one of the largest concrete dams in the world. The trace of the 1906 movement along the San Andreas fault lies 1,000 feet west of the dam. The dam, which was designed to resist earthquakes, was not damaged by the 1906 earthquake.

46.3 Intersection with Crystal Springs Road.

46.7 Tectonic inclusion of rocks of the Franciscan formation within serpentine in road cut on right.

47.4 The Pleistocene erosion surface on which Skyline Boulevard was built is well exposed here.

47.8 Intersection with Black Mountain Road.

47.9 Volcanic rocks (greenstone) of the Franciscan formation altered to a red-brown friable rock.

48.1 Crystal Springs Golf Course. View westward across the San Andreas fault valley shows two erosion surfaces at about 1,200 and 1,800 feet above sea level.

49.8 Knob on right about 200 feet east of Skyline Boulevard consists of several metamorphic rocks containing the blue amphibole glaucophane. Similar isolated knobs of metamorphic rocks are common in terrain underlain by the Franciscan.

51.4 Skyline Boulevard intersection with Hillcrest Boulevard in City of Millbrae.

52.7 **STOP 5.** The observation point is on the east side of Skyline Boulevard, on greenstone of the Franciscan formation. Artificial fill, beneath the houses in the valley in the immediate foreground, conceals a formerly well-defined valley that marked the trace of the San Andreas fault. Before the houses were built, evidence of the 1906 movement of the San Andreas fault could be seen, such as a break in the San Francisco water supply pipeline and a fence offset. The fence was offset about 6 feet at the break, but it was also bent near the break so that the total offset was 13 feet. The Merced formation lies east of the fault. According to gravity surveys, the top of the Franciscan on the east side of the fault is nearly 2,000 feet below the surface of the ground, but rises eastward.

The San Bruno fault is near the base of San Bruno Mountain, which is visible to the northeast. Lawson (1914, p. 16) estimated the "differential displacement" on the fault as not less than 7,000 feet. Gravity surveys and recent geologic mapping indicate, however, that the vertical separation on the fault is much less than 7,000 feet; logs of borings show that near the south end of San Bruno Mountain the separation can be no more than a few hundred feet.

The Colma formation overlies the Merced formation in the flat valley southwest of San Bruno Mountain.

53.8 Road crosses trace of the 1906 movement of the San Andreas fault. On the right (south) sag ponds are visible in the valley. On the left (north), a small notch in the side of the hill marks the line of movement in 1906.

54.3 To the right is a view of the Chinese cemetery. South of the cemetery a well-formed terrace is visible along a branch of Colma Creek in the little valley to the right. Radiocarbon dating of wood collected at the base of this stream terrace gave an age of about 10,500 years.

54.6 The sag pond on the left (west) is also along the San Andreas fault. The trace of the 1906 movement was along the west edge of the pond.

55.6 Intersection with State Highway 1. Continue northward.

56.0 Green building straight ahead is a water reservoir. During the March 1957 earthquake water poured out of a large crack that formed in the side of the reservoir. Because of fear that the reservoir would fail completely, people were evacuated from homes immediately below it.

56.6 Westmoor Avenue. A volcanic ash was uncovered in the Merced formation during grading for the houses northeast of this intersection. This ash was traced intermittently to the northwest for about 2 miles, down to the beach. This is the lower of two ash beds that have been found in the Merced formation.

57.7 Turn right onto Alemany Boulevard. Follow sign pointing to San Francisco.

58.2 On the right is an exposure of the contact between the Colma and Merced formations. Bedding in the Colma formation is horizontal; that of the Merced formation dips about 15 degrees southeast. Determination of the true bedding in the Merced is difficult here because of color banding and local cross-bedding.

59.2 Left turn onto Junipero Serra Boulevard.

59.5 Right turn onto Alemany Boulevard. Sign reads "Civic Center—Bay Bridge—Cow Palace".

60.2 The road crosses a former railroad line into San Francisco. Road is on Colma formation; the hills on either side are of Franciscan formation.

61.4 Turn right onto Geneva Avenue, cross Mission Street, and continue on Geneva Avenue another 8 blocks.

61.8 Turn left onto Athens Street and go 5 blocks.

62.3 Turn right onto Persia Street and go about 5 blocks.

62.7 **STOP 6.** City College fault zone. Sheared sandstone, shale, greenstone, chert, and metamorphic rocks can be seen in the road cut. North of this locality the Franciscan formation includes much chert and greenstone; the sandstone generally contains no potassium feldspar. San Bruno Mountain, visible to the south, consists largely of sandstone and shale with relatively little chert or greenstone; the sandstone has as much as 20 percent potassium feldspar. The quarry visible just south of here is our next stop.

64.2 Turn right onto Santos Street. Large mass of sandstone and shale on left (east) near Geneva Avenue is a tectonic inclusion in the fault zone. The sandstone contains only a trace of potassium feldspar.

64.5 Turn right onto Geneva Avenue.

Mileage

64.9 **STOP 7.** Turn left into parking lot of Castle Lanes Sport Center. Restroom available. This former quarry provides a good exposure of the sedimentary rocks that make up San Bruno Mountain. They are well bedded, and are less faulted and sheared than at most outcrops of the Franciscan formation. Graded bedding and bedding-plane markings can be seen in the interbedded graywacke and shale. The quarry is on the northeastern limit of the potassium-feldspar-rich sandstone and is at the north end of the San Bruno Mountain mass. Attitudes of bedding in San Bruno Mountain suggest that the mountain is an asymmetric anticline with a steep limb on the southwest side and a relatively gentle limb on the northeast side. The hill north of the quarry is in the City College fault zone.

64.9 Turn right onto Geneva Avenue from parking lot.

66.1 Turn left onto Bayshore Highway.

66.7 Greenstone exposed on the left.

66.9 Turn right onto Hester Avenue. Good view of shear zone in cut on Candlestick Hill east of Bayshore Freeway where highly sheared shale and sandstone have tectonic inclusions of greenstone and chert. Chert and greenstone crop out at the crest of the hill. The hillslope has many small earthflows, some of which damaged a former public-housing project. The excavations on the side of the hill are borrow areas to obtain fill for the garbage disposal operation to the south. San Francisco's baseball park is on the east side of this hill.

67.2 Turn right onto Bayshore Highway.

67.4 Turn right onto Third Street.

68.9 Near Jerrold Avenue the route crosses the wide northwest-trending shear zone which extends across the City of San Francisco from Hunters Point to Fort Point. At this point the zone is covered by artificial fill, but serpentine and rocks of the Franciscan are found elsewhere in the zone.

69.6 Islais Creek, once a tidal inlet that extended more than a mile west of Third Street, is now the center of "Butchertown," the slaughterhouse district of San Francisco. The land was recovered from San Francisco Bay by filling. Channels cut in bedrock in this area, probably during a glacial stage of the Pleistocene epoch, are now more than 200 feet below sea level.

70.2 Turn left onto 23d Street towards Potrero Hill, which consists largely of serpentine in the Hunters Point-Fort Point shear zone.

70.5 Turn right onto Iowa Street. Public housing on the left and large gas holder are on serpentine.

70.8 **STOP 8.** South border of large tectonic inclusion of sandstone and shale of the Franciscan formation in serpentine. The contact area, which is exposed on both sides of Iowa Street, contains sheared and hydrothermally altered sandstone and serpentine. In the serpentine, magnesite veins are common and aragonite crystals, in long blades, are present on some joints. Rounded blocks of hard serpentine are embedded in a sheared serpentine matrix. This structure is common in serpentine in the Coast Ranges. Elsewhere, such as at the top of Potrero Hill, 9 blocks west of this stop, the serpentine is mostly hard blocks with little or no sheared matrix.

70.8 Turn left onto 20th Street. At the next corner turn right onto Pennsylvania Street. Sandstone inclusion in serpentine exposed to left (southwest).

71.0 View of downtown San Francisco. The low area, north of Potrero Hill, is a filled-in swamp several square miles in extent.

71.2 Turn left onto Mariposa Street. At the next corner turn right onto Mississippi Street. At the next corner turn left on 17th Street.

Mileage

71.4 Serpentine exposed on left between Missouri and Connecticut Streets.

71.9 Skyway crosses above 17th Street.

72.1 Serpentine on right near Hampshire Street.

72.4 Cross railroad tracks where 17th Street turns slightly left.

72.5 East slope of Twin Peaks visible ahead (west).

72.8 Cross Mission Street. At this place Mission Street is a continuation of the road that connected the harbor settlement near Chinatown with the Spanish Mission area; it was one of the first roads in San Francisco.

73.6 Cross Market Street, continue west on 17th Street. East portal of the 2-mile Twin Peaks Tunnel to left. Tunnel is used by streets cars only.

74.2 Cross Roosevelt Avenue. Mostly thin-bedded radiolarian chert of the Franciscan formation on right.

74.3 Turn left onto Clayton Street and go south one block.

74.4 Turn right onto Twin Peaks Boulevard. Greenstone, largely altered to clay minerals, is the brown friable material that apparently intrudes radiolarian chert in cut on right.

74.6 Intersection with Clarendon Avenue. Turn left and stay on Twin Peaks Boulevard.

74.8 Extensive exposures of red-brown radiolarian chert. Beds dip north on nose of north-plunging anticline.

75.1 Radiolarian chert hydrothermally altered to grayish-orange color in small fault on left.

75.2 Take road on west (right) side of Twin Peaks.

75.3 **STOP 9.** Road cut west side of north Twin Peaks shows radiolarian chert on greenstone. Greenstone at and near contact is altered to a soft clayey material. Chert beds 3 to 5 inches thick, separated by thin shale parting, pinch and swell and generally wedge out in 20 to 30 feet. Radiolaria, which appear as pin-head size, round, dark bodies, are abundant in both chert and shale. These rocks are believed to have been a colloidal gel formed by precipitation of silica and small amounts of iron and aluminum oxides from sea water. The shale-like partings probably represent impurities in the gel. Near the north end of the road cut, west of north Twin Peaks, the chert and shale beds are tightly folded, and fold axes are nearly horizontal. Folding evidently took place before the gel hardened. A small body of chert lying on greenstone makes up south Twin Peaks. Road cuts also reveal former valleys that are now filled with Quaternary deposits. Their size, shape, and location suggest that the former topography of the Twin Peaks summit area was not as steep or as youthful as it is today.

75.5 Continue south on road west of crest. Note pillow structure in altered greenstone southwest of south Twin Peaks.

75.8 Turn north on the circular road around the south end of Twin Peaks. View of eastern half of San Francisco. The wide street is Market Street. The U. S. Mint, the gray building north of Market Street with the long vertical windows is built on a serpentine within the Fort Point-Hunters Point shear zone. The same shear zone includes both Potrero Hill, mostly serpentine, due east and near the Bay, and Hunters Point, the hills to the south east that jut into the Bay. The south tower of Golden Gate Bridge rests on serpentine near the northwest end of the shear zone. The hills immediately east of Twin Peaks are predominantly northeast-dipping sandstone and greenstone and lenses of radiolarian chert, all of the Franciscan formation. San Bruno Mountain is the high hill far to the southeast. Yerba Buena Island, along the Bay Bridge route, is mostly northeast-dipping sandstone beds of the Franciscan formation covered with thick deposits of clayey sand. Lower Market Street area is land reclaimed from the Bay. Retrace route down Twin Peaks.

76.7 Left turn onto Clayton Street. Go one block to 17th Street.

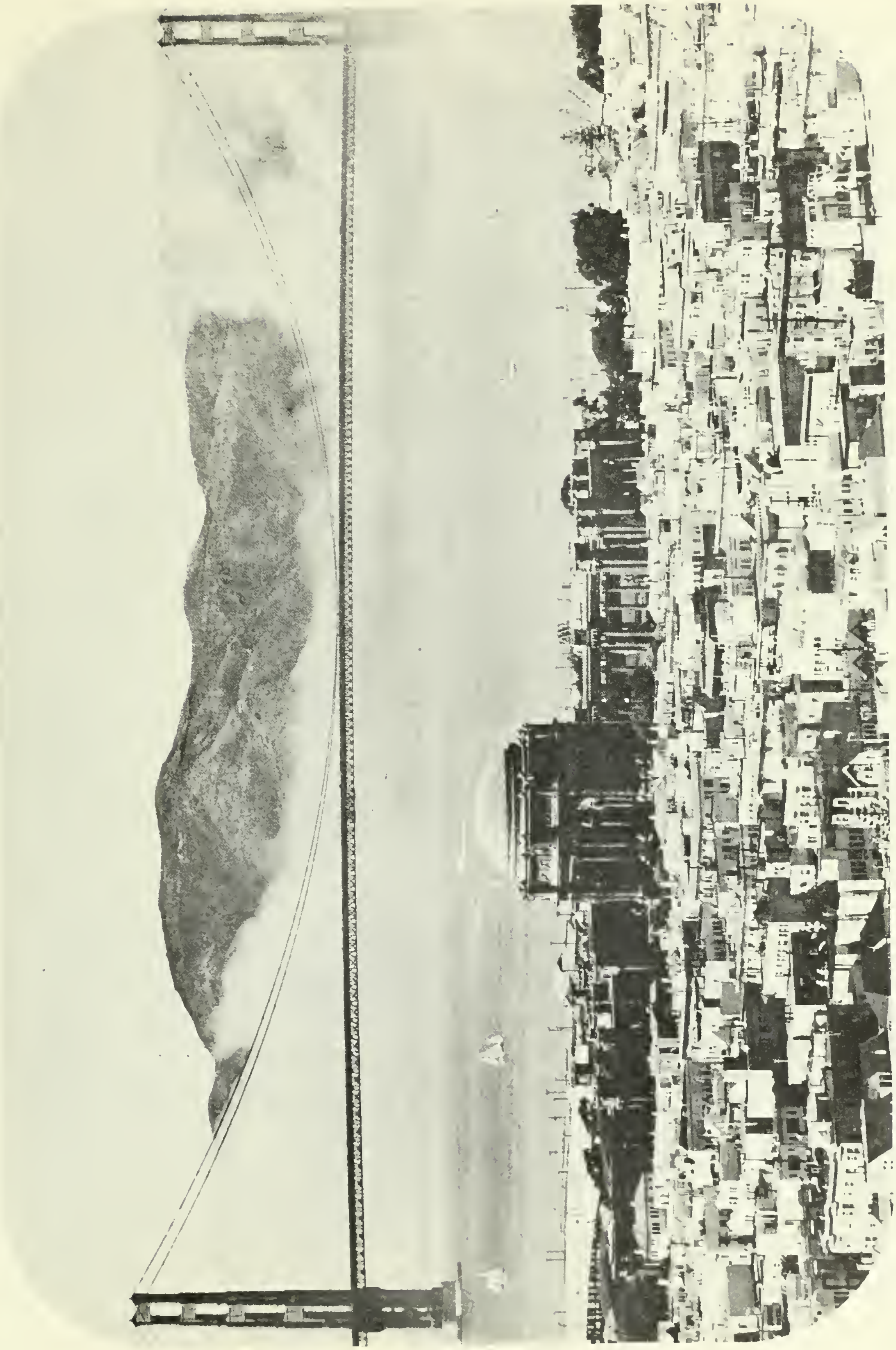


Photo 1. Palace of Fine Arts and Golden Gate Bridge in 1948. Marin County in the distance. Photo courtesy San Francisco Chronicle.

Mileage

76.8 Right turn onto 17th Street.

77.4 Cross Market Street, continue on 17th Street for three blocks to Church Street.

77.8 Turn left onto Church Street and go one block.

77.9 Turn right onto 16th Street.

78.0 Mission Dolores, one of the chain of Franciscan Missions in California that extended from San Diego to Sonoma. The mission site was selected where a small stream furnished fresh water and where the land was suitable for farming. Grazing lands on the east side of the Bay were also developed by the mission authorities.

78.9 Turn left onto Bryant Street.

79.7 Land reclaimed from Mission swamp. Buildings are tilted and otherwise disturbed by subsidence. Note irregularity of alignment of adjacent buildings.

80.0 Turn left onto Fifth Street.

Mileage

80.2 Turn left onto Shipley Street. Subsidence is especially noticeable here because a few years ago the street and sidewalks were brought up to their level before subsidence. Note that the level of the sidewalk and street is several feet above the bottom of doorways. Subsidence here is probably due to dewatering of bay mud lying below artificial fill and possibly also to lateral movement of plastic mud below load of artificial fill.

80.4 Turn right into Sixth Street. More views of subsiding buildings, especially on the right along Clementina and Tehama Streets.

80.6 Mission Street, north edge of the filled-in area.

80.8 Cross Market Street and turn half right onto Taylor Street.

81.5 Turn right onto California Street. Dune sand is more than 25 feet thick here. It rests on sheared sandstone and shale of the Franciscan formation.

81.6 Fairmont Hotel. End of trip.

Photo 2. Mission San Francisco de Asis (Dolores), established in 1776. Gabriel Moulin photo.

FIELD TRIP 5: NORTH FLANK OF MOUNT DIABLO

By IVAN COLBURN
State College for Alameda County

Jurassic-Cretaceous stratigraphy on the north flank of Mount Diablo, as demonstrated on the route Clayton—Mount Diablo quicksilver mine, Marsh Creek road—Deer Valley road.

Mount Diablo has a core composed of Jurassic (?) Franciscan rocks that have been punched up through the younger Jurassic-Cretaceous and Tertiary marine strata much as a salt plug penetrates through overlying strata. The analysis of the Jurassic-Cretaceous stratigraphy was part of a larger study that included an investigation of the structural origin of Mount Diablo and an analysis of the early Tertiary strata on the flanks of the mountain. All flanks of Mount Diablo have outcrops of Jurassic-Cretaceous and Tertiary marine strata (fig. 1).

Unnamed Jurassic-Cretaceous Formation (Late Jurassic-Cretaceous). A sequence of alternating sandstone and mudstone beds that have a composite thickness of about 30,000 feet make up the unnamed Jurassic-Cretaceous formation at Mount Diablo. Earlier workers subdivided this sequence of strata into as many as five formations (fig. 3), but the author of this report found only a few beds that could be considered distinctive marker beds, and these were not extensive enough to be called formations. The strata exposed at the base of the column are lithologically unlike those exposed at the top, but the transition takes place over a thick stratigraphic interval; therefore the author suggests that for mapping purposes this column of strata should remain unsubdivided.

The most complete and best exposed section of this unit is on the north flank of Mount Diablo. The base of the type section is at the Mount Diablo quicksilver mine at the boundary of the core of the mountain (sec. 29, T. 1 N., R. 1 E.), and the top of the section is near the old Marsh ranch house (NW corner sec. 34, T. 1 N., R. 1 E.). Marsh Creek runs almost the entire length of the section and the best exposures of the unit are found in the creek bottom (fig. 2).

This formation is characterized by mudstone and sandstone in equal amounts. Limestone beds and concretions, as well as conglomerate beds, are present in lesser amounts. A bed of radiolarian-rich, white, porcellaneous shale, a limestone breccia bed and white-tuff bed proved helpful as distinctive marker beds for mapping.

In the lower part of the unnamed Jurassic-Cretaceous formation, the mudstone is generally olive-drab, well indurated, and massive. The sandstone is thin-bedded, usually alternate with equal intervals of mudstone, and is best described as a wacke after Williams, Turner and Gilbert (1954).

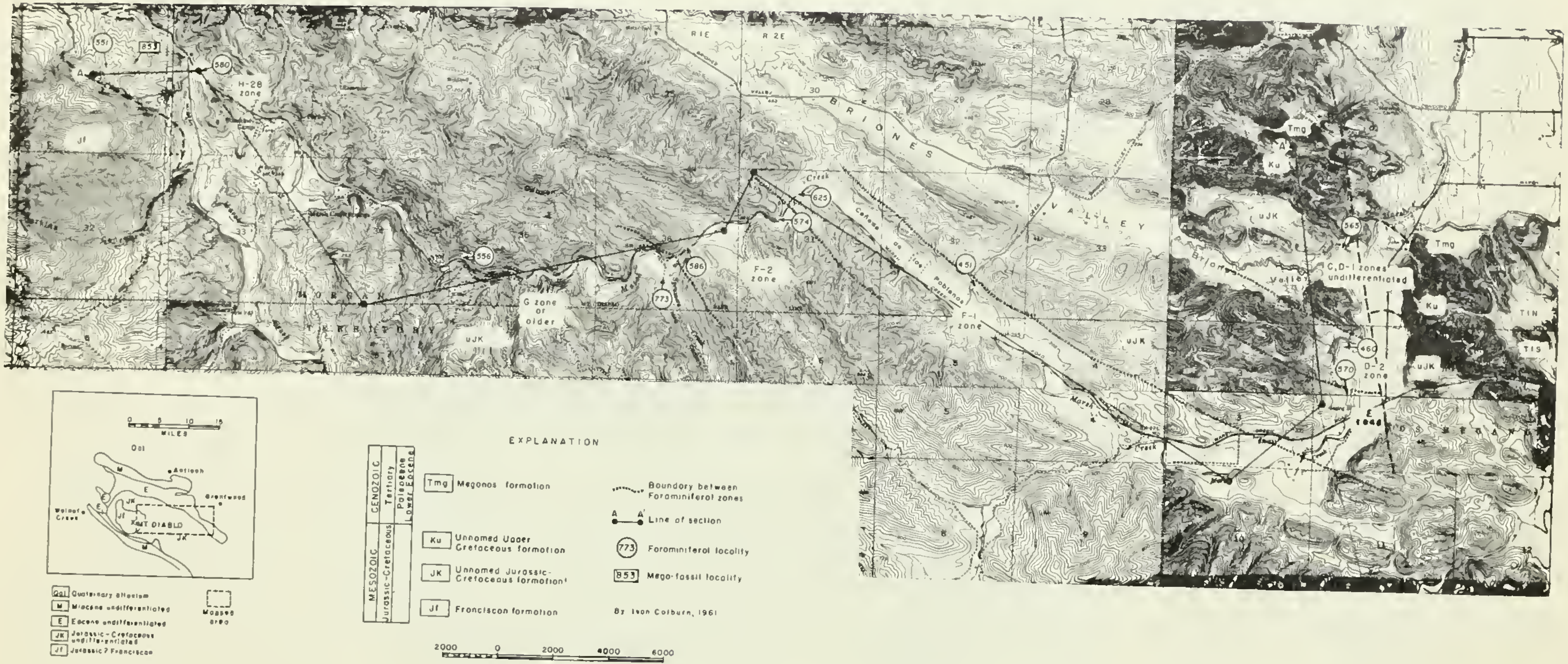
In the upper part of the section the sandstone contains very little clay, is light brown to tan in color, and is best described as arenite after Williams, Turner, and Gilbert (1954). The sandstone beds and mudstone intervals may be over 40 feet thick, but they average approximately 10 feet. The interbedded mudstone is light olive-drab to brown, and is moderately indurated.

A gradual change takes place in the lithologic character of the unnamed Jurassic-Cretaceous formation from bottom to top. It is easy to distinguish the clean, light-brown, massive sandstone and interbedded mudstone characteristic of the top part of the formation from the dark-gray to dark-green, thin-bedded sandstone and olive-drab mudstone of the basal part, but it is impossible to distinguish a boundary where the change takes place.

Petrographic analysis of the sandstone in the Marsh Creek section revealed approximately 40 percent quartz, 15 percent potash-feldspar, 18 percent plagioclase, and 27 percent matrix, miscellaneous minerals, and rock fragments, in the upper part of the section. Potash feldspar, plagioclase and quartz gradually decrease in amount toward the base of the section. Near the base of the Marsh Creek section there is 20 percent quartz, 10 percent potash-feldspar, and 10 percent plagioclase feldspar; matrix and miscellaneous minerals and rock fragments compose the remaining 60 percent of the sample.

The contact represented by the boundary of the central Franciscan core is a fault contact.

The strata and the fossils indicate that the environment of sedimentation was below wave-base at an unspecified depth, possibly open ocean, throughout the deposition of the unnamed Jurassic-Cretaceous formation. Sediment



FIELD TRIP 5

Figure 1. Geologic map of Mt. Diablo and vicinity, showing boundaries of Goudkoff's foraminiferal zones.

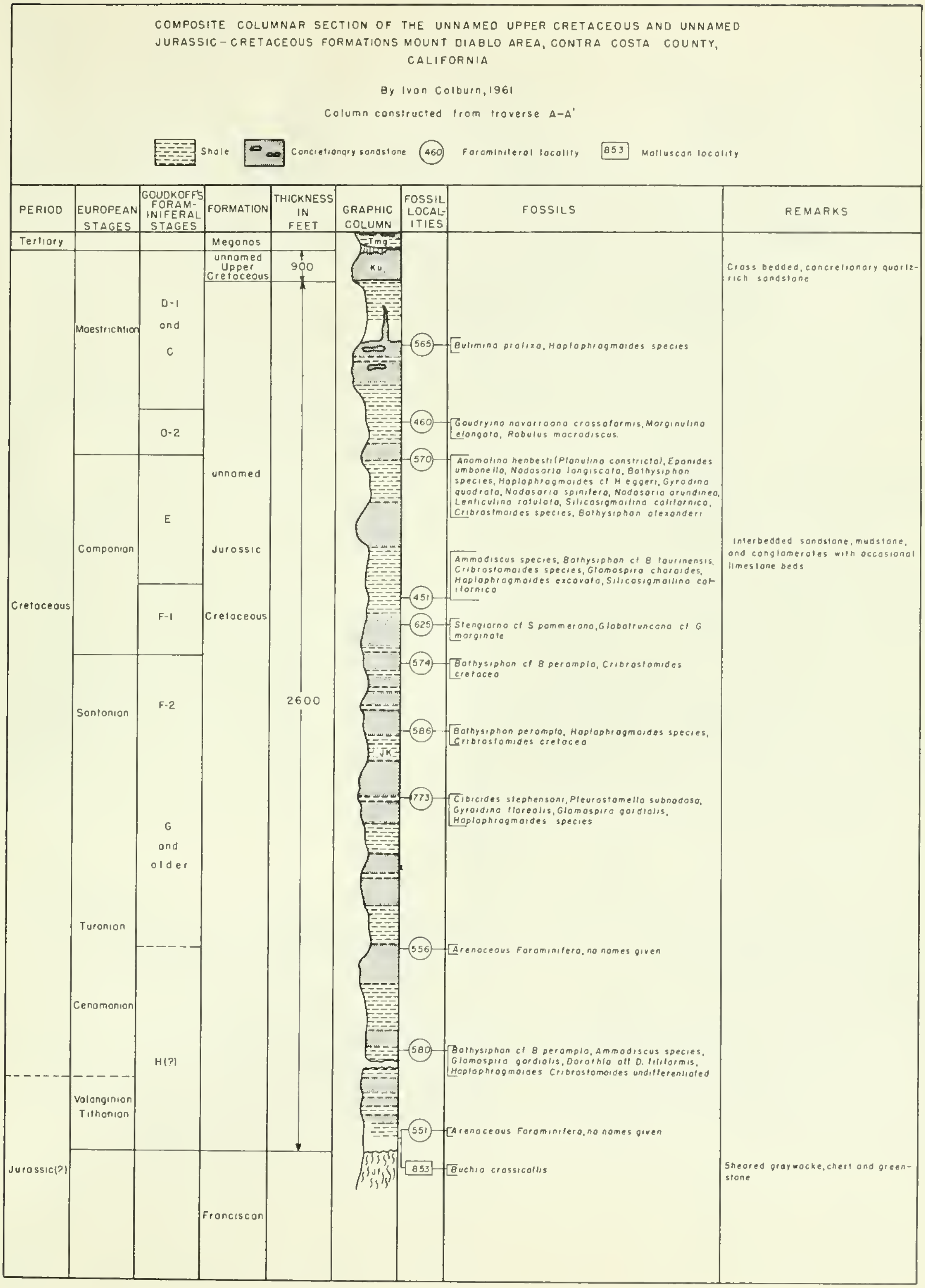

COMPOSITE COLUMNAR SECTION OF THE UNNAMED UPPER CRETACEOUS AND UNNAMED JURASSIC-CRETACEOUS FORMATIONS MOUNT DIABLO AREA, CONTRA COSTA COUNTY, CALIFORNIA
By Ivan Colburn, 1961
Column constructed from traverse A-A'
Shale
Concretionary sandstone
460 Foraminiferal locality
853 Molluscan locality
PERIOD
EUROPEAN STAGES
GOUDKOFF'S FORAM-INIFERAL STAGES
FORMATION
THICKNESS IN FEET
GRAPHIC COLUMN
FOSSIL LOCAL-ITIES
FOSSILS
REMARKS
Tertiary
Megonos
Tmg
unnamed Upper Cretaceous
900
Ku
Cross bedded, concretionary quartz-rich sandstone
Cretaceous
Maestrichtion
D-1 and C
D-2
565
Bulimina pralixa, Haplophragmoides species
460
Goudryina navarraona crassaformis, Marginulina elongata, Robulus macrodiscus.
570
Anomolina henbesti (Planulina constricta), Eponides umbonella, Nodosaria longiscata, Bathysiphon species, Haplophragmoides cf H eggeri, Gyrodina quadrata, Nodosaria spinifera, Nodosaria arundinea, Lenticulina rotulata, Silicosigmoilina californica, Cribrostmoides species, Bathysiphon alexanderi
Componian
E
unnamed Jurassic Cretaceous
Interbedded sandstone, mudstone, and conglomerates with occasional limestone beds
Ammodiscus species, Bathysiphon cf B taurinensis, Cribrostomoides species, Glomospira charoides, Haplophragmoides excavata, Silicosigmoilina californica
451
F-1
625
Stengiarna cf S pommerona, Globotruncana cf G marginate
574
Bathysiphon cf B perampla, Cribrostomides cretacea
Sontonian
F-2
2600
586
Bathysiphon perampla, Haplophragmoides species, Cribrostomides cretacea
JK
773
Cibicides stephensoni, Pleurostomella subnodosa, Gyroidina florealis, Glomospira gordialis, Haplophragmoides species
G and older
Turonian
556
Arenaceous Foraminifera, no names given
Cenomanion
H(?)
580
Bathysiphon cf B perampla, Ammodiscus species, Glomospira gordialis, Dorothia aff D. filiformis, Haplophragmoides Cribrostomoides undifferentiated
Valanginian Tithonian
551
Arenaceous Foraminifera, no names given
Jurassic(?)
Jf
853
Buchia crassicollis
Sheared graywacke, chert and greenstone
Franciscan

Figure 2.

Period	Turner: G.S.A. Bull., v. 2 1891	Dickerson: Univ. Calif. Bull., v. 6 1911	Clark: Jour. Geol., v. 29 1921	Taff: G.S.A. Bull., v. 46 1935	A.A.P.G. S.E.P.M. Guidebook to Mt. Diablo 1950	This Report 1961	Goudkoff's zones: A.A.P.G. Bull. v. 29 1945	Revised Standard, Muller–Schenck, A.A.P.G. Bull., v. 27 1943 Loeblich–Tappan U.S. Nat. Mus. Bull. 215, 1951	
Tertiary	"Tejon"	"Martinez"	"Martinez"	"Martinez"	"Martinez"	"Martinez"			
								Landinian	
			unconf.	unconf.		unconf.	A–1 A–2	Danian	
Cretaceous	Chico	Chico	Chico	Moreno	Moreno	unnamed Upper Cretaceous	C	Maastrichtian	
							D–1		
						unnamed Jurassic – Cretaceous	D–2	Campanian	Senonian
				Panoche			E		
							F–1		
				Chico			F–2	Santonian	
							G–1	Coniacian	
							G–2	Turonian	
				Shasta			H	Cenomanian	
								Albian	
								Aptian	
								Berremian	Neocomian
								Hauterivian	
								Valinginian	
								Berriasian	
Jurassic				Knoxville				Tithonian	
				'Franciscan		Franciscan			

Figure 3. Chart illustrating evolution of stratigraphic nomenclature.

transport was mainly by turbidity currents for the clastic rocks. Flute casts, slump folds, etc., suggest that the clastic sediments moved along a northwest-southeast axis in the basin.

An abundance of microfossils and megafossils were found in this formation (fig. 2). Foraminifera were useful in dating the Upper Cretaceous strata only, and they indicated that all of Goudkoff's Late Cretaceous zones were represented in the formation. Ammonites, belemnites, and Buchias were useful for dating the lower part of the section. The age of this formation ranges from Late Jurassic (Tithonian) to Late Cretaceous (Maastrichtian).

Many areas in the California Coast Ranges have strata with the same age-range and rock types as the unnamed Jurassic-Cretaceous formation at Mount Diablo. The monotonous lithology of this formation probably makes impossible a bed-for-bed correlation of the strata at Mount Diablo with formations in other regions of the state.

Unnamed Upper Cretaceous Formation (Late Cretaceous). A prominent ridge-forming coarse-grained sandstone caps the lithologically monotonous rocks of the unnamed Jurassic-Cretaceous formation on the north flank of Mount Diablo. This distinctive sandstone interval is the unnamed Upper Cretaceous formation. It is a newly recognized cartographic unit that includes the youngest Cretaceous strata at Mount Diablo.

This formation is typically exposed in the southeast corner of sec. 27, T. 1 N., R. 2 E., near the old Marsh ranch house. In this area it is approximately 700 feet thick.

The basal 15 feet of the unnamed Upper Cretaceous formation is light-gray, silty, fine sandstone that locally changes color to sea-green because of concentrations of glauconite. The body of the formation is a cross-bedded, tan, medium- to coarse-grained arenite that is thick-bedded. Locally, calcarous sandstone concretions as large as 10 feet in diameter weather as bare, resistant knobs. Thin beds of metamorphic and igneous pebbles and layers of thick-shelled mollusks are commonly seen in this formation. Very few mudstone intervals were noted and they were only a few inches thick and a few tens of feet in lateral extent.

The base of the unnamed Upper Cretaceous formation is easily observed in the face of the ridge that forms the east side of Briones Valley. Clearly, a gradational contact separates the sandstone of the unnamed Upper Cretaceous formation from the chocolate-brown mudstone of the underlying unnamed Jurassic-Cretaceous formation.

In the northeast corner of Section 35 near the old Marsh ranch house, the early Eocene Meganos formation rests on the unnamed Upper Cretaceous formation with an angular discordance in dip and strike of 5°.

Several features of this formation suggest that it was deposited in a near-shore, above wave-base, open-ocean environment of sedimentation. These features are the large-scale cross-bedding (several feet in amplitude), many beds of thick-shelled mollusks such as *Meekia sella* and *Venus varians*, absence of appreciable mudstone, and the coarse grain size of the sandstone.

Mega-fossils such as ammonites and mollusks suggest a Maastrichtian age. This suggestion is supported by the stratigraphic position of the unit. The unnamed Upper Cretaceous formation is overlain by the Paleocene Martinez and the Paleocene and early Eocene Meganos formations. Foraminifera indicative of Goudkoff's C and D-1 (Maastrichtian) zones were collected from the beds just underneath the unnamed Upper Cretaceous formation.

ROAD LOG

Distance	*Cumulative mileage*	
0.0	0.0	Union Square, San Francisco, at Stockton and Geary Streets. Follow Stockton Street south. This becomes Fourth Street at Market Street.
0.1	0.1	Fourth and Market Streets. Veer slightly east to strike Fourth Street.
0.3	0.4	Fourth and Folsom Streets. Turn right on Folsom Street. Continue to Fifth Street.
0.2	0.6	Folsom and Fifth Streets. Turn left onto Fifth Street.
0.2	0.8	Bay Bridge on-ramp at Fifth and Bryant Streets. Cross Bay Bridge and continue east on MacArthur to Broadway.
9.3	10.1	MacArthur Boulevard and Broadway. Turn left (east) onto Broadway (State Highway 24).
3.8	13.9	Broadway Tunnel. Continue through and onto Mt. Diablo Boulevard (Walnut Creek-Concord Freeway).
8.8	22.7	Wye junction point of Highways 24 and 21. Keep to the left toward Concord.
0.8	23.5	Ygnacio Valley off-ramp. Turn east onto Ygnacio Valley road. Cross Ygnacio Valley and go by the idle Cowell Cement plant.
7.8	31.3	Junction of Ygnacio Valley Road and Clayton Road. Turn right and head south toward Clayton.
1.4	32.7	Clayton in front of "Chubby" Humble's Pioneer Inn. Set odometer back to zero again.
0.0	0.0	Drive east out of Clayton on the paved road now called Marsh Creek Road.
4.6	4.6	Junction of Marsh Creek and Morgan Territory Roads. Turn right and head south down Morgan Territory Road.
0.1	4.7	Entrance to the Mount Diablo quicksilver mine property. Turn right through the gate and stop at the second house on your right; ask Vic Bloomberg for permission to visit localities 551 and 853. Proceed up the hill through the mine property.

Distance	*Cumulative mileage*	
1.1	5.8	Top of the Mount Diablo quicksilver mine property. Localities 551 and 853 are on the knoll to your right. The *Buchia (Aucella) piochi* indicative of Late Jurassic (Tithonian stage) age of Locality 853 are collected from the yellow limestone concretions. The Foraminifera indicative of Goudkoff's G zone or older of Locality 551 are collected from the dark green mudstone that is exposed in gullies around the side of the hill. Turn around and retrace your route to the junction of Marsh Creek and Morgan Territory Road.
0.1	5.9	Large quarry cut on your right. Here is exposed Franciscan graywacke that makes up part of the basement core of Mount Diablo. The contact (not exposed) between the basement core and the surrounding unnamed Jurassic-Cretaceous formation is between this quarry and localities 551 and 853.
1.0	6.9	Junction of Marsh Creek and Morgan Territory Roads.
0.0		Turn right on Marsh Creek Road and head east to the top of the first hill.
0.1	7.0	You will see green mudstone in the road cuts at locality 773 that yields Foraminifera indicative of Goudkoff's H zone or older. Proceed east along Marsh Creek Road.
2.6	9.6	Locality 556 is to your left, off the highway, in the bottom of Marsh Creek. Here the dark green mudstone will yield Foraminifera indicative of Goudkoff's G zone or older.
4.3	13.9	Locality 773 is an auger hole in the field to your right. The road cuts on your left will yield equivalent Foraminifera indicative of Goudkoff's G zone or older. Continue east along Marsh Creek Road.
4.55	18.45	Locality 586 to your left in the mudstone of the road cut will yield Foraminifera indicative of Goudkoff's F-2 zone. Continue east along Marsh Creek road.
5.3	23.75	Locality 574 to your left in the mudstone of the road cut will yield Foraminifera indicative of Goudkoff's F-2 zone. Continue east along Marsh Creek Road.
5.5	29.25	Foraminifera indicative of Goudkoff's F-1 zone may be obtained from locality 625 in the road cut to your right. Continue along Marsh Creek Road to the southwest.
7.0	36.25	Turn left on Deer Valley Road.
7.3	43.55	Locality 451 is in the road cut to your right just across the bridge over Marsh Creek. Here Foraminifera from the top of Goudkoff's F-1 zone may be collected. Retrace your route to Marsh Creek Road.
0.3	43.85	Junction of Marsh Creek and Deer Valley Roads.
0.0	0.0	Turn left on Marsh Creek Road and head southeast along Marsh Creek Road.
3.1	46.95	Stop by the bridge over Marsh Creek. Get out of your car and go down to the bed of the creek. The last three localities will be pace distances along the bottom of Marsh Creek, measured from the concrete abutment for the bridge. Start pacing north (down stream) from the concrete abutment.

Distance	
334 paces	Locality 570 in the mudstone exposed in the cut banks of Marsh Creek yielded Foraminifera characteristic of Goudkoff's E zone.
1,111 paces	Locality 460, in the dark brown mudstone of the cut bank to your left, yielded Foraminifera characteristic of Goudkoff's D-2 zone.
2,875 paces	Locality 565, in the dark brown mudstone of the cut bank, yielded Foraminifera characteristic of Goudkoff's C—D-1 zone undifferentiated.

Photo 1. Stone mansion built by John Marsh in 1855, from whom Marsh Creek Road takes its name. The old building still stands. Photo courtesy Pacific Gas and Electric Company.

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IAN CAMPBELL, CHIEF

STATE OF CALIFORNIA
DEPARTMENT OF CONSERVATION

BULLETIN 181 PART 4
MAP 1

Production at Los Medanos gas field from upper Eocene Nortonville Sd and middle Eocene Domengine Sands above and below Mt Diablo Thrust

Production at Willow Pass gas field from Nortonville and Domengine Sands above Mt Diablo Thrust and probably in lower plate

EXPLANATION

QUATERNARY
Qal - Alluvium
Qmz Montezuma
Qt Terrace material

PLIO-PLEIST
Pw - Wolfskill fm
Psv - Sonoma volcanics

MIO-PLIOCENE
Por Orinda fm
Plr - Lawlor tuff
Pp - Pinole tuff

MIOCENE
Msp - San Pablo Undiff
Mn - Neroly ss
Mc - Cierbo ss
Mb - Briones ss
San Pablo
Mm - Monterey Undiff
Mr - Rodeo sh
Mh - Hombre ss
Mt - Tice sh
Monterey

PALEO-EOCENE
Emk - Markley ss
En - Nortonville sh
Ed - Domengine ss
Pmz - Martinez fm

CRETACEOUS
Kc - "Chico" fm
Kkh - Horsetown fm

JURASSIC
Jf - Franciscan fm

Ø Abandoned well
◇ Abandoned well
◆ Producer (gas)
✦ Abandoned producer

GENERALIZED. Based on Weaver, Patton, MS, Shell Oil Co - Tom Wooten, Standard Oil Co, Gulf Oil Corp - Lowell Garrison, Brazos Oil & Gas Co - Bruce O Brooks and unpublished sources

GEOLOGIC MAP OF PORT CHICAGO AND VICINITY

1 ½ 0 1 2 3 Mile

49599

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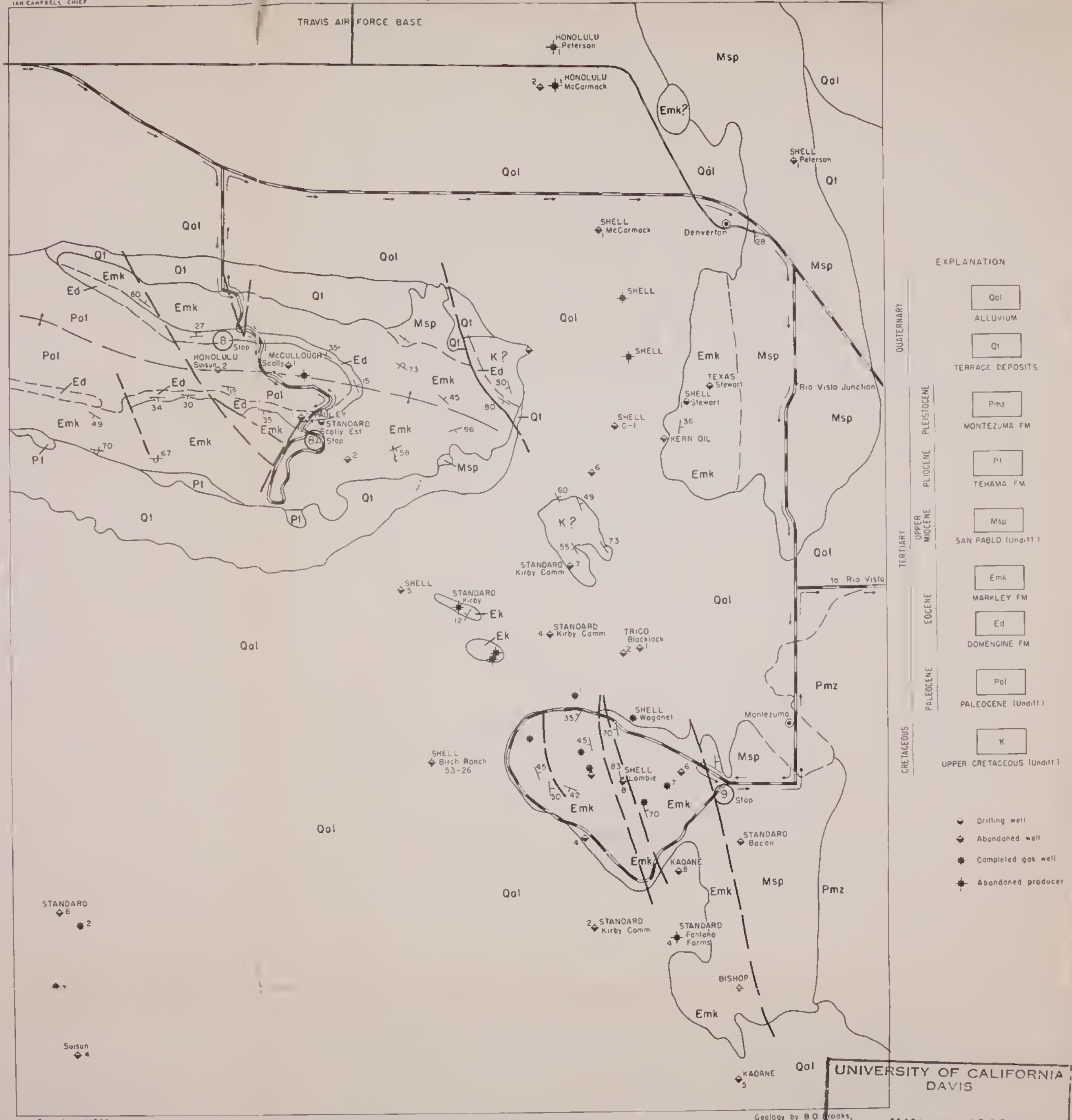
DEPARTMENT OF CONSERVATION

BULLETIN 181 PART 4
MAP



Base from USGS
Denverton Quadrangle

Geology by B O Brooks,
D A Rogers and P Day

GEOLOGIC MAP OF POTRERO-KIRBY HILLS

1 ½ 0 1 MILE

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BULLETIN 181 PART 4
MAP 3

GEOLOGIC MAP OF PUTAH CREEK
MAP 3

Compiled by D.O. Emerson and R.Q. Roberts from
J.M. Kirby (1943) A.A.P.G. Bull. v. 27
H.G. Thomasson, Jr., F.H. Olmsted, E.F. LeRoux (1960) U.S. Geol. Surv. Water Supply Paper 1464
C.E. Weaver (1949) G.S.A. Mem. 35 and
the unpublished work of:
H.A. Boyd, Jr., B.D. Brooks, S. Chuber, D.W. Day, Jr., J.M. Kirby, T.H. Crook, R.A. Marin, E.V. Pease, A.A. Phelps.

Base prepared by Evers Drafting Service from the Monticello Dam, Winters, Mt. Vaca, Allendale, Fairfield North and Elmira U.S. Geol. Surv. 7½" topographic quadrangles

GEOLOGIC COLUMN

AGE		SYMBOL	FORMATION
QUATERNARY		Qyal	Young alluvium
		Qoal	Old alluvium
		Qls	Landslide blocks
TERTIARY	Pliocene	Tt Tta	Tehama formation with Nomlaki tuff member
	Miocene	Tsp	San Pablo
		Tv	Putnam Peak basalt
	Eocene	Tmk	Markley
		Tdn	Domengine-Nortonville undifferentiated
		Tc	Capay
	Paleocene	Tmz	?Martinez formation
CRETACEOUS	Upper	Kuu	Upper Cretaceous undifferentiated ?-E zone
		Kpv	Pleasants Valley shale formation
		Kfu Kfm Kfd	Forbes formation with Upper, Middle, & Dobbins shale members
		Kfdk Kg	Dobbins & Funks undifferentiated Guinda
		Kfs	Funks shale
		Ks	Sites
		Ky	Yolo
		Kv	Venado
		Kb	Basal Upper Cretaceous
	Lower	Kl Klg	Lower Cretaceous rocks with Gordon sandstone

49599

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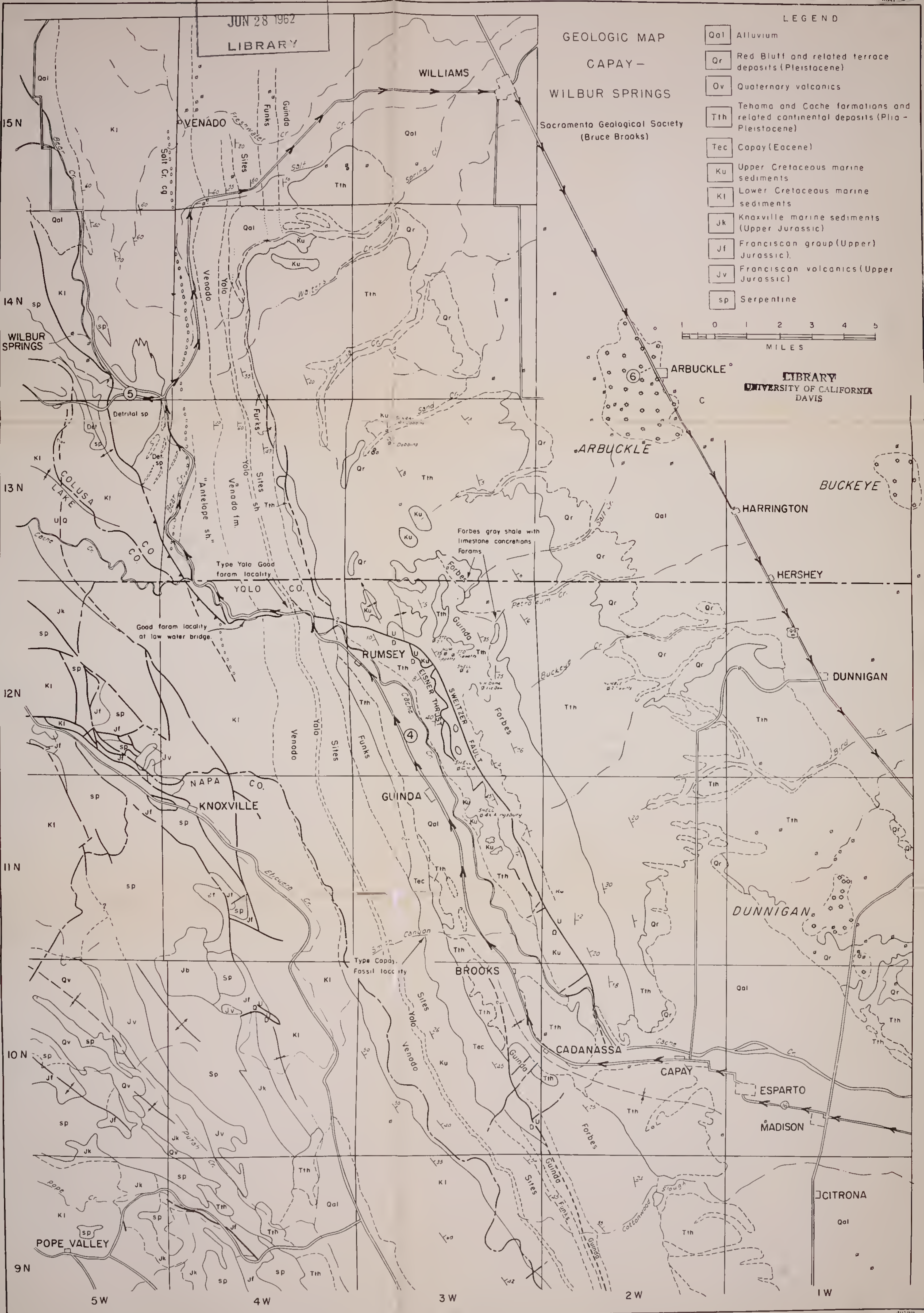
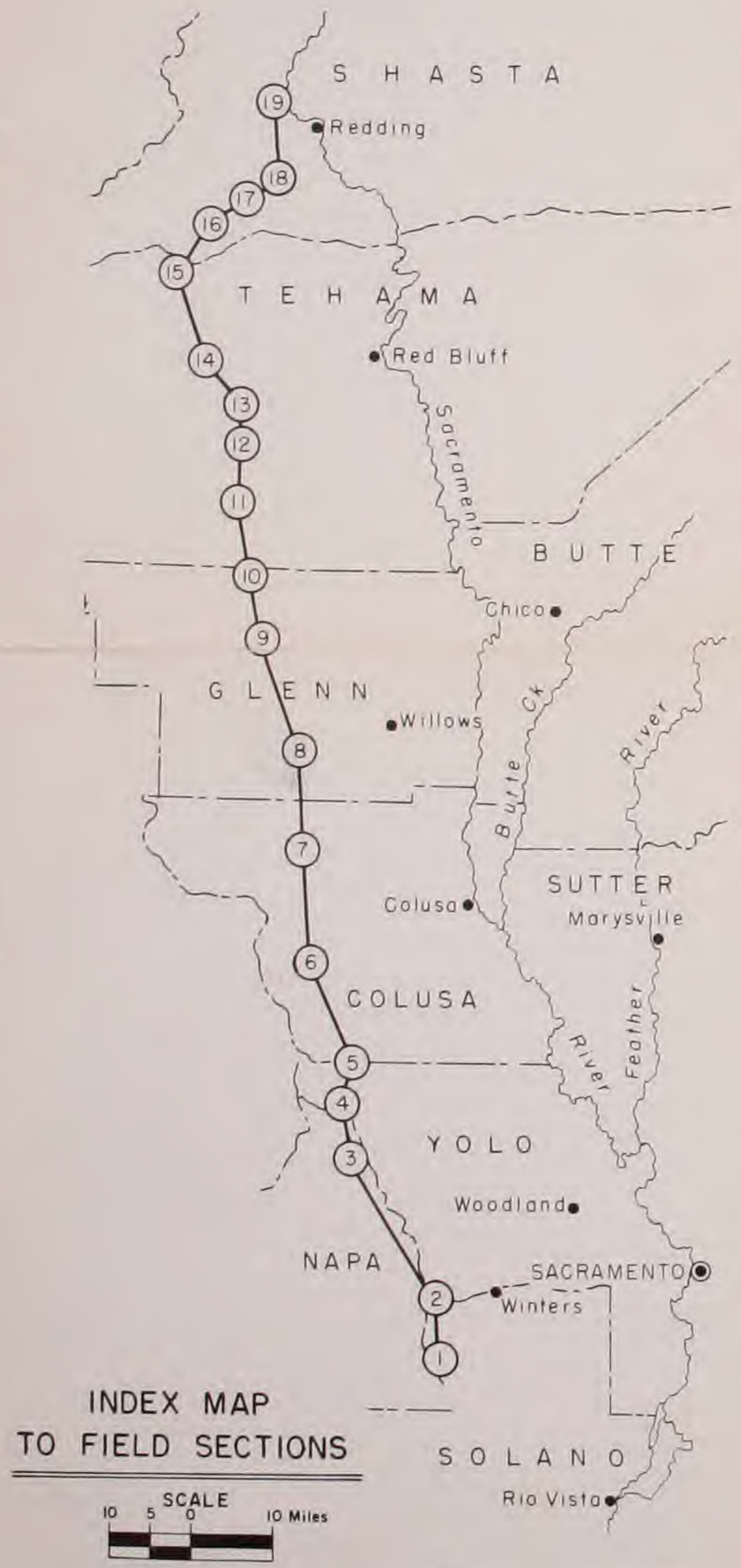
BULLETIN 181 PART 4
MAP 4



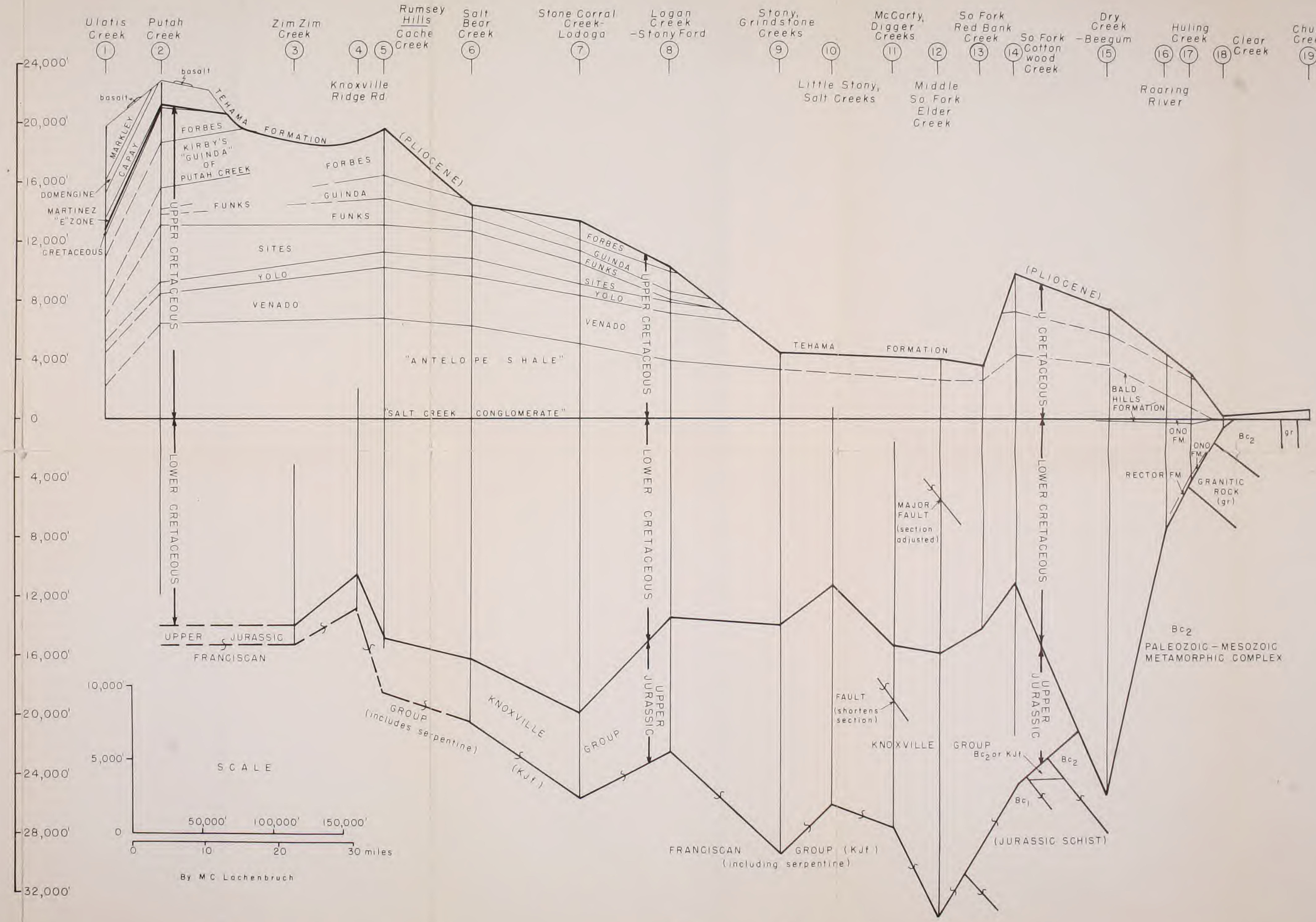
GEOLOGIC MAP
CAPAY – WILBUR SPRINGS

Sacramento Geological Society
(Bruce Brooks)

Index map to field sections.

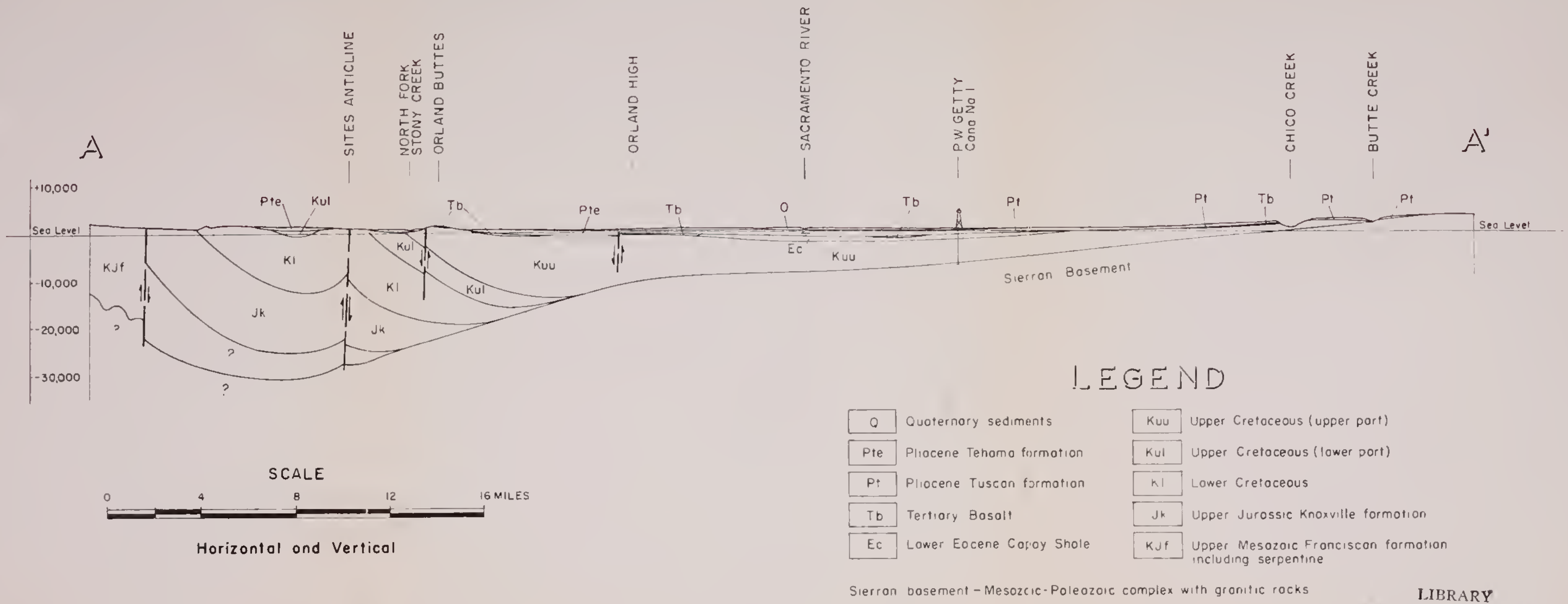


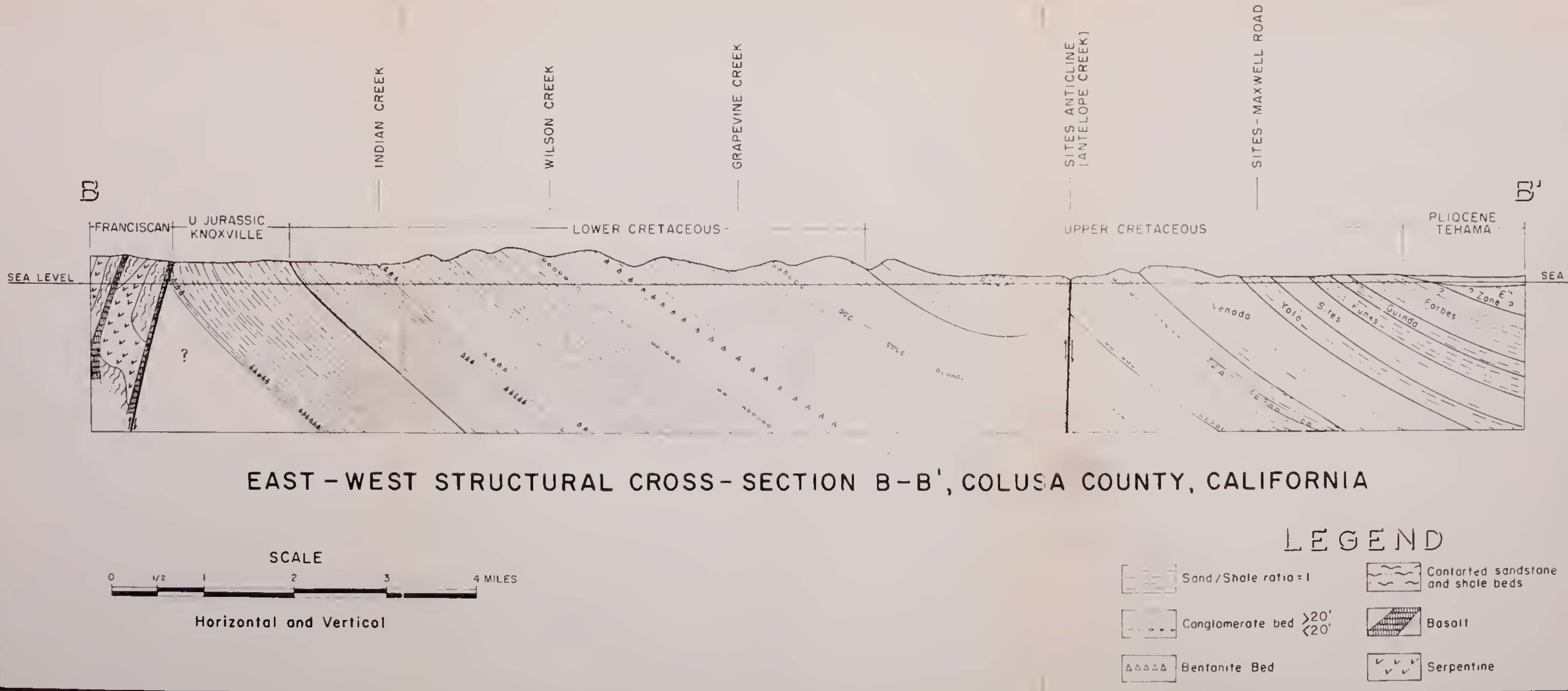
INDEX MAP TO FIELD SECTIONS



By M C Lachenbruch

GENERALIZED CROSS SECTION ALONG LINE A-A' ACROSS SACRAMENTO VALLEY





EAST-WEST STRUCTURAL CROSS-SECTION B-B', COLUSA COUNTY, CALIFORNIA

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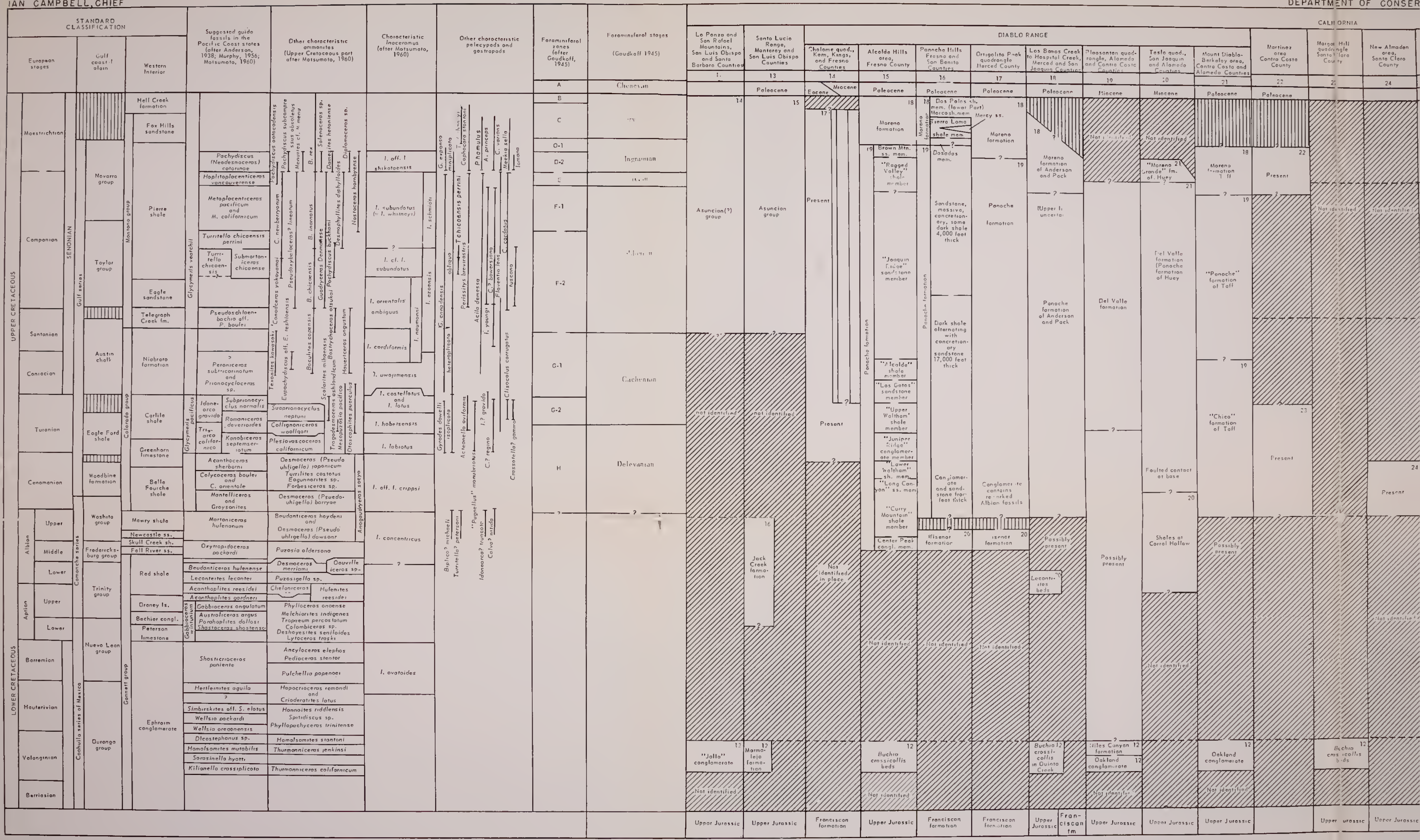
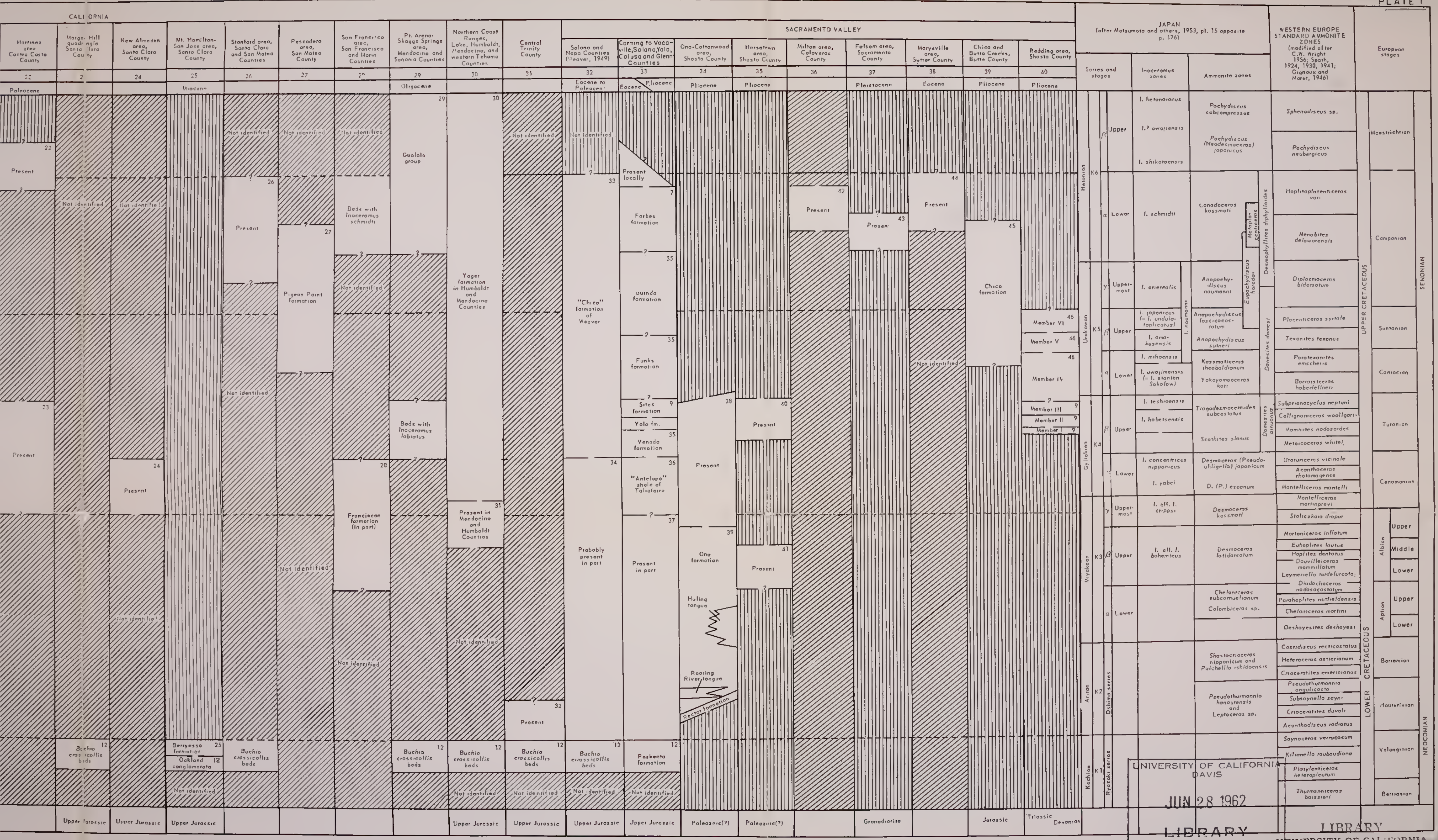
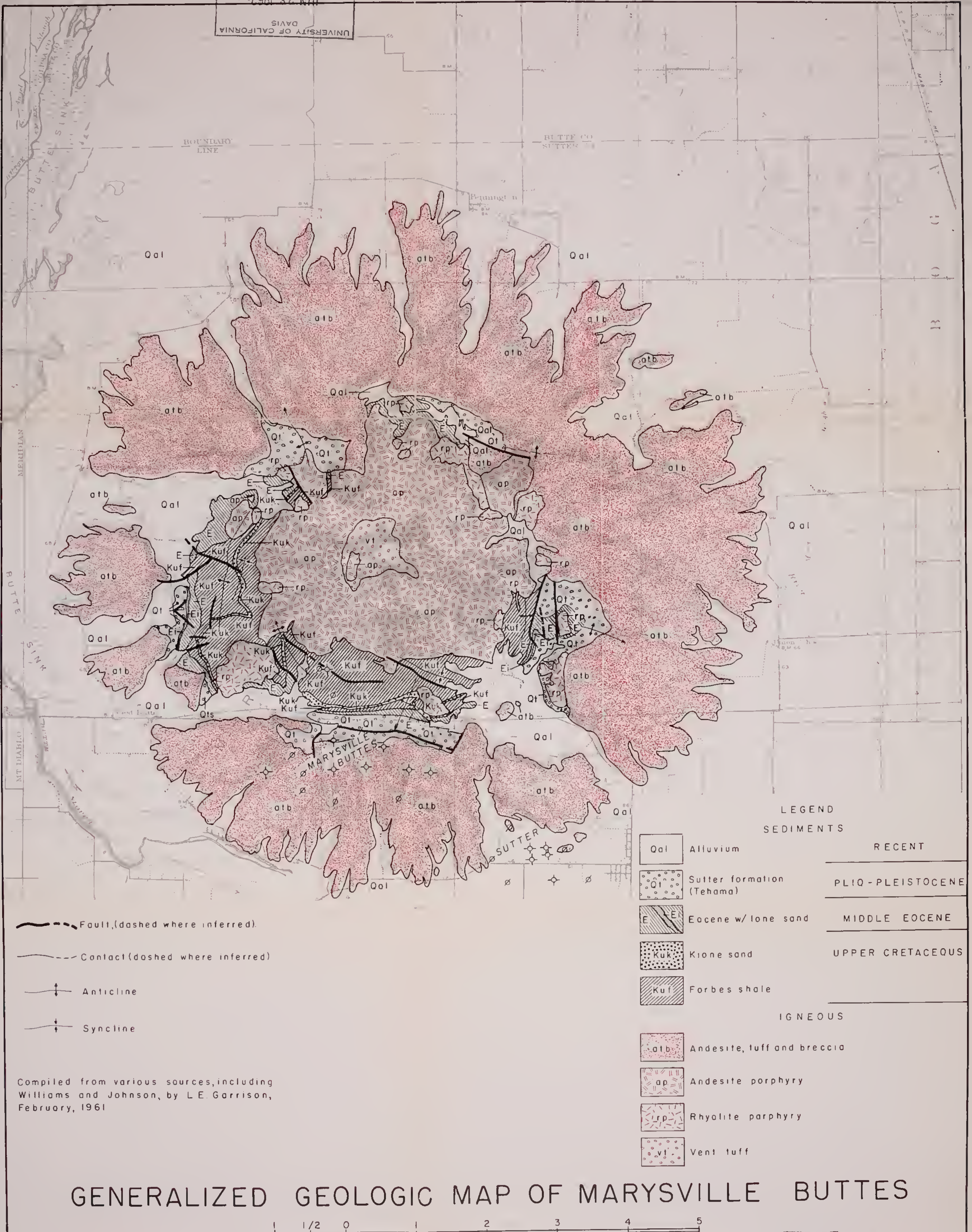
DEPARTMENT OF CONSER



STATE OF CALIFORNIA
DEPARTMENT OF CONSERVATION

BULLETIN 181
PLATE 1





LEGEND

SEDIMENTS

Qal	Alluvium	RECENT
Qt	Sutter formation (Tehama)	PLIO-PLEISTOCENE
E Ei	Eocene w/ Ione sand	MIDDLE EOCENE
Kuk	Kione sand	UPPER CRETACEOUS
Kuf	Forbes shale	

IGNEOUS

atb	Andesite, tuff and breccia
ap	Andesite porphyry
rp	Rhyolite porphyry
vt	Vent tuff

Fault, (dashed where inferred).

Contact (dashed where inferred)

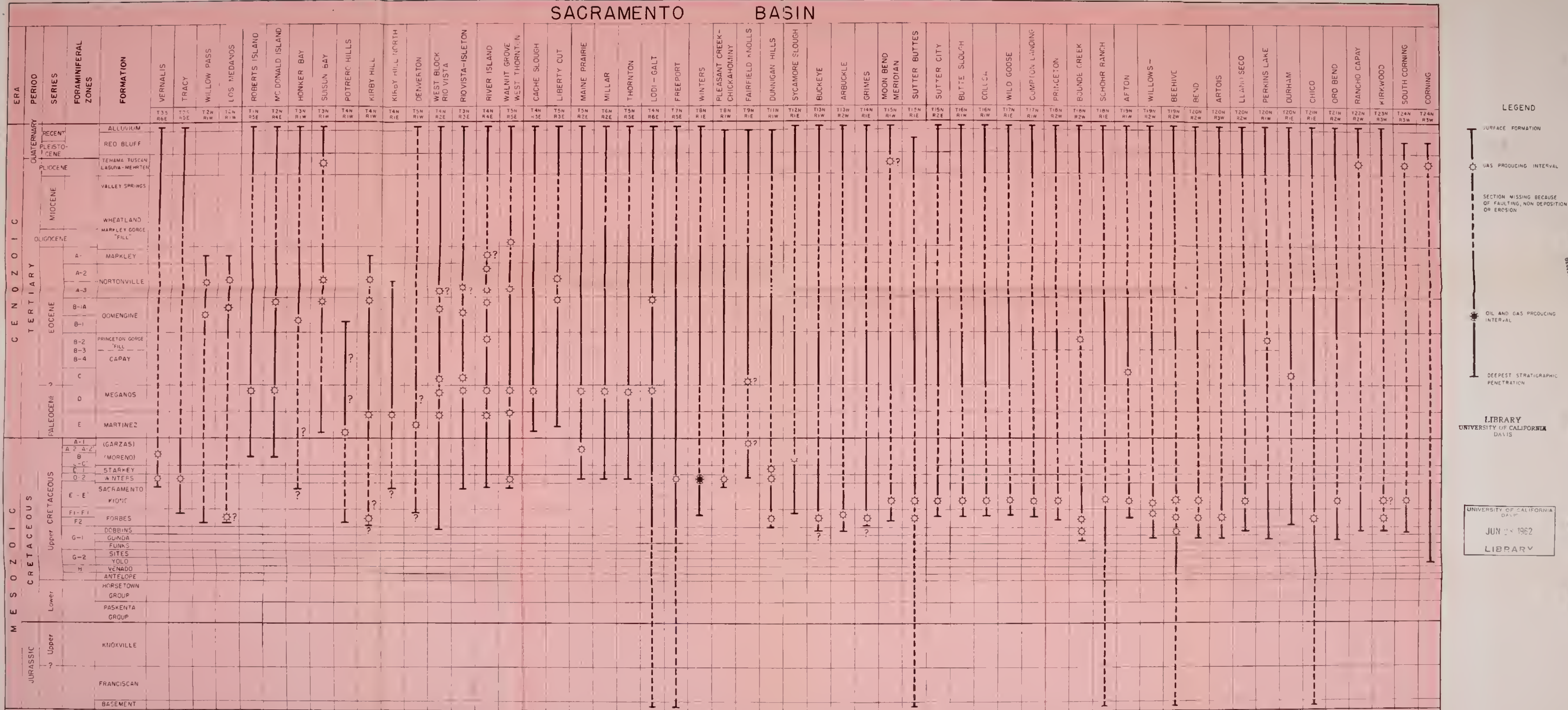
Anticline

Syncline

Compiled from various sources, including Williams and Johnson, by L. E. Garrison, February, 1961

GENERALIZED GEOLOGIC MAP OF MARYSVILLE BUTTES

SACRAMENTO BASIN



	VERNALIS	TRACY	WILLOW PASS	LOS MEDANOS	ROBERTS ISLAND	MC DONALD ISLAND	HONKER BAY	SUISUN BAY	POTRERO HILLS	KIRBY HILL	KIRBY HILL NORTH
	T3S R6E	T2S R5E	T2N R1W	T2N R1W	T1N R5E	T2N R4E	T3N R1W	T3N R1W	T4N R1W	T4N R1W	T4N R1E
YEAR OF FIRST DISCOVERY	1941	1935	1959	1958	1942	1936	1944	1944	1938	1945	1953
PRODUCING WELLS 3-15-60	21	0	4	2	12	16	0	5	0	10	0
GAS PRODUCTION 1959 (MCF/D)	1,366	Abd	Shut-in	310	8,096	82	Abd	7,331	Abd	4,976	Abd
GAS PRODUCTION(MMCF)CUMULATIVE 1-1-60	10,247	13,775	0	139	11,592	151,402	300	30,394	21	34,277	187
EST ORIG. RECOVERABLE RESERVES(MMCF)	14,000	13,700	—	—	25,250	182,000	299	75,000	22	45,200	187
BTU/CU FT	920	930	1,010	1,020	955	962	—	1,030	—	990	—

	DENVERTON	WEST BLOCK RIO VISTA	RIOVISTA-ISLETON	RIVER ISLAND	WALNUT GROVE WEST THORNTON	CACHE SLOUGH	LIBERTY CUT	MAINE PRAIRIE	MILLAR	THORNTON	LODI-GALT
	T5N R1W	T4N R2E	T3N R3E	T4N R4E	T5N R5E	T4N R3E	T5N R3E	T5N R2E	T6N R2E	T5N R5E	T4N R6E
YEAR OF FIRST DISCOVERY	1948	1936	1938	1950	1956	1945	1953	1945	1944	1943	1943
PRODUCING WELLS 3-15-60	0	150		50	19	4	4	20	3	11	7
GAS PRODUCTION 1959 (MCF/D)	Abd	159,369		8,553	1,442	1,061	58	10,121	104	6,782	3,071
GAS PRODUCTION(MMCF)CUMULATIVE 1-1-60	231	1,960,068		37,167	598	10,825	170	28,939	9,494	39,646	14,002
EST ORIG. RECOVERABLE RESERVES(MMCF)	231	3,125,000		49,000	—	12,200	—	67,250	20,500	127,000	—
BTU/CU FT	—	990 to 1,070		1,000	950	1,000	996	1,040	980	960	715

	FREEPORT	WINTERS	PLEASANT CREEK-CHICKAHOMINY	FAIRFIELD KNOLLS	DUNNIGAN HILLS	SYCAMORE SLOUGH	BUCKEYE	ARBUCKLE	GRIMES	MOON BEND MERIDIAN	SUTTER BUTTES
	T7N R5E	T8N R1E	T8N R1W	T9N R1E	T11N R1W	T12N R1E	T13N R1W	T13N R2W	T14N R1E	T15N R1W	T15N R1E
YEAR OF FIRST DISCOVERY	1952	1946	1948	1937	1946	1953	1960	1957	1960	1954	1933
PRODUCING WELLS 3-15-60	1	11	3	0	11	3	5	26	4	1—1	10
GAS PRODUCTION 1959 (MCF/D)	293	4,542	Standing	Abd	718	305	Shut-in	10,287	Shut-in	Shut-in	1,285
GAS PRODUCTION(MMCF)CUMULATIVE 1-1-60	1,628	18,276	3,579	2,521	9,303	517	0	7,418	0	0	15,109
EST ORIG. RECOVERABLE RESERVES(MMCF)	3,000	27,000	6,500	2,500	13,200	2,200	—	80,000	—	—	29,200
BTU/CU FT	910	900	990	—	970	—	1,015	1,000	1,000	—	1,000

	SUTTER CITY	BUTTE SLOUGH	COLUSA	WILD GOOSE	COMPTON LANDING	PRINCETON	BOUNDE CREEK	SCHOHR RANCH	AFTON	WILLOWS-	BEEHIVE
	T15N R2E	T16N R1W	T16N R1W	T17N R1E	T17N R1W	T18N R2W	T18N R2W	T18N R1E	T19N R1W	T19N R2W	T19N R2W
YEAR OF FIRST DISCOVERY	1952	1955	1943	1951	1955	1953	1956	1957	1944	1953	1954
PRODUCING WELLS 3-15-60	4	1	0	9	8	3	4	3	2	80	
GAS PRODUCTION 1959 (MCF/D)	4,569	Shut-in	—	15,186	2,515	1,391	7,272	82	226	80,006	
GAS PRODUCTION(MMCF)CUMULATIVE 1-1-60	6,688	0	—	33,768	1,185	2,637	3,042	37	4,098	73,191	
EST ORIG. RECOVERABLE RESERVES(MMCF)	—	—	—	98,000	17,200	5,700	—	—	5,700	275,000	
BTU/CU FT	900	—	—	810	810	980	990	840	770	973 to 993	

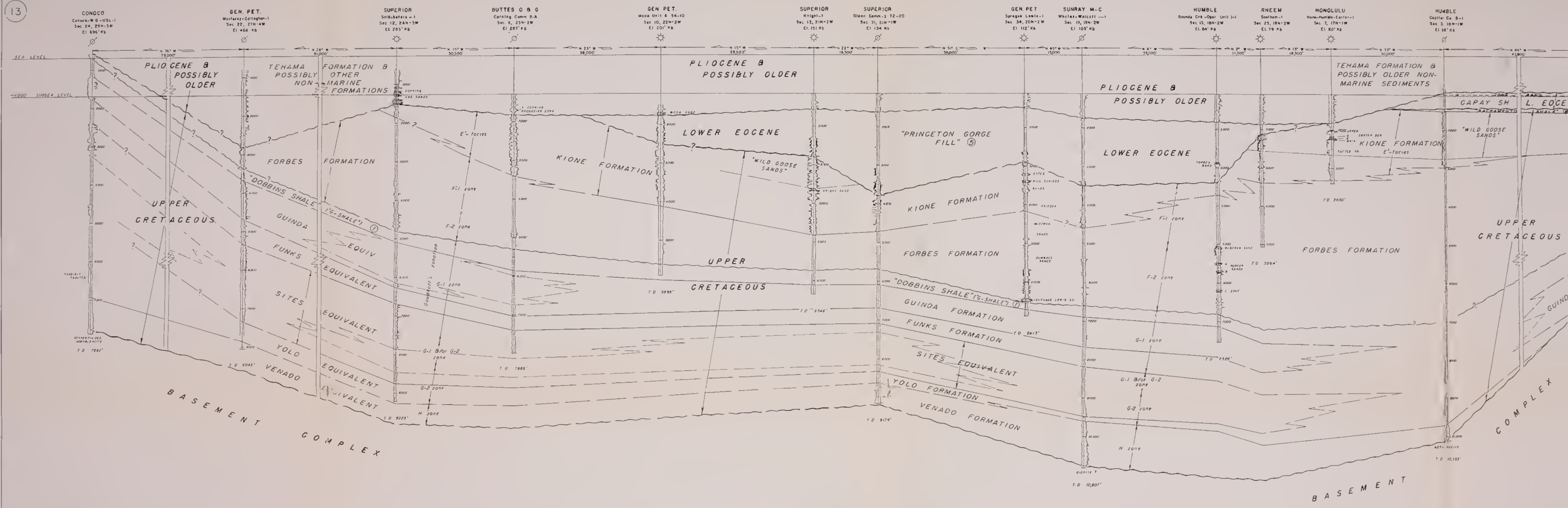
	BEND	ARTOIS	LLANO SECO	PERKINS LAKE	DURHAM	CHICO	ORO BEND	RANCHO CAPAY	KIRKWOOD	SOUTH CORNING	CORNING
	T20N R2W	T20N R3W	T20N R2W	T20N R1W	T20N R1E	T21N R1E	T21N R2W	T22N R2W	T23N R3W	T24N R3W	T24N R3W
YEAR OF FIRST DISCOVERY	1938	1959	1954	1955	1946	1944	1943	1959	1958	1951	1944
PRODUCING WELLS 3-15-60		1	0	5	4	1	3	1	4	4	13
GAS PRODUCTION 1959 (MCF/D)		4	1,119	6,283	2,599	81	890	Shut-in	Shut-in	0	2,983
GAS PRODUCTION(MMCF)CUMULATIVE 1-1-60		1.6	2,241	6,764	6,684	1,194	8,086	0	0	556	5,741
EST ORIG. RECOVERABLE RESERVES(MMCF)		—	2,500	28,500	11,300	1,700	14,500	—	—	4,500	28,700
BTU/CU FT		1,010	960	950	720	865	910	860	—	870	760

SACTO PET ASSOC

PENETRATION CHART- OIL AND GAS FIELDS OF SACRAMENTO BASIN

DIVISION OF MINES AND GEOLOGY
IAN CAMPBELL, CHIEF

STATE OF CAL
DEPARTMENT OF CO



CORRELATION SECTION
LONGITUDINALLY NORTH-SOUTH THROUGH
SACRAMENTO VALLEY
FROM
RED BLUFF TO RIO VISTA
CALIFORNIA

PREPARED BY THE SACRAMENTO VALLEY SUB-COMMITTEE OF THE
A A P G COMMITTEE ON STRATIGRAPHIC CORRELATIONS

[illegible] CHAIRMAN

[illegible]
[illegible]

HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION 10

[illegible] 1960

PUBLISHED BY PACIFIC SECTION
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

[illegible]

[illegible]
Pacific Coast Sub-Committee on Stratigraphic Correlation
[illegible]

PUBLISHED CORRELATION SECTIONS

①	SACRAMENTO VALLEY-SOUTH	(1951)
②	VENTURA BASIN-EAST	(1952)
③	LOS ANGELES BASIN	(1952)
④	SALINAS VALLEY	(1952)
⑤	VENTURA BASIN-WEST	(1952)
⑥	NORTHERN SACRAMENTO VALLEY	(1954)
⑦	VENTURA BASIN-CENTRAL	(1956)
⑧	SAN JOAQUIN VALLEY-SOUTH	(1957)
⑨	SAN JOAQUIN VALLEY-CENTRAL	(1957)
(10N) (10S)	SAN JOAQUIN VALLEY-CENTRAL AND LONGITUDINAL	(1958)
⑪	SAN JOAQUIN VALLEY-WESTSIDE	(1959)
⑫	SANTA MARIA BASIN	(1959)
⑬	SACRAMENTO VALLEY-NORTH-SOUTH	(1960)

NOTES

THE FOLLOWING UNPUBLISHED SUBSURFACE UNITS HAVE BEEN ADOPTED FOR USE ON THIS CORRELATION SECTION

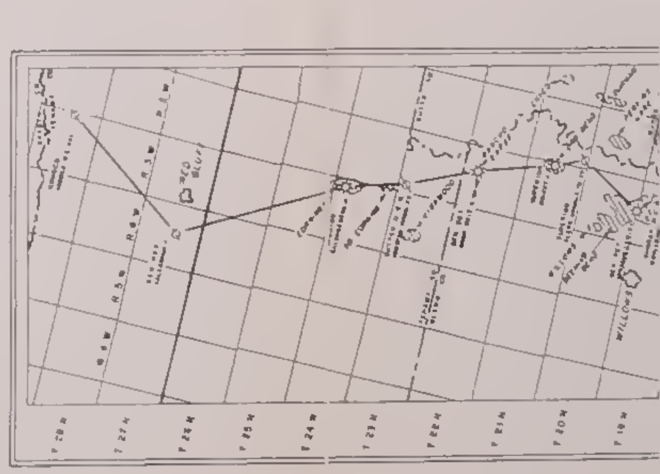
① "DOBBINS SHALE", ALSO KNOWN AS "G-SHALE", IS THE SHALE PRESENT IN THE INTERVAL 822 TO 1138' IN THE SUNRAY MID-CONTINENT OIL COMPANY DOBBINS UNIT NO 1, SECTION 5, T-13-N, R-3-W, M D B & M, ABANDONED AUGUST 1956. THE "DOBBINS SHALE" IS BENTONITIC, GRAY TO BLUISH GRAY IN COLOR, UPPER CRETACEOUS IN AGE, AND CONTAINS RADIOLARIAN FLOODS AND FORAMINIFERAL FAUNAS EQUIVALENT IN AGE TO P P GOUDKOFF'S G-1 FAUNAL ZONE. THIS UNIT WAS INCLUDED IN THE BASE OF THE FORBES FORMATION BY J M KIRBY ON THE CREST OF RUMSEY HILLS, HOWEVER, THE FORBES FORMATION IS HERE RESTRICTED TO THE OVERLYING SANDS AND SHALES WHICH NORMALLY CONTAIN F ZONE FAUNAS. THE "DOBBINS SHALE" UNCONFORMABLY UNDERLIES THE SANDS AND SHALES OF THE RESTRICTED FORBES FORMATION AND OVERLIES THE SANDSTONES OF THE GUINDA FORMATION.

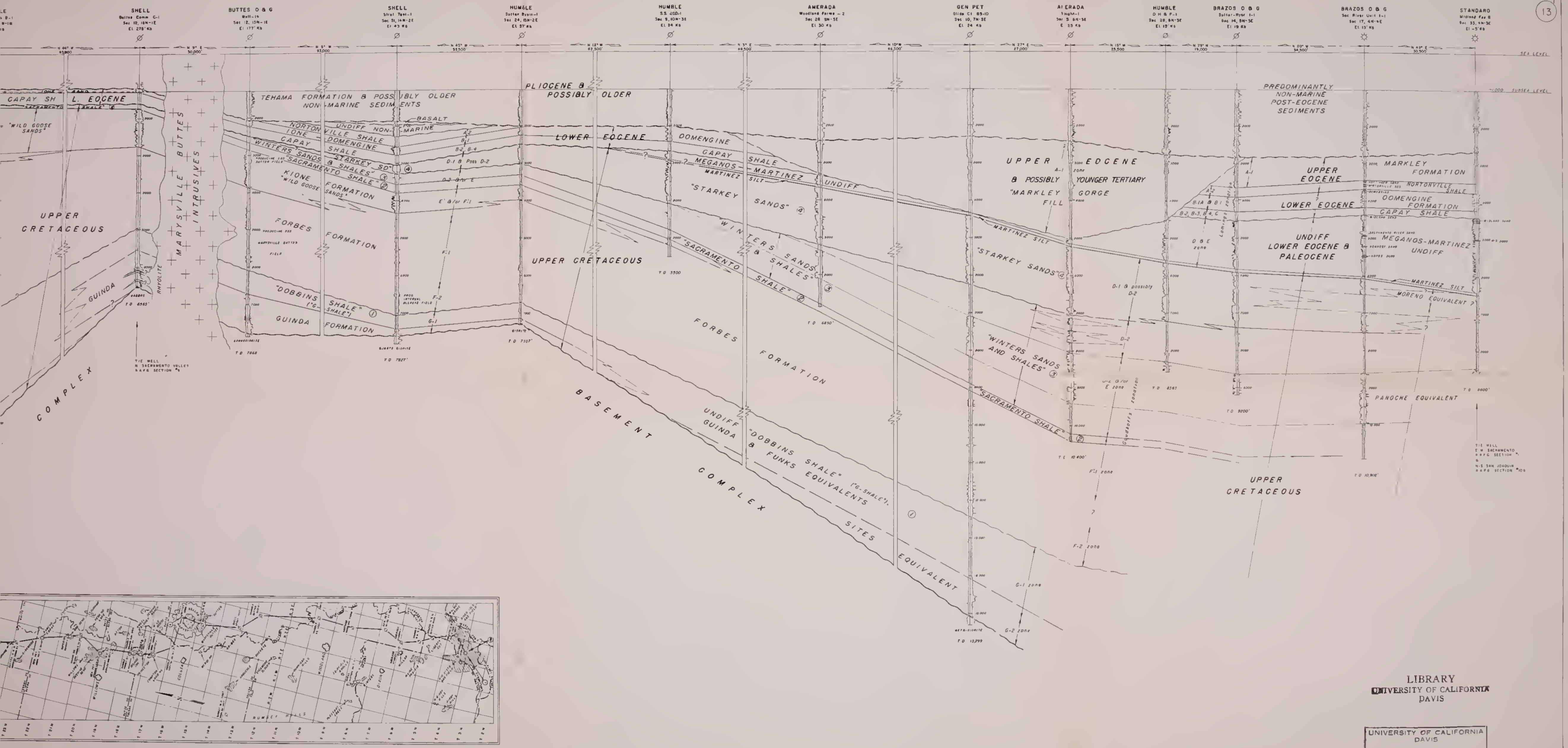
② "SACRAMENTO SHALE", WAS DESCRIBED BY A A HOPKINS BEFORE THE PACIFIC SECTION, A A P G, 1955 CONVENTION AS THE SILTSTONE WHICH CONFORMABLY OVERLIES THE KIONE SAND AND IS CONFORMABLY OVERLAIN BY THE "WINTERS SAND". THE "SACRAMENTO SHALE" IS TYPICALLY 150 TO 300' THICK AND LIGHT GRAY IN COLOR. IT OFTEN CONTAINS RADIOLARIAN FLOODS AND HAS FORAMINIFERAL FAUNAS EQUIVALENT IN AGE TO GOUDKOFF'S UPPER CRETACEOUS F AND F-1 ZONES. THIS UNIT IS PRESENT IN THE CENTRAL AND SOUTHERN PORTIONS OF THE SACRAMENTO VALLEY.

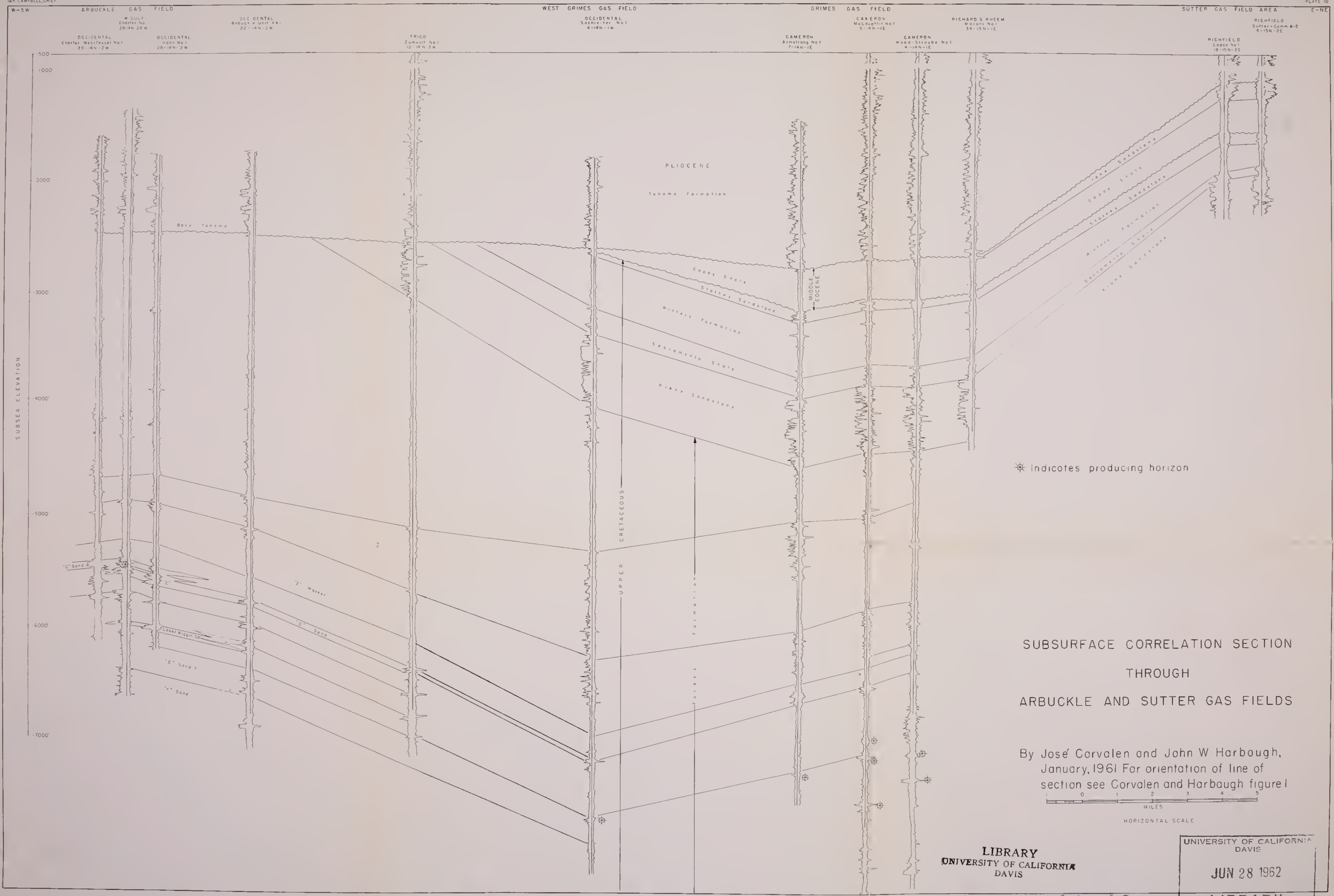
③ "WINTERS SANDS AND SHALES" ARE THOSE SANDS AND SHALES IN THE INTERVAL 4405 TO 8875' IN THE SHELL OIL COMPANY WINTERS UNIT NO 2-1, SECTION 18, T-8-N, R-1-E, M D B & M, GAS WELL COMPLETED MARCH 1947. THIS UNIT COMMONLY CONSISTS OF AN UPPER AND LOWER SHALE MEMBER INTERBEDDED WITH THIN SANDS AND A MIDDLE MEMBER OF MASSIVE, THICK LIGHT GRAY SANDS. THE "WINTERS SANDS AND SHALES" ARE UPPER CRETACEOUS AND RANGE IN AGE FROM GOUDKOFF'S D-2 TO E ZONE. THE UNIT CONFORMABLY OVERLIES THE SACRAMENTO SHALE AND LOCALLY UNCONFORMABLY UNDERLIES THE STARKEY SANDS IN THE AREA SOUTH OF THE MARYSVILLE BUTTES.

④ "STARKEY SANDS", ARE THOSE SANDS PRESENT IN THE INTERVAL 5596 TO 8087' IN THE AMERADA PETROLEUM CORPORATION STARKEY FEE NO 1, SECTION 2, T-8-N, R-2-E, M D B & M, GAS WELL COMPLETED AUGUST 1944. THE "STARKEY SANDS" ARE LIGHT GRAY, THICK AND MASSIVE. THEY ARE UPPER CRETACEOUS IN AGE AND ARE TYPICALLY EQUIVALENT TO GOUDKOFF'S D-1 ZONE. FAUNA OF D-2 AGE HAVE OCCASIONALLY BEEN NOTED IN THE LOWER PORTION AND C ZONE FAUNA HAVE BEEN ENCOUNTERED IN SHALES EQUIVALENT TO THE UPPER PORTION. THE "STARKEY SANDS" ARE GENERALLY FOUND IN THE SOUTHERN HALF OF THE SACRAMENTO VALLEY, WHERE THEY LOCALLY UNCONFORMABLY OVERLIE THE "WINTERS SANDS AND SHALES" AND ARE OVERLAIN BY THE PALEOCENE MARTINEZ SILT.

⑤ "PRINCETON GORGE FILL" IS THAT UNIT PRESENT IN THE INTERVAL 1826 TO 5414 IN THE HUMBLE OIL & REFINING COMPANY MANUEL S TORRES NO B-1, HOLE 2, SECTION 12, T-18-N, R-2-W, M D B & M, GAS WELL COMPLETED JANUARY 1957. THE "PRINCETON GORGE FILL" TYPICALLY CONSISTS OF A THICK, HOMOGENEOUS, LIGHT GREENISH-GRAY SHALE AND A BASAL CONGLOMERATE. LOCALLY, INTERBEDDED SANDS AND CONGLOMERATES OCCUR THROUGHOUT THE SECTION. THE UNIT CONTAINS A DEPAUPERATE FAUNA OF LOWER EOCENE AGE AND OVERLIES THE UPPER CRETACEOUS WITH MARKED UNCONFORMITY. IT IS IN TURN UNCONFORMABLY OVERLAIN BY THE TEHAMA FORMATION. THIS UNIT IS MOST COMMONLY FOUND IN THE NORTHERN HALF OF THE SACRAMENTO VALLEY.




SHELL
BUTTES O & G
SHELL
HUMBLE
HUMBLE
AMERADA
GEN PET
AMERADA
HUMBLE
BRAZOS O & G
BRAZOS O & G
STANDARD
SEA LEVEL
-1000 SUBSEA LEVEL
CAPAY SH
L. EOCENE
"WILD GOOSE SANDS"
UPPER CRETACEOUS
GUINDA
COMPLEX
RHYOLITE
MARYSVILLE BUTTES INTRUSIVES
TIE WELL N. SACRAMENTO VALLEY A.A.P.G. SECTION #5
TEHAMA FORMATION & POSSIBLY OLDER NON-MARINE SEDIMENTS
BASALT
NORTONVILLE SHALE
UNDIFF NON-MARINE
IONE - DOMENGINE
CAPAY SHALE
WINTERS SANDS & "STARKEY SD"
"SACRAMENTO SHALES"
KIONE FORMATION
"WILD GOOSE SANDS"
FORBES FORMATION
"DOBBINS SHALE" ("G-SHALE")
GUINDA FORMATION
PLIOCENE & POSSIBLY OLDER
LOWER EOCENE
DOMENGINE
CAPAY SHALE
MEGANOS - MARTINEZ UNDIFF
MARTINEZ SILT
"STARKEY SANDS"
"WINTERS SANDS & SHALES"
"SACRAMENTO SHALE"
UPPER CRETACEOUS
FORBES FORMATION
BASEMENT COMPLEX
UNDIFF GUINDA & "DOBBINS SHALE" ("G-SHALE"), FUNKS EQUIVALENTS
SITES EQUIVALENT
UPPER EOCENE & POSSIBLY YOUNGER TERTIARY
"MARKLEY GORGE FILL"
MARTINEZ SILT
"STARKEY SANDS"
"WINTERS SANDS AND SHALES"
SACRAMENTO SHALE
PREDOMINANTLY NON-MARINE POST-EOCENE SEDIMENTS
MARKLEY FORMATION
UPPER EOCENE
NORTONVILLE SHALE
DOMENGINE FORMATION
LOWER EOCENE
CAPAY SHALE
UNDIFF LOWER EOCENE & PALEOCENE
MEGANOS-MARTINEZ UNDIFF
MARTINEZ SILT
MORENO EQUIVALENT ?
PANOCHE EQUIVALENT
UPPER CRETACEOUS
TIE WELL E.W. SACRAMENTO A.A.P.G. SECTION #7 & N-S SAN JOAQUIN A.A.P.G. SECTION #10
D-1 & possibly D-2
F-1 zone
F-2 zone
G-1 zone
G-2 zone
T.D. 10,400'
T.D. 13,399
T.D. 9200'
T.D. 10,900'
T.D. 6650'
T.D. 5500
T.D. 7107'
T.D. 7827'
T.D. 7868
T.D. 6565'
DUNNIGAN HILLS



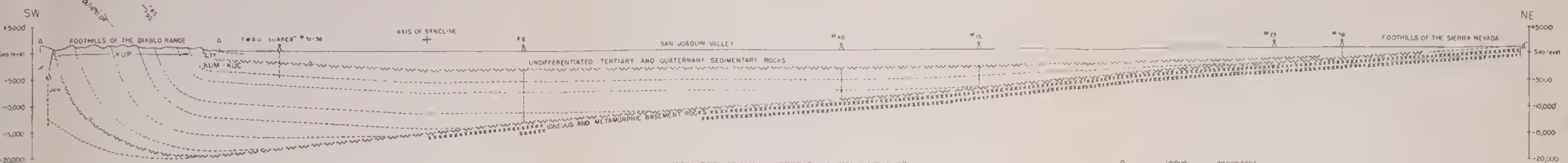
✻ Indicates producing horizon

SUBSURFACE CORRELATION SECTION
THROUGH
ARBUCKLE AND SUTTER GAS FIELDS

By José Corvalen and John W Harbaugh, January, 1961 For orientation of line of section see Corvalen and Harbaugh figure 1

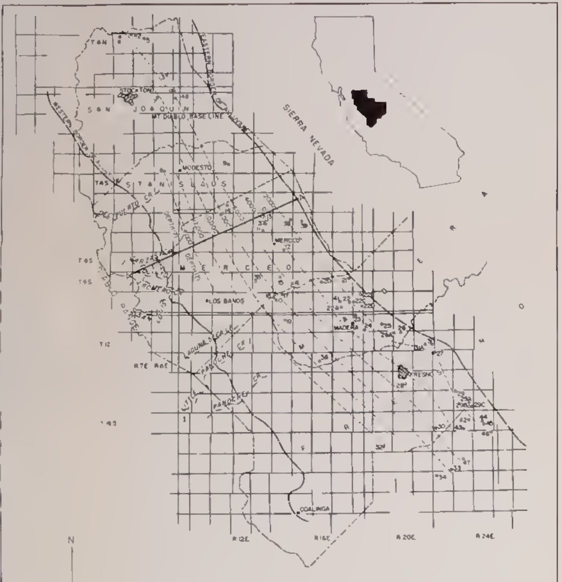
plate 10

GENERALIZED GEOLOGIC MAP ALONG LINE OF SECTION A–A'

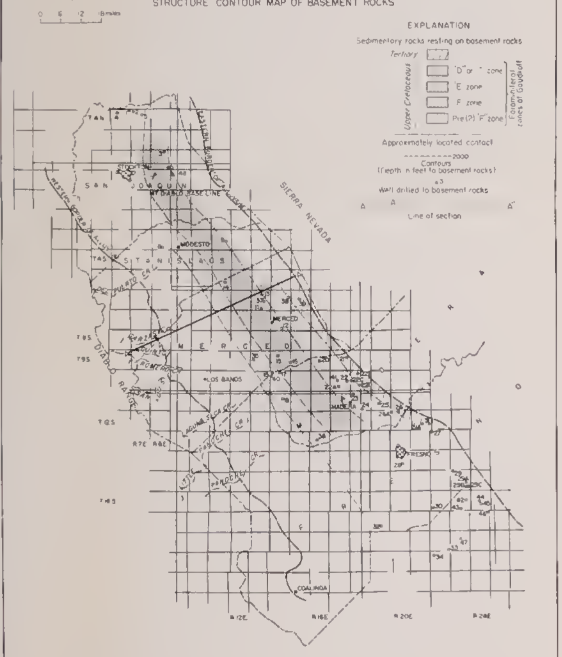


GENERALIZED GEOLOGIC SECTION ALONG LINE A A'

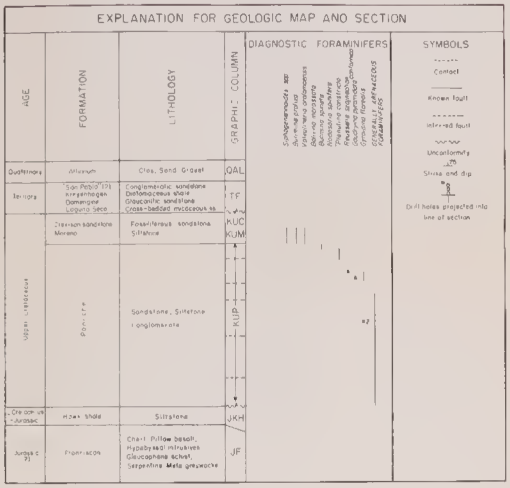
0 10,000 20,000 FEET



STRUCTURE CONTOUR MAP OF BASEMENT ROCKS



MAP SHOWING AGE OF SEDIMENTARY ROCKS OVERLYING BASEMENT ROCKS



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Taliaferro, Nicholas L., 1943, Franciscan-Knoxville Problem: Am. Assoc. Petroleum Geologists Bull., v. 27, p. 129.

The author is particularly indebted to geologists of the Humble Oil and Refining Company, Union Oil Company of California and the Ohio Oil Company for information obtained from wells and for critically reviewing this section.

Grateful thanks are extended to S. W. Muller for his helpful comments and suggestions.

NUMBER	NAME	DEPTH TO BASEMENT (FEET)	AGE OF SEDIMENT OVERLYING BASEMENT [1]	BASEMENT ROCK
1	Bankline Oil Co.; Community 2-1	5,702	F zone	Diorite.
2	Union Oil Co.; Union-Brazos-Gruessendorf 1.	4,804	do	Granitic
3	Amerada Petroleum Corp., Martinet 25-2.	4,319	Probably E zone	Dark gray slate underlain by abundantly pyritized, fractured gneiss.
4	Sunray Mid-Continent Oil Co., Shell-Brovelli 1.	7,298	F zone	
5	Amerada Petroleum Corp., Comm. 9-1.	4,471	F zone	
6	Lee-Cal. Co. and J. W. Wood, Unit No. 1.	5,072	D zone	
7	Richfield Oil Corp.; East Stockton 1	8,544	E zone	Quartz diorite.
8	Standard Oil Co., Young Comm. 1	13,683	G(?) zone	Granitic
9	Cooper, Paul L. and others, Meissner	3,301	Upper Cretaceous, younger than E zone	Do.
10	Richfield Oil Corp., Parker 1	3,689	E zone	Do.
11	Richfield Oil Corp., Henderson 1	4,613	D zone or thin E zone	Do.
12	Richfield Oil Corp., Fancher 54-34.	4,110	D zone or possibly thin E zone.	Slightly metamorphosed sediment
13	Malis, Sam, Parker 1	3,623	D zone or thin E zone	Granitic.
14	Ohio Oil Co.; Evans and Cook 1	6,552	D zone or possibly thin E zone.	Granodiorite
15	Richfield Oil Corp.; Silveira 1	6,159	Probably E zone (D-2 to E)	Diorite
16	Shell Oil Co.; Elias 47X-19	5,493	E zone	Granitic
17	Shell Oil Co., Stratigraphic Test 1.	7,289	E zone	Granodiorite
18	Tidewater Oil Co., Southern Realty 1-6.	8,369	F zone	Do.
19	Shell Oil Co.; Chowchilla Farms 74-9.	9,062	do	Granular amphibolite.
20	Union Oil Co., Gamble 7	3,085	E zone, possibly basal D-zone.	Granitic
21	Pacific West Oil Corp. and Getty, George F., Clifford 1	[illegible]		
22	Von Glahn Oil Co., Inc., Mendoza 1.	[illegible]		Granitic
22A	Blake, Thomas M., Chuck 1	3,816	Probably D-2 zone	Top schist, 3,8[illegible] feet, top granite 4,[illegible] feet
22B	Willard, E. T.; Hay 2	1,180		Granitic
22C	Union Oil Co.; Archibald 1	71.		Diorite.
22D	Union Oil Co., Moses 1	1,746		Quartz monzonite
23	Union Oil Co., Floto 1	2,677	D-1 zone	Serpentine-biotite-quartz [illegible]
24	Union Oil Co.; Pacific Land 1	3,670	D-1 or 2 zone	Granodiorite
25	Union Oil Co., Smith 1	[illegible],195	do	Do
26	Brown and Dawson, No. 1	957		Granitic
26A	Union Oil Co., Foss 1	1,134		Diorite
27	Taylor Oil Co.; No. 1	2,120		
28	Mid-Cal Oil and Gas Co., Mid-Cal-Suglian 1	4,500		Granitic
29	Riverbend Oil Corp., Guggenbine 1	1,401		
29A	Amerada Petroleum Corp., Community 2-1.	1,010		
29B	Amerada Petroleum Corp., Community 5-1	815		
29C	Amerada Petroleum Corp., Community 6-1.	1,088	Undifferentiated continental beds.	
30	Superior Oil Co., Wite 1	5,468	Cretaceous continental beds	Quartz diorite
31	Kirk, L. J. and Plakeman, Harry, Lehman 1.	350		Granitic
31A	Kirk, L. J. and Sagniere	355		Do.
32	Amerada-Lawton 58-26	12,9[illegible]	F zone	Metamorphosed shale or argillite-bearing *Pseudomonotis* (dip 6[illegible])
33	Continental Oil Co., Drummond 1	7,847		Diabase.
34	Standard Oil Co., Mills 1	9,211	Upper Cretaceous	
35	Western Gulf Oil Co., Potter 1	8,374	F zone	Granitic
36	Texas Gill 38-16	9,154	do	Serpentine
37	Wadley, Jennings 1	3,465	D zone or thin E zone	Granitic.
38	Richfield, Smith 1	1,860	Post-Cretaceous	Do.
39	Richfield, Crocker Huffman	694		Andalusite hornfels
40	Pure Oil Co., Chowchilla 1	8,344	F zone	Quartz diorite
41	Barnhardt-Morrow, Arnold 1	3,204	D zone or possibly E zone	Do.
42	Gene Reid, Giannini-1	2,447	Undifferentiated Continental beds.	Slate at 2,357 feet, igneous rock at 2,411 feet
43	Transcal Drilling Co., Harris 1	2,603		Quartz-graphite-sericite schist
44	Amerada Petroleum Corp., Comm. 21-1.	518		Gabbro.
45	Amerada Petroleum Corp., Comm. 28-1.	907		Diorite.
46	Schneider, Winifred, Pritchett 1	1,334		Quartz diorite
47	McDuffie, Wm. C., Bennett 1	5,370	Undifferentiated Upper Cretaceous marine and non-marine strata	Quartz-sericite schist with graphite
48	Richfield Oil Corp.: Stockton 2	6,340	E zone	Do.

[1] In terms of Upper Cretaceous Foraminiferal "zones" of Goudkoff.

GENERALIZED GEOLOGIC SECTION OF THE CENTRAL SAN JOAQUIN VALLEY, CALIFORNIA

GEOLOGY BY F.A. SCHILLING JR. 1960

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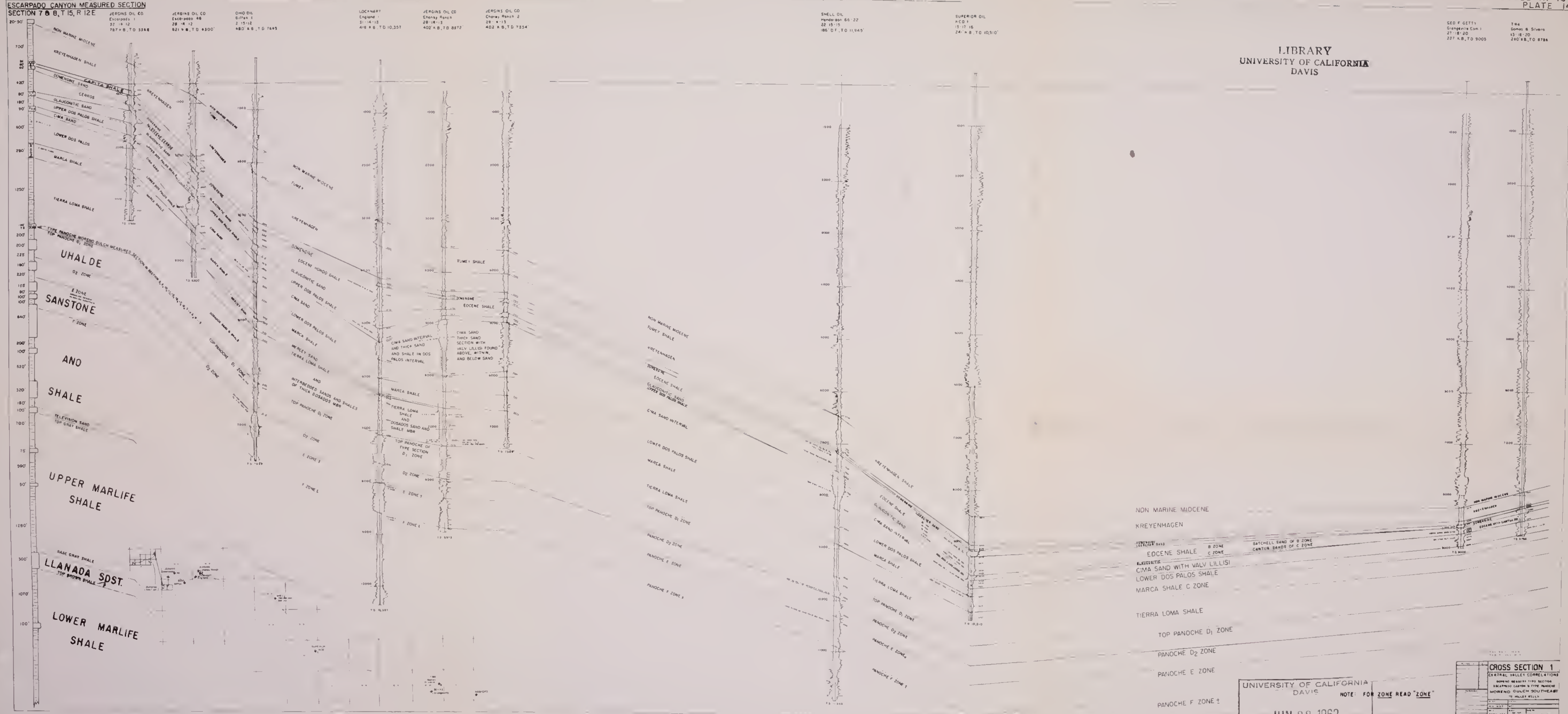
DEPARTMENT OF CONSERVATION

BULLETIN 181
PLATE 14



NOTE: FOR ZONE READ "ZONE"

CROSS SECTION 1
CENTRAL VALLEY CORRELATIONS
MORENO GULCH TYPE SECTION
ESCARPADO CANYON & TYPE PANOCHE
MORENO GULCH SOUTHEAST
TO VALLEY WELLS

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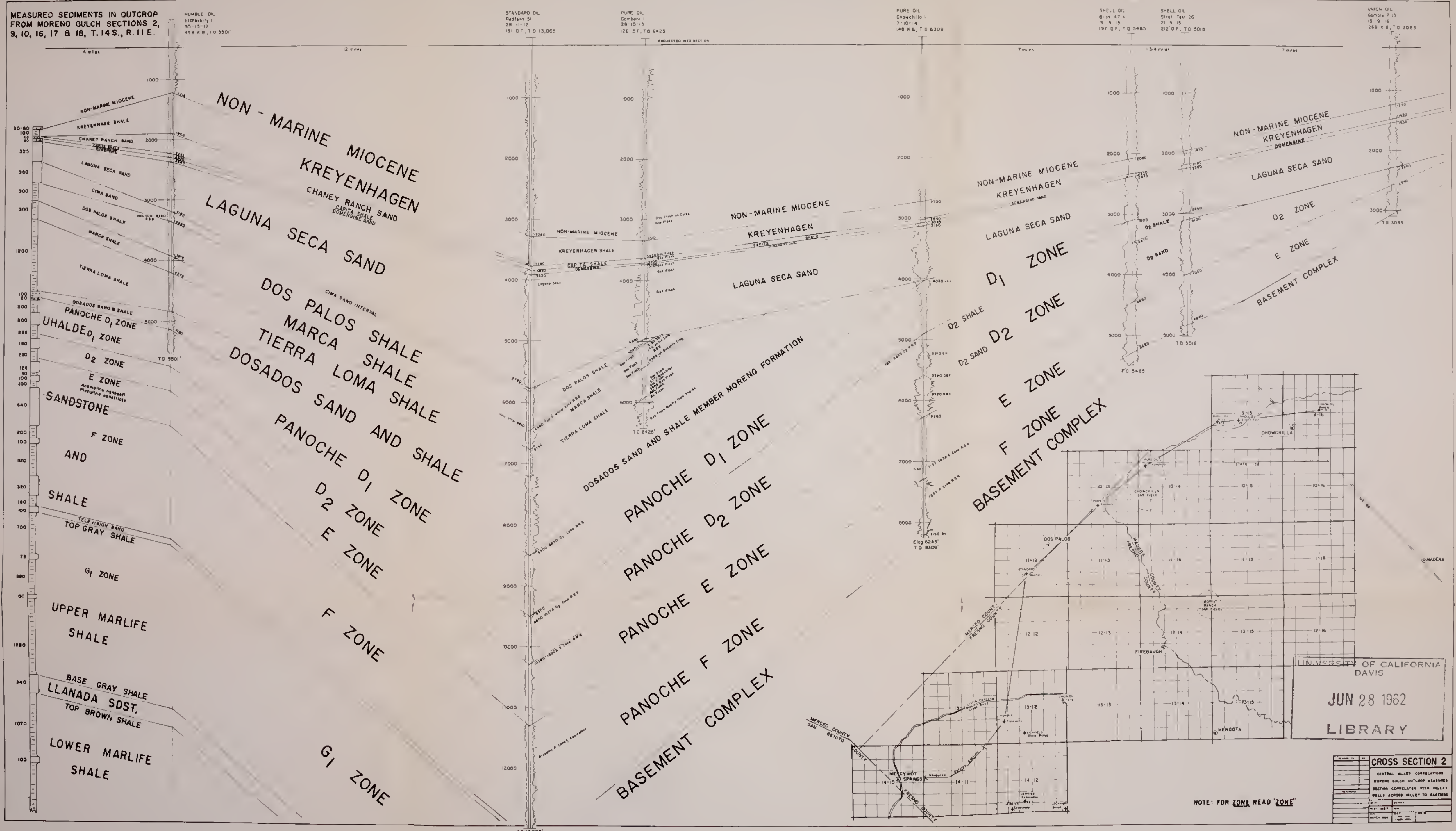
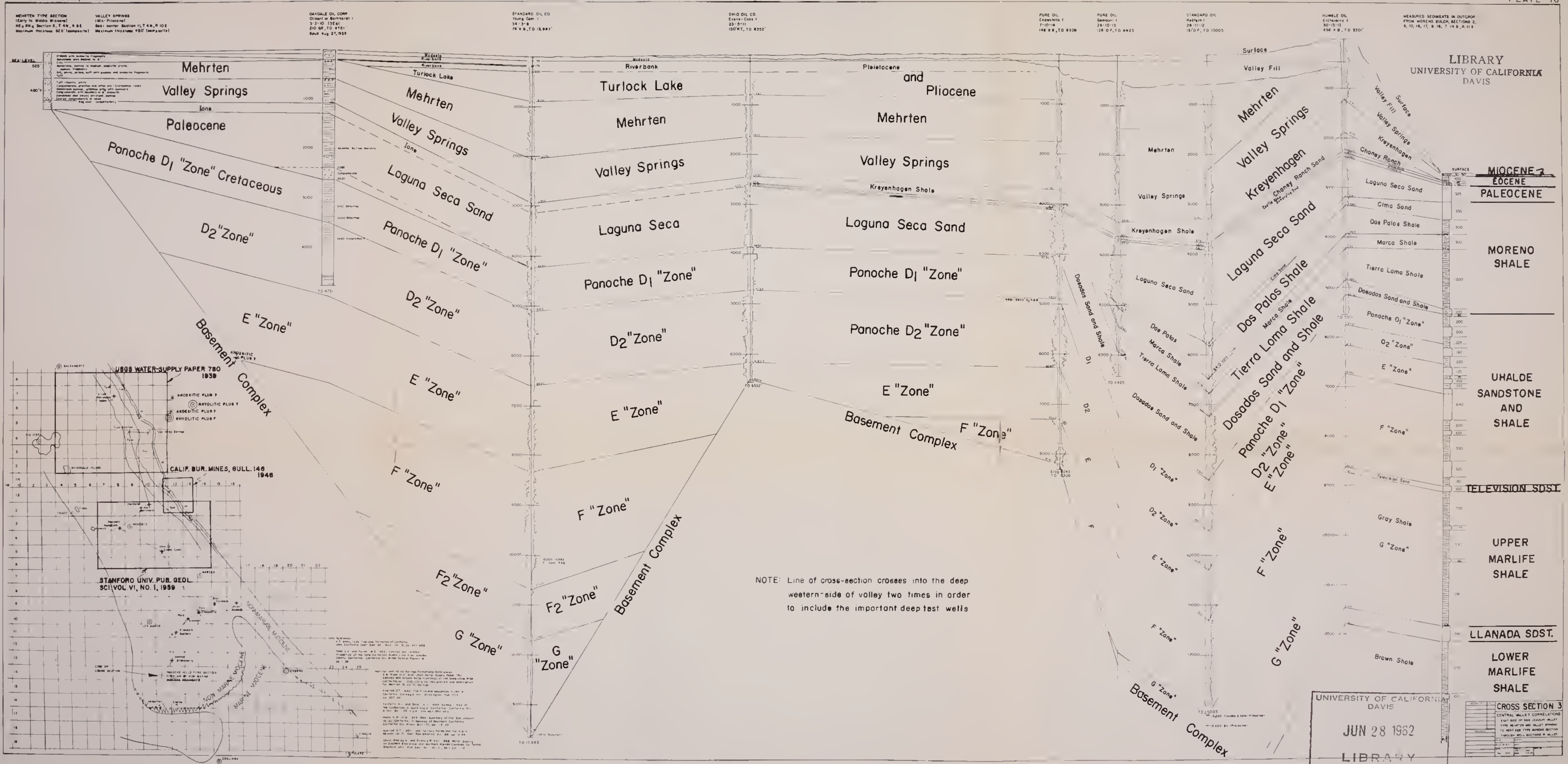
BULLETIN 181
PLATE 15



NOTE: FOR ZONE READ "ZONE"

CROSS SECTION 2

CENTRAL VALLEY CORRELATIONS
MORENO GULCH OUTCROP MEASURED
SECTION CORRELATED WITH VALLEY
WELLS ACROSS VALLEY TO EASTSIDE



NOTE: Line of cross-section crosses into the deep western-side of valley two times in order to include the important deep test wells

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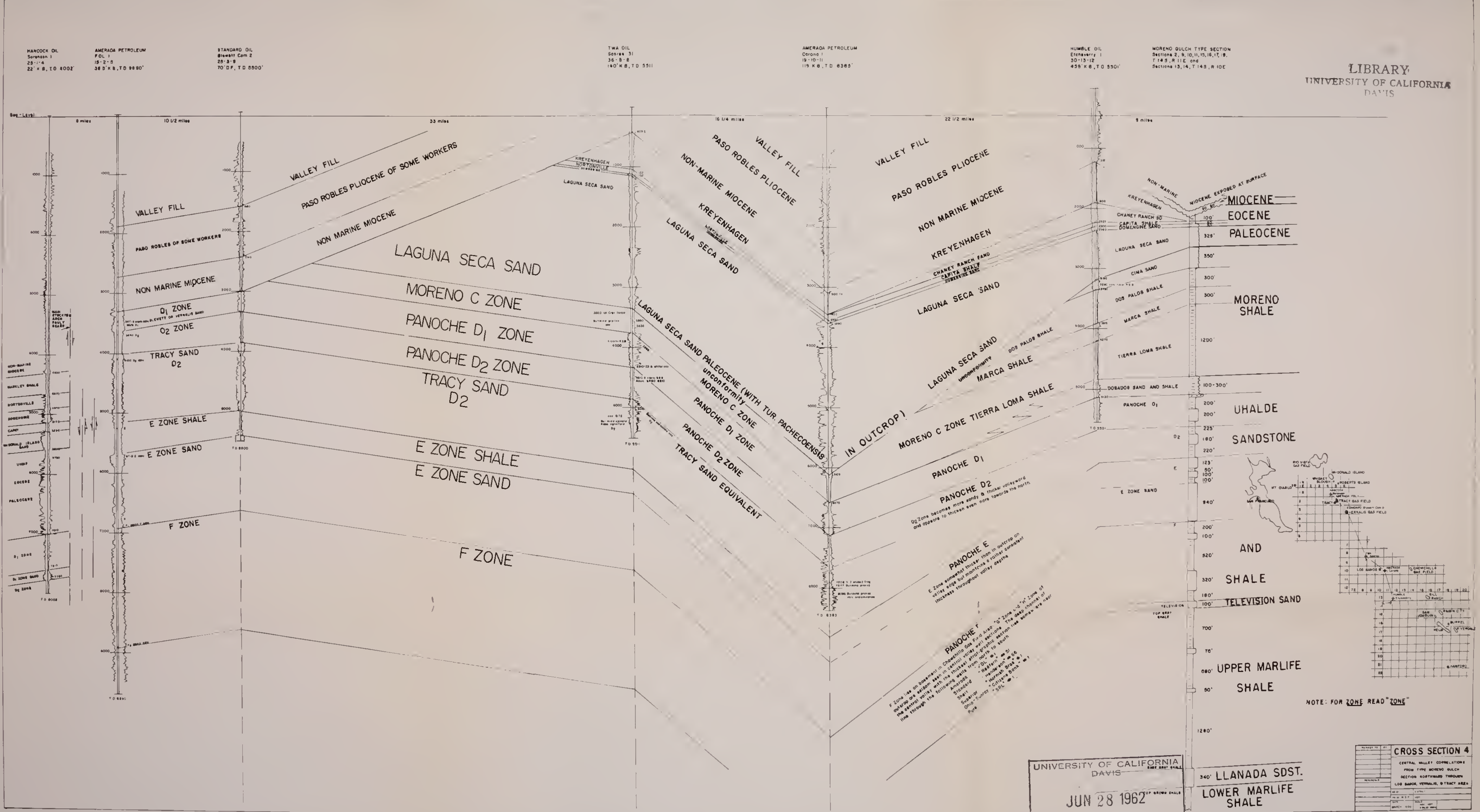

NOTE: FOR ZONE READ "ZONE"

CROSS SECTION 4

CENTRAL VALLEY CORRELATIONS FROM TYPE MORENO GULCH SECTION NORTHWARD THROUGH LOS BANOS, VERNALIS, & TRACY AREA

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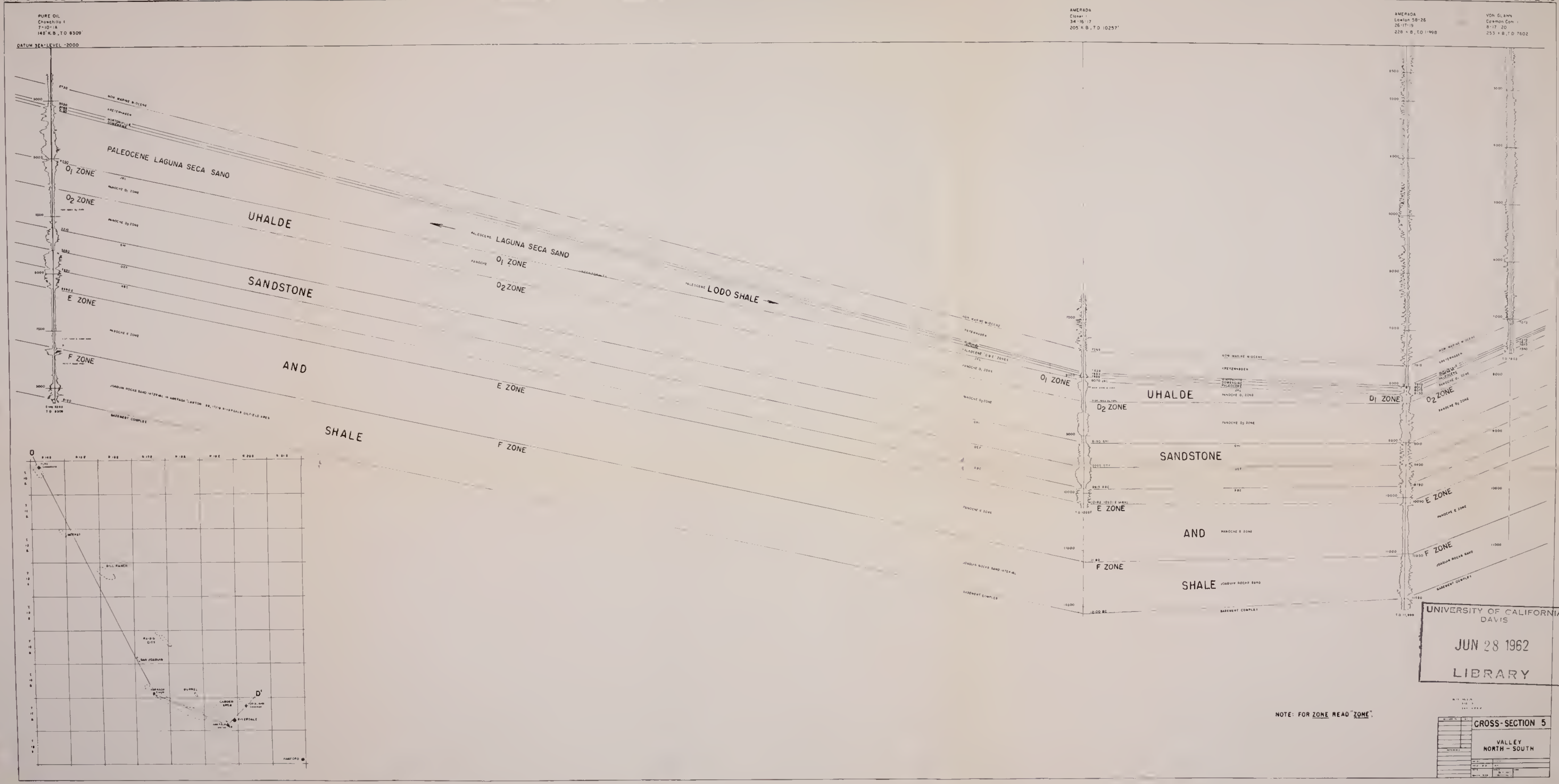
BULLETIN 181
PLATE 18



NOTE: FOR ZONE READ "ZONE".

CROSS-SECTION 5

VALLEY
NORTH – SOUTH

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BULLETIN 181
PLATE 19

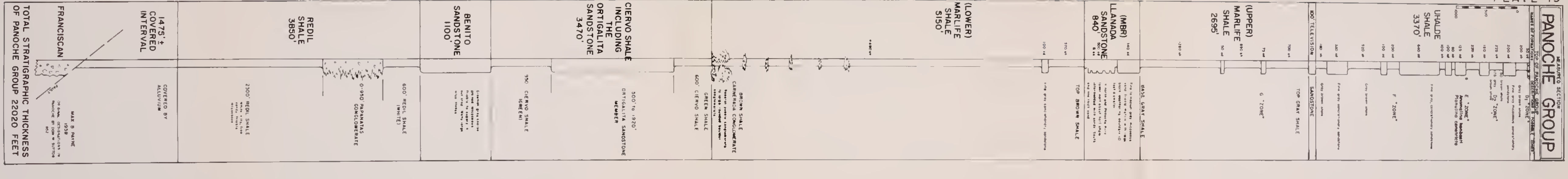

plate 20

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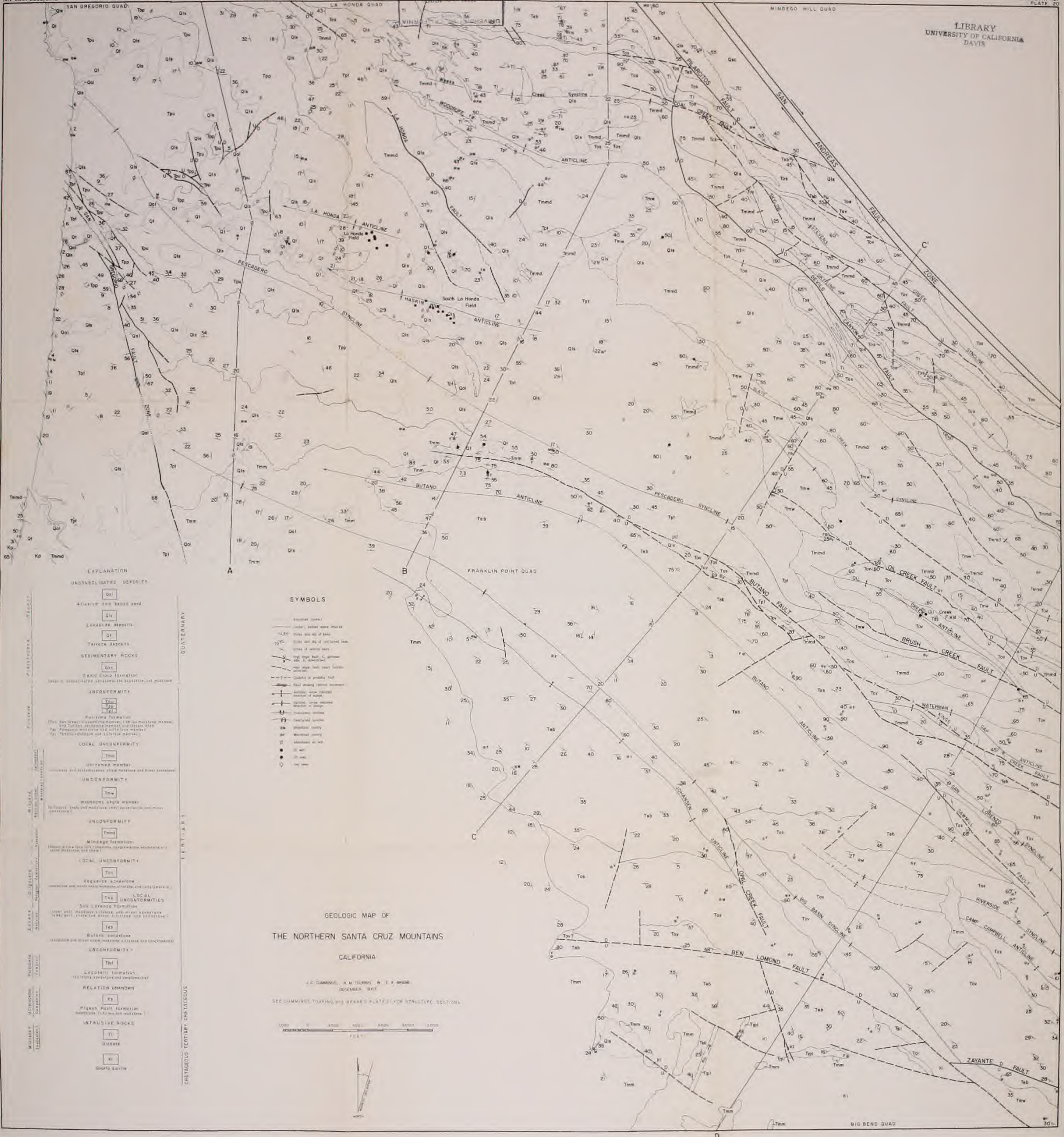
BULLETIN 181
PLATE 20



EXPLANATION

UNCONSOLIDATED DEPOSITS

Qal
Alluvium and beach sand

Qls
Landslide deposits

Qt
Terrace deposits

SEDIMENTARY ROCKS

Qsc
Santa Clara formation
(poorly consolidated conglomerate, sandstone, and mudstone)

UNCONFORMITY

Tpu
Tpp
Tpt
Purisima formation
(Tpu: San Gregorio sandstone member, Lobitos mudstone member, and Tunitas sandstone member, undifferentiated
Tpp: Pomponio mudstone and siltstone member
Tpt: Tahana sandstone and siltstone member)

LOCAL UNCONFORMITY

Tmm
Unnamed member
(siliceous and diatomaceous shale, mudstone and minor sandstone)

UNCONFORMITY

Tmw
Woodhams shale member
(siliceous shale and mudstone, chert, porcelanite and minor sandstone)

UNCONFORMITY

Tmmd
Mindego formation
(basalt pillow lava, tuff, limestone, conglomerate, sandstone, siltstone, mudstone, and shale)

LOCAL UNCONFORMITY

Tov
Vaqueros sandstone
(sandstone and minor shale, mudstone, siltstone, and conglomerate)

Tos
LOCAL UNCONFORMITIES
San Lorenzo formation
(upper part: mudstone, siltstone, and minor sandstone
lower part: shale and minor siltstone and sandstone)

Teb
Butano sandstone
(sandstone and minor shale, mudstone, siltstone and conglomerate)

UNCONFORMITY ?

Tpl
Locatelli formation
(siltstone, sandstone, and conglomerate)

RELATION UNKNOWN

Kp
Pigeon Point formation
(sandstone, siltstone, and mudstone)

INTRUSIVE ROCKS

Ti
Diabase

Ki
Quartz diorite

QUATERNARY
TERTIARY
CRETACEOUS
TERTIARY CRETACEOUS

Recent
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
U. Cretaceous
Miocene?

SYMBOLS

Accurate contact
Contact, dashed where inferred
Strike and dip of beds
Strike and dip of overturned beds
Strike of vertical beds
High angle fault, U, upthrown side, D, downthrown
High angle fault, exact location uncertain
Doubtful or probable fault
Fault showing relative movement
Anticline, arrow indicates direction of plunge
Syncline, arrow indicates direction of plunge
Overturned anticline
Overturned syncline
Megafossil locality
Microfossil locality
Abandoned oil test
Oil well
Oil seep
Gas seep

GEOLOGIC MAP OF

THE NORTHERN SANTA CRUZ MOUNTAINS

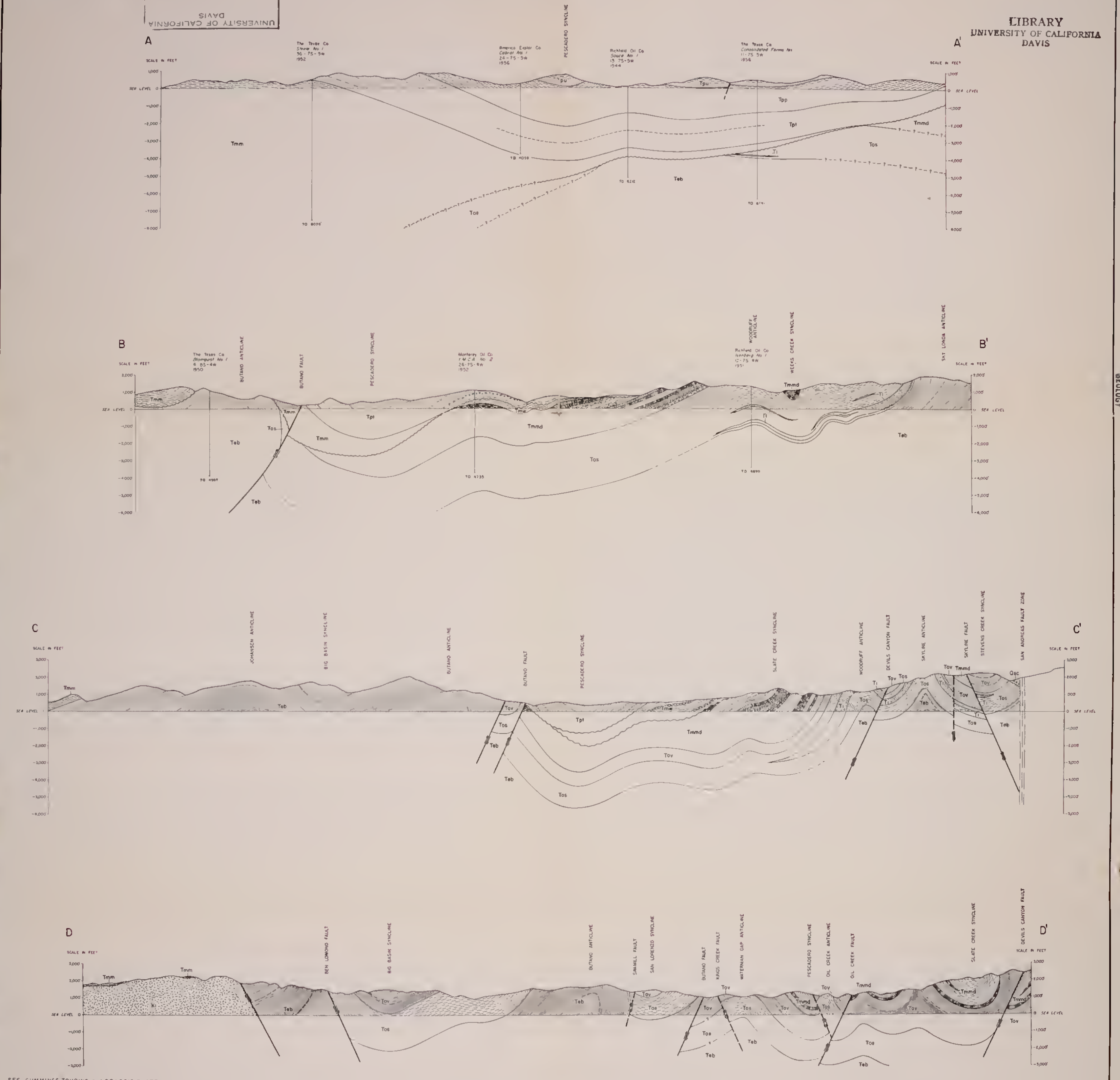
CALIFORNIA

J. C. CUMMINGS, R. M. TOURING & E. E. BRABB
DECEMBER, 1960

SEE CUMMINGS, TOURING, and BRABB'S PLATE 21 FOR STRUCTURE SECTIONS

STATE OF CALIFORNIA
DEPARTMENT OF CONSERVATION

plate 21



SEE CUMMINGS TOURING and BRABB'S PLATE 20 FOR LINES OF SECTIONS

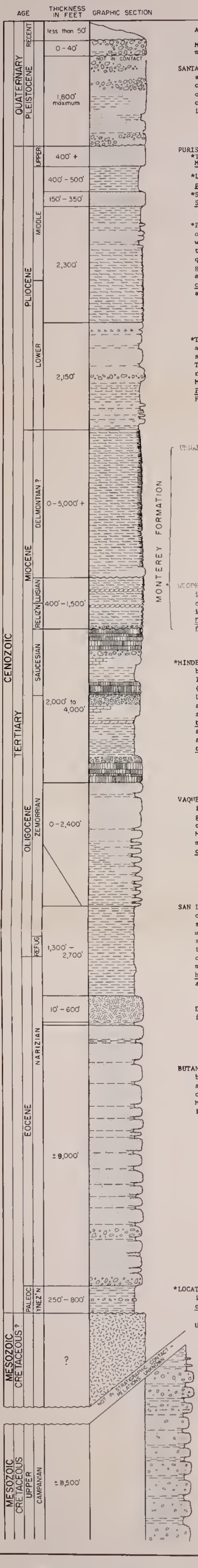
STRUCTURE SECTION THROUGH NORTHERN SANTA CRUZ MOUNTAINS

SCALE 1 0 1 MILES
HORIZONTAL

SCALE 0 10,000 FEET
VERTICAL

By Cummings, Touring, and Brabb

COLUMNAR SECTION – NORTHERN SANTA CRUZ MOUNTAINS



LITHOLOGIC DESCRIPTION

Alluvium, beach sand and landslides

Marine terraces - interbedded coarse sands & water-worn gravel, local development of mud & silt with Ostrea lurida, Elphidium hughesi, stream terraces along major creeks.

SANTA CLARA FORMATION - lenticular interbeds of gray, green & reddish-brown conglomerate, sandstone and mudstone, clasts up to several feet in diameter composed of dark-colored chert, graywacke, altered basalt and diabase, greenstone, glaucophane schist and an older very indurated conglomerate unlike any nearby composed of clasts of acidic volcanic rocks, granite porphyry and quartzite. Fresh water mollusks and plant remains including whole logs of trees are present.

PURISIMA FORMATION -

*Tunitas member - greenish-gray, very fine-grained, massive concretionary ss with Miopleiona oregonensis, Neptunea purisimaensis and several other living mollusks.

*Lobitos member - dark-gray, massive, silty mudstone with Neptunea stantoni, Crepidula princeps, several living mollusks and common foraminifers.

*San Gregorio member - greenish-gray, fine-grained to pebbly, massive, sandstone with Scutellaster oregonensis, Cryptomya californica and other mollusks.

*Pomponio member - in the type area along Pomponio Creek a rhythmically-bedded sequence of 2 to 6 inch beds of light-gray or white-weathering silicified mudstone alternating with medium-gray silty mudstone beds from a fraction of an inch to 6 inches thick, the upper part is slightly more sandy. In the north, especially in the Half Moon Bay quadrangle, the upper part of the member consists of several greenish-gray, very fine-grained, fossiliferous sandstone beds interbedded with dark-gray, massive, concretionary, fossiliferous mudstones. Mollusks include Schizothaerus pajaroanus, Cardita californica and Yoldia thraciaeformis. Foraminifera are abundant in the upper mudstones but are less common in the siliceous beds.

*Tahana member - principally greenish-gray, very fine to medium-grained volcanic arenites and wackes interbedded with sandy chert-pebble conglomerates, dark-gray siltstones and mudstones, light-gray punky diatomites, and pure white vitric tuff. Typically the sandy beds contain about 10% heavy minerals - green hornblende, reddish-brown basaltic hornblende, enstatite, hypersthene, biotite and glaucophane. Megafossils are common and include Lucinoma acutilineata, Mytilus coalingensis, Pecten healeyi, Tegula lahondaensis and many other species, mostly living today. Foraminifers common.

UNNAMED MEMBER - a rhythmically bedded sequence of 2 to 6 inch beds of siliceous or diatomaceous mudstone alternating with thin beds of silty or sandy mudstone. There are a few sandstone beds throughout the formation and a widespread basal sandstone which locally contains abundant glauconite. Fossils include fish scales, diatoms, arenaceous foraminifers, and Delectopecten lompicoensis.

*WOODHAMS SHALE MEMBER - dark brownish-gray, laminated siliceous shale interbedded with siliceous mudstone, porcellanite, and opaline chert. A basal arkosic sandstone as much as 200 feet thick occurs in the southern part of the area mapped. The shale contains Delectopecten peckhami, Siphogenerina branneri and other common foraminifers.

*MINDEGO FORMATION - predominantly dark gray, amygdaloidal basalt, pillow lava, flow breccia, water-laid lithic tuff, and sandstone and conglomerate consisting largely of basalt debris, with minor interbeds of bioclastic calcarenite (limestone), sandstone, siltstone, and mudstone in the vicinity of Mindego and Langley Hills. Elsewhere the formation consists largely of dark brown mudstone and shale with minor interbeds of volcanic rocks, arkosic sandstone, glauconitic siltstone, and dolomite. The calcarenites contain Pecten magnolia, Chione temblorensis subtemblorensis, echinoid spines, oysters, and barnacle fragments; siltstones in the lower part of the formation contain Siphogenerina nodifera, and many other foraminifers; siltstones in the upper part contain Siphogenerina transversa, Bolivina marginata adelaidana, and other foraminifers.

VAQUEROS SANDSTONE - light gray, very fine to very coarse-grained arkosic sandstone in beds from a fraction of an inch to 30 feet thick, interbedded with medium gray siltstone and dark gray mudstone and shale. Pebble, cobble, and boulder conglomerate are locally interstratified in the upper part of the formation. Megafossils, including Pecten magnolia and Pecten sanctaecruzensis, and such microfossils as Uvigerina gallowayi, Cassidulina crassipunctata and Buliminella curta are common.

SAN LORENZO FORMATION - locally and informally subdivided into a lower shale member consisting of olive gray laminated shale and a few interbeds of very fine-grained sandstone and siltstone, and an upper mudstone member consisting of olive gray massive mudstone, medium and light gray siltstone, and very fine-grained sandstone. Megafossils are rare in the lower shale member but foraminifers, including Amphimorphina jenkinsi, Bulimina sculptilis, and Globigerina, are common. Megafossils, including Acila dalli, are locally abundant in the upper mudstone member; microfossils, including Uvigerina cocoaensis and Planulina haydoni in the lower part and Uvigerina gallowayi, Cassidulina crassipunctata, and Miogypsina panamensis in the upper part, are common.

Diabase sills - probably genetically related to the volcanic rocks in the Mindego formation but most commonly found intruding the lower part of the San Lorenzo fm.

BUTANO SANDSTONE - light gray, very fine to very coarse-grained arkosic sandstone in beds from a fraction of an inch to 30 feet thick, interbedded with medium gray siltstone and dark gray mudstone and shale. Pebble, cobble, and boulder conglomerates are locally interstratified in the lower part of the formation. Megafossils are exceedingly rare; foraminifers, common in the mudstone and shale, include Uvigerina churchi and Valvulina curta.

*LOCATELLI FORMATION - yellowish brown and dark gray sandy, micaceous siltstone with interbedded conglomerate and sandstone. Fossils include Silicosigmoilina californica, Vaginulina cf. V. simondsi, and Palmula delicatissima.

Unnamed quartz diorite of plutonic origin & presumably of late Mesozoic age.

PIGEON POINT FORMATION - an interbedded sequence of dark-gray laminated silty mudstone, siltstone, bluish-gray, fine to coarse-grained sandstone, pebbly mudstone and sandy conglomerate. Rhythmic alternation of dark-gray siltstone and brownish-gray sandstone is common. Abundant primary features suggests turbidity currents were active at time of deposition. Rare fossils include Glycymeris veatchii, Marssonella oxycona, Epistomina caracolla and a few other foraminifera.

* New names

By Cummings, Touring, and Brabb
1960

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BULLETIN 181
PLATE 24

STRATIGRAPHIC DISTRIBUTION
OF
MEGAFOSSILS
FROM THE
PURISIMA FORMATION
SAN MATEO COUNTY, CALIFORNIA

Cummings, Touring, and Brabb

● present
cf compared with this species
R related species

	Tunitas sandstone member	Lobitos mudstone member	San Gregorio sandstone member	Pomponio sandy mudstone member	Tahana sandstone member	Careaga sandstone	Foxen mudstone	Sisquoc formation	San Joaquin formation	Etchegoin formation	Wildcat Group, Humboldt Co., California	Empire formation, Coos County, Oregon	Montesano formation, Grays Harbor Co., Wash.	Quinault formation, Grays Harbor Co., Wash.	Recent. Pacific Coast of North America	Lower Merced formation, San Mateo County
	Purisima formation San Mateo County California					Santa Maria District California Woodring & Bramlette (1950)			Kettleman Hills, California Woodring, *et al* (1940)		Ogle (1953) Martin (1916)	Weaver (1942) Dall (1909)	Weaver (1942)	Weaver (1942)	Burch (1944–46)	Martin (1916)
ECHINOIDS																
Dendraster cf. *D. ashleyi* (Arnold)			●			●										
Dendraster gibbsii (Rémond)			●						●	●						
Scutellaster oregonensis (W. B. Clark)			●								●	●	●			
GASTROPODS																
Aletes squamigerus Carpenter ?					●	●	●	●							●	
Bittium cf. *B. vancouverense* Dall & Bartsch				●		R	R	R		R					●	R
Calyptraea fastigiata Gould		●				cf		cf	R	R		R			●	R
Crepidula princeps Conrad	●	●	●	●	●	●	●	●	●	●		●	●			●
Fusitriton oregonensis (Redfield)				●			cf	cf			●	●			●	
Miopleiona oregonensis Dall	●			●		●	●	●				●				
Mitrella gouldii (Carpenter)				●		R	R	R	R	R	●				●	●
Nassarius moranianus (Martin)	●				●	●		●		●						●
Nassarius cf. *N. perpinguis* (Hinds)	●			●	●										●	R
Natica clausa Broderip & Sowerby					●	R	R				●				●	●
Neptunea cf. *N. andersoni* (Martin)				●							●					
Neptunea purisimaensis (Martin)	●															
Neptunea stantoni (Arnold)		●		●			cf									●
Neptunea tabulata (Baird)					●						●				●	R
Olivella baetica Carpenter	●		●			cf	cf		●		●	●	●		●	●
Polinices lewisii (Gould)	●			●	●	cf	cf		cf	cf	●				●	
Tegula lahondaensis (Arnold)					●							R				
Thais lamellosa (Gmelin)					●	R	R				●	●			●	●
Trimusculus reticulatus (Sowerby)					●										●	
Turcica imperialis brevis Stewart					●	●			●			R				
SCAPHAPODS																
?*Dentalium* sp.			●													
PELECYPODS																
Acila castrensis (Hinds)				●	●	●			●		●	R	R	R	●	
Anadara trilineata (Conrad)			●	●	●	●	●	●	●	●		●				●
Cardita (*Cyclocardia*) *californica* (Dall)				●		●	●	●								
Chlamys parmeleei (Dall)				●	●	●	R		R	R						
Clinocardium nuttallii (Conrad)	●		●									●	●		●	
Compsomyax subdiaphana (Carpenter)	●	●	●	●	●	cf		cf	cf	cf	R	R			●	●
Crenella columbiana Dall				●											●	
Cryptomya californica (Conrad)	●		●	●		cf		cf	R		●	●			●	●
Lima sp.					●											
Lucinoma acutilineata (Conrad)					●						●	●				
Lucinoma annulata (Reeve)				●	●	cf	cf	cf		R	●				●	●
Macoma brota Dall var. *lipara* Dall					●	R	R					R			●	
Macoma calcarea (Gmelin)			●	●	●						●	●			●	
Macoma nasuta (Conrad)				●					cf	cf	●	●			●	●
Macoma cf. *M. inconspicua* (Broderip & Sowerby)					●										●	
Macoma cf. *M. yoldiformis* Carpenter					●	cf					●				●	
Macoma cf. *M. planiuscula* Grant & Gale					●										●	
Modiolus directus Dall				●	●				R			●	●			R
Mytilus coalingensis Arnold					●	cf	cf		●	●						
Ostrea cf. *O. erica* Hertlein			●			●		●								
Pandora punctata Conrad	●									cf	R				●	R
Panomya chrysis Dall			●	●	●						●	●			●	
Panope generosa Gould					●	cf	cf	cf	cf	cf					●	
Pecten (*Patinopecten*) *healeyi* Arnold					●	●	●		cf		●					
Pecten (*Patinopecten*) aff. *P. healeyi* Arnold				●												
Pecten (*Patinopecten*) *lohri* Hertlein			●	●				●		●						
Pecten (*Patinopecten*) *purisimaensis* Arnold		●?			●											
Periploma discus Stearns	●	●													●	
Pholadidea cf. *P. penita* (Conrad)					●	●	●	●	●			●			●	
Protothaca staminea (Conrad)					●	R		R	R		●	●			●	●
Protothaca tenerrima (Carpenter)				●	●	cf		cf		cf					●	●
Schizothaerus pajaroanus (Conrad)		●	●	●	●	R	R	R	R	R	●	●	R			●
Securella securis (Shumard)					●						●	●				
Siliqua cf. *S. alta* Broderip & Sowerby			●								R				●	R
Solen sicarius Gould			●	●	●	R		R	R	R					●	●
Spisula albaria (Conrad)			●	●	●						●	●	●	●		●
Spisula cf. *S. catilliformis* Conrad	●					cf					●				●	●
Spisula cf. *S. voyi* (Gabb)					●						●				●	
Spisula sp. A					●											
Thracia trapezoides Conrad				●		cf					●	●			●	
Yoldia scissurata Dall var. *strigata* Dall		●		●	●						●	●	●			
Yoldia thraciaeformis (Storer)	●	●		●	●										●	
BARNACLES																
Balanus (*Tamiosoma*) *gregarius* Conrad				●	●					cf						
Balanus cf. *B. nubilis* Darwin	●			●	●										●	
Balanus cf. *B. aquila* Pilsbry				●		cf	cf								●	
Balanus sp.					●											
VERTEBRATES																
Cetacean bones				●	●											

Calif. Div. of mines

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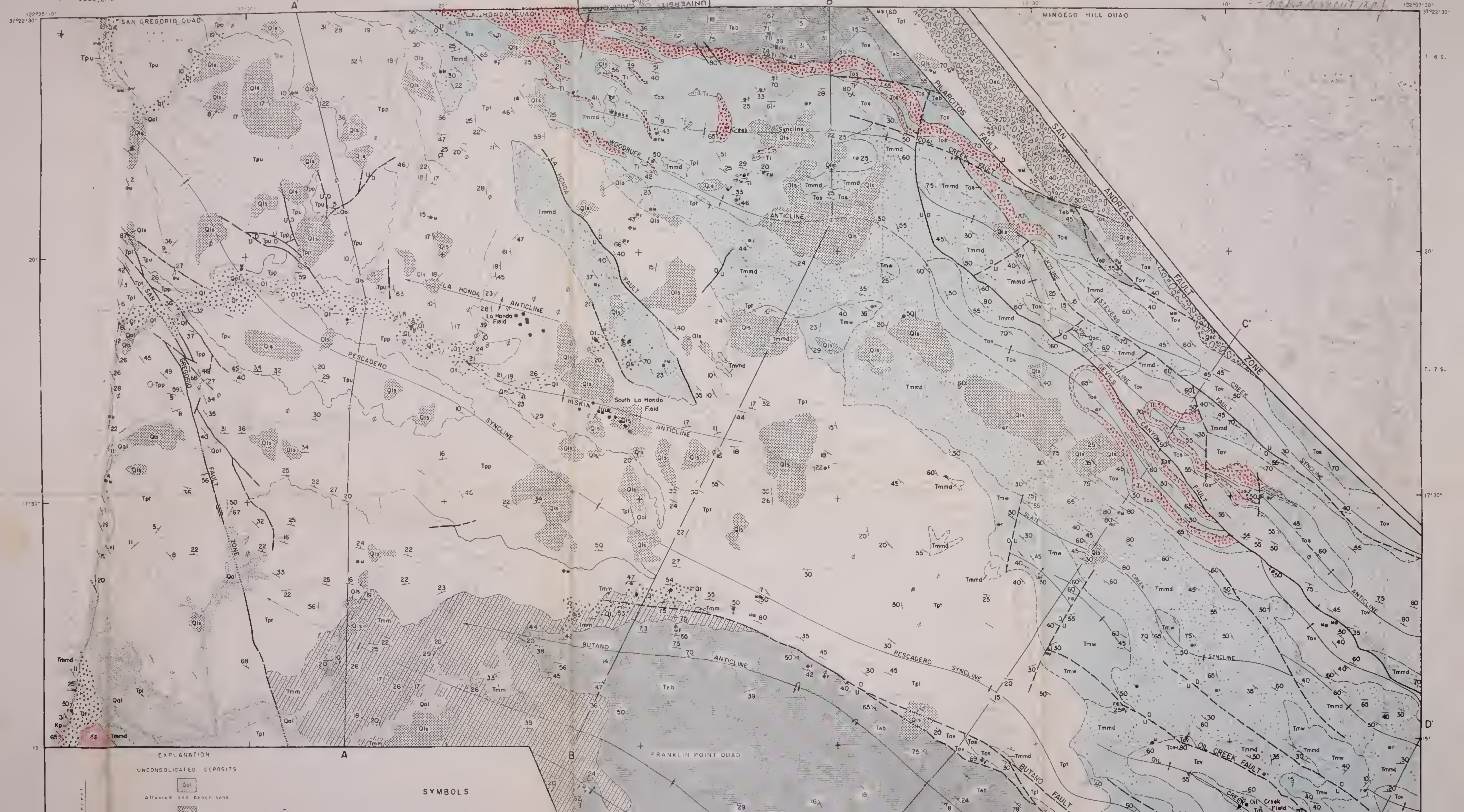
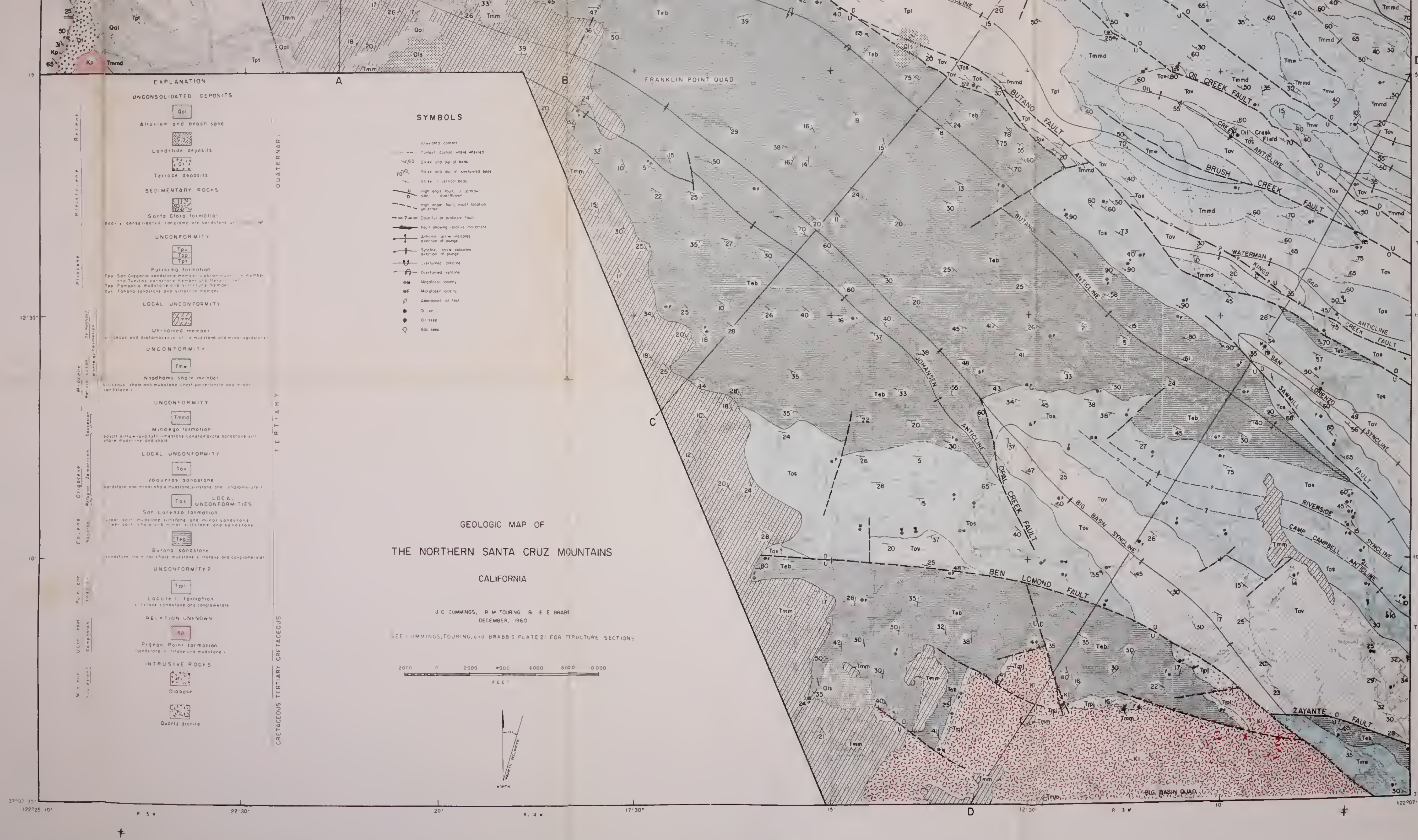
DEPARTMENT OF CONSERVATION

BULLETIN 181
PLATE 20





GEOLOGIC MAP OF

THE NORTHERN SANTA CRUZ MOUNTAINS

CALIFORNIA

J. C. CUMMINGS, R. M. TOURING & E. E. BRABB
DECEMBER, 1960

SEE CUMMINGS, TOURING, and BRABB'S PLATE 21 FOR STRUCTURE SECTIONS

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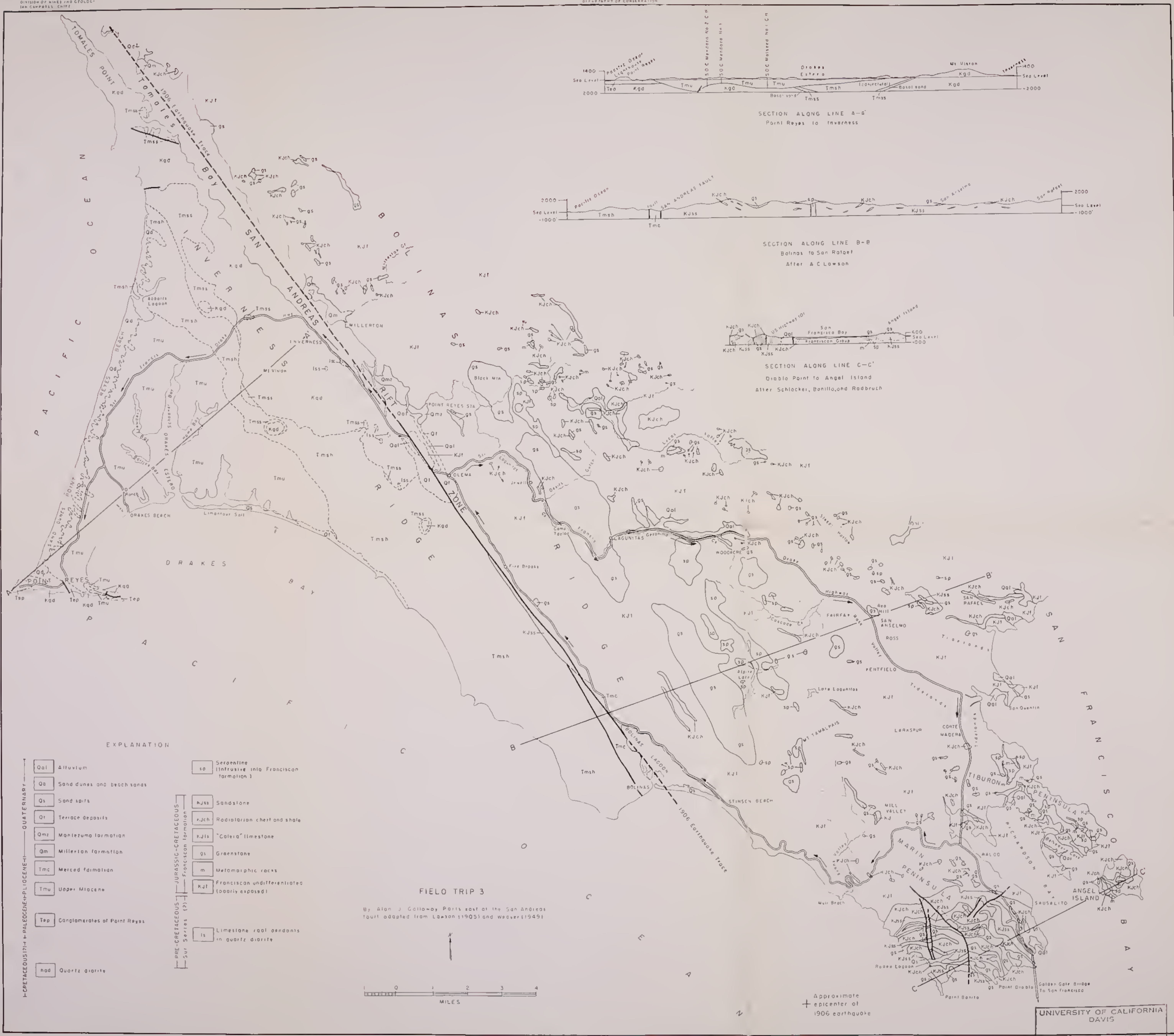
BULLETIN 181
PLATE 26



FIELD TRIP 3

By Alan J. Galloway. Parts east of the San Andreas fault adapted from Lawson (1905) and Weaver (1949)

GEOLOGIC MAP OF POINT REYES PENINSULA AND SAN ANDREAS FAULT ZONE

Plate 26

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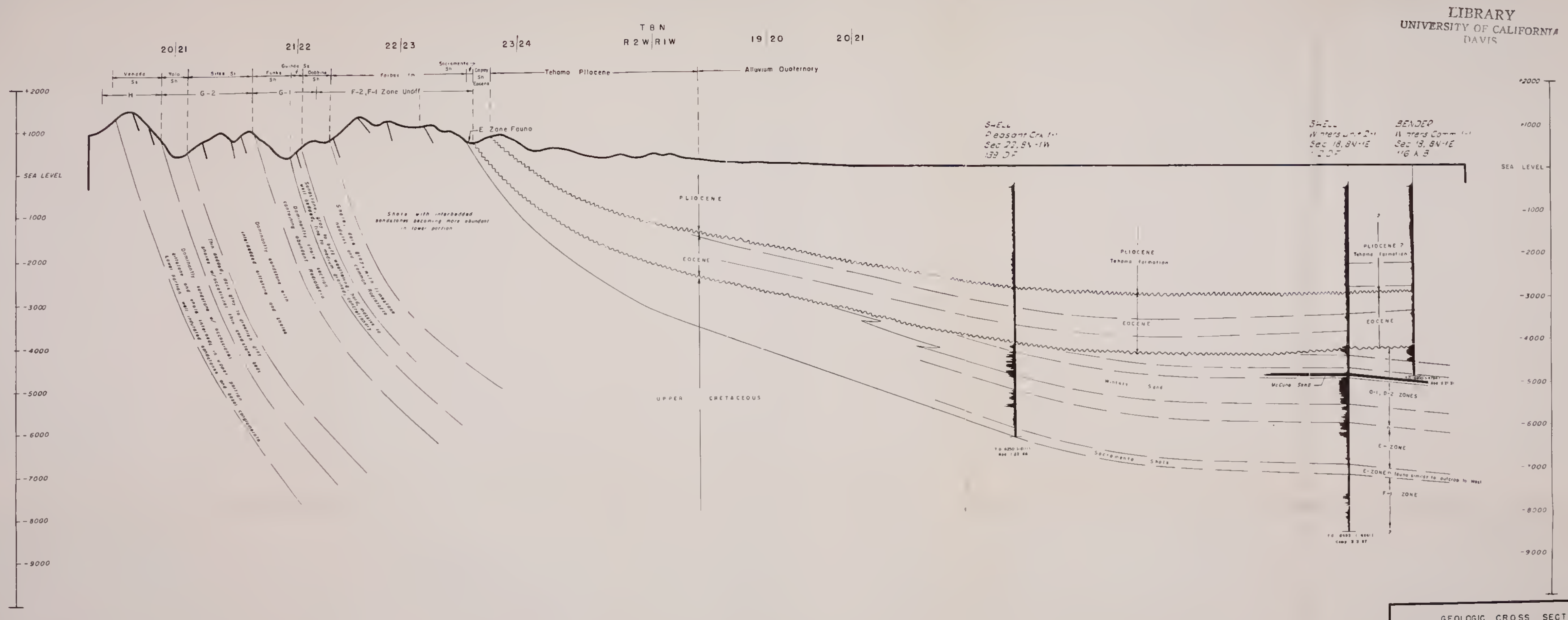
BULLETIN 181
PLATE 25



Horizontal Scale
500 0 500 1000 1500
FEET

Vertical Scale
1000 0 1000 2000 3000
FEET

GEOLOGIC CROSS SECTION
PUTAH CREEK — WINTERS GAS FIELD
YOLO COUNTY, CALIFORNIA

FEBRUARY 7, 1961
BY B D BROOKS

plate 25

[redacted] [redacted]

[redacted]