ORIGIN OF THE EOCENE SANDS OF THE COALINGA DISTRICT, CALIFORNIA

A Thesis

by

Louis J. Regan Jr.

In partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

California Institute of Technology
Pasadena, California
1943

TABLE OF CONTENTS

ABSTRACT.. Page 1

INTRODUCTION.. 2

Purpose of Investigation.......................... 3
Location of Area.......................... 3
Acknowledgments.......................... 4
Method of Study.......................... 4

STATEMENT OF DATA.......................... 11

General Geology of the Coalinga District...... 11
Age of Formations.......................... 17
Microlithologic Data.......................... 22
Method of Study.......................... 22
Heavy Minerals of Possible Eocene Source Rocks.......................... 26
Characteristics and Distribution of Eocene Heavy Mineral Assemblages...... 31
"Light Minerals" of the Eocene Sands of the Coalinga District.................. 41
Evidence Bearing on Position of Eocene Positive Areas.......................... 48

PALEOGEOGRAPHY OF THE EOCENE OF THE COALINGA DISTRICT.......................... 52

Paleogeography of the "C" Stage, and the Origin of the Cantua Sand.................. 53
Paleogeography of "B3-B4" Time, and the Origin of the Gatchell Sand................. 56
Paleogeography of "B2" Time, and the Origin of the Yokut Sand.................... 61
The Origin of the Domengine Formation......... 64

CONCLUSIONS.......................... 66

INDEX OF SAMPLE LOCALITIES.......................... 69

LIST OF ILLUSTRATIONS

Generalized Columnar Section of Eocene Rocks North of Coalinga..............................Page 14

Tentative Correlation of California Eocene Formations (after Boris Laiming)............... 19

Heavy Minerals from the "McAdams Sand"......... 28

Heavy Minerals from the Source Rock Samples.... 28

Tentative Correlation of Eocene Formations in the Coalinga District, showing Distribution of Heavy Mineral Assemblages.................. 32

Eocene Heavy Mineral Assemblage #1............. 34

Eocene Heavy Mineral Assemblage #2............. 35

Eocene Heavy Mineral Assemblage #3............. 38

Eocene Heavy Mineral Assemblage #4............. 40

Isopach Map (Showing Interval Between Base of Kreyenhagen and Top of Cretaceous)............. 47

Paleogeography of the "C" Stage................ 54

Paleogeography of "B3-B4" Time................. 57

Paleogeography of"B2" Time..................... 62

Isometric Diagram Showing Distribution of Heavy Mineral Assemblages of the Coalinga District... 68

ABSTRACT

The purpose of this paper is to attempt to explain the origin and the conditions of deposition of the Gatchell and related Eocene sands of the Coalinga district, California. The method of study has been to gather data bearing on the position of the Eocene basin of deposition, location of positive areas, and sources and direction of movement of the sediments; such data is grouped into three types:

1. The age and correlation of Eocene formations are of prime importance in the problem. The correlations used in this study are based largely on Foraminifera; in some instances, where paleontological data is lacking, correlations are based on heavy minerals.

2. Lithologic data presented in this report deals in part with the distribution of sands and silts in the Coalinga district. However, the main body of this data comprizes a considerable number of heavy mineral analyses, including analyses of Eocene sands and also of possible Eocene source rocks. Four distinct assemblages of heavy minerals are present in the Eocene sands studied, each assemblage indicating a change in source rocks. These analyses can be correlated with possible source rock analyses, which include granitic, Franciscan, and Cretaceous rocks. In addition to heavy mineral data, a smaller amount of data on the "light minerals" of the various Eocene sands is presented.

3. Evidence bearing on the position of positive areas includes structural data dealing with the main unconformities in the Eocene section, and stratigraphic data dealing with the thicknesses of Eocene formations in various parts of the area. It is concluded that during the Eocene, there were three contemporaneously existing positive areas bordering the area of deposition.

The final part of the report deals with the interpretation of the data outlined above. A number of maps have been constructed showing probable progressive stages during the deposition of the Eocene sediments. The Cantua sandstone is believed to have been derived from the granitic rocks now exposed west of the San Andreas fault in the approximate latitude of Coalinga. The Gatchell sand is believed to have been derived largely from Cretaceous rocks in a positive area west of the present Reef Ridge; it is pictured as having been deposited as a spit built northward from this positive area, across the southeastern end of the Vallecitos channel. The Yokut is regarded as having a Coast Range source. The Domengine was very clearly derived from the Franciscan rocks of the Coast Ranges.

ORIGIN OF THE EOCENE SANDS OF THE COALINGA DISTRICT

By

Louis J. Regan Jr.
California Institute of Technology
April, 1943

INTRODUCTION

Early in 1938 an Eocene test well was drilled on the East Coalinga Anticline, a few miles northeast of the town of Coalinga, California, which resulted in the discovery of a new oil field. The discovery well, drilled by the Petroleum Securities Company, was completed in an Eocene sand at a depth of 6,908'; since the well was located on the Gatchell lease, the sand is known as the Gatchell sand. The Gatchell sand has a maximum thickness in the East Coalinga Field of about 800'; it disappears to the west with striking abruptness, the western or up-dip limit of sand deposition resulting in a large closure. The up-dip pinchout of the sand, when viewed in plan, is an unexpectedly straight line, trending approximately N-S for a distance of at least 12 miles. Other wells drilled in the area suggest that the Gatchell sand also thins to the east, although there is insufficient data to show the character of the eastern limit of sand deposition. The Gatchell sand forms a remarkable and unique sand body, which may be pictured as an extremely elongate sand lens, with a remarkably straight western edge.

In the vicinity of Coalinga there are a number of other large Eocene sand deposits, most of which are confined to the Lower and Middle Eocene. All of these sands are characterized by moderate to extreme lenticularity, a factor which makes it extremely difficult to work out the relationship between the Gatchell sand, and the other Eocene sands in the Coalinga District.

Purpose of Investigation

The purpose of this paper is to attempt to explain the origin and the conditions of deposition of the Gatchell and related sands of the Coalinga District, California. The study was made with the hope that a synthesis of lithologic, microlithologic, paleontologic, and structural data might lead to an understanding of the factors controlling the distribution of sand and silt in the Eocene strata of this area.

The work forming the basis for this paper was done at the California Institute of Technology, Pasadena, California, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Location of Area

All of the outcrop and well sections studied are within a few miles or tens of miles of the town of Coalinga, California. Coalinga is in Fresno County, on the southwestern side of the San Joaquin Valley, at the eastern base of the Diablo Range.

Acknowledgments

The writer is greatly indebted to the following companies for financial assistance in connection with this project: The Texas Company; The Superior Oil Company; R. S. Lytle, Operator; The Seaboard Oil Company; and the Honolulu Oil Company.

Numerous other companies and a large number of individuals have taken an interest in the study. In particular the writer is indebted to Hampton Smith, Hans Ashauer, J. M. Hamill, and Boris Laiming, all of The Texas Company; to G. C. Gester, W. S. W. Kew, and W. F. Barbat, of The Standard Oil Company; to R. K. Patterson and F. Taylor with R. S. Lytle, Operator; to D. McCloskey of The Amerada Petroleum Corporation; to Wayne Smith of The Wilshire Oil Company; to E. Edwards of The General Petroleum Corporation; and to R. B. Hutcheson of The Superior Oil Company.

Grateful acknowledgments are due to J. P. Buwalda, J. H. Maxson, Ian Campbell, and F. D. Bode, all of the California Institute of Technology, for many helpful discussions of various aspects of the problem.

Method of Study

The research was begun with a more or less detailed study of the structure, texture, and composition of the Gatchell sand in the East Coalinga Oil Field. However, it was soon apparent that this data was on too local a basis to permit any satisfactory conclusions as to the genesis of the sand because it was impossible to gain much of an idea of the source of the material or the direction from which it came. Therefore, with the termination of this early phase of the work, a somewhat different method of approach was adopted.

Any problem of this type, involving as it does the distribution of sediments, is essentially a paleogeographic investigation. If a paleogeographic map could be drawn showing the location of the positive areas, position of the basin, and direction of movement of the sediments during Gatchell time, the origin of the Gatchell sand should be apparent. With this aim in mind, three main types of data have been assembled; these will be described below. The study has been limited to the sediments between the base of the Kreyenhagen and the Cretaceous, or to the Lower and Middle Eocene, since it is within this interval that the Gatchell sand and related sediments were deposited.

One of the most important types of data needed in constructing a paleogeographic map is biostratigraphic data, using the term in the same sense as Kleinpell.

> "The term biostratigraphy applies to that phase of the science of paleontology which relates fossils to the containing strata, in distinction from "paleobiology" which is the more essentially systematic phase of the science."[1]

---

1. Kleinpell, R. M. Miocene Stratigraphy of California, AAPG, 1938

If in a given area a large number of stratigraphic sections show an identical sequence of fossil assemblages, independent of lithologic variations, then a series of biostratigraphic units, each characterized by a unique association of forms, can be safely established. Biostratigraphic units, which are independent of facies, are essentially time-stratigraphic units, since their thickness indicates the amount of sediment deposited during the time a definite assemblage of forms lived together. In practice, facies problems, and often the lack of sufficient fossil material, result necessarily in approximations of the ideal just described, a fact which causes considerable difficulty in the present problem. It should be noted that in an area of widespread, thin, uniform formations, lithologic contacts and biostratigraphic units may be expected to be much more nearly parallel than in areas in which formations are highly lenticular.

Valid biostratigraphic units are of great value for our purpose, for they provide a measuring stick for determining the rate of sedimentation in different parts of an area, they provide a safe method of correlating lithologically diverse formations, and conversely, they enable us to determine the type of sedimentation which took place in various parts of an area at any given time.

The second type of data used in paleogeography is lithologic data. In the simplest sense, this includes the distribution of sands, silts, shales, and other lithologic types. More useful for the present purpose, however, is detailed data on micro-lithology, including the distribution of heavy mineral assemblages, the distribution of various types of pebbles, variations in quartz-feldspar ratios, and finally, variations in texture of sediments and roundness of constituents. When this microlithologic data is combined with the biostratigraphic data, conclusions may be drawn as to the probable direction of movement of the sediments.

A considerable portion of this investigation was devoted to the gathering of data on the heavy mineral assemblages of the Eocene sands, and for this reason the following paragraphs will be devoted to a discussion of the principles governing the interpretation of this information.[1]

The two chief applications for heavy mineral data in the present study are: a. as an indication of the source rock of a sediment, and b. as a basis for the correlation of sediments.

The chief factor determining the heavy mineral content of a sand is the source rock, for it is obvious that the composition of a sediment will be controlled by the composition of the source. Sediments derived from a single

---

1. For an interesting discussion of some of these principles, see: Milner, H. B. Sedimentary Petrography, 3rd Ed. Thomas Murby and Co., London, 1940, pp 431-514.

source should have a uniform assemblage of heavy minerals, except for local variations which might be caused by a selective sorting action of the agent depositing the sediment or by secondary alteration and weathering subsequent to the deposition of the material. A change in the heavy mineral content of a series of sediments would usually indicate a new source of material, but in some cases, changing climatic conditions might cause some types of variations. Under conditions of deep weathering a given source would produce a different assemblage of heavy minerals than the same source would, when contributing unweathered debris. Such weathered rocks should result in a relative impoverishment in the amount and variety of minerals present.

When two or more sources are contributing debris to a basin of deposition, the problem of the probable distribution and variations of the heavy mineral content of the resulting sediments becomes more complicated. Indeed, one of the most important assumptions used in the interpretation of heavy mineral work arises in this connection. The assumption is that where two or more different but contemporaneous heavy mineral assemblages are found in an area, two or more sources are implied, and each assemblage should be found nearest its source. To clarify the meaning of this assumption, consider for a moment the case of an elongate basin which is receiving sediments from both sides, and assume that the source rocks on each side are very different. In this case it seems very reasonable that the sediment deposited on one side of the basin will be more like the source rocks on that side, while the sediments on the opposite side will be most like its source rocks; between these two areas, there would probably be an area of mixing of the sediments of the two types.

The use of heavy mineral assemblages for correlating sands is subject to the same difficulties as ordinary lithologic correlations. A reliable heavy mineral zone should display the same characteristics shown by a good "marker" bed, i. e. it should be an unique zone of small vertical and large horizontal extent.

The third type of data of use in constructing a paleogeographic map is the evidence suggested by unconformities and overlaps. This kind of structural evidence is useful in deducing the position of positive areas and areas tending to be positive during a given time.

The ideas outlined above are rather simple, but as will be apparent in the present study, when one attempts to apply them, a great many difficulties arise. In the first place, the accuracy of paleogeographic conclusions is proportional to the amount of available data of the three types described above. But this data is often lacking or scarce, particularly in certain areas which then become very important key areas. The biostratigraphic data on the Eocene of the Coalinga District has been satisfactory in parts of the area, but nevertheless the evidence favoring a few of the correlations tentatively accepted is not very strong. Because of these weaknesses the reader may not reach the same conclusions as the author, regarding the origin of the various Eocene sands in the Coalinga district. For this reason, the report will be divided into two parts; the data will first be set forth, and the final section will state the author's interpretation of this information.

STATEMENT OF DATA

General Geology of the Coalinga District

The stratigraphy and structure of the Coalinga District have been adequately described[1] and there is no need to re-describe them in detail at this time. The purpose of this chapter is to give a brief sketch of the geology of the area, insofar as this information has a bearing on the present problem.

A number of surface and subsurface stratigraphic sections of the rocks in the interval between the base of the Kreyenhagen and the top of the Cretaceous have been studied in this investigation. The sections and wells all lie in the area embracing townships 12-24 S., and ranges 12-20 E. The Isopach Map, page 47, shows the total thickness of the stratigraphic interval under discussion; the areas in which the formations comprising this interval outcrop; and the location of all wells and sections studied.

---

1. Arnold and Anderson; Geology and Oil Resources of the Coalinga District, California. USGS Bull 398, (1910)

   Anderson and Pack; Geology and Oil Resources of the West Border of the San Joaquin Valley, North of Coalinga, California. USGS Bull 603, (1915)

   Reed and Hollister; Structural Evolution of Southern California. AAPG, Tulsa, Okla. (1936)

   White, R. T. Eocene Yokut Sandstone North of Coalinga, California. AAPG Bull V24, 1722-1751, (1940) The southwestern third of area delineated above is characterized by hilly to mountainous topography, while the remainder is a nearly flat to gently undulating plain. The town of Coalinga lies in a long, narrow synclinal valley, Pleasant Valley, which trends in a northwest-southeast direction. Pleasant Valley is bordered on the north by a long anticlinal ridge, Joaquin Ridge, which is parallel to the Pleasant Valley Syncline. The Joaquin Ridge Anticline plunges southeastwardly in the vicinity of the town of Coalinga, but rises again further to the southeast, to form the domal structures in the Kettleman Hills. Southwest of Pleasant Valley there is another anticlinal ridge, known as the Jacalitos Anticline, whose trend is also more or less parallel to the Pleasant Valley Syncline. The most prominent topographic feature near the southwest border of Pleasant Valley is a long sawtooth ridge known as Reef Ridge.

The area north of Joaquin Ridge is characterized by hilly topography; the relief increases westward, away from the San Joaquin Valley. The dominant structure north of the Joaquin Ridge anticline is a large southeastward trending syncline, known as the Vallecitos syncline.

Stratigraphy

Cretaceous- The Upper Cretaceous rocks outcropping north of Coalinga were grouped into two formations by Anderson and Pack in 1915: 1. The Panoche formation and 2. The Moreno formation.

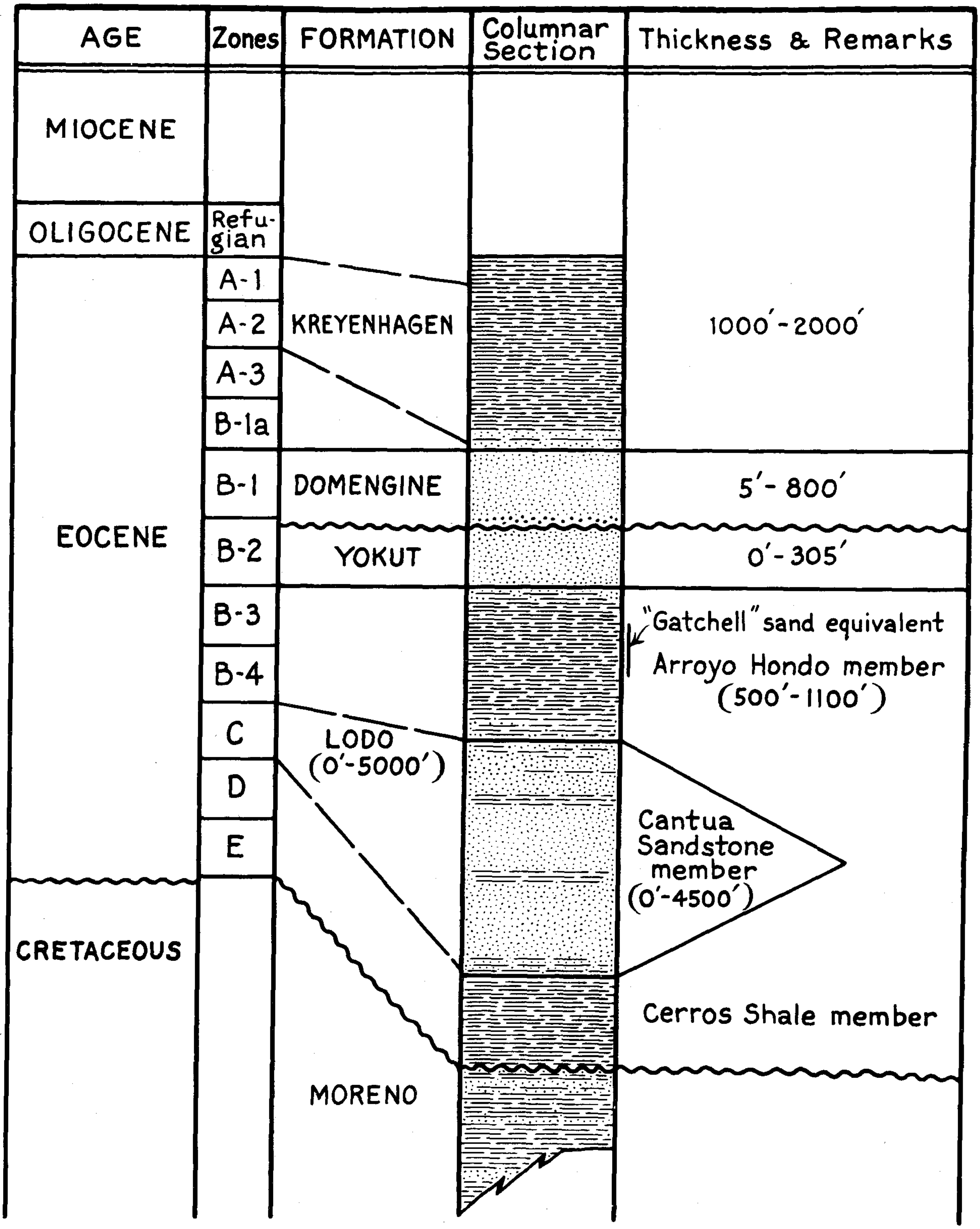
<u>The Panoche Formation</u> of Anderson and Pack comprises all the Upper Cretaceous strata lying below the purple weathered Moreno shale, and as mapped by them, it rests unconformably on the Franciscan. It contains beds of very diverse lithology, including conglomerate, sandstone, siltstone, and shale, with an aggregate thickness of over 20,000 feet.

<u>The Moreno Formation</u> of Anderson and Pack conformably overlies the Panoche, and is composed of foraminiferal and diatomaceous chocolate brown and purple colored, sometimes siliceous, organic shale. The average thickness of the Moreno is approximately 2000 feet. Occasional lenses of sandstone and conglomerate are present.

<u>Eocene</u>- A generalized column of the Eocene formations outcropping north of Coalinga is shown on page 14. The following paragraphs will be devoted to a brief description of these rocks.

<u>The Lodo Formation</u> of White is composed of massive, gray, locally sandy, silt, with a large lens (Cantua sand) composed of thick, massive, coarse-to fine-grained, concretionary sandstone beds, separated by thin gray silt partings. The thickness of the Lodo formation is extremely variable, due mainly to the lenticularity of the Cantua sand lens, whose thickness varies from 0 to over 4000 feet. Where the Cantua sandstone member is present, White proposes the terms Cerros shale for the shale beneath the sand, and

GENERALIZED COLUMNAR SECTION OF EOCENE ROCKS NORTH OF COALINGA[1]



1. Data from:
   a. White. Bull. A.A.P.G., vol. 24, no. 10, Oct. 1940.
   b. Laiming, Boris. Foraminiferal correlations in Eocene of San Joaquin Valley, Calif. Bull. A.A.P.G., vol. 24, no. 1.

Arroyo Hondo shale for that above the sand.

The base of the Lodo is not well exposed, so that the nature of the contact is difficult to judge; the contact appears to be conformable with the underlying Moreno shale. Outcrops of the Lodo formation extend from Joaquin Ridge to the northern end of the area.

The Yokut Sand is the unit lying between the Lodo Formation and the Domengine formation. The upper part of the Yokut is a white, medium-to fine-grained, fairly clean sand; downward the sand becomes silty, and grades into the underlying Lodo formation. Outcrops of the Yokut sand extend from the Oil City Section on Joaquin Ridge, to the northern end of the area.

The Domengine Formation unconformably overlies the Yokut. The base of the Domengine is marked by a pebbly to gritty zone composed mainly of black chert pebbles, with minor amounts of quartzite and volcanic pebbles, in a medium to coarse, calcareous sandstone matrix. The pebble bed, known as the Domengine Reef, is overlain by interbedded gray to brown, poorly sorted silty sand and sandy silt.

The base of the Domengine formation is an unconformity, and the Domengine completely overlaps the Yokut and Lodo formations north of Tumey Gulch, and south of Oil City. The Domengine is overlain by the Kreyenhagen shale, the base of which is usually marked by a glauconitic sand a few feet thick. The base of the Kreyenhagen is also, locally at least, an unconformity, for the Domengine is overlapped by the Kreyenhagen in two of the sections studied by the author; these localities are: a. on the ridge north of Cantua Creek, and b. at the location of the Seaboard Hagood #2 well.

South of Joaquin Ridge, the stratigraphy is somewhat different from that described above. Strata underlain by Cretaceous rocks and overlain by the Kreyenhagen shale outcrop in two areas south of Oil City, as is indicated on the Isopach Map, page 47. These areas deserve special treatment, and are briefly described below.

The Coal Mine Canyon Eocene- Coal Mine Canyon is located in the low foothills, west of the town of Coalinga. At this locality there are about 230' of beds exposed between the base of the Kreyenhagen and the Cretaceous. The lower 200' of these beds are composed of medium-to fine-grained, white to gray, silty to fairly clean sandstone, interbedded with seams of lignite, and gray, locally purplish colored clayey silt beds up to 20' thick. Overlying this member is a 10' hard, calcareous, fossiliferous sandstone bed, which is pebbley and fossiliferous at the base. Above the calcareous sand and below the glauconite at the base of the Kreyenhagen, there is approximately 20' of gray clayey silt.

North of Coal Mine Canyon the thickness of the sand-coal-silt member decreases considerably, and about a mile north the thickness amounts to only 65'. The relative position of sand beds and lignite beds in the Coal Mine Canyon Section and in sections a few thousand feet to the north, suggests that the thinning may be due to an unconformity at the base of the calcareous, pebbley sand member.

It is noteworthy that the Coal Mine Canyon Eocene beds do not rest on the Moreno as is the casein the Oil City Section and other sections to the north; instead, at Coal Mine Canyon the Eocene rocks lie unconformably on a sand member in the Panoche formation. This sand is found approximately 1600' below the top of the Panoche on Joaquin Ridge.

The Garzas Creek Section on Reef Ridge: The Avenal Sand

The strata exposed on Reef Ridge between the base of the Kreyenhagen and the Cretaceous consist entirely of massive, medium-to coarse-grained, locally concretionary sand. This sand, the Avenal sand, has a thickness of 350-400 feet in Garzas Creek. The Avenal sand rests with considerable angular unconformity on an horizon at least 1600' below the top of the Panoche formation.

Age of the Formations

The two principle sources of published paleontologic data dealing with the present problem are the work of

Laiming[1] on the Eocene Foraminifera and the work of Vokes[2] on the Eocene Mollusca.

Because micropaleontological data is available from many more sections in the district than is molluscan data, and because the Foraminifera apparently permit division of the sections into smaller units, most of the correlations used in this paper are based on Foraminifera.

In addition to the published material already cited, the author has had the benefit of discussions with Boris Laiming on the correlation of various subsurface sections. Moreover, in order to gain some first hand information and experience in regard to Eocene foraminiferal correlations in this area, the author has studied the foraminiferal assemblages in the Oil City Section, and in a number of subsurface sections.

Laiming has divided the California Eocene section into a number of zones; a copy of his chart showing tentative foraminiferal correlations of California Eocene formations in shown on page 19 of this report. As is well known, the Middle Eocene faunas of the San Joaquin Valley generally indicate relatively shallow water environments. Because

1. Laiming, Boris; Some Foraminiferal Correlations in the Eocene of The San Joaquin Valley, California. Proc. Sixth Pacific Sci. Congress, pp 535-568, (1939).
2. Vokes, H. E. Molluscan Faunas of the Domengine and Arroyo Hondo Formations of the California Eocene, Annals New York Acad. Sci., Vol. 38, pp 1-246, (1939).

TENTATIVE FORAMINIFERAL CORRELATION OF EOCENE FORMATIONS IN CALIFORNIA[1]

MOLLUSCAN STAGES CLARK & VOKES 1936	FORAMINIFERAL ZONES* IN THE EOCENE OF CALIFORNIA		NEAR SAN DIEGO	SIMI VALLEY NORTH SIDE	EAST OF TECUYA CREEK	COAL MINE CANYON	OIL CITY COALINGA	CANTUA CREEK	CIERVO HILLS	NORTH OF MT. DIABLO	VACA VALLEY	MARTINEZ	OREGON	FORAM. ZONES	MOLLUSCAN STAGES CLARK & VOKES 1936
GAVIOTA	UVIGERINA COCOAENSIS	REFUGIAN				ABSENT	KREYEN-HAGEN 1000'±	KREYEN-HAGEN 1800'±	TUMEY 1700'	? ?	? ?		BASSENDORF	REFUGIAN	GAVIOTA
TEJON AND TRANSITION	PLECTOFRONDICULARIA JENKINSI	A-1		SESPE ?					KREYEN-HAGEN (ATWILL) 2500'±	MARKLEY 2720'	MARKLEY 5100'		COALEDO ? ?	A-1	TEJON AND TRANSITION
	UVIGERINA CHURCHI	A-2				KREYEN-HAGEN 400'				SHALE AT NORTONVILLE 540'	DUNNS PEAK SS. 350'			A-2	
	PLANULINA PSEUDOWUELLERSTORFI	A-3	POWAY CGL. 1000'	? ?	UPPER TEJON SHALE 600' ? ?						150' / "VACAVILLE" SHALES 2200'		? ?	A-3	
DOMENGINE	AMPHIMORPHINA CALIFORNICA	B-1A	? ?				ABSENT	ABSENT	ABSENT	ABSENT ? ?	ABSENT			B-1A	DOMENGINE
	CIBICIDES COALINGENSIS	B-1	ROSE CANYON MEMBER	LLAJAS 1700'		ABSENT ?	DOMENGINE 70'	DOMENGINE 120'	DOMENGINE 150'	"DOMENGINE" SS. 400'			TYEE	B-1	
CAPAY	MARGINULINA MEXICANA var. B	B-2	LA JOLLA 300'				LODO (WHITE) 620'	YOKUT SS. 100'±	YOKUT SS. 300'	IONE WHITE SS. 450'	SHALES WITH "CAPAY" FORAMINIFERA 2050'		? ?	B-2	CAPAY
	MARGINULINA MEXICANA var. C	B-3	? ?	MEGANOS (KEW) BASAL 300'				LODO (WHITE) 2200'	LODO (WHITE) 3600'	? ? MEGANOS DIV. E & D (CLARK & WOODFORD) 1840'			UMPQUA	B-3	
	PSEUDOUVIGERINA WILCOXENSIS	B-4												B-4	
	BOLIVINA APPLINI	C		MARTINEZ (KEW) 4200'		GRAY SHALE ABOVE AVENAL		CANTUA SS 1300'	CANTUA SS. 1800'			"MARTINEZ" OF CUSHMAN & BARKSDALE		C	
MEGANOS	GUMBELINA GLOBULOSA	D				"AVENAL"?	ABSENT	CERROS MEMB (MEGANOS & MARTINEZ FORAMINIFERA)	CERROS MEMB. (MEGANOS & MARTINEZ FORAMINIFERA)	MEGANOS DIV. A-C 1460'	?			D	MEGANOS
MARTINEZ	MARGINULINA SUBACULEATA	E								MARTINEZ 600'		MARTINEZ		E	MARTINEZ

* THE BIOLOGICAL DESIGNATION OF THE ZONES IS HERE PROPOSED INFORMALLY PENDING THEIR MONOGRAPHIC TREATMENT.

FIG. 9.—In a recent article, "Eocene Yokut Sandstone North of Coalinga, California," by Robert T. White, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 10 (October, 1940), pp. 1722–51, the Yokut sandstone has been defined as a separate formation, distinct from either the Lodo or the Domengine formations. Therefore, the Yokut should not have been included in the Lodo formation, as it is shown in Figure 4 and Figure 9 of the present article.

1. After: Laiming, Boris, "Foraminiferal Correlations in Eocene of San Joaquin Valley, California", Bull. AAPG, Vol. 24, No. 11 pp 1923-1939.

of this, facies elements are likely to enter into the faunal differences and similarities, and the question arises as to whether the divisions based on faunal changes represent true time intervals. The fact that the same sequence of faunas has been found over a wide area by Laiming, is good evidence that the divisions are valid zones.

In the correlation chart appearing on page 32 of this report, the author has attempted to show the relations between foraminiferal zones, formations, and heavy minerals in the principle sections studied in this investigation. The chart shows three stratigraphic cross sections in the Coalinga District; for the sake of simplicity, no effort has been made to construct these sections to scale, but the thickness of the formational units is indicated under each formational name. Sections AB and CD are both north-south cross sections; the former is drawn through the outcrop sections measured by the author, and the latter is crawn through wells located on a line extending north from the Garzas Creek Section to the Texas Company's SPL 27-13 Well. (See the Isopach map, page 47, for the location of the sections and wells). Section CD is a southwest-northeast stratigraphic section from Domengine Creek to the General Petroleum Corporations Burrel #1 Well. A study of this chart will be useful in the understanding of the paragraphs below.

In the present work, Laiming's "B" and "C" zones are probably of most interest, since the major Eocene sands of the area were deposited during this period of time. During "C" time, the tremendously thick Cantua sandstone was deposited. In spite of the great thickness, the area of deposition of sand was rather limited, the sand thinning north, south, and east of Cantua Creek. The sand thickens to the west, attaining its maximum thickness approximately 8 miles west of the author's Cantua Creek section. Silts equivalent in age to the Cantua sandstone are present, although thin, over most of the area studied.

During "B3-B4" time, the Gatchell sand was deposited. As in the case of the Cantua sand, the Gatchell was deposited in a rather limited area, but silts of equivalent age have a much wider distribution. The Yokut sand, present in most outcrop sections, was deposited during "B2" time. In some well sections sand is present which is of "B2" age; the "Fleishaker sand" (Bandini Petroleum Company's 48-18 well) and at least a part of the so-called "Blanket sand" (The Texas Company's SPL 27-13 well) are believed to be the equivalent of the Yokut sand are present. "B1" time was apparently a period of transgression, for the Domengine formation, which is entirely "B1" in age is recognizable in sections scattered over the whole area. Moreover, the Domengine tends to overlap the older Eocene, and in places rests on Lower Eocene or on Cretaceous strata.

It is difficult to correlate sands in the Coal Mine Canyon Section, Reef Ridge Area, and Kettleman Hills Section. According to Vokes, the Coal Mine Canyon Eocene sand and the Avenal sand of Reef Ridge are Domengine in age, that is, deposited during Laiming's B1 time. Laiming points out that the mollusca listed by Vokes, from these sands, contain few typically Domengine species, and on the basis of microfaunal evidence from the gray shale overlying the sand, he advocates an age at least as old as "C" for the sands of the two areas, rather than Domengine or "B1". However, he points out the weakness of the foraminiferal evidence in that area.[1]

The microlithologic data gathered by the author suggests still another possibility for the age of these sands. As will be shown below, the Coal Mine Canyon sand is very similar to the Yokut sand, while the Avenal sand of Reef Ridge is identical with the Gatchell sand. This suggests that the Coal Mine Canyon sand is to be correlated with the Yokut formation, and the Gatchell sand with the Avenal formation.

Microlithologic Data

Method of Study- The author has very little to add to

---

1. It is well known among California micropaleontologists that the 10-30' of gray silt found at the base of the Kreyenhagen, particularly in the Coal Mine Canyon Reef Ridge area, contains a fauna practically identical to that of the "C" zone. Two explanations have been given for this; 1. Reworking of "C" material, and 2. Recurrent facies.

the already voluminous literature on the technique of heavy mineral analysis.[1] The method used is as follows:

1. Sample disaggregated; acids used where necessary.
2. Sample washed from a 100M onto a 150M screen.
3. Sand caught on 150M screen then separated with bromoform.
4. Permanent mount made in Canada Balsam.
5. 100 clear grains identified and counted; percentage of constituents calculated.

The method of washing samples was found highly satisfactory; when sieved dry the sand grains remain coated with clay and silt, and washing by decantation is both ineffective and time consuming.

In a number of samples biotite was so abundant that it "flooded" out all other minerals. In order to remove the biotite, a large sheet of cardboard was used; the cardboard was elevated at one end, the sample spread out on the elevated end, and the cardboard then gently jarred. As a sample moves down the slope, biotite lags behind effecting a fairly clean separation. In a series of tests it was found that this process alters the ratios of the minerals present to some extent; hornblende especially tends to stay

---

1. Useful in this connection were:

Milner, H. B. Sedimentary Petrography, Thomas Murby and Co., London, 3rd Ed., 1940.

Krumbein and Pettijohn; Manual of Sedimentary Petrography, D. Appleton Century Company, New York, 1938.

Findlay, W. A. Sources of Miocene Sediments in Southwestern San Joaquin Valley, Ph.D. Thesis, Calif. Inst. of Tech., 1939.

behind with the biotite. However the changes in the ratios are not thought to be large enough to be important.

Assemblages- The results of the heavy mineral analyses have been plotted on a number of charts; similar analyses have been grouped together into assemblages. It should be emphasized that plotting the analyses as assemblages involves an element of interpretation, and the data are no longer in the "raw" form. The actual grouping of analyses was done in the following manner: The result of each analysis was plotted graphically on a separate card, so that the analyses could be easily compared. When this had been done it was apparent that there were groups of analyses which were identical, or at least similar enough to be grouped together, considering the experimental errors involved in the method. In this way, instead of having to deal with a great many separate analyses, we can discuss four main groups of analyses which represent more or less unique associations or assemblages of minerals.

It may be argued that the procedure outlined above is a purely arbitrary one, and that the assemblages can have no significance. However, one must keep in mind the factors which determine the mineralogy of a sediment, the most important of which are: 1. the source rock, and 2. changes in minerals present due to changes brought about by the transportation and deposition of the sediment, and by secondary changes in the sediment itself. Thus the assemblages of minerals can be interpreted as due to different source rock conditions, provided the other factors can be considered to be of minor importance.

The characters of the four main assemblages are briefly discussed below. Only the "flood" minerals, or minerals which are abundant in some group of samples are plotted. Secondary minerals such as barite have also been excluded. A number of other minerals have been noted in very small amounts in samples of all assemblages. These include corundum, staurolite, kyanite, and piedmontite; they are probably too rare to have any significance.

A few notes on some of the minerals charted are outlined below:

The amphiboles include tremolite, actinolite, green hornblende and brown hornblende. By far the most abundant of these is green hornblende, which is often a deep bluish green color; the other varieties are very rare in the samples studied.

Andalusite is generally distinctly pleochroic. Very pale andalusite was distinguished from barite with some difficulty.

Epidote varies from colorless to very deeply pleochroic varieties, and from shapeless grains to perfect elongated crystals.

Garnet varies considerably in color; red, colorless, brown, and green types were noted.

These varieties were counted separately, but the results show no definite trends.

Tourmaline is also remarkably variable in its colors. The various varieties were counted separately, as in the case of garnet, but this differentiation seems to be of little value. In general, brown tourmaline is most abundant, green tourmaline next in abundance, and blue tourmaline is persistently present but rarer than the others.

The Heavy Minerals of Possible Eocene Source Rocks

It is desirable at this point to discuss the heavy minerals present in possible Eocene source rocks, so that the reader will have this information in mind when the Eocene assemblages are discussed. Therefore the following section will deal with data derived from a study of source rock samples.

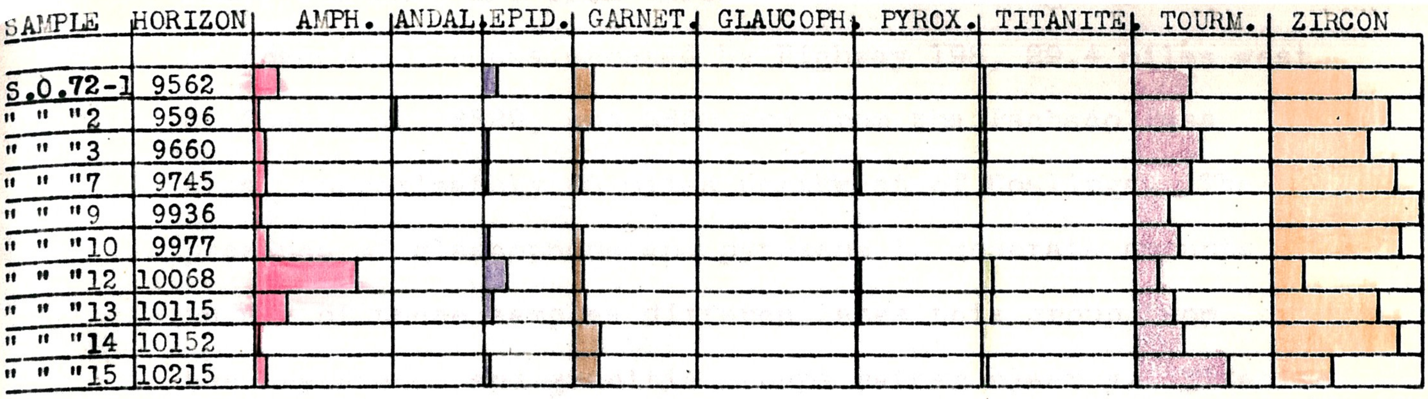
In order to obtain some data on possible sources for the constituents of the Eocene rocks, a number of Cretaceous, Franciscan and granitic rocks occurring in adjacent areas have been sampled and studied. These samples have been of two types; 1. actual samples taken from outcrops of the different rocks, and 2. samples of recent sands taken from streams draining areas in which the possible source rocks outcrop. In addition to the author's own analyses, similar work by Findlay (Op. Cit. page 23) is available which serves to supplement the data.

Of analyses of Cretaceous rocks shown on the chart, page 28, the first 10 analyses represent outcrop samples of Cretaceous, while the last two were obtained from samples of stream sand. The sample DpC is from the Cretaceous sand immediately underlying the Coal Mine Canyon Eocene, and the sample GC 1 is from the Cretaceous sand immediately below the Avenal sand in Garzas Creek. The remaining 8 Cretaceous outcrop samples were collected on the 1941 field trip of the Society of Economic Paleontologists and Mineralogists, which dealt with the Cretaceous rocks of the area west of Coalinga. The samples are arranged in stratigraphic order on the chart, and they are all from the Panoche formation; the names used on the chart indicate members which were pointed out in the course of the field trip. The samples were collected along Highway 198 a few miles west of the town of Coalinga; most of them were collected at the SEPM localities. The recent sand samples are from small creeks draining this area of Panoche outcroppings.

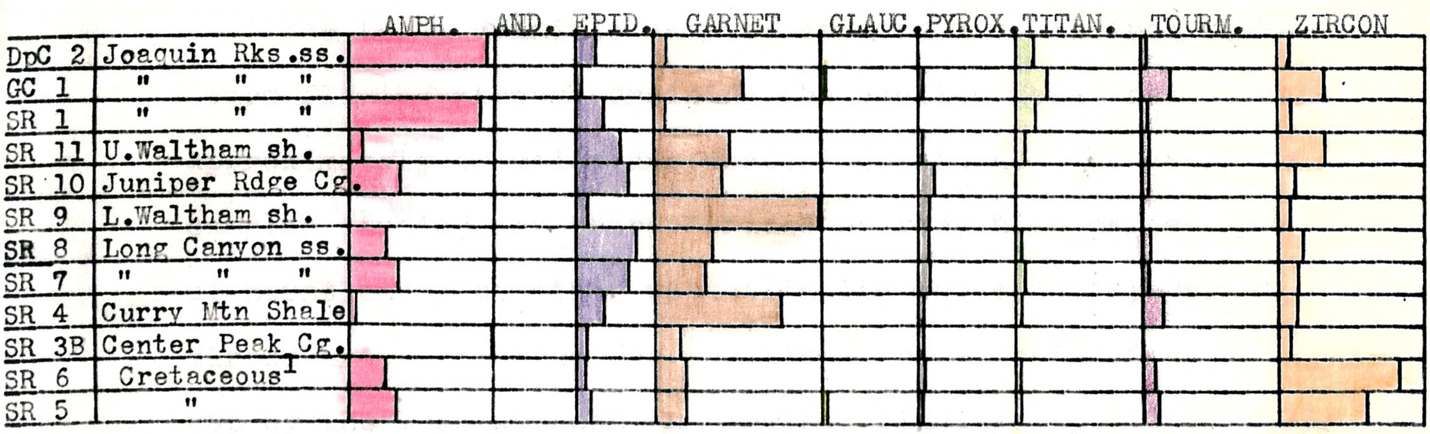
Somewhat variable, but high, percentages of garnet, epidote, zircon, sporadically high percentages of amphibole, and smaller amounts of tourmaline and titanite all seem most characteristic of the Cretaceous. Glaucophane is present in very small amounts in two of the samples. Zircon, garnet, and tourmaline are more abundant in the Cretaceous than in any other source rock samples.

The analyses of Franciscan sources all represent

HEAVY MINERALS FROM THE "McADAMS SAND" - S.O. Co. 72-3P
TOP SAND- 9520

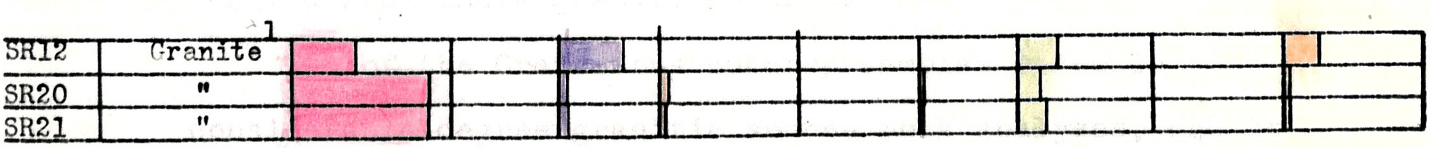


CRETACEOUS(SOURCE ROCK SAMPLES)



FRANCISCAN (SOURCE ROCK SAMPLES)

GRANITE (SOURCE ROCK SAMPLES)



1" = 100%

1. These samples are recent sands from streams draining Cretaceous, Franciscan and granitic rocks.

samples taken from recent stream beds. Samples SR26, SR27, and SR28 are from three streams draining the area of Franciscan rocks crossed by Highway 198, 29.4 miles west of Coalinga. SR29, and SR30 are from the Pacheco Pass Area, approximately 60 miles northwest of Coalinga. The presence of glaucophane and pyroxene in moderate amounts in all of these samples differentiates this group from the Cretaceous and granitic groups rather clearly. Titanite is somewhat more abundant, and tourmaline rarer than in the Cretaceous.

The three granitic samples studied are all from westward flowing streams draining the Gabilan Mesa area, located approximately 40 miles due west of Coalinga. The granitic samples studied are characterized by very high percentages of hornblende, together with titanite and epidote; garnet, zircon and tourmaline are relatively rare, being flooded out by the more abundant minerals. Findlay (Op. Cit. p. 23) shows analyses of sands from a number of streams draining the Southern Sierra Nevada Mountains; his analyses appear to be very similar to those shown here. The similarity between the assemblages derived from Coast Range and Sierra Nevada granitic rocks discourages any hope of differentiating, on a purely mineralogical basis, between sediments derived from these granitic sources.

Two of the Cretaceous outcrop samples resemble to a considerable degree granitic source rock analyses, and it seems fairly clear that the source of these two samples may well have been largely a granitic one. If these Cretaceous rocks with a high amphibole percentage were eroded without deep weathering, and redeposited without severe attrition during transportation and deposition, the resulting sediment might again be very similar to the granitic assemblage. However, under average conditions there would probably be some impoverishment in the heavy mineral content of a sediment in the second cycle of deposition, and under severe conditions there would be a very large effect on the assemblage. The probable impoverishment in heavy minerals of a sediment derived from the Cretaceous sediments, together with the considerable average difference between the Cretaceous and granitic assemblages, would seem to offer a fairly secure basis for differentiating sediments derived from the two possible sources.

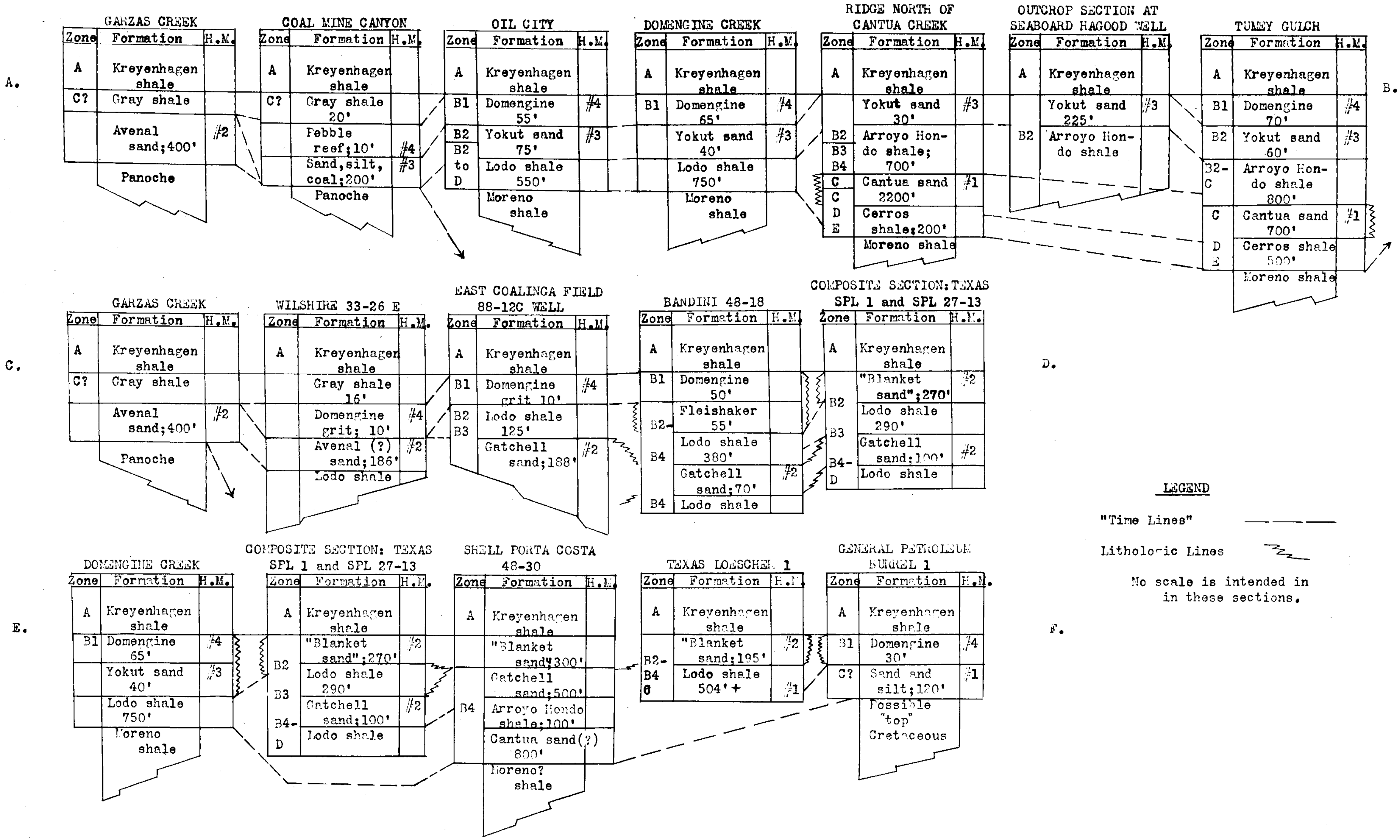
So far as is known, the sodic amphibole glaucophane is confined to the Coast Ranges; it has never been reported as being present in the possible source rocks on the east side of the San Joaquin Valley. For this reason the Franciscan assemblage, and glaucophane in particular, assumes a very important role in paleogeographic problems, for it provides us with a definite index for the Coast Range origin of a sediment. The absence of glaucophane would not rule out the possibility of a Coast Range source for a sediment, but the presence of glaucophane even in rather small percentages, would indicate a major source in the Coast Range, since the glaucophane does not occur in large percentages, even in pure Franciscan debris.

Characteristics and Distribution of Eocene Heavy Mineral Assemblages

In the following section the character of each mineral assemblage will be briefly described, and its distribution will be summarized. In connection with the discussion of the distribution of the assemblages, a study of the stratigraphic sections described above, appearing on page 32, and of the isometric diagram on page 68, will be found helpful.

Assemblage #1 This assemblage is characterized by high percentages of titanite, together with zircon, tourmaline, garnet, and varying amounts of epidote and hornblende; a small amount of andalusite and pyroxene is also present. The assemblage is a rich one, both from the point of view of the mineral species and also the total percentage of heavy minerals present. The group has been divided into three sub-assemblages: groups 1a, 1b, and 1c. At first glance these minor groups may appear too different to be classed together; however, it must be remembered that the order in which the analyses are listed is not a stratigraphic order, and within a given section these three assemblages are mixed, that is they alternate with each other. Separ-

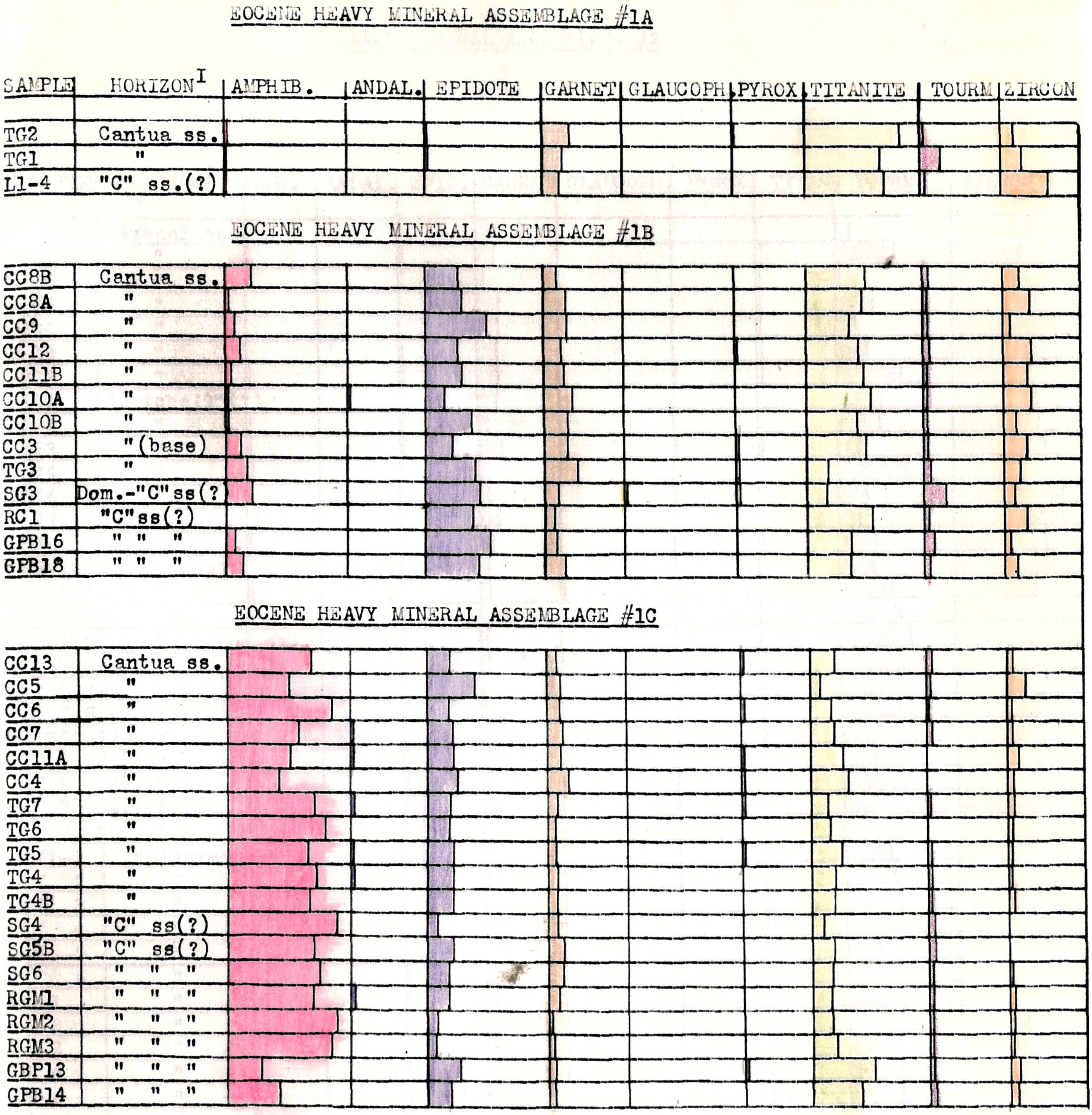
TENTATIVE CORRELATION CHART OF EOCENE FORMATIONS IN THE COALINGA DISTRICT, SHOWING THE DISTRIBUTION OF THE HEAVY MINERAL ASSEMBLAGES



ating them into similar groups emphasizes the amount of variation between samples, and indeed, a considerable variation in the ratios of the minerals present, from one sample to the next, seems characteristic of the assemblage. For our purposes the three sub-assemblages can be conveniently grouped together, for they resemble each other more than any other assemblage studied. It should be noted that if a large number of samples of the Cantua Sandstone were studied, it might be possible to zone the sand on the basis of these variations.

The Isometric Diagram, page 68, shows the stratigraphic and geographic position of the Eocene samples studied, the distribution of each assemblage being indicated by variously colored symbols. The stratigraphic sections shown on the preceding page represent a simplification of the three dimensional diagram. All analyses of the Cantua sand, both in Tumey Gulch and in Cantua Creek contain heavy mineral assemblage #1. Section AB indicates that as far as the outcrop sections are concerned, the assemblage is confined to the Cantua sand. The assemblage has also been encountered in the northeastern half of the area, in the lower part of the Eocene sediments in the following wells: The Texas Company Loescher #1, The General Petroleum Corporation Burrel #1, The Shell Oil Company Raisin City #1, The Herndon Bottoms well, the Rio Grande Mosesian well, and in the Seaboard Gill well.

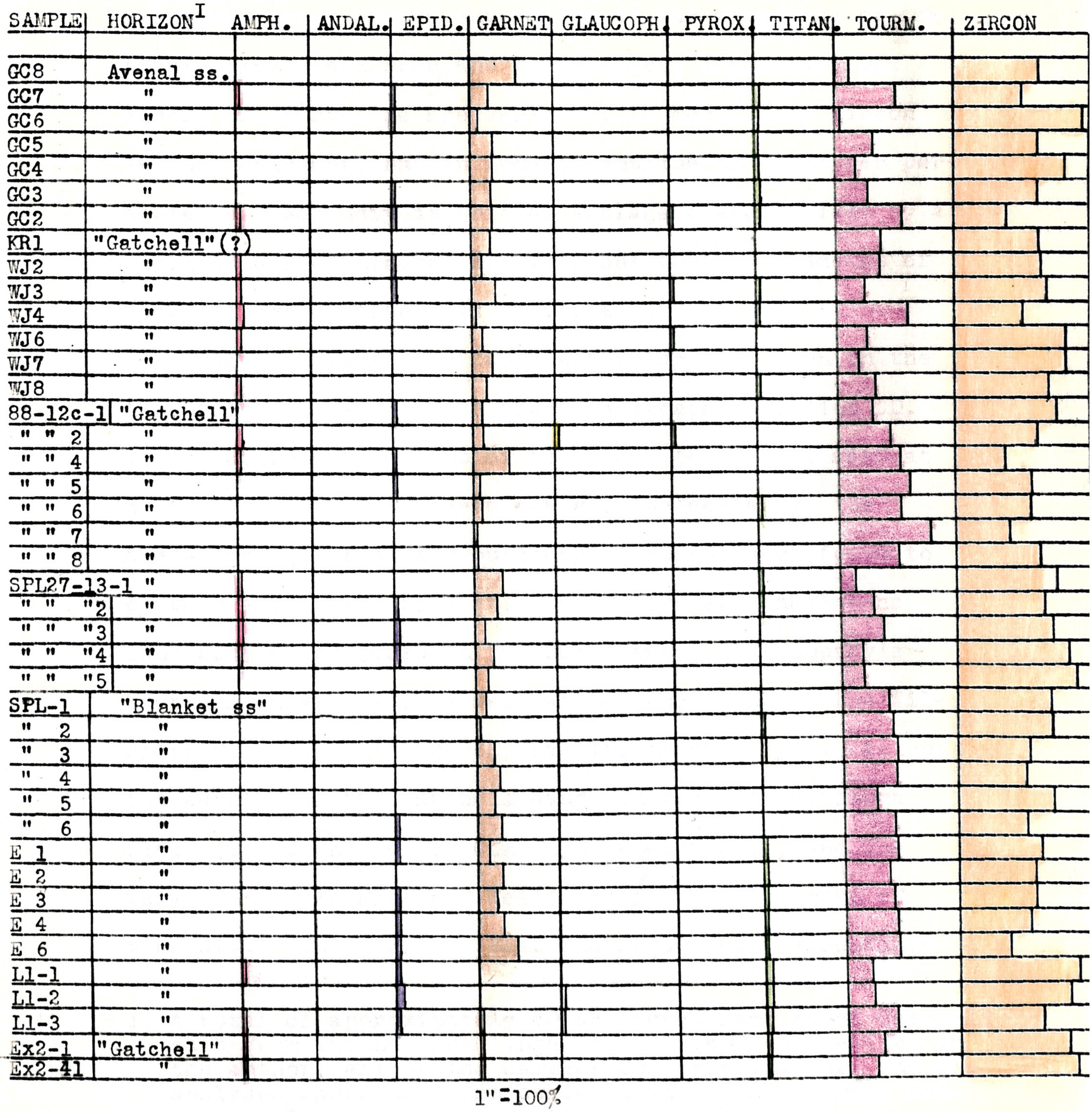
Assemblage #2 is characterized by a high percentage of



1" = 100%

I. For exact location of the samples, see index of sample localities.

EOCENE HEAVY MINERAL ASSEMBLAGE #2



I. For exact location of the samples, see index of sample localities.

zircon and tourmaline, a large relative amount of opaque minerals, and smaller percentages of garnet; a small percentage of hornblende is present in a few samples, but the striking aspect of the assemblage is the abundance of the stable minerals zircon and tourmaline. The ratios of zircon to tourmaline are variable; in most cases zircon is more abundant, but in some tourmaline is in higher percentages. Not only is this assemblage characterized by a small number of mineral species, but the total amount of heavy minerals present is very small.

The distribution of this assemblage is shown on the isometric diagram, and on the stratigraphic section CD. In the southwestern part of the area, the Avenal sand at Reef Ridge contains assemblage #2; incidentally, the Avenal sand is the only outcropping Eocene sand found to contain a similar association of minerals. The Eocene sand body encountered in the Continental Oil Company's Kreyenhagen #1 Well, as well as the one found in the Wilshire Oil Company's 33-26E, is also of this type. All of the samples of the Gatchell sand, in the East Coalinga Field (The Standard Oil Company's 88-12C Well, and The Texas Company's Exeter 2 Well) contained this group of minerals.[1] North of the East Coalinga Field, assemblage

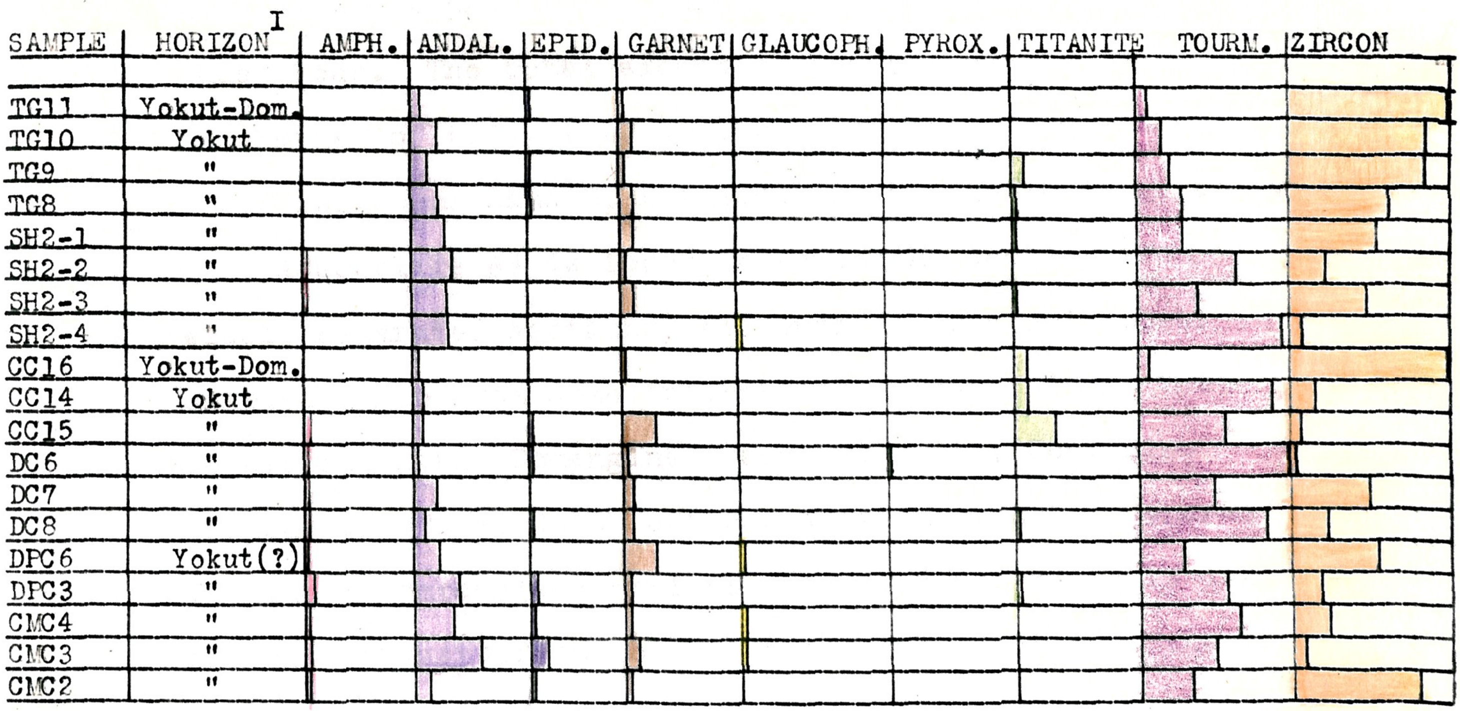
1. A total of approximately 40 scattered samples of Gatchell sand from the East Coalinga Field have been examined by the author; all of the samples are very similar, and the analyses shown here are believed to be an accurate representation of the heavy mineral assemblage of the "type" Gatchell sand.

#2 is found in sands of "B3-B4" age in The Texas Company's SPL 27-13 Well; this sand is probably the extension of the Gatchell sand body. In this area, assemblage #2 extends upward into the "Blanket sand" (see chart page 32) which is probably B2 and B1 in age. Thus the "Blanket sand" which, on the basis of Foraminifera, is probably equivalent in age to the Yokut-Domengine sands of the outcrop sections, contains a mineral assemblage like the Gatchell sand. It is probably significant that in well sections southeast of The Texas Company's SPL 27-13, the "Blanket" and Gatchell sands form an uninterrupted sand section, in which it is very difficult to differentiate the two sand bodies.

Assemblage #3 is characterized by the persistent presence of a notable amount of andalusite. In other respects, that is, in the stable aspect of the assemblage, the relative rareness of heavy minerals, and abundance of opaque minerals, the assemblage is similar to assemblage #2. The amount of andalusite varies from a few percent to a maximum of 35% in one sample.

Assemblage #3 is characteristic of the Yokut sand. Samples from a number of outcrop sections of this sand body are very similar, and all contain andalusite. The assemblage has also been found in the Eocene sands of Coal Mine Canyon. The occurrence there of the Yokut type of heavy mineral assemblage is interesting in the light of the

EOCENE HEAVY MINERAL ASSEMBLAGE #3



1" = 100%

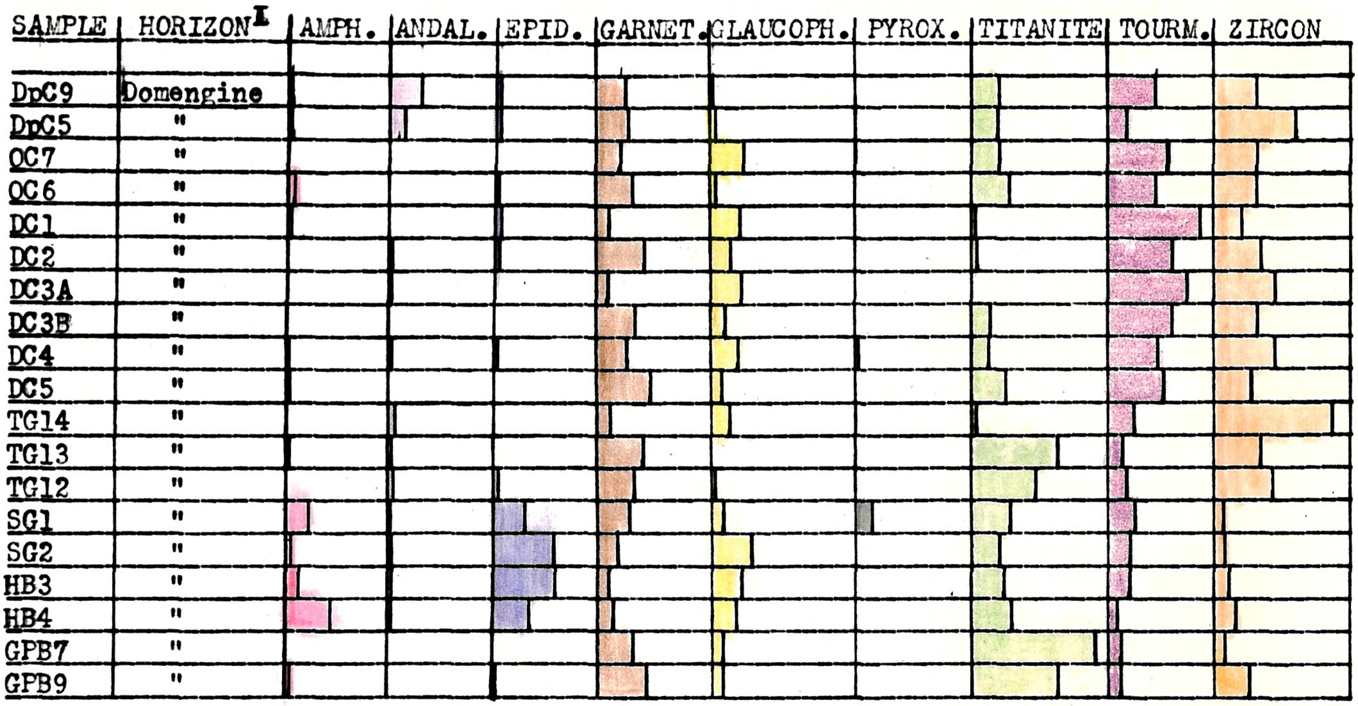
I. For exact location of the samples, see index of sample localities.

confusion over the position of the Coal Mine Canyon Sand in the Eocene Section.

Assemblage #4 is characterized by notable amounts of glaucophane, together with titanite, garnet, tourmaline, zircon, and in some samples, epidote and hornblende; andalusite is present in small amounts in many samples of this group. The total amount of heavy minerals present in samples of this group is larger on the average than those in groups 2and 3, but smaller than those in group 1.

Assemblage #4 is found in Domengine samples from widely separated sections, although it does not appear in samples taken from some intermediate areas. It is best developed in the Domengine Creek, Oil City, Coal Mine Canyon, and Tumey Gulch outcrop sections, in the General Petroleum Company's Burrel #1 well, and in the wells located northwest of the Burrel Well. The fact that the assemblage does not appear in the samples taken from sections in intermediate areas is probably explained by two factors; a. the thinness of the zone which contains this assemblage, together with the large intervals between samples in some sections, so that, while the assemblage may be present it was missed in coring, b. the fact that the base of the overlying Kreyenhagen is, at least locally, an unconformity, suggesting the possibility that the sand containing the glaucophane assemblage has perhaps locally been partially or totally removed. Also, north of Cantua

EOCENE HEAVY MINERAL ASSEMBLAGE #4



1" = 100%

I For exact location of the samples, see index of sample localities.

Creek, where the sand section between the base of the Kreyenhagen and the top of the Lodo formation is only about 30' thick, the Domengine has probably been overlapped by the Kreyenhagen.

"McAdams Sand" Samples

A series of samples from the Standard Oil Company's 72-3P well, in the North Dome of Kettleman Hills has been studied, and their analyses are presented on page 28; the well penetrated over 500' of sand below the base of the Kreyenhagen, and the samples were obtained throughout this interval.

These analyses are characterized by high percentages of zircon and tourmaline, sporadically high percentages of amphibole, and small percentages of garnet and epidote; a small percentage of titanite is present in most of the samples.

The assemblage on the whole is probably more like that of the Gatchell sand, than any other Eocene sand studied, but there are consistent differences between the heavy minerals of the Gatchell and Kettleman Hills sands. Because of the absence of foraminiferal data, the age relations between the two sands is not known.

"Light Minerals" of the Eocene Sands of the Coalinga District

The total time spent in studying the "light mineral" (minerals with a specific gravity less than 2.87) content of Eocene sands has been relatively small, because other lines of approach to the problem seemed to produce more useful data. However, it seemed desirable to obtain some data of the following types; 1. to determine in a general way if there is any relation between the quartz-feldspar ratios and "heavy mineral" variations, and 2. to study the black rock particles of granule and in some cases pebble size present in most of the sands.

The "light minerals" were studied in about 45 thin sections and the following statements seem to be true:

1. The Cantua sandstone is the most arkosic of all sands studied. It contains up to 40% potash feldspar (orthoclase, microcline, and perthite) and 15% andesine; the remainder is composed of quartz, black rock particles (described below), and a small percentage of heavy minerals.

2. In the Gatchell sand, up to 30% of potash feldspar has been noted. Plagioclase is practically absent; none of the author's slides show more than 1%. Samples of Yokut sand, Coal Mine Canyon Eocene, and Avenal sand similarly contain very little plagioclase and abundant potash feldspars.

3. Samples of the Domengine, on the other hand, show as much as 15 percent plagioclase in association with abundant potash feldspar.

<u>Rock Grains</u>:

Black and dark gray rock fragments occur in small amounts in all of the Eocene sands of the Coalinga district. In the "Reef Bed" of the Domengine, and in some of the coarser sands, these fragments are of pebble size; usually however, they are only granules and small grains mixed with the sand. These rock particles are generally fairly well rounded in contrast to the associated angular quartz and feldspar grains.

R. B. Hutcheson suggested to the author that these black rock fragments might be of some stratigraphic importance. In an effort to determine what rock types are present and to discover if the distribution of these types could be used to differentiate between the various sands, the author has used the following technique:

1. 20 samples, including typical samples of Cantua, Yokut, Gatchell, and Domengine sands were chosen.

2. From each of these samples, between 25 and 75 of the black rock particles were separated with a needle under a binocular microscope.

3. R. Von Huene then prepared thin sections of these groups of rock particles by a special technique. Each thin section contains all of the grains picked from a given sample.

From a study of these sections the author has been unable to determine any large or consistent difference between rock particles present in the different sands. In all cases, by far the most abundant constituent is chert. An occasional grain of impure quartzite, of dark argillite (?), and a very few grains of volcanic rock have been noted. One sample, from the Seaboard Gill well SG2, caontains in addition several very fresh fragments of glaucophane schist.

A more detailed description of the rock types is given below:

Chert Grains- The types referred to chert are rather variable; some are very fine grained, others only fine grained; some are clear and others very dark with included matter; in some cases the grains are broken by veinlets of coarser silica. One of the most interesting points in regard to the cherts is that, in a large percentage of them, remains of micro-organisms are clearly visible. These are never well preserved, but their general spherical form and structure suggests radiolaria. Indeed much of the chert in these sands is probably a radiolarian chert.

Argillite(?)- A few very fine grained pebbles, dark with included organic matter, and containing shreds of sericite and in some cases detrital quartz grains have been referred to the term argillite.

Quartzite- A few granules made up mainly of quartz grains, intergrown with sutured borders, and containing sometimes, small amounts of ferromagnesian minerals and opaques have been called quartzite.

Volcanics- A few grains of definitely volcanic rock have been noted. In one case, a grain could be identified as andesite, but in others too little of the rock was present to identify.

The Significance of Anauxite

The clay mineral anauxite is another topic which deserves comment in connection with the light minerals of the Eocene sands of the Coalinga area. Anauxite has been described by Allen[1] from the Ione formation (see chart page 19) and a few other California Eocene sediments. In the Ione formation, abundant white mica-like crystals with a definitely pearly luster occur in a quartz sand containing a heavy mineral assemblage characterized by zircon, tourmaline, garnet, and andalusite. The white mica-like crystals are, according to Allen, anauxite.

In the Gatchell sand and also in the Yokut sand, an occasional plate of an anauxite-like mineral may be found.[2]

---

1. Allen, V. T. The Ione Formation of California, U. of C. Pub. Dept. Geol., Vol 18, No. 14, pp 347-448, (1929)

   Eocene Anauxite Clays and Sands in the Coast Range of California, GSA Bull. Vol 52, pp 271-294, (1941)

2. The anauxite-like mineral first came to the author's attention in spring of 1941, when R. B. Hutcheson mentioned its presence in the Gatchell sand.

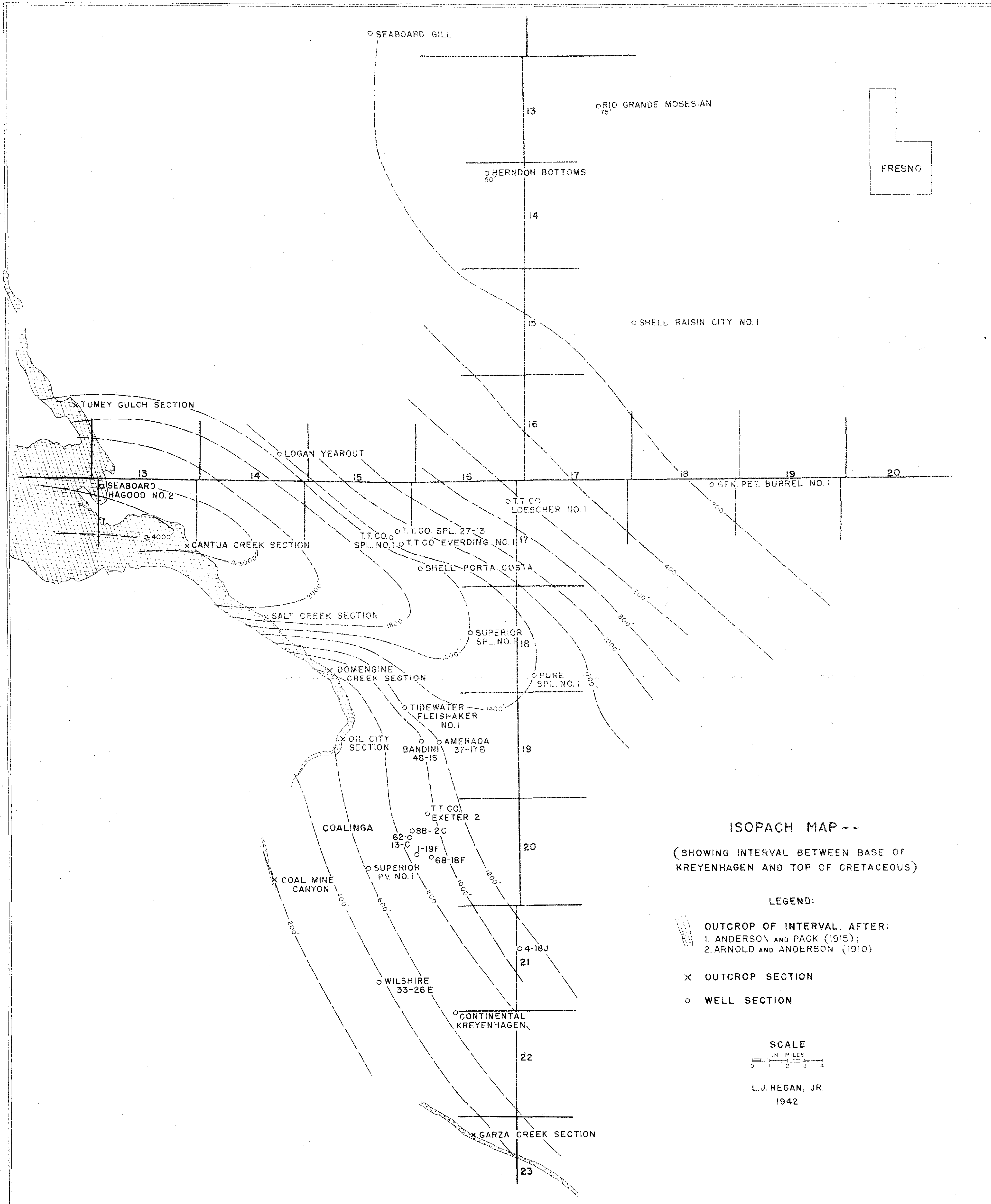
In none of the samples studied is the mineral abundant, nor is sufficient data available to conclude that the mineral is actually anauxite.

According to Ross and Kerr (1931) it is impossible to differentiate anauxite from kaolinite by any method other than chemical analyses. However, the anauxite-kaolinite group can be differentiated from other clay minerals by X-ray methods. The X-ray patterns of the anauxite-like mineral in the Gatchell and anauxite from the Ione have been compared.[1] The two patterns are practically identical, and on this basis, it is possible to say that the mineral in the Gatchell sand belongs to the kaolinite-anauxite group.

Some workers use the presence of grains of the anauxite-like mineral, in Eocene sands of the San Joaquin Valley, as a basis for a correlation with the Ione. In this connection, L. J. Simons recently supplied the author with a sample from the Moreno which contains an abundance of an anauxite-like mineral; the sample was collected in Moreno Gulch about 3100 feet below the top of the Moreno. This mineral seems identical with the Ione anauxite in its general appearance, optical properties, and X-ray pattern, and hence, its presence in the Cretaceous would seem to vitiate its value as a marker mineral.

---

1. The writer is greatly indebted to C. S. Lu of the Calif. Institute of Tech., who made a number of X-ray photographs of these minerals, and also discussed the significance of the patterns with the author.



SEABOARD GILL
13
RIO GRANDE MOSESIAN
75'
FRESNO
HERNDON BOTTOMS
50'
14
15
SHELL RAISIN CITY NO. 1
16
TUMEY GULCH SECTION
LOGAN YEAROUT
13
14
15
16
17
18
19
20
SEABOARD HAGOOD NO. 2
GEN. PET. BURREL NO. 1
T.T. CO. LOESCHER NO. 1
200'
4000
CANTUA CREEK SECTION
3000
T.T. CO. SPL. NO. 1
T.T. CO. SPL. 27-13
T.T. CO. EVERDING NO. 1
17
SHELL PORTA COSTA
400'
600'
2000
SALT CREEK SECTION
1800
800'
SUPERIOR SPL. NO. 1
18
1600
1000'
DOMENGINE CREEK SECTION
PURE SPL. NO. 1
1200'
TIDEWATER FLEISHAKER NO. 1
1400
OIL CITY SECTION
AMERADA 37-17B
BANDINI 48-18
19
T.T. CO. EXETER 2
COALINGA
88-12C
62-
13-C
1-19F
68-18F
20
SUPERIOR P.V. NO. 1
COAL MINE CANYON
400'
600'
800'
1000'
1200'
200'
4-18J
21
WILSHIRE 33-26 E
CONTINENTAL KREYENHAGEN
22
GARZA CREEK SECTION
23
ISOPACH MAP--
(SHOWING INTERVAL BETWEEN BASE OF KREYENHAGEN AND TOP OF CRETACEOUS)
LEGEND:
OUTCROP OF INTERVAL, AFTER:
1. ANDERSON AND PACK (1915);
2. ARNOLD AND ANDERSON (1910)
× OUTCROP SECTION
○ WELL SECTION
SCALE
IN MILES
0 1 2 3 4
L. J. REGAN, JR.
1942

<u>Evidence Bearing on Position of Eocene Positive Areas</u>

The remarks below will be clarified and amplified by referring to the following charts:

1. The map, page 47, showing the total thickness of the interval between the base of the Kreyenhagen and the top of the Cretaceous. Areas in which the formations comprising this interval outcrop are also shown.

2. The stratigraphic cross sections, page 32.

3. The paleogeographic map of C time, page 54.

There is good evidence that the area, in which the Eocene formations under discussion were deposited, was bordered by three distinct land areas. These land areas, furthermore, contributed sediments which can be distinguished by heavy mineral assemblages. These areas are located, (see paleogeographic map, page 54):

1. Southwest of a line connecting Coal Mine Canyon and Reef Ridge.

2. Northwest of Tumey Gulch

3. East of the thin sections of Eocene present in General Petroleum's Burrel well, and other wells in the northeastern part of the area.

The positive area in the southwest part of the region is indicated by structural and stratigraphic evidence, most of which has already been mentioned at various places in the text above. To understand the following discussion the reader should refer to the stratigraphic sections, page 32.

A study of section AB will show that in the vicinity of Oil City and in outcrop areas to the north, the Eocene rests with an apparently conformable contact, on the Moreno formation; in Coal Mine Canyon, however, the base of the Eocene rests on a Panoche sand member, located about 1600' stratigraphically below the top of the Panoche formation. In Garzas Creek on Reef Ridge, the base of the Eocene rests on an horizon even farther stratigraphically below the top of the Panoche formation. In the Coal Mine Canyon area, a small angular discordance between the Eocene and Cretaceous rocks was noted, while in Garzas Creek a considerable discordance, amounting to at least 15 degrees was noted. Thus north of Oil City the Eocene appears to be conformable on the Cretaceous, while to the south the base of the Eocene becomes an unconformity which cuts out several thousand feet of Cretaceous rocks. The progressive overlap of the Eocene on the Cretaceous rocks, south of Oil City, is accompanied by a considerable thinning of the Eocene sediments. On the basis of heavy mineral work, the author has suggested that the Coal Mine Canyon Eocene below the "Reef Bed" should be correlated with the Yokut, while the "Reef Bed" represents the Domengine; it is also suggested that the Avenal sand should be correlated with the Gatchell sand. If these correlations can be accepted, then the "B" sediments may be interpreted as overlapping the lower Eocene to rest unconformably on upturned and eroded Cretaceous rocks.

The above arguments suggest that in the time between the close of the Cretaceous, and preceding the deposition of the Eocene sediments under discussion, the area southwest of Coal Mine Canyon and Reef Ridge was uplifted and considerably eroded. During the Eocene, the sea progressively transgressed over the positive area. The lower Eocene sea did not reach the Coal Mine Canyon -Reef Ridge areas, but the sea of "B" time extended well up on the positive area, and its sediments now rest unconformably on Cretaceous rocks.

The Eocene land area north of Tumey Gulch is indicated largely on data derived from published geologic maps of this area. It appears that in this area there is a situation analogous to that described above, for north of Tumey Gulch the interval between the base of the Kreyenhagen and the Cretaceous again becomes very thin, and the Domengine apparently overlaps the older Eocene rocks and rests on the Cretaceous. These facts suggest that there was another positive area here, similar to the one described above, upon which the sea was transgressing during Lower and Middle Eocene.

The third probable Eocene land area was located east of the General Petroleum Burrel well. The western edge of this land mass cannot be located accurately at present, due to the scarcity of wells drilled in this part of the district. The stratigraphic section EF, page 32, shows that the interval between the base of the Kreyenhagen and the Cretaceous, in the Burrel well, is less than 200' thick;

the interval thickens rapidly to the west, while no marine Eocene rocks are present a few miles to the east, in the foothills of the Sierra Nevada Mountains. The Eocene rocks below the base of the Kreyenhagen in the Burrel well consist of Domengine sand and silt which rests on sandy silt of Lower Eocene? age. Similar sections are present in the wells studied north of the Burrel well.

On the basis of the above discussion, the author believes that during the Lower and Middle Eocene, there were three contemporaneous positive areas in the Coalinga district; sufficient data is not available to demonstrate the exact size and amount of variation of these areas during the various stages of the Eocene. However, the Domengine sea seems to have been the most transgressive, and the land areas were probably of smallest extent in Domengine time.

PALEOGEOGRAPHY OF THE EOCENE OF THE COALINGA DISTRICT

The following part of this report will be devoted to the interpretation of the data previously described. The outline of the Eocene basin of deposition, the location of Eocene positive areas, the distribution of various types of sediments, and the probable sources and directions of transportation of the sediments, are all of significance in this interpretation. A number of maps have been constructed showing probable progressive stages during the deposition of the Eocene sediments.

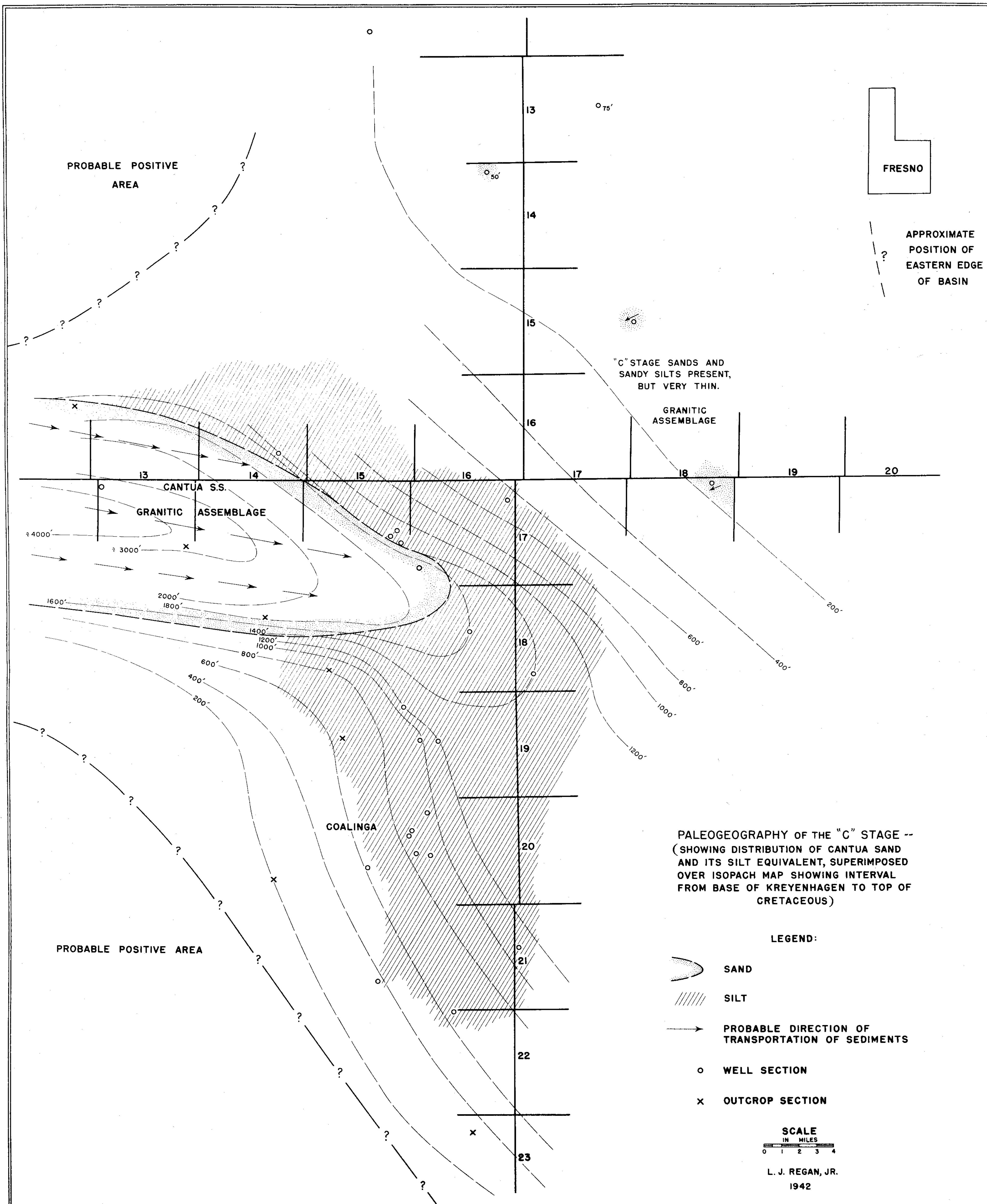
The maps and conclusions are based on all information at present available; new and additional data may change these conclusions. The largest source of error is probably in some of the correlations, for as stated above, conclusive evidence is sometimes lacking. However, the writer believes that his conclusions come fairly close to approximating the actual events.

The isopach map, page 47, has been used as the base for the paleogeographic maps; that is, the paleogeographic conclusions have been superimposed over the isopachs showing the thickness of the sediments lying between the Kreyenhagen and the top of the Cretaceous rocks. It is the author's opinion that the isopachs more or less outline the basin during this interval of time. Evidence has been presented above indicating the presence of three contemporaneous positive areas during this time. These positive areas have been roughly outlined on the paleogeographic maps. Thus the isopach map roughly indicates the approximate distribution of land and sea during the deposition of the sediments under discussion. Paleogeographic maps published by Reed[1] indicate the presence, during the Eocene, of a large marine embayment occupying the approximate position of the San Joaquin Valley, with a long narrow channel (Vallecitos channel) extending from north of Coalinga northwestward to the Pacific Ocean. The author's maps may be regarded as a more detailed study of the area around Coalinga, at the confluence of the main San Joaquin embayment and the narrow channel. On these maps, the area east and north of Coalinga may be regarded as a portion of the San Joaquin embayment, while that extending westward between the two positive areas, or west of Cantua Creek, is a portion of the Vallecitos channel shown by Reed.

Paleogeography of the "C" Stage, and the Origin of the Cantua Sand

During "C" time the southeastern end of the Vallecitos channel was subsiding to receive the Cantua sand which, as is shown on the map, page 54, was practically confined to the southeastern end of this channel. East of the Cantua sand body, in the San Joaquin embayment itself, mainly silts and

1. Reed, R. D. California's Record in the Geologic History of the World, In Calif. Div. of Mines Bull. 118, part II, (1941)


PROBABLE POSITIVE AREA
FRESNO
APPROXIMATE POSITION OF EASTERN EDGE OF BASIN
"C" STAGE SANDS AND SANDY SILTS PRESENT, BUT VERY THIN.
GRANITIC ASSEMBLAGE
CANTUA S.S.
GRANITIC ASSEMBLAGE
COALINGA
PROBABLE POSITIVE AREA
4000'
3000'
2000'
1800'
1600'
1400'
1200'
1000'
800'
600'
400'
200'
PALEOGEOGRAPHY OF THE "C" STAGE -- (SHOWING DISTRIBUTION OF CANTUA SAND AND ITS SILT EQUIVALENT, SUPERIMPOSED OVER ISOPACH MAP SHOWING INTERVAL FROM BASE OF KREYENHAGEN TO TOP OF CRETACEOUS)
LEGEND:
SAND
SILT
PROBABLE DIRECTION OF TRANSPORTATION OF SEDIMENTS
WELL SECTION
OUTCROP SECTION
SCALE IN MILES
0 1 2 3 4
L. J. REGAN, JR.
1942

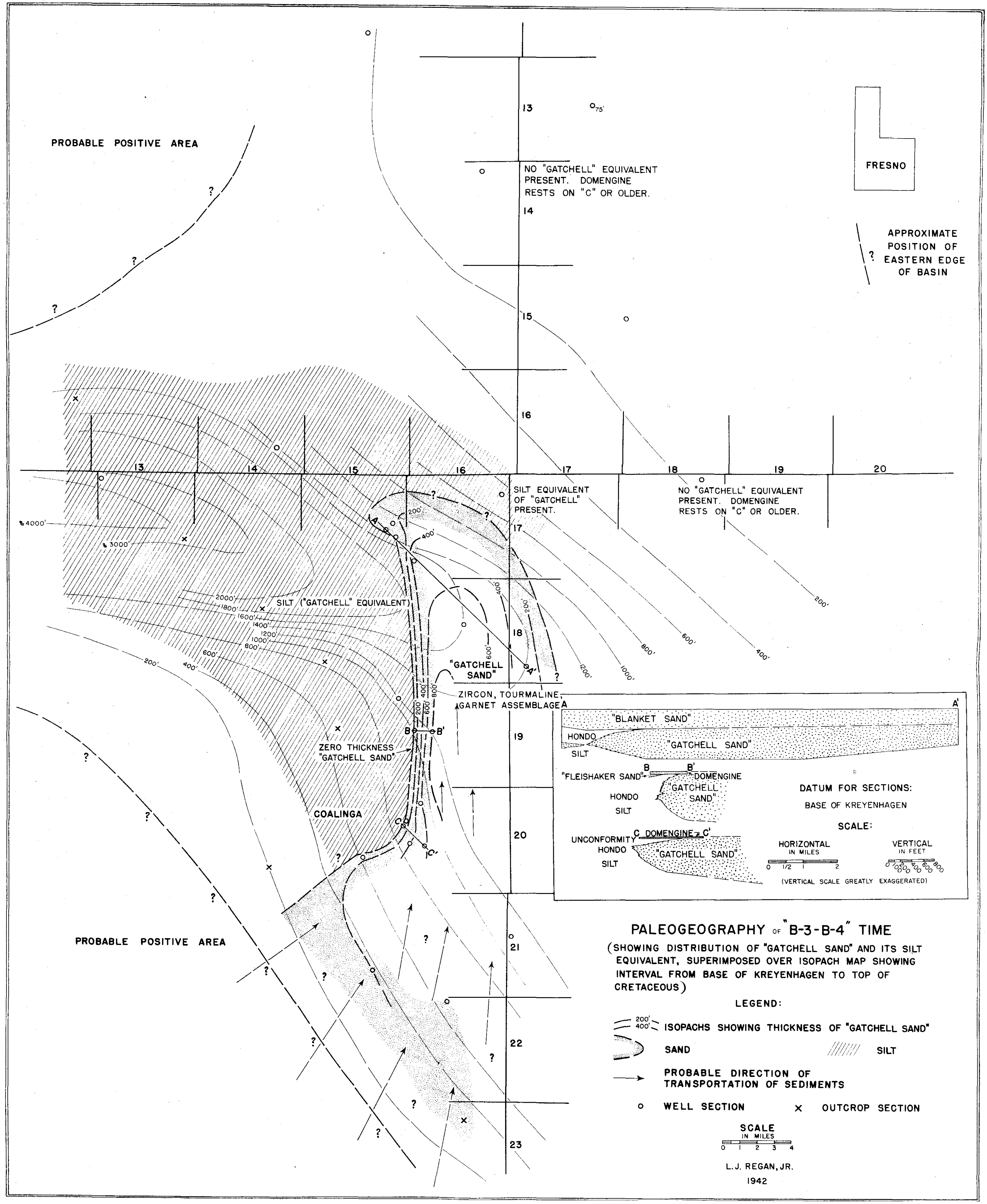
sandy silts were deposited. At the eastern border of the San Joaquin embayment, a thin section of fine sand and silty sand, equivalent in age to the silt of the San Joaquin embayment and to the Cantua sand, was deposited. As has been described above, all samples of "C" sands contained a very rich heavy mineral assemblage, characterized by abundant hornblende, epidote, and titanite, together with zircon, garnet, and tourmaline. The analyses are all very similar to granitic source samples, described above. Thus both the Cantua sandstone and equivalent sands on the eastern side of the San Joaquin embayment probably had granitic sources.

Large masses of granitic rocks are present both east and west of the present San Joaquin Valley, and the author knows of no mineralogical differences which could be used to distinguish sediments derived from the two possible granitic sources. However, the fact that the Cantua sandstone is largely confined to the Vallecitos channel area strongly indicates that the source of this sand was on the west; for, if it had come from the east, we should find the sand extending across the San Joaquin embayment, where, instead, we find silts. Moreover, the volume, abundance of heavy minerals, arkosic nature, and coarse-grain-size of the sand all suggest an origin nearer at hand. A large area of granitic rocks outcrops only a few miles from the most westward exposures of the Cantua sand, in the Coast Ranges, west of the San Andreas fault. Because this granite is apparently overlain only by Miocene volcanics and Pliocene sediments, it may well have been a positive area during the Eocene. For the reasons outlined above, these granitic rocks are regarded as the source of the Cantua sand.

The paleogeography of the "C" stage is shown on the map, page 54. The San Joaquin embayment and the Vallecitos channel were clearly developed at this time; a positive area was present a few miles west of Cantua Creek contributing granitic debris to the Vallecitos channel. The channel was probably subsiding, but the water was probably always shallow as is indicated by the abundant cross bedding, and by the coarse nature of the sand. On the eastern side of the San Joaquin embayment, granitic sources were contributing fine sand and silts which are represented in the General Petroleum Company's Burrel well. In other parts of the area, very fine sediments were deposited, indicating, perhaps that the other areas bordering the basin were of lower relief.

Paleogeography of "B3-B4" Time, and the Origin of the Gatchell Sand

The map on page 57 shows the thickness of the Gatchell sand, the distribution of both the Gatchell and sands correlated with the Gatchell, and the distribution of silts equivalent to the Gatchell. Three sections through the line of "zero thickness" are also shown. As has been


PROBABLE POSITIVE AREA
NO "GATCHELL" EQUIVALENT PRESENT. DOMENGINE RESTS ON "C" OR OLDER.
FRESNO
APPROXIMATE POSITION OF EASTERN EDGE OF BASIN
SILT EQUIVALENT OF "GATCHELL" PRESENT.
NO "GATCHELL" EQUIVALENT PRESENT. DOMENGINE RESTS ON "C" OR OLDER.
SILT ("GATCHELL" EQUIVALENT)
"GATCHELL SAND"
ZIRCON, TOURMALINE, GARNET ASSEMBLAGE
ZERO THICKNESS "GATCHELL SAND"
COALINGA
PROBABLE POSITIVE AREA
"BLANKET SAND"
HONDO SILT
"GATCHELL SAND"
"FLEISHAKER SAND"
DOMENGINE
HONDO SILT
"GATCHELL SAND"
UNCONFORMITY
DOMENGINE
HONDO SILT
"GATCHELL SAND"
DATUM FOR SECTIONS: BASE OF KREYENHAGEN
SCALE:
HORIZONTAL IN MILES
VERTICAL IN FEET
(VERTICAL SCALE GREATLY EXAGGERATED)
PALEOGEOGRAPHY OF "B-3-B-4" TIME
(SHOWING DISTRIBUTION OF "GATCHELL SAND" AND ITS SILT EQUIVALENT, SUPERIMPOSED OVER ISOPACH MAP SHOWING INTERVAL FROM BASE OF KREYENHAGEN TO TOP OF CRETACEOUS)
LEGEND:
ISOPACHS SHOWING THICKNESS OF "GATCHELL SAND"
SAND
SILT
PROBABLE DIRECTION OF TRANSPORTATION OF SEDIMENTS
WELL SECTION
OUTCROP SECTION
SCALE IN MILES
L.J. REGAN, JR.
1942

mentioned previously, the age of the Avenal sand of Reef Ridge is a much argued subject; an age varying from Domengine or younger to "C" has been suggested by different workers. Because sands which are mineralogically identical are found in the wells drilled in the East Coalinga Field, in the Wilshire Oil Company's 33-26E well, in the Continental Oil Company's Kreyenhagen 1, and on Reef Ridge; and because there is no paleontoligical évidence to prove that these sands are not of the same age; the author has concluded that the Gatchell sand extends from Reef Ridge northward, at least as far as The Texas Company's SPL 27-13 well.

As in the case of the Cantua sandstone, the distribution of the Gatchell sand throws some light on the location of its source. From the East Coalinga Oil Field north to the Texas Company's SPL 1, the "zero thickness" line of the sand is apparently straight. The silt equivalent to the Gatchell sand is probably present west of the sand throughout the area, and probably extends westward into the Vallecitos channel. It is unfortunate that more data are not available on the east side of the sand body, for the lack of this data makes the origin of the Gatchell sand more difficult to determine. However, the presence of silt, which is equivalent to the Gatchell sand, in the Texas Company's Loescher 1 suggests there is silt of equivalent age on the northeast, as well as on the north and west sides of the sand body. If the silts of the Loescher well extend southward, then they isolate the Gatchell sand completely from a possible source on the east, just as the "C" silts cut the cantua sand off from an eastern granitic source.

The above discussion seems to limit the possible sources of the Gatchell to two possibilities: 1. from the southwest, and 2. from the east. Since the Avenal sand (Gatchell sand?) lies directly on the Cretaceous rocks which formed a positive area in the southwest, the Cretaceous is a likely source for much of this sand. A very stable association of minerals, such as the one found in the Gatchell sand, has been interpreted by some workers as indicating a reworked sediment. As already noted the Cretaceous contains greater proportions of zircon, tourmaline, and garnet, together with hornblende, and titanite, than any other source rock examined. The Gatchell assemblage could have been derived from the Cretaceous sediments provided hornblende and titanite were removed in the second cycle of sedimentation. The resulting sand would contain relatively high percentages of zircon and tourmaline, but would be poor in heavy minerals, and contain abundant opaque minerals; the resulting assemblage would thus be identical with that found in the Gatchell sand.

The possibility that a part of the Gatchell was derived from the east cannot be completely eliminated, because of the lack of data from areas east of the main body of sand.

The mineralogical data do not refute this possibility, for it is possible that the stable minerals of the Gatchell sand could result from the deep weathering of granite rocks. Allen[1] concluded that the Ione formation, which is characterized by a very stable mineral association, was derived from granitic and metamorphic rocks in the Sierra Nevada region. However, the Ione is characterized by abundant andalusite and since the Gatchell sand contains no andalusite, it is unlikely that the Gatchell sand was derived from sources similar to those supplying the Ione.

In general form, the Gatchell sand body is very elongate and lens shaped (see map page 57). The maximum observed thickness is 800', and the sand thins rapidly to the west, where the isopach line of zero thickness is remarkably straight; eastward the sand apparently thins gradually. These facts are illustrated by the cross sections accompanying the map on page 57.

In the light of the above data the author believes the Gatchell sand is best explained as a spit, built from a beach located somewhere in the present vicinity of Reef Ridge, northward partly across the Vallecitos channel. The principle source of the sand is believed to be the

---

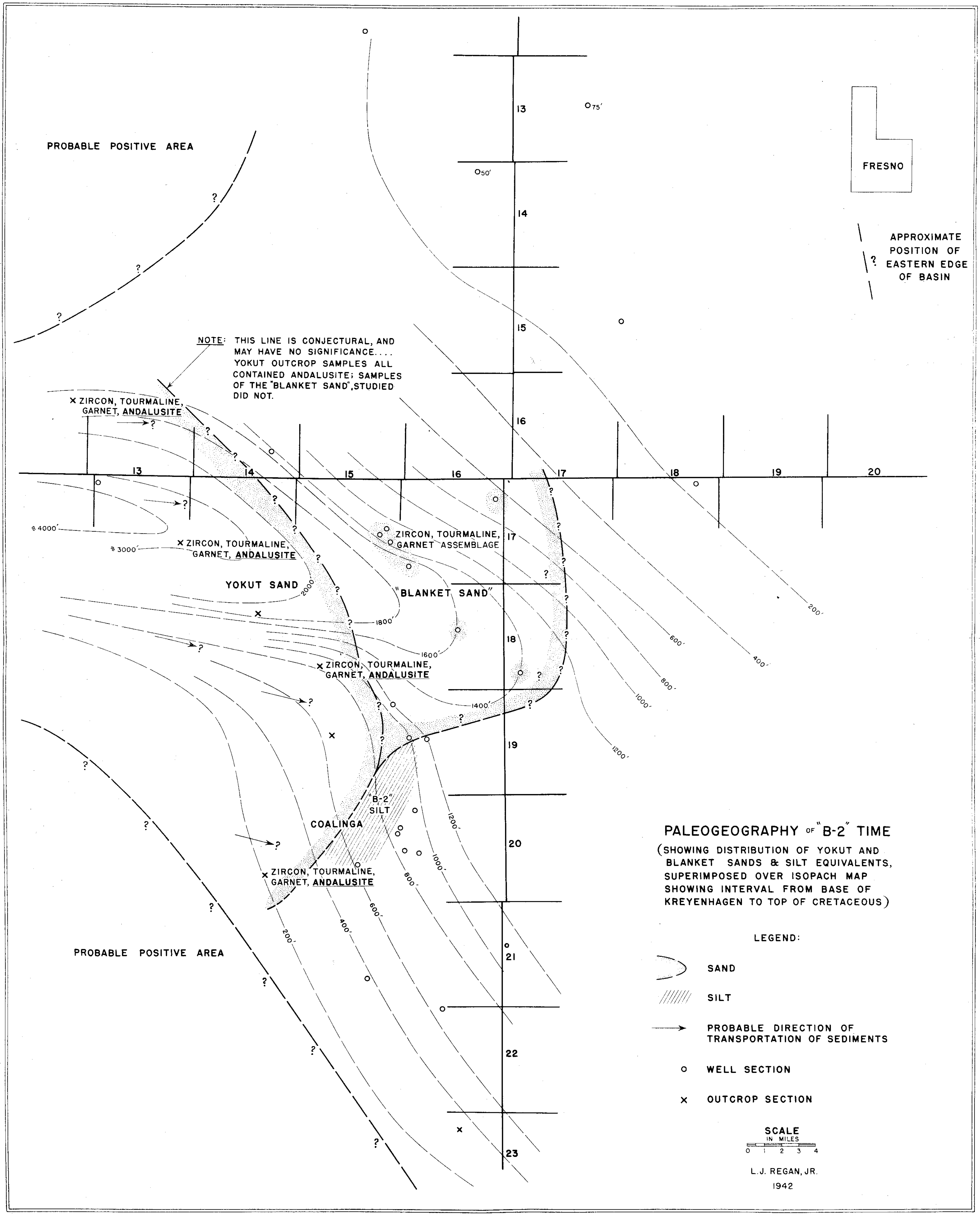
1. Allen, V. T. The Ione Formation of California, U. of C. Pub. Dept. Geol., Vol 18, No. 14, pp 347-448, (1929)

Cretaceous rocks exposed in the positive area west of Reef Ridge. The greatest weakness in the spit hypothesis is the lack of data on the southeast side of the Gatchell sand body. Another weakness in the hypothesis is the large size of the sand body; the author knows of no existing spits or bars with dimensions comparable to those of the Gatchell sand body.

Thus during "B3-B4" time, the general relations of land and sea were probably much as they were in "C" time. In the southeastern end of the Vallecitos channel, however, silt was being deposited rather than sand, which may indicate that the water there was somewhat deeper, or that weaker currents were present than during the deposition of the Cantua sand. At the same time, west of Reef Ridge a positive area was being eroded, which is believed to have been the principle source of the Avenal (Gatchell) sand. It seems likely that sand derived from this headland was swept northward across the southeastern end of the Vallecitos channel, where it was deposited, forming a spit-like sandbody. Elsewhere in the area, silt was being deposited, on the basis of the data at hand.

Paleogeography of "B2" Time, and The Origin of the Yokut Sand

The principle outcropping sand of "B2" age is the Yokut sand. This sand is present in a belt extending from north of Tumey Gulch to Oil City. It is believed by the author that the Yokut is also present in Coal Mine Canyon.



PALEOGEOGRAPHY OF "B-2" TIME

(SHOWING DISTRIBUTION OF YOKUT AND BLANKET SANDS & SILT EQUIVALENTS, SUPERIMPOSED OVER ISOPACH MAP SHOWING INTERVAL FROM BASE OF KREYENHAGEN TO TOP OF CRETACEOUS)

L.J. REGAN, JR.

1942

At Coal Mine Canyon, the sands with the coal seams contain the typical Yokut assemblage of heavy minerals (zircon, tourmaline, garnet, and andalusite), while the "Reef Bed" overlying these sands contains the typical Domengine assemblage of minerals. Thus the sequence of mineral assemblages at Coal Mine Canyon is very similar to the sequence at Domengine Creek, where definite Yokut and Domengine sands are present.

East of the Oil City area, in wells of the East Coalinga Field, the Yokut is represented by silts. However in wells north of the East Coalinga Field a sandstone 300' thick (see Stratigraphic Section CD, page 32) is present below the Kreyenhagen, the age of which is probably in part B2. This sand has sometimes been called the "Blanket sand". To the east this sand rests on and is very similar to the Gatchell sand, although westward they are separated by silt. The age of the "Blanket sand" is somewhat in question; the upper part may be "B1" or younger.

The presence of andalusite in the Yokut sand might be interpreted by some workers as indicating a Sierran, or eastern, source. However, the writer believes that the Yokut sand was derived from the west, for, as is shown on the paleogeographic map, page 62, the Yokut sand is separated from the eastern side of the San Joaquin embayment by silt and sands which contain no andalusite. Since andalusite is a common mineral in argillaceous metamorphic rocks, there is no basis for excluding the mineral from source rocks in the Coast Range. As a matter of fact, andalusite is present in the Domengine together with an assemblage rather clearly derived in large part from the Franciscan in the Coast Ranges. It is present, also, in relatively small amounts in the Cantua sand, which is believed to have been derived from the west. In this connection, Findlay[1] placed the source of a similar andalusite rich assemblage (found in Miocene rocks further to the south) in the Coast Ranges.

The source of the "Blanket sand" was probably similar to the Gatchell sand. However, insufficient data is available on the distribution of the "Blanket sand" to permit a definite determination of its source.

<u>The Origin of The Domengine</u>

The source from which the Domengine sands were derived can be more definitely established than for any other Formation studied. Microlithologic data clearly indicates that the source of the Domengine was in the Coast Ranges, for it contains an assemblage of heavy minerals very similar to the analyses of Franciscan source rock samples presented above. The Domengine sands are unique among the Eocene sands of this area, in containing consistently, a notable

---

1. Findlay, W. A. Sources of Miocene Sediments in Southwestern San Joaquin Valley, Ph. D. Thesis, Cal. Inst. of Tech., (1939)

amount of glaucophane; the value of glaucophane as an indicator of Coast Range source rocks has been discussed above. A study of the Geologic Map of California will show that large areas of Franciscan Rocks outcrop in the Coast Ranges west of Coalinga, and these rocks are the logical source of the Domengine formation. The abundant radiolarian chert grains present in the Domengine should be mentioned in this connection, since similar chert is common in the Franciscan formation.

The Domengine is a very widespread formation in this region, but its distribution is not yet clearly understood, because of its absence in some sections. Possible reasons why the Domengine is not present in all sections, have been discussed above. Wherever the Domengine formation is found it is characterized by the Franciscan assemblage of heavy minerals, even in the wells located near what was probably the eastern border of the San Joaquin embayment, such as the General Petroleum Burrel well. The Domengine was a transgressive stage, and its sea probably extended well up on the positive areas.

CONCLUSIONS

A. Suggested Correlations- The relations of both the Avenal sand and the sands in Coal Mine Canyon to other sands in the Coalinga area are difficult to determine because of the lack of fossils. The author offers the following suggestions regarding the correlation of these sands.

1. On the basis of mineral analyses, the Gatchell sand, the Eocene sandbody in the Wilshire Oil Company's 33-26E, the Continental Oil Company's Kreyenhagen 1, and the Avenal sand on Reef Ridge are all believed to be part of one formation.

2. Also on the basis of mineral analyses, the coal bearing sand at Coal Mine Canyon is believed to be part of the Yokut formation, while the "Reef Bed" at the top of the coal bearing sand is believed to be the Domengine formation.

B. Eocene Positive Areas- The location of three positive areas during the Eocene in the Coalinga District are suggested.

These are:

1. An area southwest of a line connecting Coal Mine Canyon and Reef Ridge.

2. An area north of Tumey Gulch.

3. An area east of General Petroleum's Burrel well.

C. Origin of the Eocene Sands

1. The Cantua Sandstone

The Cantua Sandstone is believed to have been derived from the granitic rocks now exposed west of the San Andreas fault in the approximate latitude of Coalinga. This granitic debris was deposited in the southeast end of the Vallecitos channel

2. <u>The Gatchell Sand</u>

The Gatchell (Avenal) sand is believed to have been derived largely from Cretaceous rocks in the positive area in the southwest. It is pictured as having been deposited as a spit built northward from this positive area, across the Vallecitos channel.

3. <u>The Yokut Sand</u>

The Yokut is believed to have been derived from the Coast Ranges, even though the sand is characterized by andalusite, a mineral which some workers consider an indicator of Sierran origin. This conclusion was reached on the basis of the distribution of the sand. The source of the sand is probably reworked older sediments.

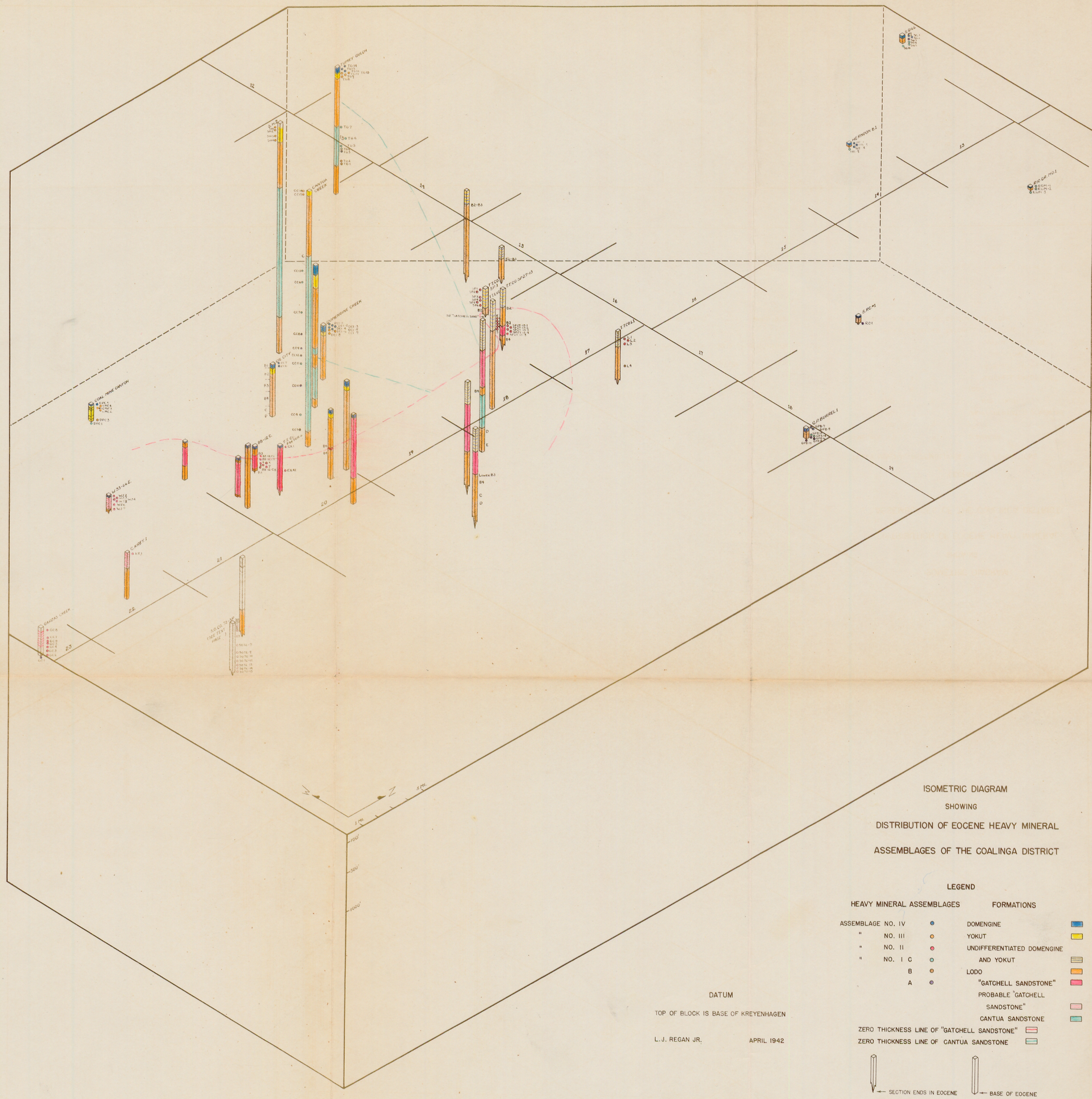
4. <u>The Domengine Formation</u>

The sands of the Domengine formation were clearly derived from Franciscan rocks. The glaucophane rich assemblage is widespread over the area, and indicates that large areas of Franciscan rocks in the west were exposed during Domengine time.

The conclusions outlined above are graphically expressed in the paleogeographic maps showing progressive stages in the deposition of the Eocene rocks.

PAGE 68 [redacted]

Regan_lj-1943



ISOMETRIC DIAGRAM

SHOWING

DISTRIBUTION OF EOCENE HEAVY MINERAL

ASSEMBLAGES OF THE COALINGA DISTRICT

LEGEND

HEAVY MINERAL ASSEMBLAGES		FORMATIONS
ASSEMBLAGE NO. IV		DOMENGINE
" NO. III		YOKUT
" NO. II		UNDIFFERENTIATED DOMENGINE AND YOKUT
" NO. I C		LODO
B		"GATCHELL SANDSTONE"
A		PROBABLE "GATCHELL SANDSTONE"
		CANTUA SANDSTONE

ZERO THICKNESS LINE OF "GATCHELL SANDSTONE"

ZERO THICKNESS LINE OF CANTUA SANDSTONE

SECTION ENDS IN EOCENE

BASE OF EOCENE

DATUM

TOP OF BLOCK IS BASE OF KREYENHAGEN

L. J. REGAN JR. APRIL 1942

INDEX OF SAMPLE LOCALITIES

SAMPLES FROM OUTCROP SECTIONS

Cantua Creek Section- These samples were collected along the ridge north of Cantua Creek.

CC 16	Immediately below base of Kreyenhagen
CC 14	20' above #15
CC 15	Base Yokut Sand
CC 13	100' above #6
CC 6	400' above #7
CC 7	300' above #8 (A-B)
CC 8(A-B)	200' above #9
CC 9	100' above #12
CC 12	100' above #11(A-B)
CC 11(A-B)	300' above #10(A-B)
CC 10(A-B)	400' above #4
CC 4	200' above #3
CC 3	Base of Cantua Sand

Coal Mine Canyon Section

CMC 4	10' below "Reef Bed" at base of grey shale
CMC 3	28' below "Reef Bed"
CMC 2	50' below " "

Deep Canyon Section- Canyon 7600' N. of Coal Mine Canyon.

DPC 9	Top of "Reef Bed"
DPC 5	Base of "Reef Bed"
DPC 6	10' below " "
DPC 3	20' above base Eocene Sand
DPC 2	Near top of Joaquin Rocks Sand, below Coal Mine Canyon Eocene Sand.

Domengine Creek Section (SE $\frac{1}{4}$ Sec. 29, T 18S/R15E)

DC 1	Green Sand, Base Kreyenhagen
DC 2	20' below #1
DC 3A	12' below #2
DC 3B	3' below #3A
DC 4	20' below #3B
DC 5	15' below #4, from "Reef Bed"
DC 6	3' below "Reef Bed"
DC 7	19' below #6
DC 8	15' below #7

Garzas Creek Section

GC	1	Immediately below base of Avenal Sand
GC	2	Base Avenal Sand
GC	3	60' above #2
GC	4	50' above #3
GC	5	50' above #4
GC	6	10' above #5
GC	7	40' above #6
GC	8	90' above #7

Oil City Section

OC	7	Green Sand, Base Kreyenhagen
OC	6	Domengine Reef Bed

Seaboard Hagood Outcrop Section- The following samples were collected from the white sand outcropping a few hundred feet east of the Seaboard Hagood 2 well.

SH2-1	Top of white sand
SH2-2	60' below #1
SH2-3	40' below #2
SH2-4	50' below #3, 15' above base of white sand

Tumey Gulch Section

TG	14	Top Domengine
TG	13	10' below #14
TG	12	40' below #13
TG	11	20' below #12, near top of Yokut sand
TG	10	10' below #11
TG	9	15' below #10
TG	8	20' below # 9
TG	7	Top Cantua Sand
TG	6	100' below #7
TG	5	60' below #6
TG	4(A-B)	50' below #5
TG	3	50' below #4
TG	2	140' below #3
TG	1	Base Cantua Sand

SAMPLES FROM WELL SECTIONS

Conoco Kreyenhagen #1

KR	1	9430

General Petroleum Burrel #1

GPB	7	7939
GPB	9	7959
GPB	13	8050
GPB	14	8065
GPB	16	8085
GPB	18	8104
GPB	19	8144

<u>Herndon Bottoms 1</u>

HB 2	5100-5112
HB 3	5118
HB 4	5137
HB 5	5185

<u>Rio Grande Mosesian 1</u>

RGM 1	4408
RGM 2	4430
RGM 3	4485

<u>Seaboard Gill 1</u>

SG 1	4194
SG 2	4220
SG 3	4242
SG 4	4305
SG 5	4353
SG 6	4382

<u>Shell Raisin City #1</u>

RC 1	6410

<u>Standard Oil Company, SO 72-3P</u>

SO 72-1	9562
2	9596
3	9660
7	9745
9	9936
10	9977
12	10068
13	10115
14	10152
15	10215

<u>The Texas Co., Everding 1</u>

E 1	9135
2	9156
3	8170
4	9196
6	9235

<u>The Texas Co., Exeter 2</u>

Ex 1	Top Gatchell Sand
Ex 41	325' below top Gatchell Sand

<u>The Texas Co., Loescher #1</u>

L1-1	8993
2	9015
3	9056
4	9353

The Texas Co., SPL 1	
SP 1	8801
SP 2	8827
SP 3	8945
SP 4	8965
SP 5	8986
SP 6	9039

The Texas Co., SPL 27-13	
SPL 27-13-1	9340
2	9365
3	9397
4	9433
5	9448

Wilshire 33-26E	
WJ 2	5770-80
WJ 3	5780-90
WJ 4	5821
WJ 6	5851-61
WJ 7	5901-11
WJ 8	5930-40

Well 88-12C, Coalinga Nose	
88-12C-1	6800
2	6825
4	6879
5	6895
6	6925
7	6950
8	6968

SOURCE ROCK SAMPLES

SR 1 Sample from lower part of Joaquin Rocks Sandstone. Locality #5 of the SEPM field trip in 1941, on ridge west of Coal Mine Canyon.

SR 3 Sample from the Center Peak Conglomerate, from locality #8 of the SEPM field trip. 1.8 miles from Fresno Hot Springs (located north of Highway 198, a few miles west of Coalinga).

SR 4 Sample from Curry Mtn. Shale, 2.2 miles from Fresno Hot Springs.

SR 5 Recent sand from creek bed at same locality as SR 4.

SR 6 Recent sand from creek 3 miles downstream from Hot Springs.

SR 7 Bottom of Long Canyon Sandstone. From Long Canyon Sandstone outcrop a few miles west of Coalinga, on Highway 198. (SEPM locality)

SR 8 Top Long Canyon Sandstone, from outcrop on Highway 198. (SEPM locality)

SR 9 Approximately the middle of the Lower Waltham Shale outcrop on Highway 198. (SEPM locality)

SR 10 Juniper Ridge Conglomerate, from outcrop on Highway 198, west of Coalinga. (SEPM locality)

SR 11 Sample from Upper Waltham Shale outcrop on Highway 198. (SEPM locality)

SR 20 Recent stream sand, from granitic sources. On road from Gonzales to San Benito. From creek crossed by the road a few miles east of Gonzales, at foot of grade. Creek flows west.

SR 12 Recent stream sand, from granitic sources. Same road from Gonzales to San Benito. This sample is from the east flowing creek beside the road, about 5.5 miles east of SR 20. Locality is 1.5 miles east of the divide.

SR 21 Recent stream sand, from granitic sources. From the mouth of Chualar Creek (a few miles northeast of Gonzales, California).

SR 26 Recent stream sand, from Franciscan sources. From a short, steep creek bed, crossing Highway 198, 29.4 miles west of Coalinga.

SR 27 Recent stream sand, from Franciscan sources. From a short, steep creek, crossing Highway 198, about 5 miles west of SR 26.

SR 28 Recent stream sand, from Franciscan sources. From main east-west flowing stream, paralleling Highway 198, approximately 30 miles west of Coalinga. Sample taken where road, running from Highway 198 to Pinnacles, crosses stream.

SR 29 Recent stream sand, from Franciscan sources. Pacheco Pass road, under bridge, 6.2 miles east of point where Hollister and Gilroy roads join Highway 152.

SR 30 Recent stream sand, from Franciscan sources. Pacheco Pass road, under bridge, 2.5 miles east of SR 29.

THE LOWER AND MIDDLE EOCENE FORAMINIFERA

OF THE

COALINGA DISTRICT, CALIFORNIA

A Thesis

By

Louis J. Regan Jr.

In partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

California Institute of Technology
Pasadena, California
1943

TABLE OF CONTENTS

Abstract....................................Page 1

Introduction.................................. 2

Acknowledgments................................ 5

Method of Investigation........................ 6

Stratigraphy................................... 7

Oil City Section............................. 7

Universal Consolidated Oil Company Leavitt Hinze Well...................................... 8

Composite Section, East Coalinga Field......... 9

Wilshire-Bandini Petroleum Company 48-18 Well.. 9

Foraminiferal Assemblages...................... 11

Check List of Foraminifera present in the Oil City Section..................................... 11

Correlation 15

Ecologic Significance of Foraminiferal Assemblages. 16

ABSTRACT

During the last three years, the author has been gatherind data on the texture, composition, and distribution of the Gatchell sand and other Eocene sands in the vicinity of Coalinga, California, with the hope that detailed knowledge of this type would lead to an explanation of the origin of the Gatchell sand body, and to an understanding of the factors controlling the distribution of sand and silt in the Eocene sediments of this area. Because of the extreme lenticularity of the Eocene formations, a uniform basis for correlations is required for the correct interpretation of the data described above. The Eocene shales contain abundant Foraminifera, and these organisms provide such a basis for detailed correlation.

This paper deals with the Foraminiferal assemblages occuring in the interval between the base of the Kreyenhagen, and the Cretaceous; this interval was chosen, since it contains the sands related to the general problem outlined above. One outcropping section, located at Oil City, a few miles north of the town of Coalinga, was studied, and the data from this section was corroborated and amplified by the study of three well sections; the location of these four sections is shown on the index map, page 4. A check list of species identified is presented, together with a chart showing the ranges of these species in each of the sections. The faunal changes agree very closely with the Eocene B, C, and D zones described by Laiming, and these divisions have been indicated on the Range Chart.

The ecologic significance of the assemblages is considered, and it is concluded that there was a shallowing and a warming of the sea from deep, cold water conditions in D time to warm, shallow conditions in B3 time, followed by shallow warm water conditions in B2 and B1 time.

THE LOWER AND MIDDLE EOCENE FORAMINIFERA OF THE COALINGA DISTRICT, CALIFORNIA

By

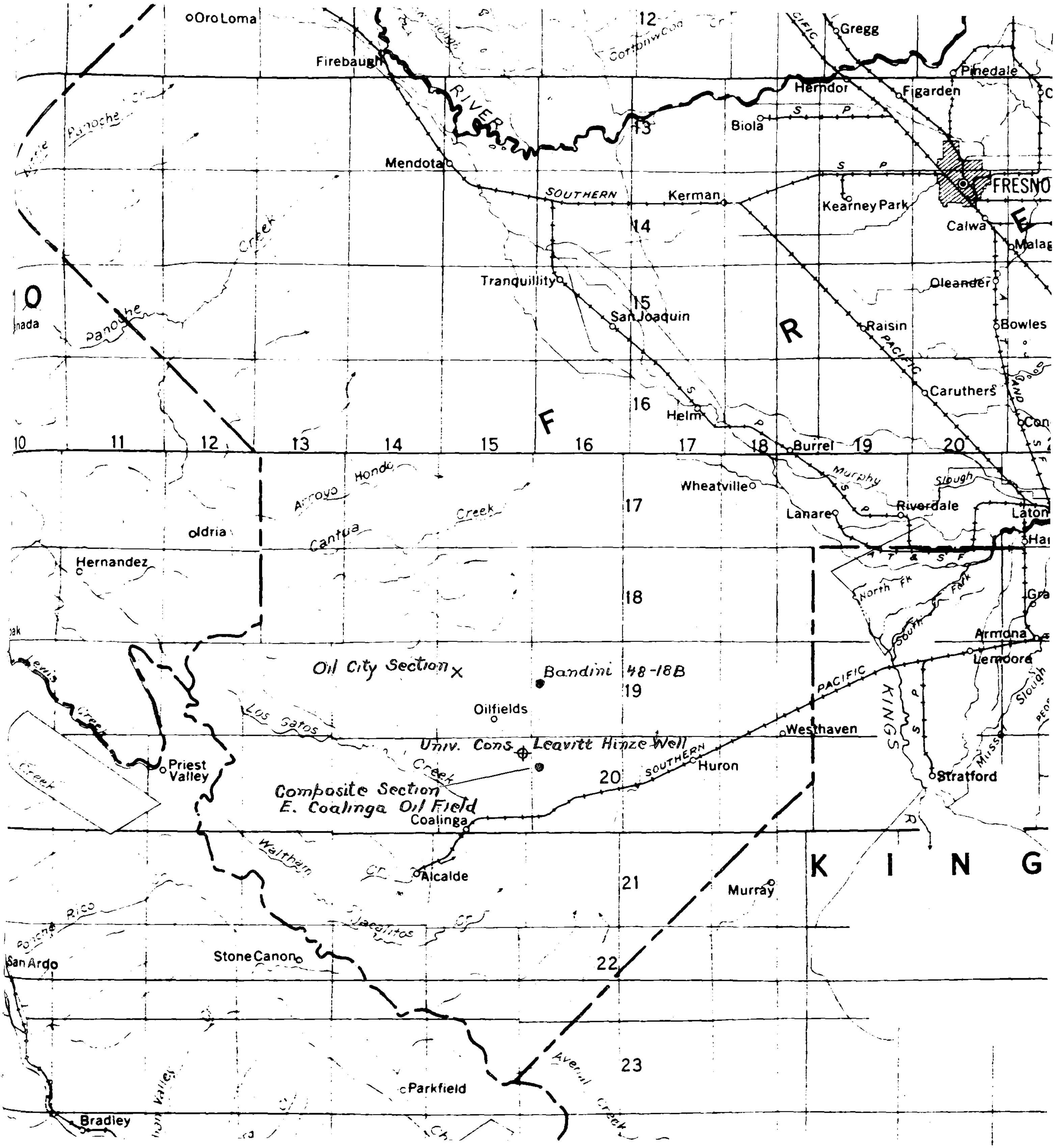
Louis J. Regan Jr.
California Institute of Technology
Pasadena, California

1943

INTRODUCTION

Early in 1938 an Eocene test well was drilled on the East Coalinga anticline, a few miles northeast of the town of Coalinga, California, which resulted in the discovery of a new oil field. The discovery well, drilled by the Petroleum Securities Company, was completed in an Eocene sand at a depth of 6,908'; since the well was located on the Gatchell lease, the sand is known as the Gatchell sand. Subsequent drilling has given us considerable data on the distribution of the Gatchell sand body, which has proven to be a remarkable and unique reservoir in a number of respects. The sand has a maximum thickness in the East Coalinga Field of about 800'; the sand body disappears to the west with striking abruptness, the western or up-dip limit of sand deposition resulting in a large closure. The up-dip pinchout of the sand, when viewed in plan, is an unexpectedly straight line, trending approximately north-south, and extending for a known distance of at least 12 miles. The westward disappearance of the Gatchell sand is probably due in part to a lateral change from sand to silt, for foraminiferal correlations indicate that silt of the same age as the sand is present west of the sand body, and time lines based on Foraminifera cross from silt to sand. Other wells drilled in the district suggest that the sand thins to the east, although the data is insufficient to show the character of the eastern limit of sand deposition. In a general way the Gatchell sand body may be pictured as an extremely elongate, thick sand lens, with a remarkably sharp western edge.

There are a number of other large sand deposits in the Lower and Middle Eocene sediments of the Coalinga district, and these, in common with the Gatchell sand, exhibit extreme lenticularity. The largest sand body in the district is the Cantua sand, which forms a thick lens in the Lodo formation; the Cantua sand does not extend as far south as the sections under discussion in this paper. During the last three years the author has been gathering data on the composition, texture, and distribution of the Gatchell and other Eocene sands of the district, with the hope that this data might lead to an understanding of the origin and conditions of deposition of the Gatchell sand, and to an understanding of the factors which controlled the distribution of sand and shale in the area. Because of the extreme lateral variation shown by the Eocene formations in this area, a uniform basis for


Oro Loma
Firebaugh
Mendota
Gregg
Pinedale
Herndon
Figarden
Biola
FRESNO
Kerman
Kearney Park
Calwa
Tranquillity
San Joaquin
Oleander
Raisin
Bowles
Caruthers
Helm
Burrel
Wheatville
Lanare
Riverdale
Laton
Hernandez
Oldria
Armona
Lemoore
Oil City Section
Bandini 48-18B
Oilfields
Westhaven
Univ. Cons. Leavitt Hinze Well
Huron
Priest Valley
Stratford
Composite Section
E. Coalinga Oil Field
Coalinga
Alcalde
Murray
Stone Canon
San Ardo
Parkfield
Bradley
K I N G
SOUTHERN
PACIFIC
RIVER
Panoche
Cantua
Creek
Arroyo Hondo
Los Gatos
Waltham
Jacalitos
Avenal
Murphy
Slough
North Fk
South Fk
KINGS
A T & S F

Index Map

correlating these deposits over the district is required for the correct interpretation of the lithologic and micro-lithologic data described above. Fortunately, such a basis is provided by Foraminifera, for the shales associated with the sands are generally rich in these organisms.

This paper deals with the foraminiferal faunas occurring in the interval between the top of the Cretaceous (Moreno formation) and the top of the Domengine formation. This interval was studied since it contains the Gatchell sand as well as the other sands which may have a bearing on the general problem outlined above. A check list of species, together with a range chart showing their stratigraphic distribution in several sections will be presented. The ecologic significance of the faunas will also be considered, since the environments favored by the foraminiferal faunas may shed light on the conditions of deposition of the sediments.

The work forming the basis of this paper was done at the California Institute of Technology during the academic year 1941-1942, as a partial fulfillment of the requirements for the degree of doctor of philosophy.

Acknowledgments

Grateful acknowledgments are due to R. M. Kleinpell, and W. P. Popenoe of the geological staff of the California Institute of Technology, for many valuable suggestions and helpful discussions of various aspects of the work.

To Hampton Smith, J.M. Hamill, and Boris Laiming, all of the Texas Company, the author is greatly indebted for their continued interest in the work, and for the generous loan of a considerable number of slides. Boris Laiming has long been interested in the Eocene Foraminifera and correlations of California, and the writer received much valuable aid both from discussions with him and from his published work.

Method of Investigation

The Foraminifera occurring in one outcropping section and three subsurface sections have been determined, and their distribution charted. The location of these sections is shown on the Index Map, page 4. The Oil City section is both well exposed and rich in Foraminifera, and for these reasons, it was studied in considerable detail in the following manner.

1. The section was measured by steel tape and brunton compass, and samples were collected wherever Foraminifera were noted.

2. The Foraminifera were washed out of the shales, and assemblage slides showing the species present in each sample were prepared. Type slides were also prepared of each species present, each slide showing a single individual.

3. The type slides were compared with published figures and descriptions, and in most cases the types were

referred to described species. Boris Laiming generously assisted the author by checking these determinations.

4. The stratigraphic range and relative abundance of each species was charted.

The three subsurface sections were studied in a similar manner, but for these sections the author used assemblage slides borrowed from the Texas Company.

STRATIGRAPHY

The Oil City Section

The Oil City section was measured near the east ¼ corner, section 17, T19S, R15E, approximately 8 miles north of the town of Coalinga, California. The section includes about 675' of strata underlain by the purple weathered Moreno(Cretaceous) shale, and overlain by the glauconitic sand at the base of the Kreyenhagen shale(Tejon and Transition Stages of Clark and Vokes).

At the base of the Eocene in the Oil City section there is approximately 35' of brightly colored, dark reddish-brown and green, foraminiferal, glauconitic silt, overlain by about 515' of rather uniform light gray to dark gray silt and sandy silt, becoming very sandy in the upper 75'. These strata have recently been described by White[1], who named

1. White, R. T. Eocene Yokut Sandstone North of Coalinga, California, Bull. AAPG, Vol. 24, No. 10, 1722-1750, 1940.

them the Lodo formation.

The base of the Lodo formation is not well exposed, so that it is difficult to judge the nature of the contact; attitudes in the Lodo measured by the author appear to be very nearly the same as those in the underlying Moreno.

The Lodo formation grades upward into massive, buff colored, fine-to medium-grained, silty to fairly clean sandstone. The name Yokut sand was suggested for this member by White in 1940. The sand is about 75' thick at this locality, and is overlain by the Domengine formation.

At the base of the Domengine there is a conspicuous, 18' thick, cliff forming bed, known as the Domengine Reef. The Reef is fossiliferous and pebbley near the base; the pebbles consist mainly of black chert, but with smaller amounts of quartzite and volcanic rock present. Above the Reef there is about 35' of gray foraminiferal silt with an extremely glauconitic sand bed a few feet thick at the top, marking the base of the overlying Kreyenhagen shale.

The base of the Domengine is clearly an unconformity, for when traced northward the reef can be seen to truncate the underlying sand at a low angle, while to the south the Domengine formation overlaps the Yokut and Lodo formations and rests on the Moreno shale.

The Universal Consolidated Oil Company's Leavitt Hinze Well

This well is located near the S $\frac{1}{4}$ corner, section 12, T20S, R15E. The sediments encountered in the Leavitt Hinze well,below the base of the Kreyenhagen differ considerably from the strata described in the Oil City section, the chief variations being the absence of any sand and the considerable thinning of the Domengine formation in the well. About 12' below the glauconitic sand a pebbley grit zone was cored, which is probably the equivalent of the Domengine Reef in the Oil City section. Below the grit zone, the remainder of the section consists of hard, dark gray, carbonaceous silt.

The Composite Section from the East Coalinga Field

This section was constructed from well data from the western ½ of section 18, T20S, R16W. In the East Coalinga Field, the Domengine shows the same characteristics as in the Leavitt Hinze well, for it is represented by only 10-15' of strata with a pebbley grit zone at the base. The lithology in the East Coalinga Field differs from the sections described above, because of the presence of the Gatchell sand. As has been mentioned above, the Gatchell sand thickens rapidly to the east; between the grit and the top of the sand there is a variable thickness of hard, dark gray silt the thickness of which decreases as the amount of Gatchell sand increases. The Gatchell sand is underlain by hard, dark gray, carbonaceous silt, similar to the silt overlying the sand. The sand is a soft-friable, coarse-to fine-grained, generally clean, kaolinitic, quartz sandstone which is barren of Foraminifera.

The Wilshire-Bandini Petroleum Company Well 48-18B

This well is located near the south ¼ section 18, T19S,

TENTATIVE FORAMINIFERAL CORRELATION OF EOCENE FORMATIONS IN CALIFORNIA[1]

MOLLUSCAN STAGES CLARK & VOKES 1936	FORAMINIFERAL ZONES* IN THE EOCENE OF CALIFORNIA		NEAR SAN DIEGO	SIMI VALLEY NORTH SIDE	EAST OF TECUYA CREEK	COAL MINE CANYON	OIL CITY COALINGA	CANTUA CREEK	CIERVO HILLS	NORTH OF MT. DIABLO	VACA VALLEY	MARTINEZ	OREGON	FORAM. ZONES	MOLLUSCAN STAGES CLARK & VOKES 1936
GAVIOTA	UVIGERINA COCOAENSIS	REFUGIAN		SESPE ?		ABSENT	KREYEN-HAGEN 1000'±	KREYEN-HAGEN 1800'±	TUMEY 1700'				BASSENDORF	REFUGIAN	GAVIOTA
TEJON AND TRANSITION	PLECTOFRONDICULARIA JENKINSI	A-1							KREYEN-HAGEN (ATWILL) 2500'±	? — ? MARKLEY 2720'	? — ? MARKLEY 5100'		COALEDO ? — ?	A-1	TEJON AND TRANSITION
	UVIGERINA CHURCHI	A-2				KREYEN-HAGEN 400'				SHALE AT NORTONVILLE 540'	"DUNN'S PEAK" SS. 350'			A-2	
	PLANULINA PSEUDOWUELLERSTORFI	A-3	POWAY CGL. 1000'	? — ?	UPPER TEJON SHALE 600' ? — ?						150' / "VACAVILLE" SHALES 2200'		? — ?	A-3	
DOMENGINE	AMPHIMORPHINA CALIFORNICA	B-1A	? — ?	LLAJAS 1700'		ABSENT ?	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT			B-1A	DOMENGINE
	CIBICIDES COALINGENSIS	B-1	ROSE CANYON MEMBER				DOMENGINE 70'	DOMENGINE 120'	DOMENGINE 150'	? — ? "DOMENGINE" SS. 400'			TYEE	B-1	
CAPAY	MARGINULINA MEXICANA Var. B	B-2	LA JOLLA 300'				LODO (WHITE) 620'	YOKUT SS. 100'± / LODO (WHITE) 2200'	YOKUT SS. 300' / LODO (WHITE) 3600'	IONE WHITE SS. 450'	SHALES WITH "CAPAY" FORAMINIFERA 2050'		? — ? ÚMPQUA	B-2	CAPAY
	MARGINULINA MEXICANA Var. C	B-3	? — ?	MEGANOS (KEW) BASAL 300'						? — ? MEGANOS DIV. E & D (CLARK & WOODFORD) 1840'				B-3	
	PSEUDOUVIGERINA WILCOXENSIS	B-4		MARTINEZ (KEW) 4200'										B-4	
	BOLIVINA APPLINI	C				GRAY SHALE ABOVE AVENAL		CANTUA SS. 1300'	CANTUA SS. 1800'		?	"MARTINEZ" OF CUSHMAN & BARKSDALE		C	
MEGANOS	GUMBELINA GLOBULOSA	D				"AVENAL"?	ABSENT	CERROS MEMB (MEGANOS & MARTINEZ FORAMINIFERA)	CERROS MEMB. (MEGANOS & MARTINEZ FORAMINIFERA)	MEGANOS DIV. A-C 1460'	?			D	MEGANOS
MARTINEZ	MARGINULINA SUBACULEATA	E								MARTINEZ 600'		MARTINEZ		E	MARTINEZ

* THE BIOLOGICAL DESIGNATION OF THE ZONES IS HERE PROPOSED INFORMALLY PENDING THEIR MONOGRAPHIC TREATMENT.

FIG. 9.—In a recent article, "Eocene Yokut Sandstone North of Coalinga, California," by Robert T. White, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 10 (October, 1940), pp. 1722–51, the Yokut sandstone has been defined as a separate formation, distinct from either the Lodo or the Domengine formations. Therefore, the Yokut should not have been included in the Lodo formation, as it is shown in Figure 4 and Figure 9 of the present article.

1. After: Laiming, Boris, "Foraminiferal Correlations in Eocene of San Joaquin Valley, California", Bull. AAPG, Vol.24, No. 11 pp 1923-1939.

R16E, in the Northeast Coalinga Extension Field, about 5 miles north of the composite section of the East Coalinga Field.

Immediately below the glauconitic sand at the base of the Kreyenhagen, this well encountered about 120' of sand and sandy silt; near the middle of this member, a grit zone similar to the one described above, was cored, and this zone may be the equivalent of the Domengine Reef. The sand below the grit zone is known locally as the "Fleishaker sand". Below the sand about 380' of hard, dark gray carbonaceous silt, underlain by 70' of Gatchell sand were encountered. As in the section above, the Gatchell sand is underlain by hard, dark gray siltstone. Sufficient drilling has been done between the Northeast Extension Field, and the East Coalinga Field to indicate that the Gatchell sand forms a continuous sand body between the two areas.

FORAMINIFERAL ASSEMBLAGES

Eighty species of Foraminifera, representing 44 genera, have been identified in the Oil City section; a check list of these species is tabulated below.

Ammodiscus sp.
Anomalina coalingensis Cushman and Hanna
Anomalina dorri Cole, Var. aragonensis Nuttall (large)
Anomalina sp.
Arenobulimina sp.
Bathysiphon eocenica Cushman and Hanna
Bolivina (Loxostomum) applini Plummer
Bolivina cf. incrassata Reuss

Bulimina adamsi Cushman and Ponton
Bulimina cf. denticulata Cushman and Parker
Bulimina cf. excavata Cushman and Parker
Bulimina inflata Sequenza
Bulimina pupoides d'Orbighy
Cassidulina cf. globosa Hankten
Cibicides(Discorbis) coalingensis(Cushman and G.D. Hanna)
Cibicides martinezensis Cushman and Barksdale
Cibicides sp. D, Cushman and Mcmasters
Cibicides ungeriana(d'Orbigny)
Cibicides sp.
Clavulina cf. parisiensis d'Orbigny
Cyclamina cf. pusilla Brady
Discocyclina cf. clarki(Cushman)
Discocyclina cf. cloptoni Cushman and Mcmasters
Dentalina (Nodosaria)adolphina d'Orbigny
Dentalina approximata Reuss
Dentalina (Nodosaria) communis d'Orbigny
Dentalina consobrina d'Orbigny
Dorothea cf. principensis Cushman and Bermudez
Elphidium sp.
Epistomina eocenica Cushman and Hanna
Eponides cf. guayabalensis Cole
Eponides cf. minima Cushman
Eponides sp.
Gaudryina jacksonensis coalingensis Cushman and Hanna
Gaudryina indentata Cushman and Jarvis
Glomospira charoides(Jones and Parker)
Gyroidina florealis White
Gyroidina soldanii octocamerata Cushman and Hanna
Gyroidina sp.
Globigerina sp.
Globorotalia sp.
Haplophragmoides coalingensis Cushman and Hanna
Lenticulina sp.
Marginulina asperuliformis (Nuttall)
Marginulina mexicana (Cushman Var. A Laiming
" " " " B "
" " " " C "
" " " " D "
Marginulina subbullata Hankten
Marginulina truncana (Gumbel)
Nodosaria arundinea Schwager
Nodosaria sp. (Corkscrew ornamentation)
Nodosaria(Glandulina)laevigata Cushman and Hanna
Nodosaria latejugata Gumbel
Nodosaria cf. lepidula Schwager
Nodosaria pseudo-obliquestriata Plummer
Nodosaria cf. spinulosa (Montague)
Nodosaria sp.
Nonion halkyardi Cushman
Nonionella cf. frankei Cushman
Plectofrondicularia sp. (2 apertures)
Pleurostomella nuttalli Cushman and Siegfus

Pseudoglandulina conica (Neugeboren)
Pseudouvigerina sp. A Laiming
" " B "
Pseudouvigerina cf. wilcoxensis Cushman and Ponton
Pullenia eocenica Cushman and Siegfus
Pyrulina (Guttulina)sp.
Robulus inornatus d'Orbigny
Silicosigmoilina californica Cushman and Church(large)
Siphonina sp.
Spirillina sp. 1
Spirillina sp. 2
Spiroplectamina cf. bentonensis Carmen
Spiroplectoides eocenica Cushman and Barksdale
Textularia missippiensis Cushman
Turrillina trochoides (Reuss)
Valvulineria cf. advena Cushman and Siegfus

The stratigraphic ranges of the species listed above are shown on the range chart at the end of this report. A study of this range chart will show that in the Oil City section there are two major and three minor faunal changes, and that the same faunal changes occur in the subsurface sections. The faunal changes correspond closely to the Eocene B, C, and D zones defined by Laiming[1], and these

---

1. Laiming, Boris; Foraminiferal Correlations in Eocene of San Joaquin Valley, California, Bull. AAPG, Vol. 24, No. 11, pp 1923-1939, 1940.

---

divisions have been indicated on the range chart.

In the Oil City section, Zone D (samples 28, 27, and26) is marked by the common occurrence of Glomospira charoides, Silicosigmoilina californica (large), Bulimina excavata, and Cyclamina cf. pusilla. A considerable number of forms occurring in these samples do not range higher in the section.

The samples listed immediately above are apparently older than any of Laiming's samples from this area, since they demonstrate the presence of the D zone which was not differentiated from the C zone by Laiming.

Zone C (sample T26) is characterized by the joint occurrence of Anomalina dorri Cole var. aragonensis, Gyroidina florealis, Plectofrondicularia sp. (two apertures), Pseudouvigerina sp. B, Marginulina asperuliformis, and Gaudryina indentata. A considerable number of species are not found higher than this sample.

There are no faunal changes within the B zone comparable to the two described above, and the subdivision of the B zone depends largely on a few index species. The B zones, except for the lower part of the B4 zone, are characterized by a fauna dominated by Robulus inornatus, Eponides guayabalensis, Gaudryina jacksonensis coalingensis, and Marginulina mexicana. The B4 zone(samples T25a-14) is characterized by the joint occurrence of Cibicides martinezensis and Marginulina mexicana var. D ; the lower B4 contains the last occurrences of a number of forms ranging upward from the C zone, such as Pseudouvigerina sp. B, Nodosaria pseudobliquestriata, Marginulina asperuliformis, and Bolivina applini. The B3 zone (samples T11-11) is characterized largely by the joint occurrence of 2 varieties of Marginulina mexicana designated as varieties B and C by Laiming, and by a species of Elphidium with a very short range. Bulimina inflata is common in the lower part of the zone; Discocyclina is common in zonesB2 and B3.

The B2 zone (samples 11-T3) contains the last common occurrence of Marginulina mexicana Var. B, Bulimina adamsi, Nonionella frankei, Nonion halkyardi, and Marginulina truncana. The B1 zone is characterized by the abundant occurrence of Cibicides (Discorbis) coalingensis and Marginulina mexicana Var. A(samples T2c- T2).

CORRELATION

In the Oil City section, the Domengine is B1 in age, the Yokut sand is B2, and the silts below the Yokut range in age from B2 to D. The two major faunal breaks occur in a shale section, but it is noteworthy that the B4-C change takes place at the lithologic change from gray silt to brightly colored glauconitic silt. The glauconite present in the lower 35' of the section suggests the presence of an hiatus in the lower Eocene of the Oil City section, and the thinness of the C and D zones confirms this suspicion.

In the Leavitt Hinze well, the B1 zone was not sampled, but silt ranging in age from B2 to C is represented by samples. The zones in the interval B2 to C are all present, with about the same thicknesses as in the Oil City section. The Yokut sand in the outcrop section is represented by silt of equivalent age in the well.

All of the samples in the Composite Section of the East Coalinga Field fall in the B2 and B3 zones, and there are no species present in the oldest samples to indicate an age older than B3. The Gatchell sand is here confined to the B3 zone, and it is the equivalent of the silt in the Oil City section 200-250' below the base of the Domengine.

The samples of the upper part of the 120' of sand and sandy silt immediately below the green sand in the Wilshire Bandini well contain the B1 fauna, indicating a correlation with the Domengine at Oil City. The first sample below the "Fleishaker sand" (see page 11) contains a B2 fauna; the "Fleishaker" is apparently equivalent in age to the Yokut, and may well represent the same sand. In the silts between the "Fleishaker" and Gatchell sands, the B2 and B3 zones are present, and the B3-B4 faunal change takes place a little above the Gatchell sand; the 70' of Gatchell sand present in this well is entirely in the B4 zone. It seems logical to conclude that the Gatchell sand body is slightly older in the Northeast Coalinga Extension Field than in the East Coalinga Field.

ECOLOGIC SIGNIFICANCE OF THE LOWER AND MIDDLE EOCENE FAUNAS

In recent years there has been considerable growth in our knowledge of the ecology of living Foraminifera, and considerable pertinent data has been published.[1] However,

---

1. For a bibliography of papers dealing with the ecology of living Foraminifera, see; R. M. Kleinpell; Miocene Stratigraphy of California, AAPG, 1938, pp11-13

---

the subject is a complicated one, and a great deal more ecologic data is needed before any hard and fast conclusions may be drawn regarding the environments in which ancient sediments were deposited.

A considerable number of genera of Foraminifera appear to be more or less cosmopolitan in their habitats, and therefore are of little value to the problem. Other genera occur commonest in a certain temperature or bathymetric range, but also occur in small numbers in other very different environments. In some instances, species of the same genus have different habitats, making it very difficult to evaluate the significance of forms which are no longer living. Only a relatively small number of genera show a well limited bathymetric or temperature range.

Because of the difficulties and limitations mentioned above, the author has found it desireable to simplify the ecologic analysis of the faunas described above, by eliminating all the forms which have only a rare occurrence in the sections studied, and also by eliminating the genera which appear to be cosmopolitan.

Tabulated below is a bionomic classification of genera with a common to abundant occurrence in the Oil City Section.

COSMOPOLITAN GENERA

Bulimina
Cassidulina[1]
Cibicides
Epistomina
Eponides
Gaudryina

Haplophragmoides
Marginulina
Nonion[2]
Robulus
Spiroplectamina

1. Common in cold water.
2. Common in sheltered water, except umbilicatulus and Pompilioides groups.

COMMONEST IN DEEP COLD WATER	COMMONEST IN WARM SHALLOW WATER
Ammodiscus	Anomalina
Bathysiphon	Discorbis
Cyclamina	Dentalina
Glomospira	Discocyclina
Silicosigmoilina (?)	Nodosaria
Bulimina Inflata	Pseudouvigerina
	Siphonina
	Textularia

LITTORAL

Elphidium- Cold to warm water.

ECOLOGIC CONCLUSIONS

Since Zone D contains abundant Glomospira, Ammodiscus, Cyclamina, and Silicosigmoilina, it was probably deposited in cold, deep water. A considerable shallowing and warming of the sea is indicated for Zone C by the presence of common Pseudouvigerina, Nodosaria, and Textularia. The shallowing and warming of the sea apparently continued in the B zones, as is indicated by the appearance of common Dentalina, Siphonina, Anomalina, and in B3 of common Discocyclina. That littoral conditions might have existed during B3 time is suggested by the presence of common Elphidium in that zone; however, in view of the abundance of other genera in this zone, including

Cyclamina, Bathysiphon, and Bulimina inflata, which suggest deeper water conditions, it seems very hazardous to assign the B3 zone to the littoral bathymetric zone. The presence of very abundant Discorbis-like Cibicides in zone B1, together with abundant to common Nodosaria, and Anomalina, suggests that shallow, warm water conditions extended into B1 time.

According to Kleinpell (Op. Cit. p. 16), the Nonioninas as well as the Miliolidae are most abundant in current sheltered environments, such as partially land-locked bays. Nonioninas are not common in the Oil City section except in the middle B zones; it is possible that their common occurrence in the B2 and B3 zones may have been caused by the existence of some such current sheltered environment.