CALIFORNIA WELL SAMPLE REPOSITORY

Special Publication #3

Display of Cores and Outcrop samples from the
Monterey Formation
Coastal and San Joaquin Basin areas, California
May 2-June 10, 1983

Cal State Bakersfield

$ 3.00

TABLE OF CONTENTS

INTRODUCTION

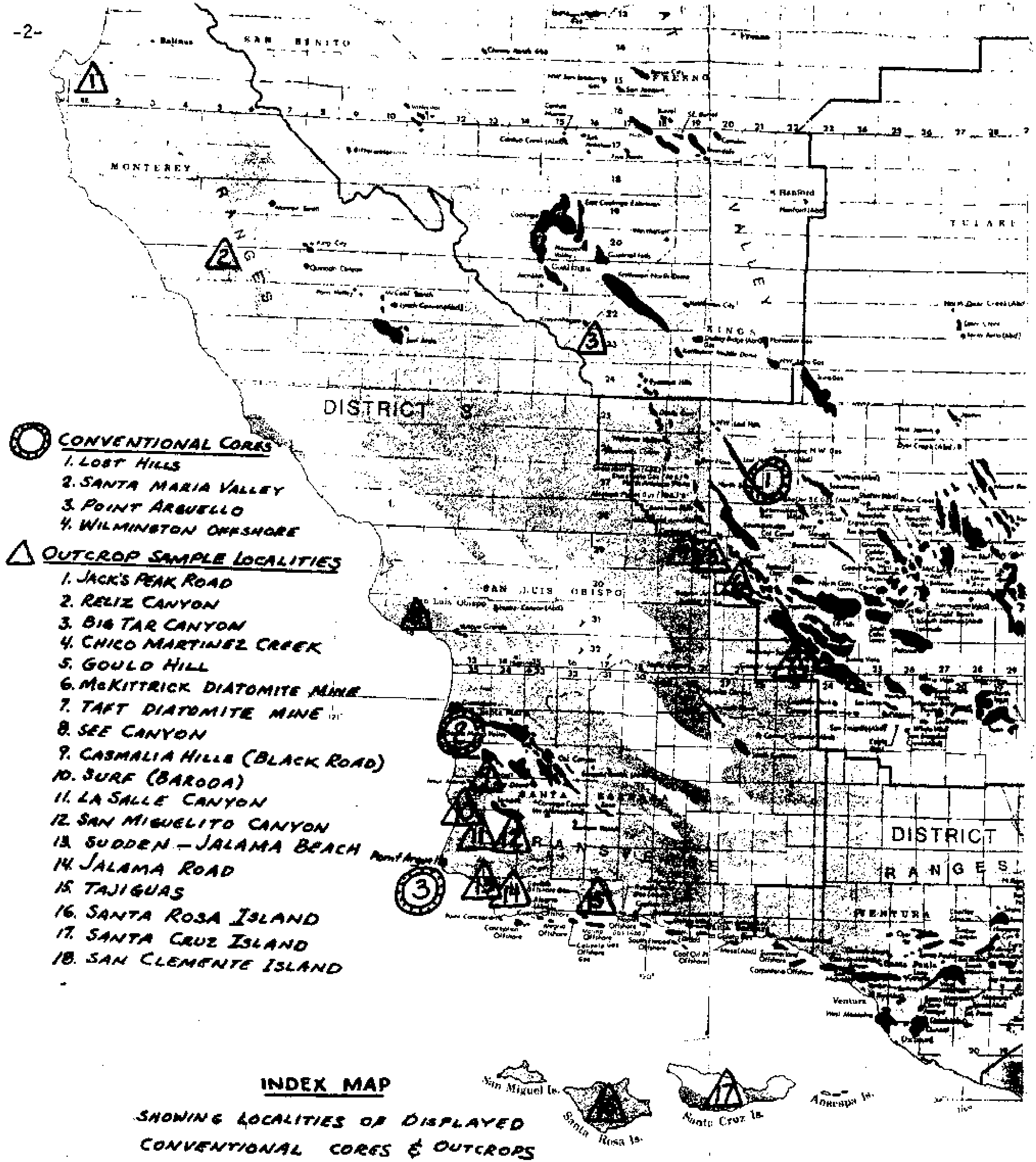
The Monterey, with equivalent beds or members such as the Modelo, Puente, McLure, Antelope, McDonald, Belridge Diatomite, Stevens, Sandholdt, and others, has long been a highly productive formation in California. In fact, nearly one hundred of California's oil fields produce from fractured shale or sand reservoirs of the Monterey or its equivalents. Recent spectacularly successful exploration and development along the Santa Barbara Channel, at Point Arguello, on- and offshore in the Santa Maria Basin, at Lost Hills, South Belridge, McKittrick, and elsewhere has revived and intensified interest and study of this complex, fascinating and economically important Miocene formation.

The California Well Sample Repository has been able to provide a unique display of representative conventional cores and outcrop samples for comparison and study. The conventional cores exhibited include recent wells at Lost Hills, Santa Maria Basin, Point Arguello, as well as a somewhat older Wilmington Offshore (THUMS) well. Of the hundreds of possible Monterey outcrop localities, eighteen were selected either for proximity to current drilling activity or for lithologic variations, or both. No attempt was made to collect complete suites at any of these localities, nor to describe or interpret them. Such studies have already been done for numerous areas with great detail and illuminating interpretation by Pisciotto, Ingle, Isaacs, Graham, Garrison, Murata, Redwine, Surdam, and others, and the results have appeared in a number of the ever-increasing publications on the Monterey.

The Advisory Board and Staff of the California Well Sample Repository believe this display and publication are important contributions to the continuing study of the Monterey. A great many companies and individuals have generously contributed time, effort, or loan of materials, without which this display could not have been made. We particularly express our thanks to the following: Getty Oil Company (and especially Leon Earnest, Rick Bowersox, and Mike McGuire); Union Oil Company of California (Don Reynolds), Chevron-Phillips (Don Zieglar and Orville Hart), ARCO (Dave Woltz and Bill Dahleen), Division of Oil and Gas (George Borkovich); Dr. John R. Coash, Dean, School of Arts and Sciences, Cal State Bakersfield, and some of his staff (Marie Covin, Suzanne Milling, and Chuck Bloomquist, photographer) and Jack Tucker, curator for the Repository. Special thanks go to Dr. Caroline M. Isaacs, U.S. Geol. Survey; Norman Hamisch, Sun Oil Co.; M. McGuire, L. J. Earnest, J. R. Bowersox, Getty Oil Co.; and King F. Vaughn, Core Laboratories, for the preparation of the interesting and informative articles included in this publication.

We hope you will find this display and publication interesting and useful. Any comments or suggestions you may wish to make for future displays will be most appreciated.

Victor Church
Project Director



CONVENTIONAL CORES
1. LOST HILLS
2. SANTA MARIA VALLEY
3. POINT ARGUELLO
4. WILMINGTON OFFSHORE

OUTCROP SAMPLE LOCALITIES
1. JACK'S PEAK ROAD
2. RELIZ CANYON
3. BIG TAR CANYON
4. CHICO MARTINEZ CREEK
5. GOULD HILL
6. McKITTRICK DIATOMITE MINE
7. TAFT DIATOMITE MINE
8. SEE CANYON
9. CASMALIA HILLS (BLACK ROAD)
10. SURF (BARODA)
11. LA SALLE CANYON
12. SAN MIGUELITO CANYON
13. SUDDEN – JALAMA BEACH
14. JALAMA ROAD
15. TAJIGUAS
16. SANTA ROSA ISLAND
17. SANTA CRUZ ISLAND
18. SAN CLEMENTE ISLAND

INDEX MAP

SHOWING LOCALITIES OF DISPLAYED CONVENTIONAL CORES & OUTCROPS

SOUTHERN PORTION, OIL AND GAS FIELDS OF CALIFORNIA

SCALE

10 5 0 10 20 30 40 Miles

1982

INFLUENCES ON LITHOLOGY
MONTEREY FORMATION, CALIFORNIA

by

Caroline M. Isaacs
U.S. Geological Survey
Menlo Park, California 94025

The Miocene Monterey Formation, which is widely exposed in the Southern Coast and Transverse Ranges of California, has long been known as a major petroleum source rock in California. Partly because of its unusual lithology, however, the Monterey has frequently been overlooked as an important petroleum reservoir rock - except in some areas, such as the San Joaquin Valley and the Santa Maria basin. Petroleum discoveries in the Santa Ynez Unit in the late 60's and recent potentially giant discoveries in the offshore Santa Maria area where the Monterey is the principal petroleum target have focused intense interest on the formation.

Lithologically, the Monterey Formation is extremely heterogeneous, containing a wide range of fine-grained rocks (diatomite, porcelanite, chert, marl, phosphatic shale, dolomite, limestone, etc.) as well as interbeds of sandstone or tuff and tuffaceous sandstone in some localities. The wide variety of lithology results from two main influences: depositional and diagenetic.

Depositionally, the Monterey Formation is generally a hemipelagic deposit - that is, rock derived from biogenous ooze deposited in basins comparatively near to the shoreline. The basins in which the Monterey was deposited were generally broad marginal basins which developed at the end of the Oligocene as a result of tectonic plate adjustments. Because of rapid subsidence simultaneous with globally rising sea level, most terrigenous debris was trapped near shore throughout much of the Miocene. As a result, the Monterey is composed mainly of the "background" biogenous debris, and sediment variations strongly reflect variations in oceanographic conditions. Important oceanographic influences include intense upwelling (which results in high productivity in surface waters and a plankton dominated by diatoms which have silica tests), moderate upwelling (which results in a plankton dominated by coccoliths which have calcareous tests), corrosiveness of bottom water (which dissolves calcite), and intense oxygen-minimum zones (which preserve annual layers deposited in the sediment). Because of high plankton productivity, low oxygen in bottom waters, and the fine grain size of the sediment, abundant "oil-prone" organic matter is also preserved in the Monterey, making it an excellent petroleum source rock. Fine-grained terrigenous debris (clay material) was also deposited at the same time, and its abundance reflects to some extent the nearness to the strandline. In some localities, in addition, turbidites were intermittently deposited; these beds are common in the San Joaquin Valley, the Ojai area, and in parts of the Santa Maria basin and make excellent reservoir rocks, "sandwiched" as they are between excellent source rocks.

After deposition, diagenetic processes had important influences on the lithology. The most important of these processes were silica phase transformations and formation of the mineral dolomite. With respect to silica, diatom frustules are composed of an x-ray amorphous form of silica known as opal-A ("opal-amorphous") which is synthesized by the diatom. Once buried beneath the surface, opal-A is quite resistant to solution, and the frustules are amazingly resistant to compaction (as much as 70% porosity is commonly retained in highly diatomaceous rocks to depths in excess of 2000 feet). However, opal-A is geochemically unstable; mainly as a function of temperature, it converts (at about 45°C) to a crystalline silica known as opal-CT ("opal-cristobalite/tridymite") by a comparatively abrupt solution-precipitation process. Diatomaceous rocks lose considerable porosity during this process (from 65 to 35% dry porosity, a compaction nearly in half), and the resultant rocks are much harder and brittler than before; they are generally known as cherts (vitreous surface), porcelanites (matte surface) and siliceous/porcelaneous shales/mudstones (grainy surface), where cherts generally have sparse clays and siliceous mudstones abundant clays. With increasing temperature (over a range of about 75-90°C) opal-CT transforms to quartz, again by a solution-precipitation process with another (but smaller) porosity loss (from 35% to 10% dry porosity). Both opal-CT-bearing and quartz-bearing rocks are quite brittle - especially where they are highly siliceous - and fracture readily.

In addition to these typical diagenetic changes in silica, another process of importance in some carbonate-rich sequences, such as in the Santa Maria and Santa Barbara areas, is silica replacement which results in massive quartz cherts relatively early in diagenesis. Although not yet well understood, the formation of quartz cherts is of great interest as these rocks are widely thought to be particularly susceptible to fracturing.

At the same time as the silica phases are changing, other diagenetic processes are influencing the carbonate in the rocks. Where coccoliths are abundant (as in the Santa Maria and Santa Barbara areas), their calcite slowly dissolves and reprecipitates with increased burial. In addition, for reasons not fully understood at present, dolomite forms from biogenous calcite in some sequences (usually at temperatures $>50^{\circ}$C) and dolostones form locally, possibly within tens of feet beneath the sediment surface. Formation of dolomite can be important to reservoir character inasmuch as dolomitization embrittles rocks and can form breccias which are locally important to fracture production.

The result then of the depositional and diagenetic processes influencing Monterey rocks is a wide array of rock types - nearly all of which are fine-grained and few of which are typical of the usual petroleum reservoir rocks.

DIAGENETICALLY ENHANCED ENTRAPMENT OF HYDROCARBONS SOUTHEASTERN LOST HILLS FRACTURED SHALE POOL, KERN COUNTY, CALIFORNIA

McGuire, M.D., Bowersox, J.R., and Earnest, L.J.
Getty Oil Company, Bakersfield, California

Paper presented at SEPM "Monterey Symposium,"
Pacific Section of AAPG Convention, Sacramento, California, May 1983

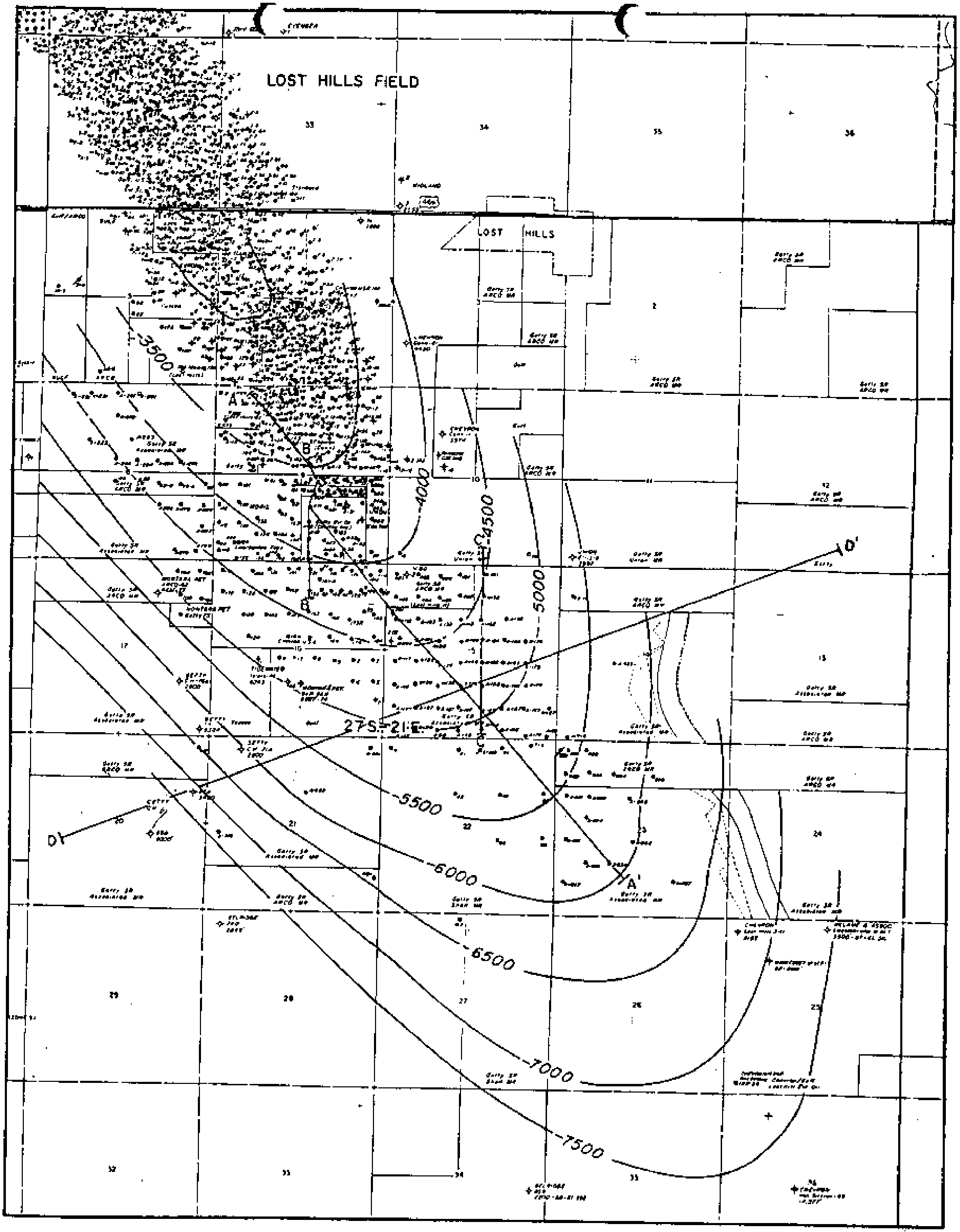
The Lost Hills Field is a narrow northwesterly-trending anticline. The fractured shale pool lies on the southwest flank and southeastern axial plunge of the fold. The coincidence of anticlinal structure and an abrupt facies change provides a complex trap for oil and gas. Wells have produced from upper Miocene fractured shales along the axis of the Lost Hills anticline since the early 1900's. Recent wells, however, have delineated the full extent of stratigraphic/structural traps wrapping around the southwest limb of the fold.

Detailed correlation of well logs, combined with X-ray diffraction analyses, indicate that hydrocarbons are trapped by a diagenetically enhanced facies change in the middle Miocene Monterey Shale and the upper Miocene Reef Ridge Shale. Diatomaceous mudstones (Opal-A) lense out updip into less clayey diatomites which have been diagenetically altered to porcelanite (Opal-CT). Dissolution of Opal-A and precipitation of Opal-CT has reduced porosity in the porcelanites. Clay inhibition of silica diagenesis has preserved primary porosity and permeability in the uppermost mustones lenses.

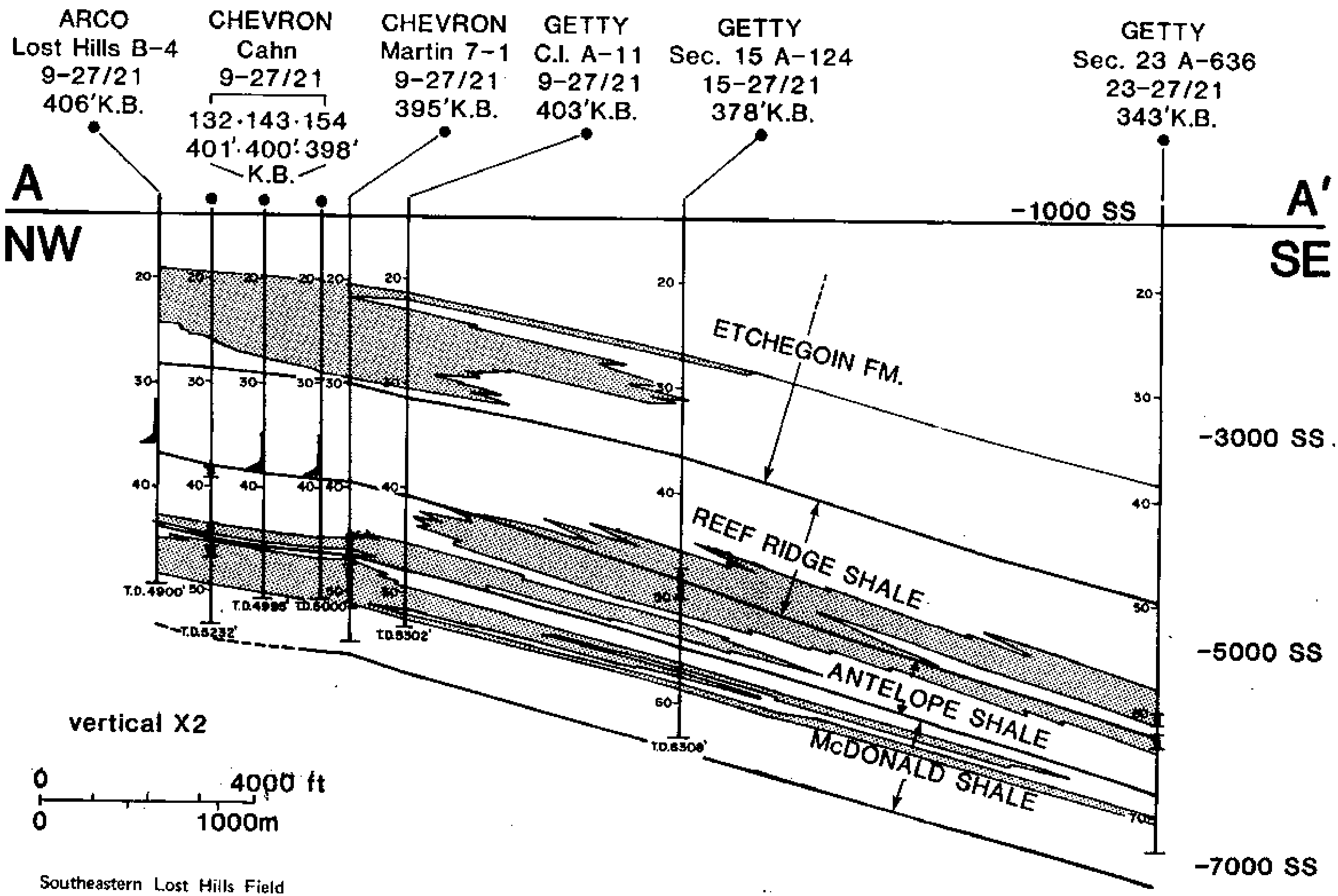
These relationships suggest that hydrocarbons have accumulated due to the following sequence of events: (1) Conversion of Opal-A to Opal-CT occurred early in diatomites before the onset of hydrocarbon generation; (2) Compaction, porosity reduction, and increased capillary pressures resulted; (3) Deeply buried mudstones began generating hydrocarbons while undergoing conversion of Opal-A to Opal-CT; (4) The increaesd capillary pressures expelled hydrocarbons into the updip portions of the mudstone lenses which retained primary porosity; (5) Updip diffusion was halted by the facies change; (6) With increasing burial, Opal-CT in the mudstones was converted to quartz, further concentrating hydrocarbons in the updip portion of the stratigraphic trap. Since these processes have been controlled by depth of burial, productive zones are encountered at approximately the same subsea depth throughout the pool.

The better producing wells lie just downdip of the facies change. A formation pressure 1200 psi above hydrostatic has been measured in one of these wells. Data from oriented cores suggest that this overpressuring has dilated fractures experiencing tectonically induced tensile stress. In general, well logs recorded through producing intervals in these walls exhibit higher electrical resistivities along with attenuation and delayed arrival of sonic waves.

Paleobathymetric maps, isochore maps, and syndepositional relationships suggest a late Miocene depositional environment with the following characteristics: (1) Lost Hills was the site of active anticlinal folding; (2) uplift produced a raised bank protected from bottom-seeking sediment gravity flows; (3) the bank-top received mostly hemipelagic sediments; (4) clastics were channeled mainly along the basin axis lying to the southwest; (5) some plumes of suspended fines ascended and covered the upper bank slopes. The porcelanite facies represents diagenetically altered, bank-top diatomites isolated from clastic contamination. The diatomaceous mudstone facies represents down-slope mixtures of biogenous and clastic sedimentation.



Structural contours on the "N" electric log marker (top of Antelope Shale). Southeastern Lost Hills Field, McGuire, Bowersox, and Earnest.



Southeastern Lost Hills Field
McGuire, Bowersox and Earnest

Equivalence of the Monterey and Puente Formations in the Offshore Los Angeles Basin

Norman S. Hamisch
Sun Exploration and Petroleum Company
Dallas, Texas 75234

Germinal work on the sedimentology of the Monterey Formation and related Miocene rocks of coastal California by Pisciotto (1978) and paleo-oceanographic recreations by Ingle (1980) have provided the bases for developing a depositional model relating the various named time-equivalent rock units. The observations of Truex (1972) regarding the Long Beach Unit of the East Wilmington Oil Field and other parts of the Los Angeles basin provide insights into the relationship between the Puente and Monterey Formations. A synthesis of some of the ideas developed by these and other workers is presented here.

Although predominantly Upper Mohnian in age, the Puente has been identified as being as old as early Mohnian. The Monterey, on the other hand, has an age range of Relizian to Upper Mohnian. Paleoenvironmental data indicate a depositional range of bathyal to abyssal for the Puente and a similar range for the Monterey. Thickness of the Puente varies from 11,000 feet in the central deep of the Los Angeles basin to less than 500 feet in the offshore area.

In the offshore areas the Puente generally rests unconformably on the Catalina Schist. Locally it rests on Topanga Formation, San Onofre Breccia, and/or Miocene volcanics.

Lithologic units within the Puente are mainly or largely shales, siltstones or claystones, all with significant clastic percentages. The main exception to this is the Black Shale of the basal 237 Zone (Fig. 2) in the Wilmington Offshore area, which is a fractured black, oily, phosphatic shale. Truex correlates this basal shale with the Altamira Shale of the Monterey Formation in the Palos Verdes Hills. The character of that shale is indeed similar to Monterey shales and it is suggested here that it be regarded as Monterey.

It is proposed here that the clastic influx into the essentially quiescent Monterey depositional basin marks the end of that quiescence and the beginning of the formation of the Los Angeles Neogene tectonic basin. This transition was fairly catastrophic and resulted in a fairly thick accumulation of the characteristic sandy Puente shales, siltstones, and claystones.

Truex's observations that there is possibly no recognizable unconformity within the Black Shale (or above it) to distinguish it from the upper part of the 237 zones shows the deep-water deposition of the Puente into the Monterey basin and ultimately over sills and ridges that ponded the basin. The "ridge" bounded by the Palos Verdes and Newport-Inglewood Fault Zones is an example of such a ridge (Fig. 1). No speculations as to the timing and kind of movement of those faults are forwarded here, only the observation of the presence of little to no

Monterey deposition and the southeastward-thinning of Puente deposition. Non-deposition, rather than erosion is proposed, the implication thereof is that the main source for the Puente was to the north and northeast, filling the starved and somewhat isolated Monterey basin of the present central Los Angeles basin with deep-water clastics. Deposition continued across this ridge with similar clastics. Thicknesses in oil fields suggest that some movement of the ridge occurred during deposition. Puente deposition was followed by Repetto turbidites marking the transition from deposition into the Monterey basin into the present tectonic basin.

REFERENCES

Ingle, J. C., 1980, Cenozoic paleobathymetry and the depositional history of selected sequences within the Southern California continental borderland: Cush. Found. Spec. Publication No. 19, pp. 163-195.

Pisciotto, K. A., 1978, Basinal sedimentary facies and diagenetic aspects of the Monterey Shale, California: Ph.D. dissertation U.C. Santa Cruz, 450 pp.

Truex, J. N., 1972, Fractured shale and basement reservoir, Long Beach Unit, California: AAPG Bull., v. 56, no. 10, pp. 1931-1938.

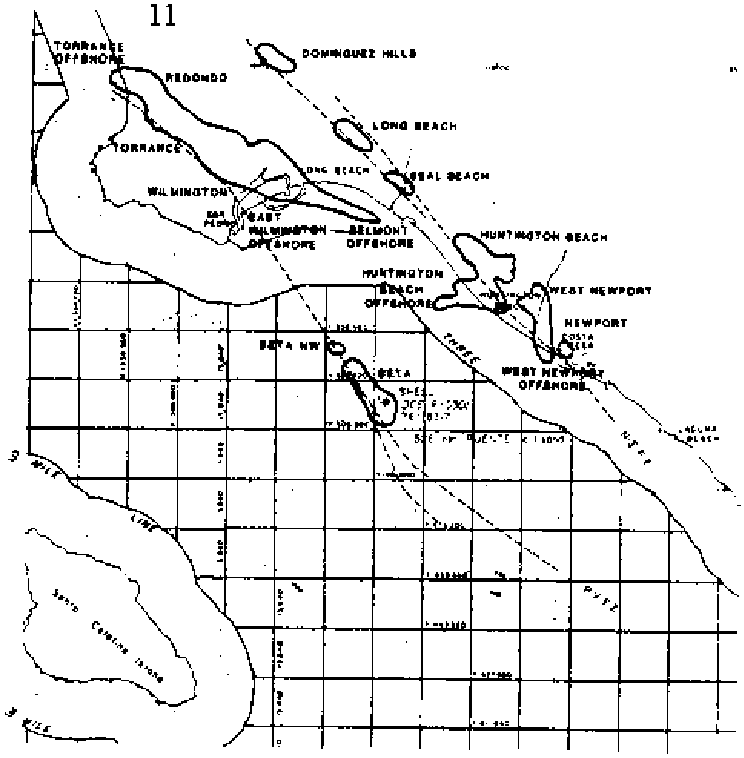


FIGURE 1. OFFSHORE LOS ANGELES BASIN

P.V.F.Z. Palos Verdes Fault Zone
N-1 F.Z. Newport-Inglewood Fault Zone

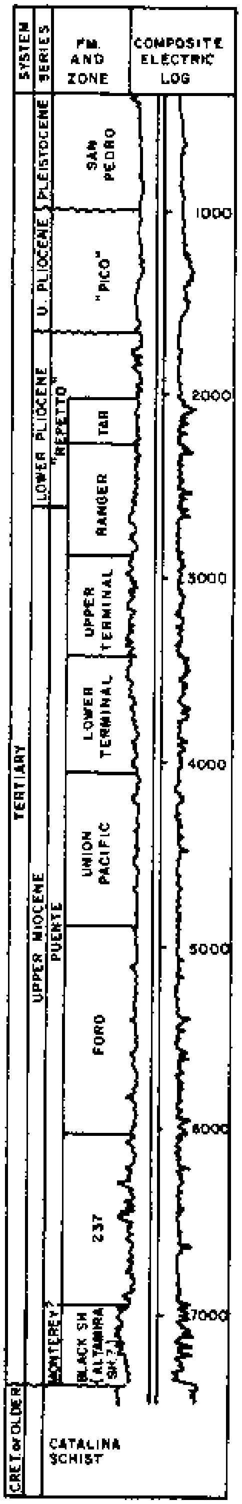


FIGURE 2.
COMPOSITE LOG
WILMINGTON OFFSHORE AREA

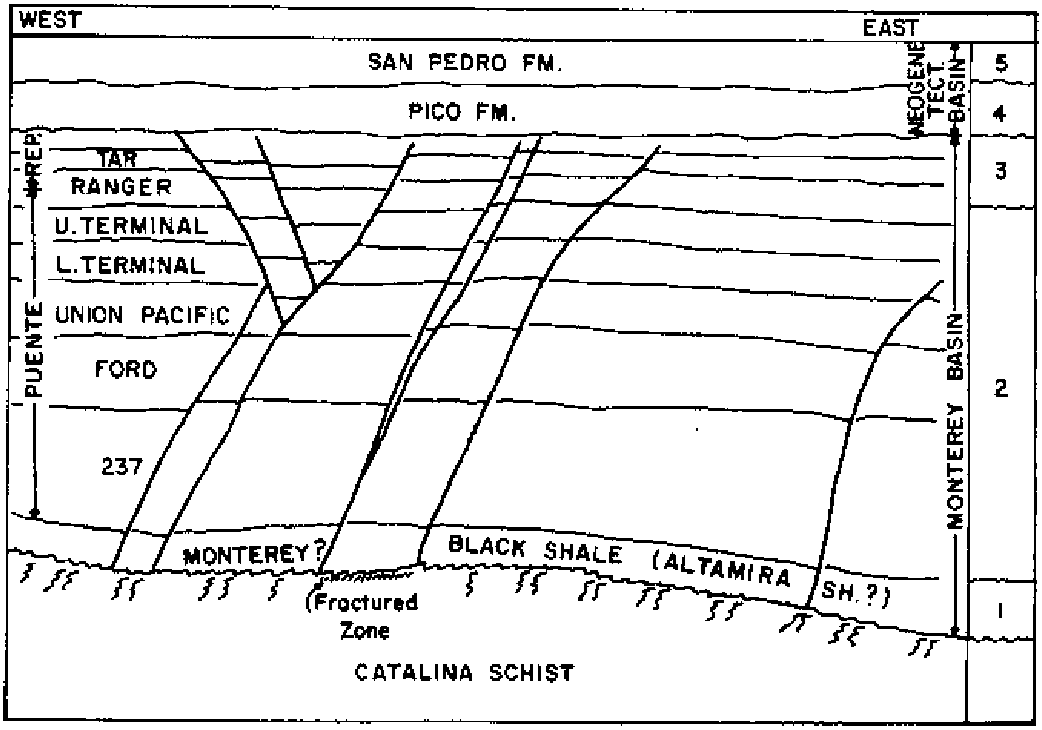


FIGURE 3. SCHEMATIC CROSS SECTION EAST WILMINGTON OFFSHORE FIELD

1. Phosphatic anaerobic basinal facies
2. Clastic proximal basinal facies and/or "ridge" facies
3. Turbidite facies
4. Proximal turbidites
5. Shallow marine facies

N.S. HAMISCH
D.L. GLOVER

CORE ANALYSIS FOR MONTEREY SHALE FORMATION

King F. Vaughn, Core Laboratories, Inc.
516 East 18th, Bakersfield, California

INTRODUCTION

The Monterey Shale Formation characteristics impose unique core-analysis procedures to aid in understanding reservoir anatomy. The complexity of the Monterey Shale, which changes from a diatomaceous shale, cherty shale to a calcareous shale, with varying quantities of kerogen, clays, and possible natural fractures, makes porosity and fluid saturations very difficult to obtain.

MONTEREY SHALE CORE ANALYSIS

Conventional Cores

The determination of porosity and fluids saturation is by a modified Dean-Starke technique. A plug is drilled or sawed from the conventional core, usually one per foot. A general description is made on the plug sample. A gas volume is determined on the sample by Boyles Law in a helium porosimeter with liquids present. The sample is weighed with liquids intact. The bulk volume is determined in the mercury pump. Crush the sample to approximately ten mesh. The crushed sample is reweighed (as a check to be sure of no grain loss); placed in a thimble; and then placed in the Dean-Starke to distill water into a receiving tube (which is a direct measure of water). When the extracted water stabilizes, the sample is removed and cleaned of pore hydrocarbons with solvents. The sample is then dried at 230°F to remove solvents, and reweighed to obtain a dry weight. Pore oil is determined by subtracting the sample dry weight from the total sample weight, then subtracting the water from weight difference. Then oil weight divided by oil intensity gives oil volume. The grain volume is measured in a matrix volume cup, using helium as a gas median. Porosity is calculated by either subtracting the grain volume from the bulk volume to give pore volume, or by adding gas volume, water volume, and oil volume to give pore volume. Calculations of oil saturation, water saturations, and grain density are determiend. This will yield a dry porosity and will also be the lowest residual oil saturation.

An adjacent plug is drilled and cleaned to determine matrix air permeability. If the core is fractured, a fracture permeability should be determined on the full diameter core section.

Humidifying Samples

To compensate for the potential of hydratable clays being present in the above samples, they are rehydrated in a humidity oven at 150°F and 50% humidity. This puts two molecular layers of water on hydratable clays. Samples are reweighed; if there is a weight difference, this weight difference is subtracted from the Dean-Starke water reading and added to the dry sample weight, which will give a corrected oil volume.

A grain volume is measured. Porosity is calculated and this would be an effective porosity. Assuming weight increase is from hydratable clays then this could have another purpose: to determine Cation Exchange Capacity (C.E.C.). Cation Exchange Capacity is used to supply information for the Waxman-Smits-Thomas equations used for calculation of water saturations in clay-bearing formations.

Kerogen Content

Since the samples have been cleaned of all pore oil, retorting to 1200°F would produce kerogen oil, which liquifies at 650°F. Kerogen content may be correlated with produced oil. The kerogen content could aid in log interpretation, since kerogen decreases grain density. Also an evaluation may be determined for hydrocarbon generation in commercial quantities. Shales with total organic carbon (TOC) of less than one percent are not likely candidates.

Sidewall analysis

Sidewalls can be analyzed in the same manner as conventional cores for porosity, oil saturation, water saturation, grain density, and kerogen. Permeabilities are determiend empirically from a correlation of permeability with porosity (measured) and other textural characteristics available from a careful visual inspection of the samples.

Drill Cuttings Analysis

Since the Monterey Shale core analysis method is time consuming, drill cuttings are used for evaluation to get data in a faster time. To determine porosity, a bulk volume and pore volume have to be measured. Bulk volume is difficult to measure with several small pieces of formation. A pore volume is determined by 100 percent saturation of the cuttings. The container of cuttings is washed of all mud by washing through a ten mesh screen and caught on a 35 mesh screen. A 20 gram to 30 gram weight of cuttings is desirable after washing. They are then 100 percent saturated using tap water and blotted of all surface water, and then weighed for a total weight. Sample is then placed in Dean-Starke to extract total water. After water is stabilized, the sample is removed and cleaned of pore oil by using solvents. Then the sample is dried at 230°F to remove any solvents. The sample is reweighed to determine dry weight without any fluids. Pore oil is determined by subtracting total water from the difference in total wet weight and dry weight. Oil volume is determined by dividing the oil weight by the oil density. Then the total water volume plus oil volume gives pore volume. The grain volume is measured in a matrix volume cup using helium as a gas median. Then grain volume plus pore volume equals bulk volume. Porosity, fluid saturations and grain density can then be calculated. The processes from this analysis through humidifying the sample and determining kerogen are the same as in conventional core plugs and sidewall samples.

CONCLUSIONS

1) Monterey Shale core-analysis furnishes a porosity and residual oil, accompanied by observed lithology as more useful data for reservoir description.

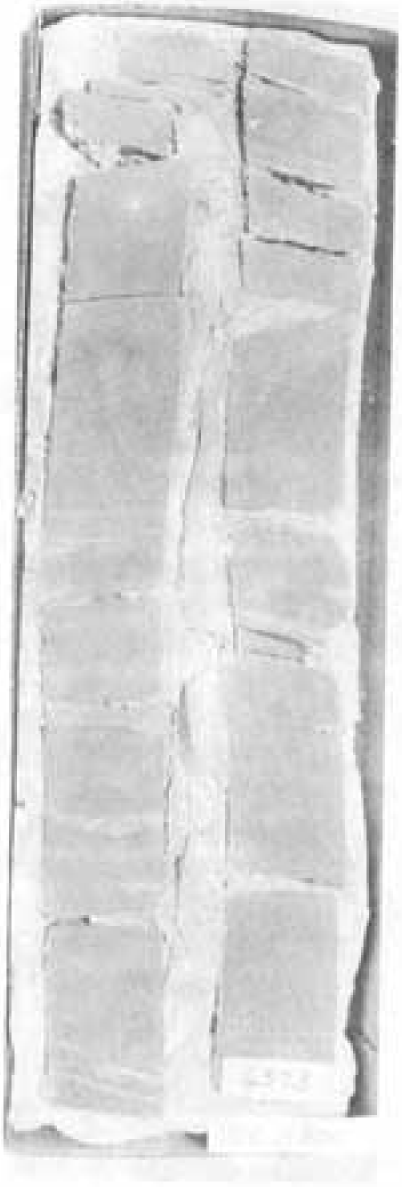
2) The rock characteristics impose unique and specific procedures to secure representative data.

3) The data on both reservoir and non-reservoir (source rock) rock provide essential information for understanding reservoir anatomy.

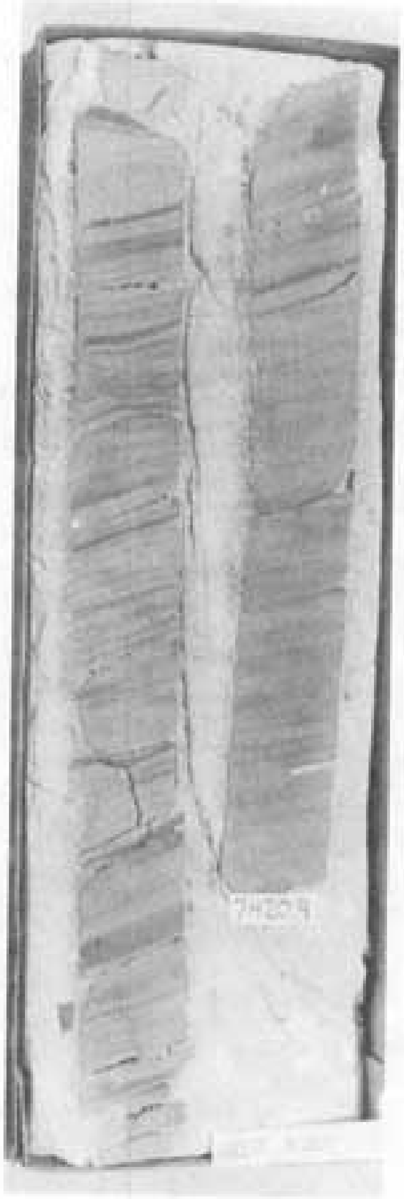
ACKNOWLEDGEMENTS

I wish to thank the California Division personnel of Core Laboratories, Bryan Bell, Dave Mazzanti, Daryl Knapp, Dave Marschall, and Allen Britton for their invaluable assistance, and Jan Gillespie for typing the manuscript.

ARCO
Lost Hills Fee K-801
sec 21 - T.27S, R.21.E



6567-73

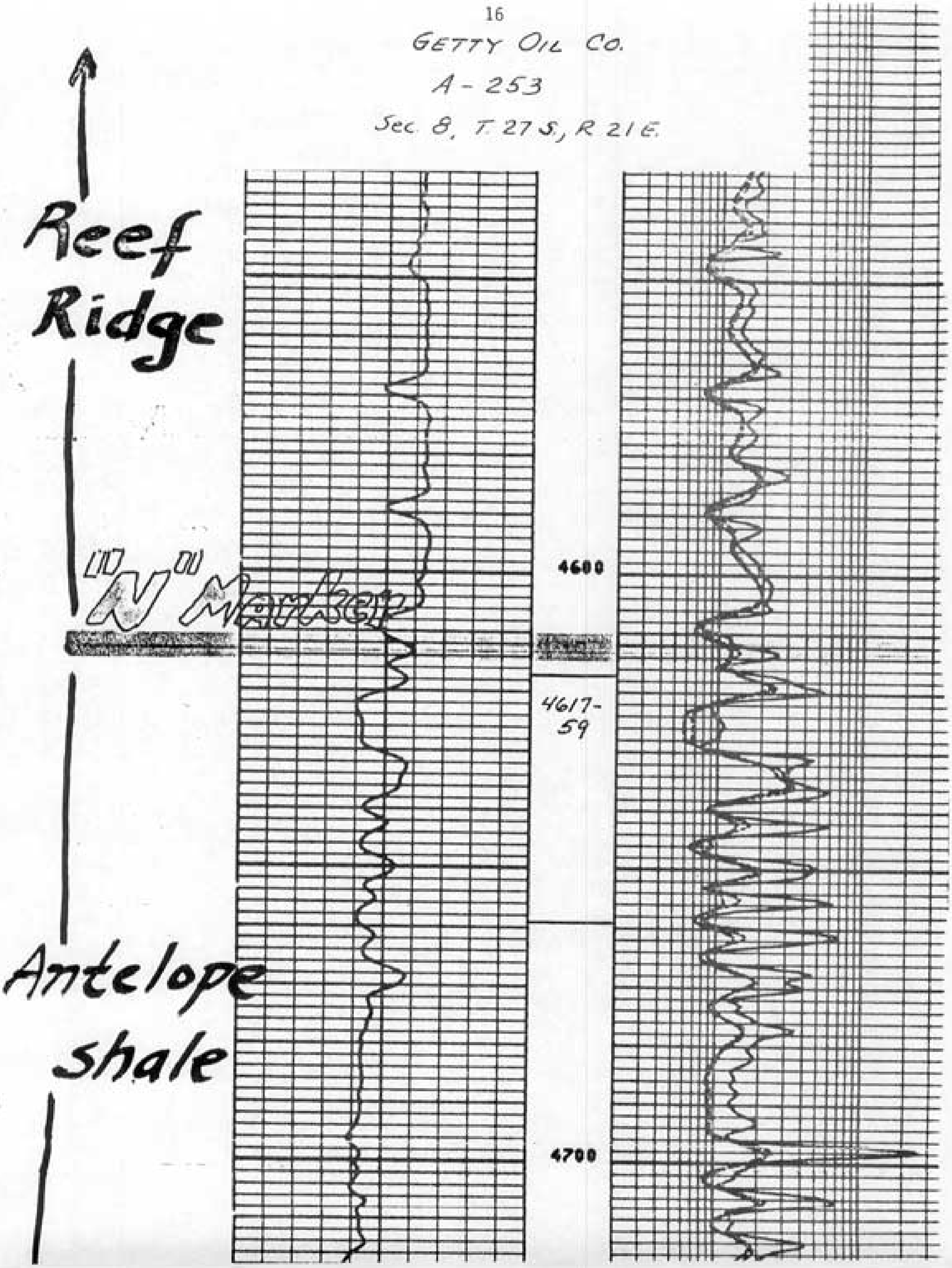


7414-21

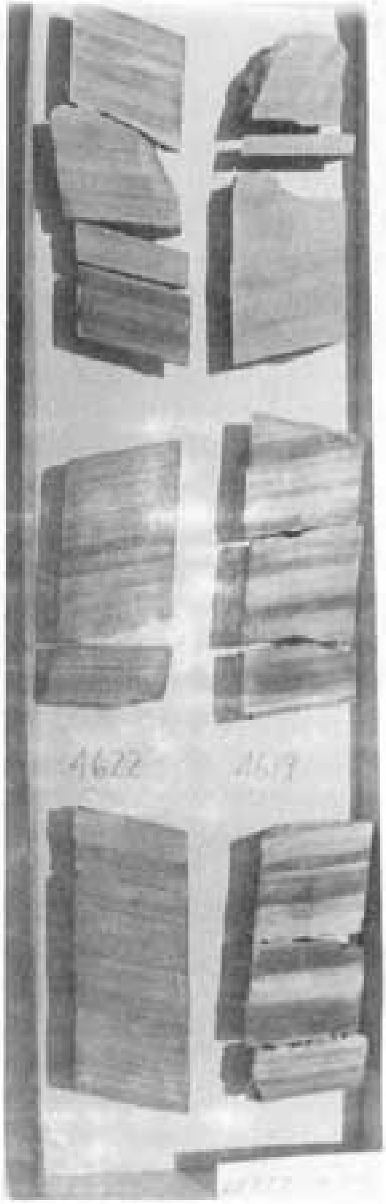
GETTY OIL CO.

A - 253

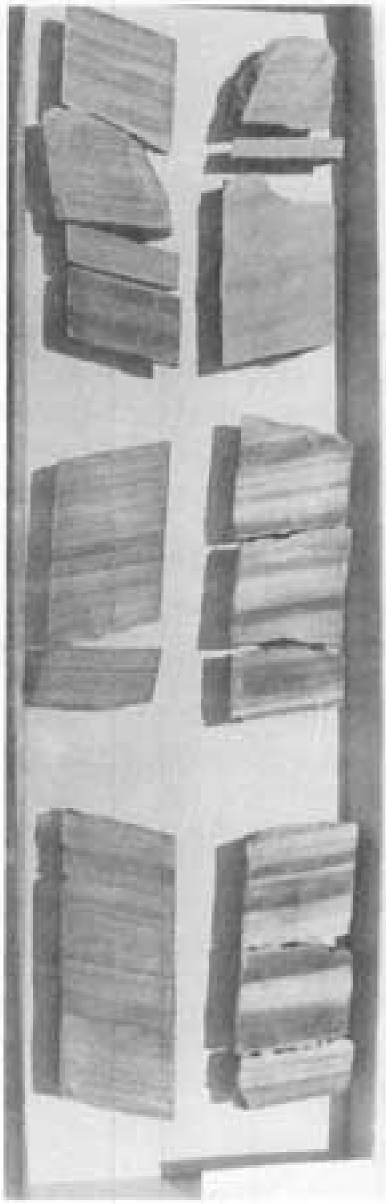
Sec. 8, T. 27 S., R 21 E.



GETTY OIL CO.
A-253
Sec. 8, T.27S., R.21E.

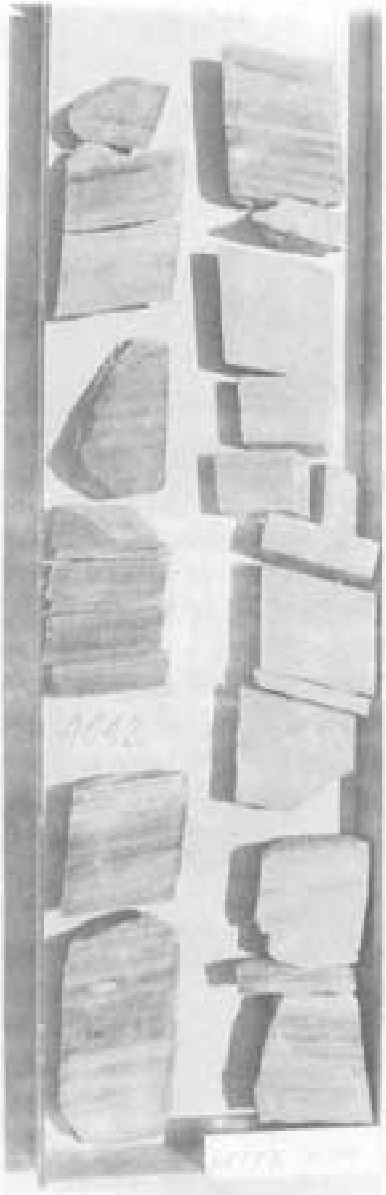


4617-23

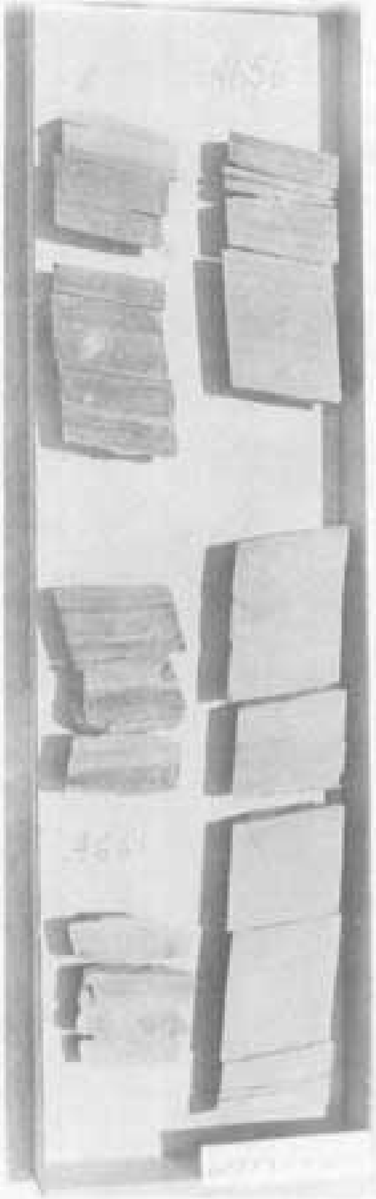


2624-30 (?)

GETTY OIL CO.
A-253
Sec. 8, T.27S., R.21E

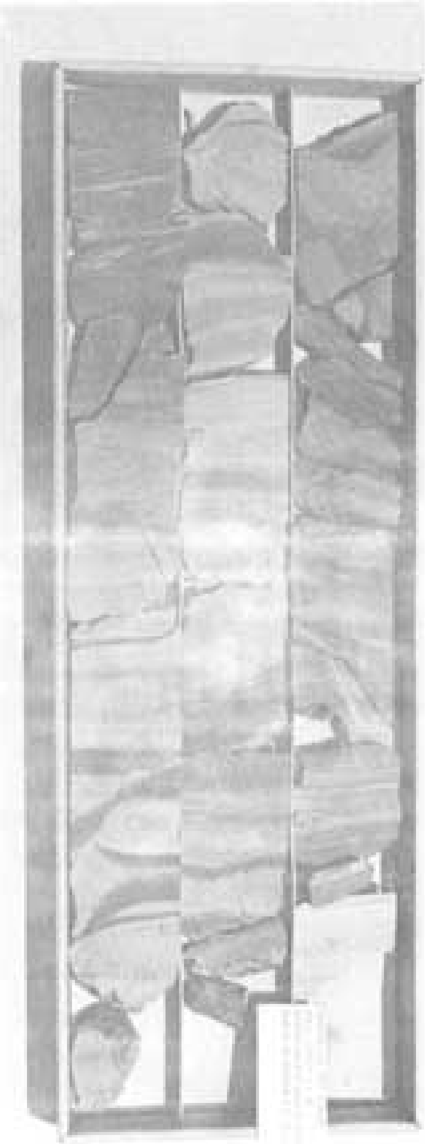


4631-44 (?)

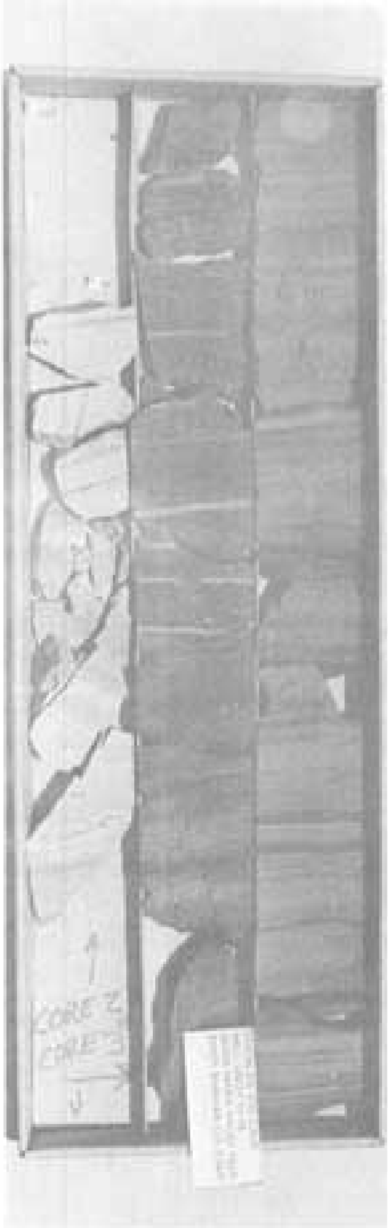


4656-62

UNION OIL CO.
LeRoy 51-18
Sec. 7; T.10N., R.35W.

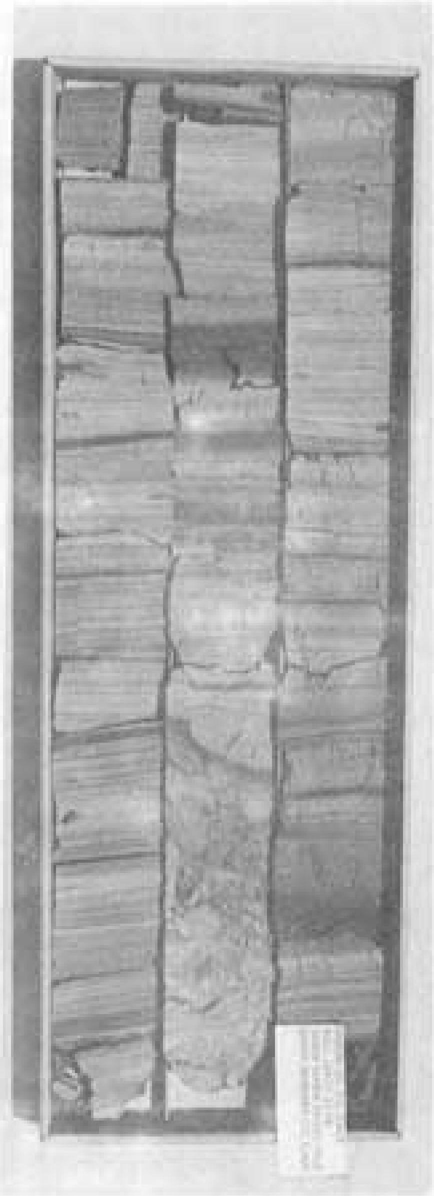


4508-16



4516-24

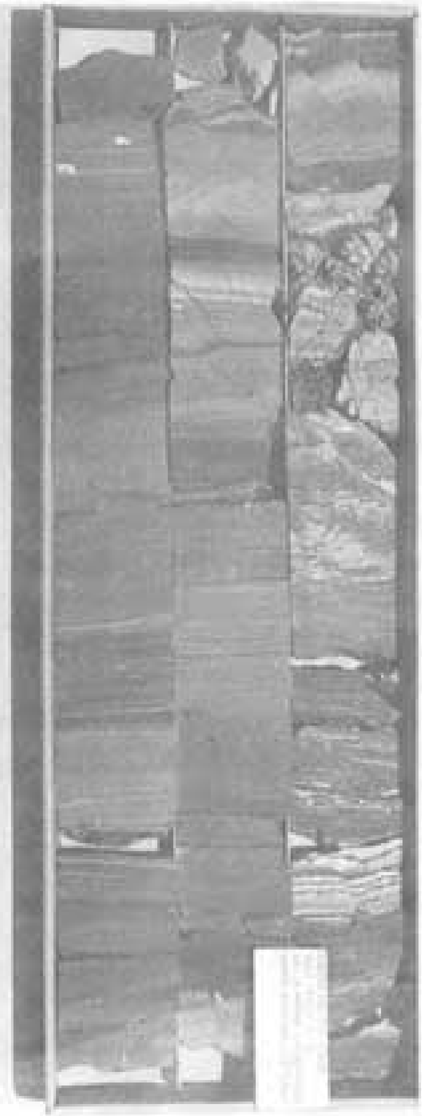
UNION OIL CO.
LeRoy 51-18
Sec. 7, T.10N., R.35W.



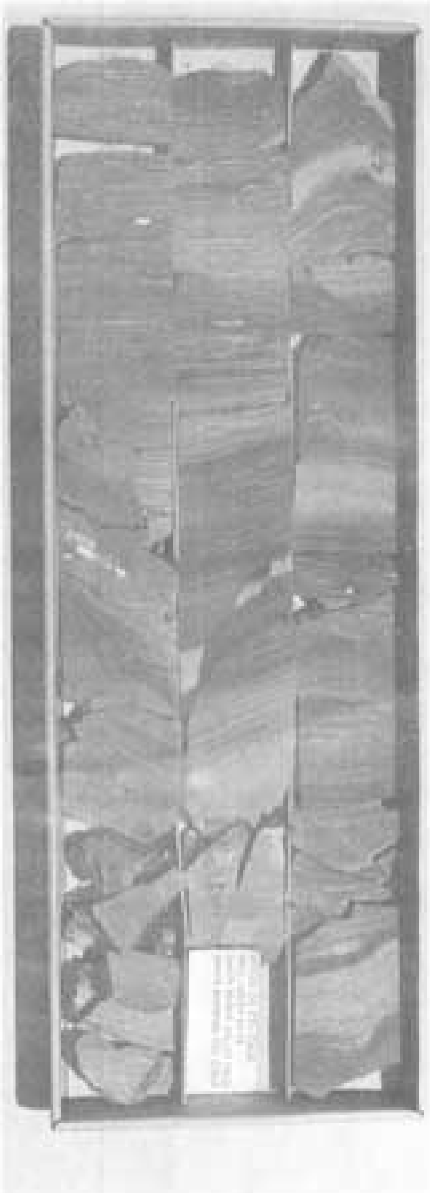
4575-84

4584-92

UNION OIL CO.
LeRoy 51-18
Sec. 7, T.10N., R.35W.



4637-47



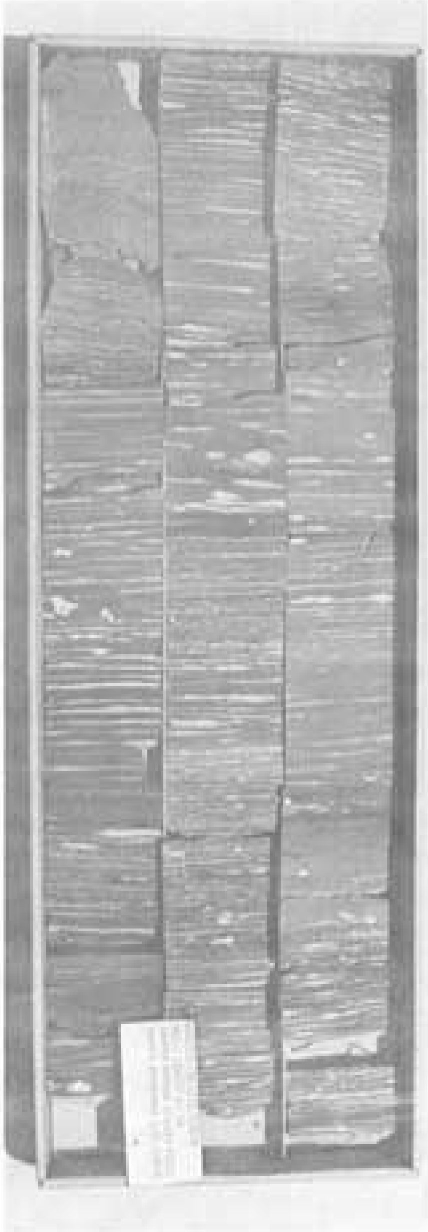
4650-59

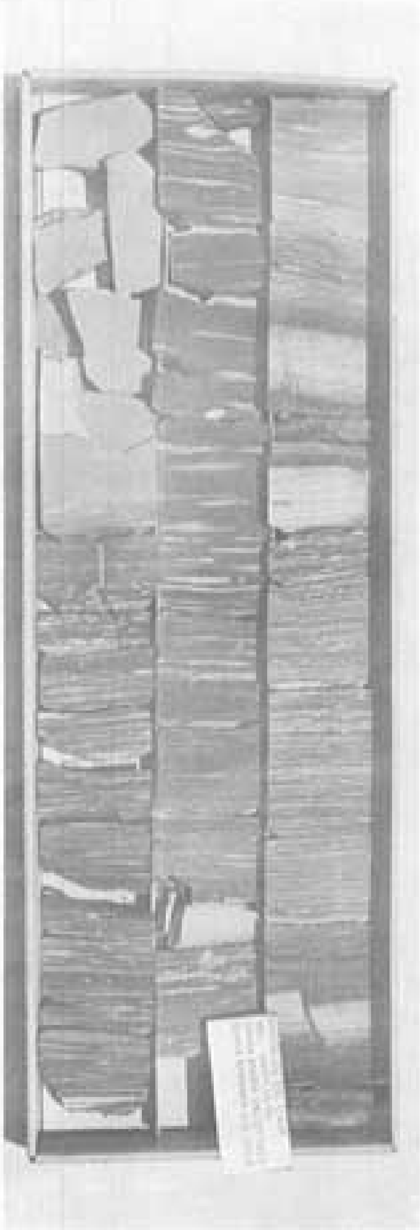
UNION OIL CO.
LeRoy 51-18
Sec. 7, T.10N., R.35W.

4659-68

4670-79

UNION OIL CO.
LeRoy 51-18
Sec. 7, T.10N., R.35W.

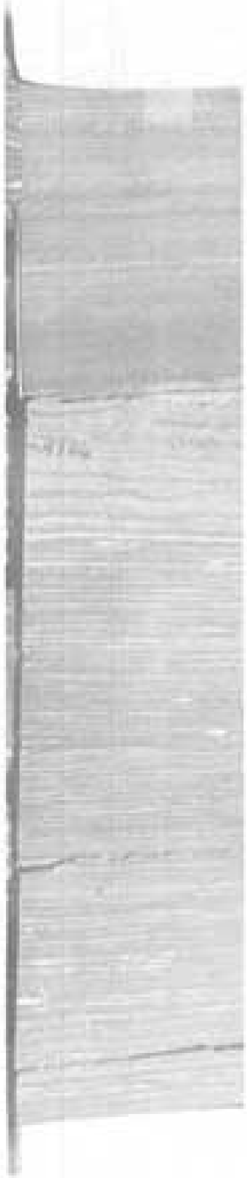




4680-88

UNION OIL CO.
LeRoy 51-18
Sec. 7, T.10N., R.35W.

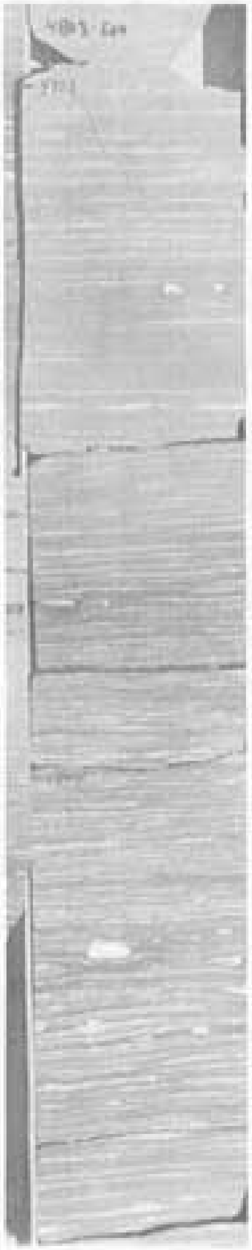
4782-91



4785-87

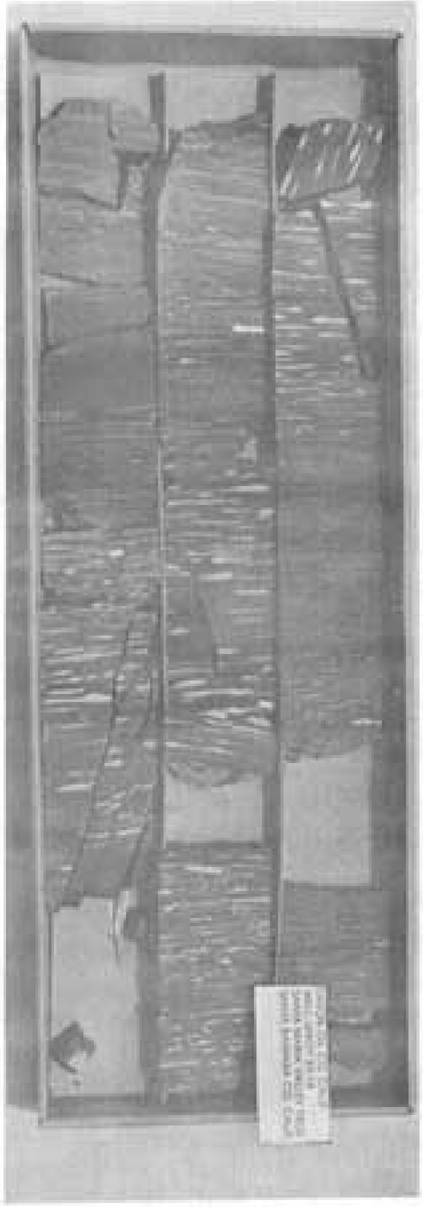
UNION OIL CO.
LeRoy 51-18
Sec. 7, T.10N., R.35W.

4800-08

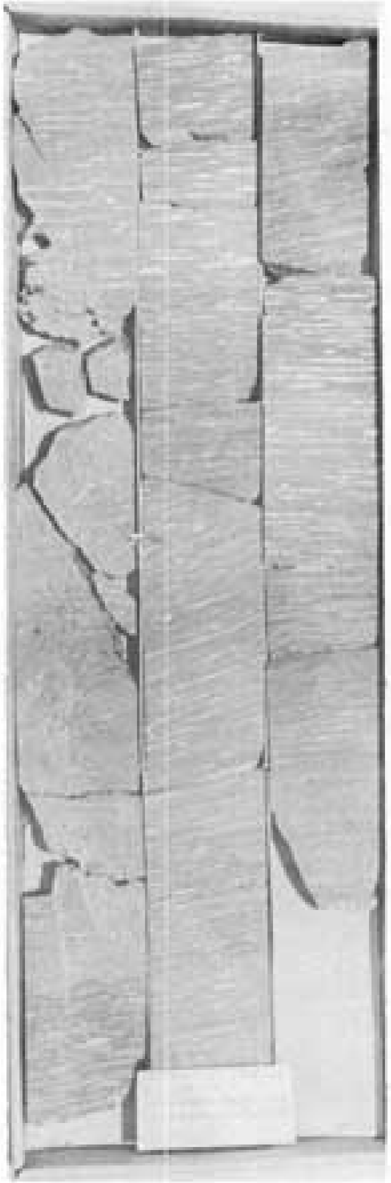


4803-05

UNION OIL CO.
LeRoy 51-18
Sec. 7, T.10N., R.35W.

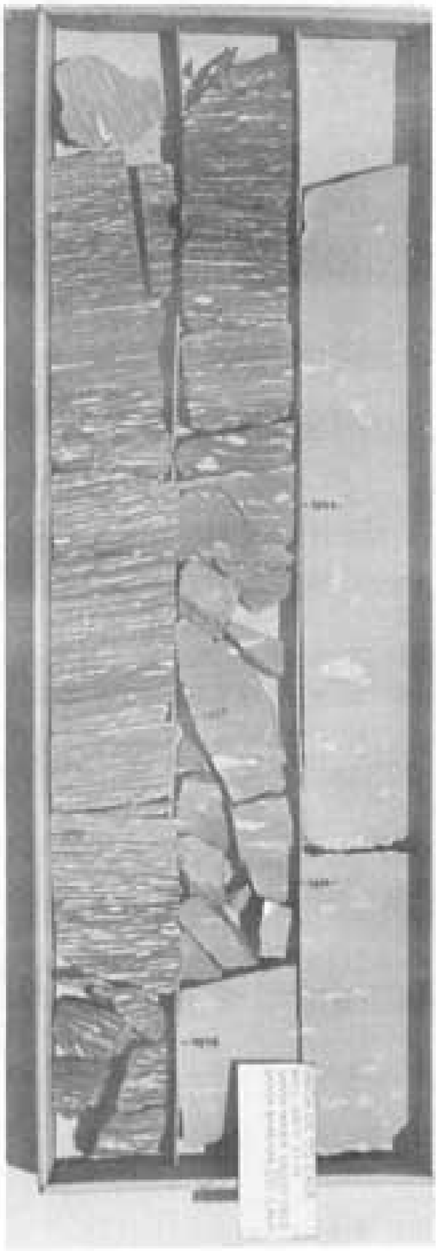


4815-22



4822-31

UNION OIL CO.
LeRoy 51-18
Sec. 7, T.10N., R.35W.

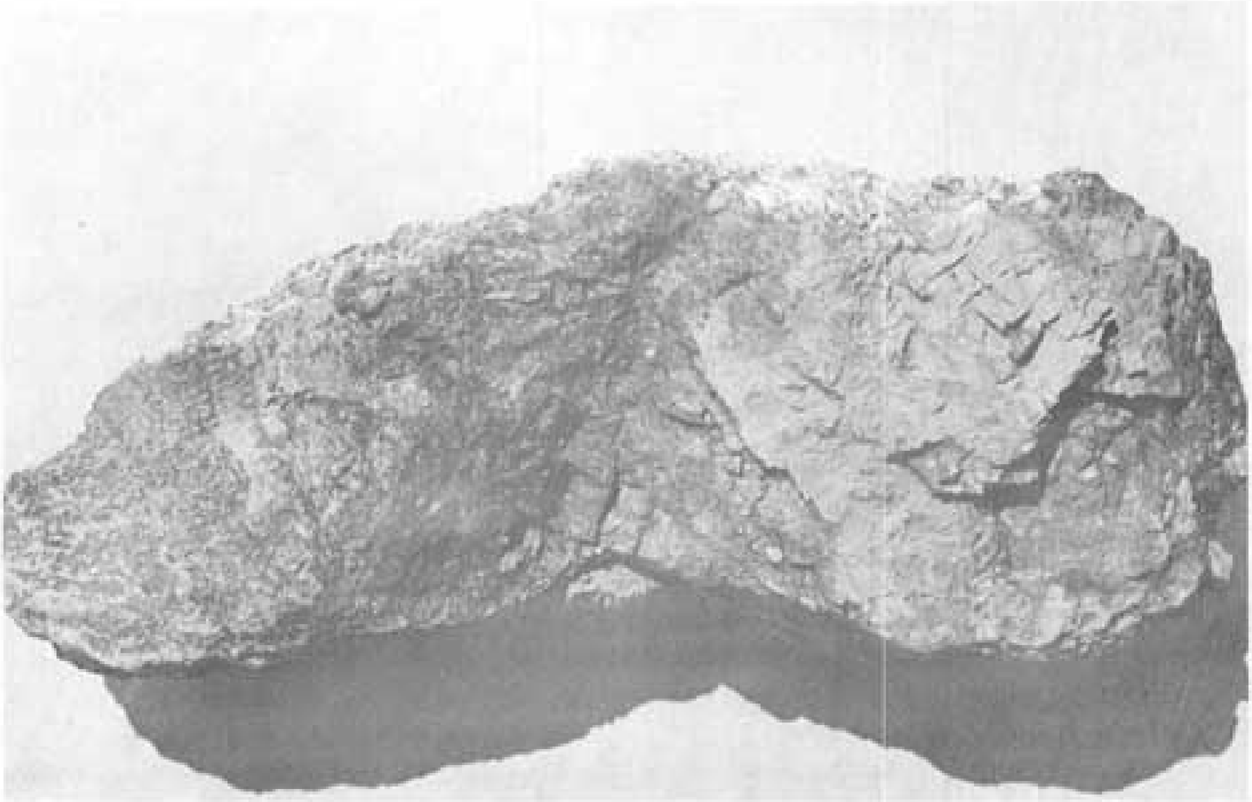


4843-51

JACK'S PEAK ROAD
("TYPE MONTEREY" AREA)
Monterey Co.

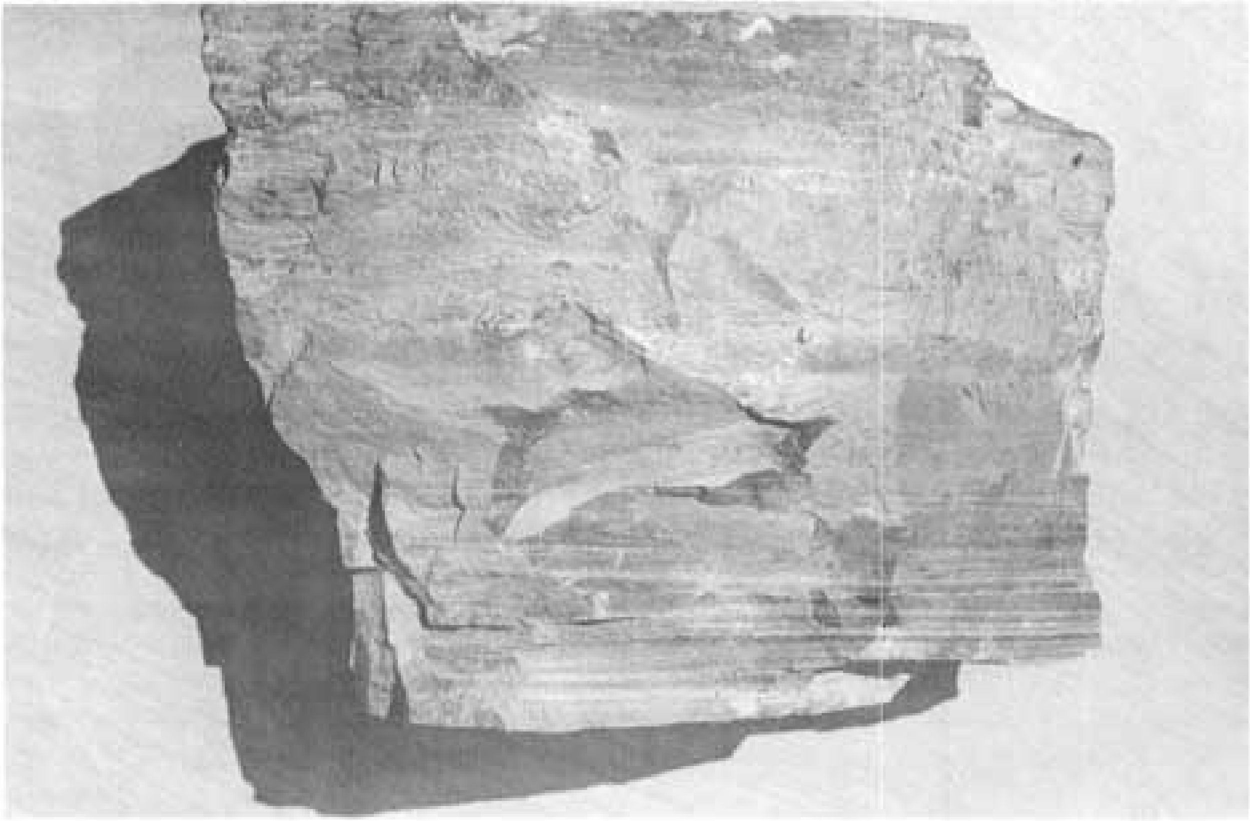
Silty diatomite/diatomaceous siltstone

Big Tar Canyon
Kings Co.



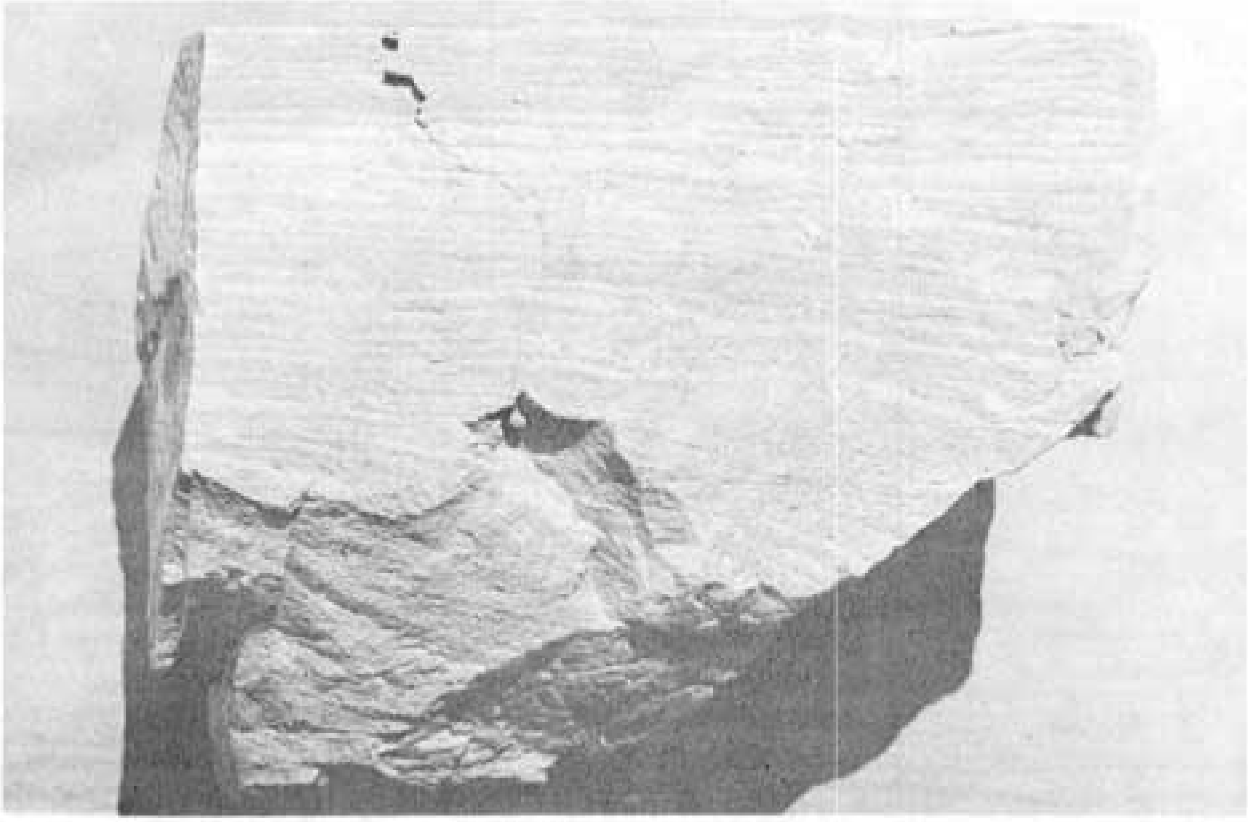
Tar-impregnated, brecciated, conglomerati sandstone

CHICO MARTINEZ CREEK
Kern Co.



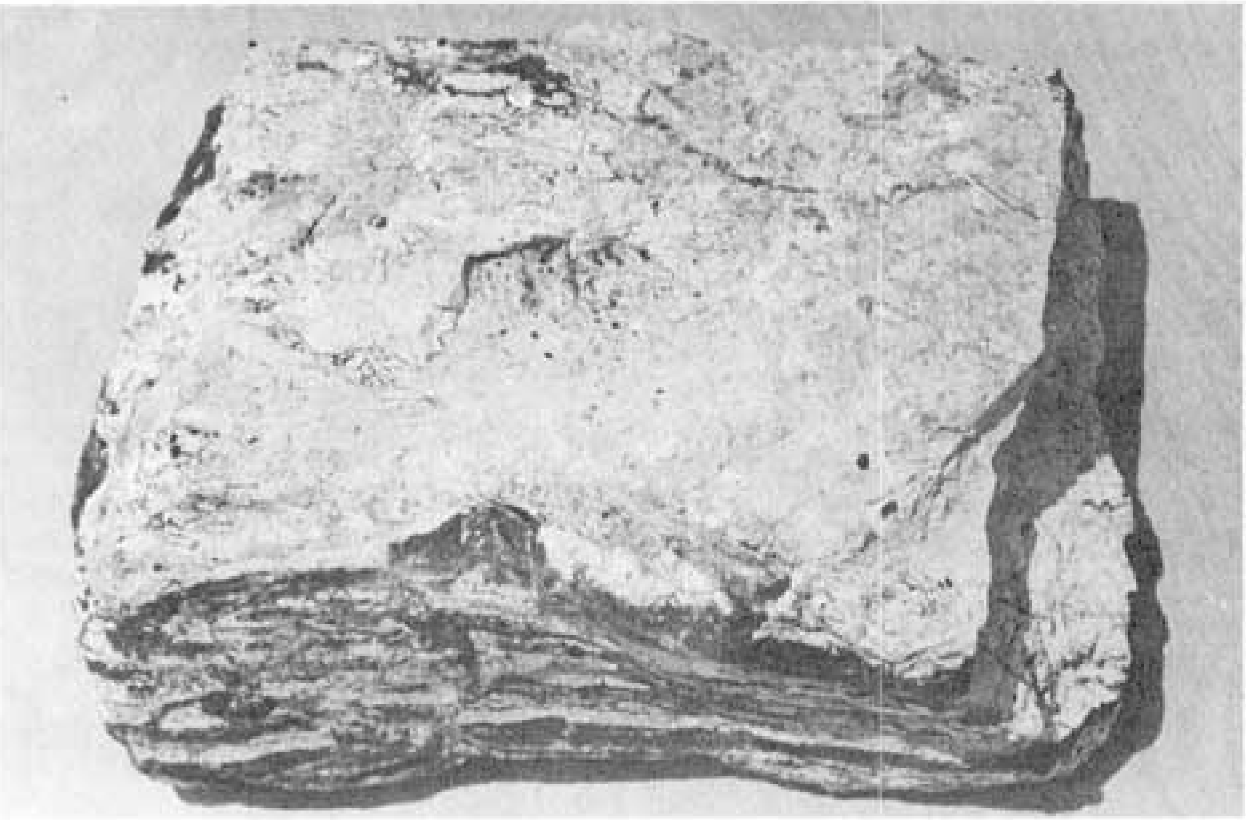
McDonald Shale

TAFT DIATOMITE "MINE"
Kern Co.



Diatomite

SUDDEN
Santa Barbara Co.



Chert and Porcelanite