GEOLOGY OF THE NODULAR SHALE OF THE MIDDLE AND UPPER MIOCENE OF THE WESTERN LOS ANGELES BASIN

by

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-Summary-

Investigations of the Geology of the Nodular Shale were carried on under the auspices of the Standard Oil Company of California. Attempts were made to arrive at some conclusions with regard to the origin of the Nodular Shale, and its relationship to the origin of Petroleum that occurs below it in several fields of the West Los Angeles Basin.

The Nodular Shale is Middle Miocene in age in the southern part of the West Los Angeles Basin, and Upper Miocene in the Northern part. It is suggested that the Nodular was laid down in seas transgressing from south to north, and that an ancestral Santa Monica Mountains formed a barrier to this transgressing sea, as evidenced by the heavy mineral content of the Nodular Shale. The Nodular Shale is folded in the areas of the Oil Fields in which it occurs, and this folding is thought to have affected the Schist surface as well. It has also been affected by faulting.

The Nodular Shale is considered to have been the source beds for most of the petroleum in the reservoir rocks that lie below it in the Playa Del Rey and El Segundo Oil Fields.

Several areas are considered to be favorable locations for new petroleum discoveries in the region studied.

It is possible that the Murray-Reynard theory for the deposition of phosphatic nodules, is applicable to the conditions that prevailed in the West Los Angeles Basin area, and that the nodules of the Nodular Shale are the result of seasonal variations of temperature in the Nodular sea, with a consequent periodic dying off of large portions of the fauna that inhabited the seas of that time.

TABLE OF CONTENTS

ABSTRACT.. p. 1

INTRODUCTION

Purpose... p. 1

Area covered.. p. 1

Methods of study.. p. 1

Maps used... p. 2

Acknowledgments... p. 3

STRATIGRAPHIC RELATIONSHIPS OF THE NODULAR SHALE

General Stratigraphy of the West Los Angeles Basin.............. p. 5

The Schist Basement... p. 6

The Schist Conglomerate... p. 7

The Nodular Shale... p. 8

DETAILED DESCRIPTION OF THE NODULAR SHALE

General Statement and Previous work............................. p. 11

Accessory Minerals of the Nodular Shale......................... p. 12

Heavy Mineral Content... p. 12

Comparison of Heavy Minerals with those of Adjacent Areas....... p. 13

Spectrographic Analysis... p. 13

Organic Content of the Nodular Shale............................ p. 14

STRUCTURE OF THE WEST LOS ANGELES BASIN

Introduction.. p. 17

Structure of the Schist Basement................................ p. 17

Structures in the Nodular Shale................................. p. 21

Age of the deformation.. p. 21

GEOLOGIC HISTORY OF WEST LOS ANGELES BASIN AND PALAEOGEOGRAPHIC CONSIDERATIONS OF THE NODULAR SHALE........................ p. 22

DISTRIBUTION OF PHOSPHORUS IN THE OCEAN AND ITS PRECIPITATION

Distribution of Phosphorus in the Ocean waters.. p. 25

Distribution of Phosphate Deposits in the Geologic Column.................................... p. 25

Theories of the precipitation of Phosphorus as Phosphates.................................... p. 26

Primary origin of Nodules............................. p. 29

DISCUSSION OF PHOSPHATIC DEPOSITION WITH REFERENCE TO THE ORIGIN OF THE NODULAR SHALE................................. p. 30

THE RELATIONSHIP OF THE NODULAR SHALE TO THE ORIGIN OF OIL

Introduction.. p. 32

Catalysts in the formation of oil..................... p. 33

Analagous area.. p. 34

Conclusions... p. 34

Possible future areas for petroleum discovery........... p. 35

CONCLUSIONS.. p. 36

BIBLIOGRAPHY

ILLUSTRATIONS

Figure 1.............Index Map.

Figure 2.............Diagram of stratigraphic relationships of the Nodular Shale.

Map 1................Contour Map of the Schist Basement.

Map 2 and 2a.........Maps of the Schist and Nodular Shale at El Segundo Oil Field.

Map 3 and 3a.........Maps of the Schist and Nodular Shale at Playa Del Rey Oil Field.

I N T R O D U C T I O N

Purpose:

The investigation of the Nodular Shale of the Middle and Upper Miocene of the Los Angeles Basin was undertaken at the suggestion of the Standard Oil Company of California, whose fellowship, the author held at the California Institute of Technology during the academic year 1941-1942. The purpose of the investigation was to try to determine the origin and mode of formation of the Nodular Shale, its palaeogeographic significance, and the relation it bears to the petroleum that occurs below it in the Playa del Rey, El Segundo and Inglewood Oil Fields of the West portion of the Los Angeles Basin.

Area covered:

The Nodular Shale was studied in particular from cores obtained from the Playa Del Rey, El Segundo, Torrance and Wilmington Oil Fields whose location appears on the Index Map, Figure 1.

The northern boundary of the area was arbitrarily taken as the north side of the Santa Monica Mountains, though the Nodular Shale has not been found on the north flank of the mountains. The southern limit is the south shore of the Palos Verdes Hills where the Nodular Shale is reported from at least three localitites.

Methods of Study:

Most of the studies were performed on samples obtained from cores in the several fields of the area in which the Nodular

Shale has been cored. The relations of the Nodular Shale to the Schist basement received particular attention in the hope of establishing the topography upon which the Nodular Shale was deposited. Samples obtained from the wells shown in Fig. 1, were examined for heavy mineral content, for the purpose of obtaining information regarding the type and location of source rocks that provided the sediments for the Nodular Shale. Some samples were also examined spectroscopically for the purpose of obtaining the distribution of such elements as Phosphorus, of which there is an abundant amount in the Nodular Shale, and such elements as Nickel, Vanadium, Copper, Chromium and Molybdenum which have been suspected as acting as catalysts in oil formation (e.g. Goster, 1941).

In plotting the maps, wherever possible, electrical logs were used for the identification of the Schist Conglomerate and Nodular Shale, Unfortunately electric logs are very scarce for the Playa Del Rey area, and as a result, the figures for the depths of the Schist, Conglomerate and Nodular Shale are not as accurate as in the other areas. In Playa Del Rey, the depths were taken from core descriptions. It is estimated by Wissler (oral communication) that the Schist depths in Playa Del Rey are good to only plus or minus 20 feet.

Maps used:

The basement outcrops, together with the outline map of the West Los Angeles Basin shown in Fig. 1, was taken directly from Eckis, (1934); oil fields, oil wells and Nodular Shale outcrops were placed on it, and the whole was reduced to its present size.

The map of the Schist basement was drawn on a base map with a scale of 4000 feet to the inch, traced and then reduced. The maps of the El Segundo and Playa Del Rey Oil fields were drawn on outlines maps to the scales of 800 and 400 feet to the inch, and then reduced photostatically to their present scale.

Acknowledgments:

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Particularly the author wishes to thank Dr. F. P. Shepard of the Scripps' Institute of Oceanography, who allowed examination of

of some recent phosphatic nodules and permitted the reading of an unpublished manuscript (Dietz, 1942) on these recent nodules dredged from off the coast of Southern California.

STRATIGRAPHIC RELATIONSHIPS OF THE NODULAR SHALE

General Stratigraphy of the West Los Angeles Basin:

The sedimentary rocks of the West Los Angeles Basin are of Miocene, Pliocene and Pleistocene age. (See Wissler, 1941, for a complete description). The oldest known rocks belong to the Middle and Upper Miocene.

The lowest portion of the sedimentary section was deposited on an old surface, here referred to as 'The Schist Basement', which consists of metamorphic rocks, questionably referred to the Fransiscan (Jurassic). Portions of the basement outcrop in the Santa Monica Mountains and in the Palos Verdes Hills (See Fig. 1) Sections of it have been cored from Playa Del Rey, El Segundo, Torrance, Wilmington and Dominguez Oil fields.

Overlying the Schist Basement is a Schist Conglomerate and sand member, which in the northern portion of its extent is of Upper Miocene Age (Corey, 1936). To the south, in the Palos Verdes Hills, it is Middle Miocene in age (Kleinpell, 1938), and in the Wilmington Oil Field, it is overlain by rocks of Middle Miocene age; so that, there, it is at least Middle Miocene in age as well. The Schist Conglomerate is absent locally over the crests of the Playa Del Rey and El Segundo structures.

The Schist Conglomerate is overlain throughout the region by the Nodular Shale. The Nodular Shale is dark in color and is characterized by the development of large phosphatic nodules. It has been assigned to the Upper Miocene (Mohnian Stage, Wissler, 1941) in its northern portion, but to the south, in the Wilmington Oil Field, Middle Miocene Foraminifera have been found in the lower half of the Nodular Shale (Goudkoff, oral communication).

In the Inglewood Oil Field, the Nodular Shale has been found to overlie ~~of~~ tuffs and sandstones. (Wissler, 1941) of Middle Miocene age.

Fig. 2, attempts to show diagramatically, but to no scale, the relationships of the Nodular Shale to the rocks lying below it, so far as it is known.

The Schist Basement:

Cores of the Schist show a varied character, but generally speaking the rock is a highly altered one, and the development of talc predominates thoughout most of the area. Petrographically the Schist has been studied by Waggoner (1939), he found the so-called diagnostic Franscican minerals Lawsonite and Glaucophane to be present in the Schist as far north as Venice. These minerals are also present in the Palos Verdes Hills outcrop area of the Schist.

In the Santa Monica Mountains, Hoots (1931) concludes that the Schist there "is the result of metamorphism by a buried body of granite, which may well form an east-west underground connection between the widely separated granitic masses now exposed" (p. 89).

In the Playa Del Rey and El Segundo Oil Fields, the surface top of the Schist shows a weathered appearance. It is also franctured in some of the cores. The upper portions of the Schist in these fields carry oil.

The Schist Conglomerate:

The Schist Conglomerate is the term applied to a section of coarse sandstones and conglomerates that are found immediately overlying the Schist in the Playa Del Rey, El Segundo, Torrance and Wilmington Oil Fields. In the Santa Monica Mountains it occurs in several localities, and was named by Hoots (1931) 'Basal Greywacke'. It also occurs in two localities in the Palos Verdes Hills: Point Fermin (Wissler 1941) and at Locality 13 of Woodring (1936).

The conglomeratic portions of the Schist Conglomerate carries angular fragments of the Schist. In the Playa Del Rey and El Segundo Oil Fields it forms part of the reservoir rock. Its thickness is irregular, being absent on the tops of the structures of those two fields, and attaining a maximum of 204 feet in the Royalty Service L-4 well in southeast Playa Del Rey. (1). In the El Segundo and Torrance areas the thickness of the conglomerate rarely attains

(1) Reese (oral Communication) states that even greater thicknesses were obtained in other wells of this portion of the Playa Del Rey Field.

150 feet.

On the basis of megafossils, Corey (1936) thought the age of the Conglomerate to be Upper Miocene. However, in the Wilmington area, the Schist Conglomerate is overlain by rocks of Middle Miocene age, and hence must be at least Middle Miocene in age, in that area. Molluscs from Locality 13 (Woodring, 1936) represent a 'Temblor' fauna (1). The forms from this locality, as well as those from Playa Del Rey represent shallow water, if not littoral conditions.

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(1) Probably Middle Miocene, as indicated in Kleinpell (1938).

The Schist Conglomerate is absent from the crests of the Playa Del Rey and El Segundo Structures, as previously mentioned. In fact Metzner (1935) suggests that the Conglomerate may not be continuous around the flanks of the structure; it thins upwards towards the crest. That is the Conglomerate is not restricted to 'valleys' in the schist, where it is the thickest. The dotted lines on Maps 2 and 3, indicate approximately the zero line of conglomerate thickness.

<u>The Nodular Shale:</u>

The Nodular Shale is the name applied to that portion of Upper and Middle Miocene rocks of the Western portion of the Los Angeles Basin which carries large phosphatic nodules, and which throughout much of its extent is a highly organic black shale. It is considered by Hoots (1931) to be Lower Modelo (Lower Puente of Wissler (1941)).

The Nodular Shale is known to underlie several fields of the Los Angeles Basin. They are Playa Del Rey (Barton, 1931; Hoots

1935; Metzner, 1935; Wissler, 1941), El Segundo (Porter, 1938; Wissler, 1941), Inglewood, (Willis, 1941; Wissler, 1941), Torrance, (Wissler, 1941), Wilmington (Wissler, 1941). It is surpected to underlie the Beverly Oil Field (Hoots, 1935), and the Lawndale Oil Field. It is possible that Nodular Shale was cored in the Union Oil Company's deep test (Callendar 79) in the Dominguez Oil Field.

Outcrops of the Nodular Shale are known from at least three places in the Santa Monica Mountains (Hoots, 1931, p. 109) and at least three places on the south side of the Palos Verdes Hills (See Fig. 1) (Woodring, 1936). Nodular Shale was cored in the Rolling Hills Petroleum Company's well in Sec. 27, T4S, R15W., on the north slope of the Palos Verdes Hills.

The Nodular Shale is thought to occur in a modified form in the Eastern Portion of the Los Angeles Basin. Wissler (1941) states that at the Richfield Oil Field occasional thin layers and spots of phosphatic material occur in the lower part of the section, (p. 222). The age of these is Lower Puente, and is thus the equivalent of the Nodular shale.

The Nodular Shale overlies the Schist and the Schist Conglomerate in the Playa Del Rey and El Segundo Fields, in Torrance and Wilmington Fields it overlies the Conglomerate, and in the Inglewood Oil Field it overlies Middle Miocene sands and volcanics.

The question as to whether or not there is an unconformity between the Schist Conglomerate and the Nodular Shale is still being debated. Hoots (1935) states on the one hand that

> "The contact of this nodular oil shale with the underlying oil-producing conglomerate is irregular, very sharp, and is marked by a concentration of phosphatic nodules. These features, together with apparently abrupt irregularities in the elevation of this contact throughout the Playa Del Rey field, suggests that an unconformity exists at this horizon". (p. 180).

Corey (1936) working after the conditions in the field were better known, thought that there was no hiatus between the deposition of the Schist Conglomerate and the Nodular Shale. He reports that in some cases the contact is gradational between the two units.

The Nodular Shale varies in thickness from 64 feet to 200 feet on the flanks of the structure at Playa Del Rey, with the average being 143 feet. Thicknesses at El Segundo and Torrance are comparable as are those of the outcrop sections (Hoots, 1931; Woodring, 1936). These figures probably represent very nearly the true thicknesses, as in most instances the dips recorded in core-descriptions do not run over 1[illegible] degrees (1), and dips of the samples obtained were all very low.

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(1) Dip recordings were very scarce in most of the descriptions examined.

- DETAILED DESCRIPTION OF THE NODULAR SHALE -

General Statement and Previous Work:

The Nodular Shale is well compacted, and can be considered a true shale. It appears to be slightly more fine-grained in the Playa Del Rey and El Segundo Fields, than in the Torrance Oil Field.

The outstanding feature of the Nodular Shale is the development within it of large phosphatic nodules, consisting of calcium phosphate. The largest are at Playa Del Rey where they attain diameters of two inches. The nodules in the El Segundo, Torrance and Wilmington sections are smaller, being about one inch in diameter. The nodules appear to be thin in their vertical dimension, being not over one half inch thick. Their long axis is parallel to the bedding of the shale in which they are entombed.

Complete thin-section descriptions of the Nodular Shale are given by Bradley in Hoots, (1935, pp. 190-194). Quartz seems to be the main constituent of the shale, but collophane is also abundant. Much organic matter was noted in the sections; it is interesting to note the alternation of organic poor and organic-rich layers that is clearly visible in the thin-sections.

Within the sections of the Nodular Shale studied, there are numerous streaks of bentonite. Sand streaks are also present but are scarce in the Playa Del Rey section. They increase in numbers to the south.

Accessory Minerals of the Nodular Shale:

While the main constituents of the shale appear to be quartz and collophane, disaggregation of samples of the rock showed the presence of glauconite, a mineral frequently associated with phosphatic deposits (e. g. Goldman, 1922).

Heavy mineral Content:

Heavy mineral separations were made from a series of samples selected from Playa Del Rey, El Segundo, Torrance and Wilmington Oil Fields, as indicated in Fig. 1. Sand samples were also separated, from Wilmington and Playa del Rey. The samples were chosen as far as possible to lie in the middle of the section of each well. They were crushed mechanically, boiled in a 2% solution of Sodium Carbonate, screened and then allowed to soak in carbontetrachloride for 24 hours. This latter treatment extracted most of the petroleum contained in the sample. Separations were made in bromoform.

The separations yielded fair crops of heavy minerals, but in most there were not enough grains to treat statistically. The minerals found to be present were as follows: garnet, both pink and colorless, zircon, epidote, tourmaline, hornblende (green) and minor amounts of apatite and purple augite, the latter at Playa Del Rey. Pyrite is scarce in small grains and probably secondary; but magnetite is abundant, especially in the sands. The micas are very abundant in the sands, but spasmodically developed in shale samples. No grains of glaucophane were found.

TABLE I

Results of the semi-quantitative spectrographic examination of the Nodular Shale. The numbers referø to an arbitrary scale of 1 - 10, in which 1 represents a small amount, and 10 a large amount, of an element. The estimates of the line densities, to which the numbers refer, are made visually.

Elements	Wave-length	Areas from which samples were taken Wilmington (Density)	Terrence (Density)	El Segundo (Density)	Playa Del Rey (Density)
Silicon	2435.2	8	8	7	4
Phosphorus	2555.4	Trace	Trace	Trace	3
Aluminium	2652.5	9	10	10	5
Magnesium	2779.9	8	9	9	7
Molybdenum	3132.6	4	3	3	4
Calcium	3179.3	10	7	8	10
Vanadium	3184.0	7	8	9	8
Copper	3247.5	7	6	7	10
Titanium	3373.8	8	9	10	10
Zirconium	3392.0	1	1	1	1
Nickel	3414.8	6	6	8	10
Potassium	3446.6	5	5	5	4
Chromium	4254.3	10	9	10	9

The following elements are present but not determinable

Tellurium
Sodium
Iron

The following elements were present throughout but their significance is not discussed.

Barium
Hafnium
Gallium

The density values in this table refer merely to the spectral line used, and have no reference to the actual amount of any element present in the shale. They show only the relative change in any given element in different samples. No one element can be compared with another as to the relative amounts present.

Comparison of Heavy Minerals with those of adjacent areas:

In his description of the Jurassic (?) Granitic rocks of the Santa Monica Mountains, (Hoots, 1931, p. 69) states:-

> "These granitic rocks are variable in character and consist of light-gray biotite granite and dark-gray diorite and granodiorite, the last consisting of green hornblende and biotite, together with apatite, zircon, and garnet in varying proportions."

Cogen (1933 and 1936) in studying heavy mineral zones of the Modelo on the North slope of the Santa Monica Mountains, seems to have found a very similar assemblage of minerals to those found in the Nodular Shale. In his report (1933) Cogen states that tourmaline is found in the Santa Monica Slate. The sources of the sediments studied by him are considered to be in part the Santa Monica Slates and in part the Topanga sediments that flank the Basin in which he worked.

It is known, (Hoots 1931), that previous to the deposition of the Modelo, the rocks in the Santa Monica Mountains region were elevated and considerably eroded. It seems plausible then, that this area could have provided detrital material to be deposited in a sea advancing from the south.

Spectrographic Analysis:

A series of samples of the Nodular Shale were analysed spectrographically. The location of the samples are shown in Fig. 1. The spectroscope was used in an attempt to attain an idea of the lateral variation of the phosphorus content of the Nodular Shale throughout its extent. In the preparation of the samples, care was taken that no contamination of the sample occurred from the nodules in the shale. That is only the true shale portion of the rock was burnt in the instrument. Table 1 summerises the elements found and the numbers in the column refer to an arbitrary scale of ten, in which the higher the number the greater the amount of that element present.

The phosphorus content is extremely low in the samples from the El Segundo, Torrance and Wilmington areas, but is considerably higher in the sample from playa Del Rey.

Little work has been done on the phosphorus content of sediments, and as such the distribution of the phosphorus in sediments, with respect to nearness to shore line, is not known. Recent studies by Størm (1938) and others have shown, that in stagnant fiords the phosphorus content as P_2O_5 is slightly higher (.23%) than the average P_2O_5 content for the 78 shale samples analysed by Clarke (1924) where he found the average to be .17%. Blowpipe tests were made on three samples of nodules from the Playa Del Rey area. The results showed a small amount of fluorine to be present.

Organic Content of the Nodular Shale:

The Nodular Shale from most localities in the area is very dark in colour, being black in well cores. When it is crushed to a fine powder it is a chocolate brown due to the free oil in it. The samples in the southern part of the basin are lighter in color than the samples from the northern portion of the area.

The recent work of Trask and Patnode on the Source Beds of Petroleum (1942), contains tables showing the organic content of sediments from many different horizons in the Los Angeles Basin. The wells in which they published information regarding the Nodular Shale are shown in Fig. 1. In their stratigraphy of the Los Angeles Basin, the Nodular Shale is included in the their Miocene 'Divison D'. When the results of the analyses of the Nodular Shale are examined, it is found that the organic content of the shale increases markedly to the northward, that is towards Playa Del Rey, where it reaches a maximum of 15% in some samples, which with one exception is the highest organic content of any shale examined from the Los Angeles Basin.

Previous work by Trask (1938 Summary p. 429) has indicated that "the organic content of sediments in the open ocean is much less than near shore". He also points out the several factors which influence the deposition and preservation of organic matter in sediments.

Submarine topography and supply of organic matter are the two principal factors which seem to be involved. The role of the submarine topography is apparently that of a trap into which the organic matter can be swept from surrounding layers, and cannot be removed.

Strøm (1938) has drawn attention to the large amounts of organic matter that have accumulated in the stagnant basins of the Norwegian Fiords.

It should be stated here that at Playa Del Rey especially, the Nodular Shale contains large quantities of free oil. Often on splitting a core, small pockets of oil are found, and all samples have a petroliferous odor. Samples from Playa Del Rey, El Segundo, Torrance and Wilmington all give a good 'cut' when soaked in carbon tetrachloride; the nodules from Playa Del Rey discolor the carbon tetrachloride.

STRUCTURE OF THE WEST LOS ANGELES BASIN

Introduction:

A map was prepared of the Schist Basement of the western portion of the Los Angeles Basin (Map 1), in an attempt to arrive at some notion as to the type of surface on which the Nodular Shale was deposited.

Maps of the Schist were also prepared for the Playa Del Rey and El Segundo Fields (Maps 2 and 3), and on these are superimposed maps of the Nodular Shale, to show the correspondance, or lack of it, in the structure on these two horizons.

Structures of the Schist Basement:

Folding:- The high areas of the Schist surface corresponding to the Playa Del Rey, El Segundo, and the Torrance- Wilmington areas, were probably produced by the folding of a relatively even surface, rather than having been carved out by pre-Schist Conglomerate erosion. Waggoner (1939) suggested this possibility for the origin of the Schist highs, but presents little evidence for it.

It is thought by the author that evidence for this statement can be found in the Schist Conglomerate and Nodular Shale. In the Playa Del Rey Oil Field, the relief in the Schist surface is of the order of 2000 feet (Map 3), while at El Segundo it is 700 feet (Map 2). It would seem that it would be impossible for sediments as relatively thin as, and of the type of the Schist Conglomerate to blanket so much of these areas, were the relief as great then as it is now.

The relief of the Schist surface to-day between the crest of the high to where the Conglomerate lenses out is variable. At Playa Del Rey it varies from 50 to 400 feet, and at El Segundo it is slightly less, the maximum being about 200 feet. This relief, were it present at the time of Nodular deposition should have caused the Nodular Shale to be much thinner on the crests of the Schist highs than on the flanks of the highs. No great amount of thinning is found.

One further point in favor of the structural origin of the highs is that the sub-surface Schist area of the West Los Angeles Basin was probably dry land during the Lower and most of the Middle Miocene, offering ample opportunities for the surface to be eroded to a relatively flat surface.

One thing particularly stands out, and that is the different types of structures that seem to be present in the Playa Del Rey and El Segundo areas. In Playa Del Rey, there seems to be a definite trend to the anticline, but in El Segundo, the high is much broader. The same situation is apparent on the contours drawn on the Nodular Shale.

Reese (oral communication) stated that the top of the Miocene in El Segundo is nearly flat, which is in great contrast to Playa Del Rey, where accumulation of oil in commercial pools occurs in the Pliocene.

<u>Faulting</u>:- Two large faults are thought to block out the northern and southern extremities of the Los Angeles Basin as it is known to-day (1). They are shown in Map 1. The Southern fault is located

(1) The Santa Monica Mountains and the Palos Verdes Hills do not belong in the Los Angeles Basin proper.

at the northern edge of the Palos Verdes Hills, and trends approximately northwest-southeast. The main evidence for this fault is found upon the examination of the log of the Rolling Hills Petroleum Company's well (sec. 27, T4S,R15W). It was drilled to a depth of about 6550 feet and bottomed in Nodular Shale whose dips were nearly vertical. (Hunter, oral communication). In connection with this, the Jergens Palos Verdes well (Sec. 34, T4S,R15W) was drilled to basement, which it hit at about 2000 feet. The distance between the two wells is under a mile, so that the degree of slope of the Schist surface between the two localities seems abnormally large and suggests a fault.

Similar discrepencies in depths of the Schist surface occur between the Southern California Drilling Company's well in Sec. 2, T5S, R15W, which penetrated Schist at about 1280 feet, which is much higher than the depth of Schist at Wilmington, where the Schist is cored at about 6800 feet. It is realized that the distance here is much greater than in the former case, but the plunge of the Torrance-Wilmington Schist anticline, suggests that the relief in this case is actually larger than indicated.

In the Northern part of the Basin, the most northernly well, that has penetrated the Schist (and Nodular Shale) is the Texas Company Anderson Spring well (Sec. 9, T2S,R15W) which cored Schist at 7336 feet. About a mile to the north of this well, the Hines Petroleum Company's Happy Days well, failed to get Schist at 7409 feet. To the

Northest in Sec. 25, T1S,R15W, the Associated Fox Hills well did not reach Schist at over 5000 feet in depth. The lowest elevation of the metamorphic basement outcrops in the Santa Monica Mountains appears from Hoots (1931, plate 16) to be about 600 feet above sea level. These rather large gradients between relatively close points suggest that a fault is present at the southern edge of the Santa Monica Mountains.

The presence of faulting along the southern edge of the Santa Monica Mountains has been suggested by Hoots (1931), and Soper, (1938, p. 175). Soper Considers the Malibu Coast Fault, south of the Central Santa Monica Mountains to represent an extension of the East-west zone of faulting, the Hollywood Fault, mentioned by Hoots (1931, p. 126). The Hollywood Fault is shown on Plate 16 as terminating a little to west of Sherman. (1)

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(1) On the Rift Club field trip to the Santa Monica Mountains in 1940, Dr. Soper, the leader of the trip, specifically stated the possibility of the Malibu Coast Fault being a continuation of the Hollywood fault of the Eastern Santa Monica Mountains.

Evidence for minor faulting occurring within the Playa Del Rey and El Segundo Oil Fields has been found in the cores of the Schist. This evidence consists mainly of slickensiding and contorting of the Schist. In Playa Del Rey the mention of a fault on the west side of the field has been made by Metzner (1936) and Hoots (1935), but, with the evidence available to the writer, it was not possible to locate this fault accurately, so that it was left out of the Schist and Nodular Shale maps.

Structures in the Nodular Shale:

Generally speaking, the Nodular Shale shows deformation to about the same extent as does the Schist surface. The one exception is the presence at Inglewood of a large thrust fault, which has developed in the lower part of the section, duplicating the Nodular Shale. (Willis, 1940, and Reese oral communication).

The Nodular Shale seems to be involved in faulting on the North slope of the Palos Verdes Hills, and the cores from the Rolling Hills Petroleum Company wells, ~~of it~~ were reported to show much slickensliding and steep dips (Hunter, oral communication). The Nodular Shale is in all probability affected by the faulting at the southern edge of the Santa Monica Mountains, this statement being based on reasoning similar to that used for the assumption of the fault affecting the Schist basement.

Age of the deformation:

All the movements of the rocks of the west Los Angeles Basin seem to involve the Nodular Shale, so that the structures seen today are post Nodular Shale. At Playa Del Rey folding has involved Pliocene rocks, (Hoots, 1935), but at El Segundo, contours drawn on the top of the Miocene suggest a nearly flat surface (1). This indicates that the tectonic activity in the region of El Segundo had practically

(1) California Institute of Technology Graduate Class work, 1941-42, and Reese, oral communication.

ceased by the end of Miocene time.

GEOLOGIC HISTORY OF WEST LOS ANGELES BASIN

AND

PALAEOGEOGRAPHIC CONSIDERATIONS OF THE NODULAR SHALE

In the Western Portion of the Los Angeles Basin, the oldest sediments that have been recognized belong to the Middle Miocene. These oldest rocks are from the Wilmington and Inglewood oil field areas, and from the south slope of the Palos Verdes Hills and have been assigned to the Luisian.

This indicates that much of the area under consideration was dry land at that time. This is further substantiated by the presence of erosional valleys, in the Schist. The best example being the large valley in the southeast portion of Playa Del Rey. Further evidence is the weathered appearance of the Schist in some of the cores.

At the conclusion of Luisian time, the Schist probably had very little relief, perhaps of the order of 200 feet, as suggested by the varying interval from the top of the Nodular Shale to the Schist surface, assuming that in as small an area as Playa Del Rey, the top of the Nodular Shale represents a time line.

At the beginning of the Upper Miocene, the sea advanced over the Schist surface from the south, covering the whole area with the exception of the crests of the Schist surface at what are now the Playa Del Rey and El Segundo Oil Fields. This permitted the deposition of the Schist Conglomerate everywhere with the exception of the highs mentioned previously, which stood above water.

Following the deposition of the Schist Conglomerate, a change in conditions, brought about the deposition of the Nodular Shale. The fact that the Schist highs were covered by sediments from the Nodular sea suggests that sinking of the basin as a whole occurred. It has already been mentioned that the lower portion of the Nodular Shale is Middle Miocene in age in the Wilmington area, where it overlies Schist Conglomerate which is thought to be Middle Miocene in age. The age of the Schist Conglomerate in this region has been determined by Woodring to be Middle Miocene (Woodring, 1936, Loc. 13).

In the northern portion of the basin we have a similar situation except that there, definite Upper Miocene Schist Conglomerate underlies definite Upper Miocene Nodular Shale. The fact that both the Nodular Shale and the Schist Conglomerate were deposited during Middle Miocene time in the southern part of the area, and were also deposited during Upper Miocene time in the northern part of the basin, clearly indicates that these formations must be related and were deposited in a sea transgressing from south to north. This parallelism of events in such closely related regions seems to be additional evidence against there being an unconformity between the Nodular Shale and the Schist Conglomerate.

The known distribution of the Nodular Shale, and the fact that it has not been reported from the north slope of the Santa Monica Mountains, or from the central Santa Monica Mountains (Soper, 1938) suggests that the Nodular phase of the Mohnian sea did not cross the area now occupied by the Santa Monica Mountains. It is known (Hoots, 1931) that the Santa Monica Mountains were uplifted following the dep-

deposition and intrusion of the Topanga rocks in that area. The heavy minerals found in the Nodular Shale could have been derived from these exposed rocks in the ancestral Santa Monica Mountains. From this evidence, it seems very likely that at the conclusion of Nodular Shale deposition, that an ancestral Santa Monica Mountains formed the shore line.

The western limit of Nodular deposition is unknown. Both Kew and Shepard (oral communication) state they have not found Nodular Shale on any of the Channel Islands that they have examined, and the implication is that the western limit of the Nodular Shale lies between these Islands and the present shore.

The very high organic content (up to 15%) of the Nodular Shale in its northern portion, suggests further that a special type of shore condition existed. It seems to the author, that a bay is required for the accumulation of such quantities of organic matter. In this connection, it must be considered that at the time of deposition, the organic content of the sediments was much higher. Trask (1936) has estimated that 40% of the original quantity of organic matter in fresh sediments is lost upon lithification.

DISTRIBUTION OF PHOSPHORUS IN THE OCEAN AND ITS PRECIPITATION

Distribution of Phosphorus in the Ocean waters:

Little seems to be known on the actual occurrence of phorsphorus in the ocean waters of the present day. The following broad generalizations seem to be justified.

1- The amount of phosphorus occurring in sea water as P_2O_5 increases from the surface downward (Harvey, 1928).

2- The surficial waters show a marked seasonal variation in phosphorus content (Harvey, 1928).

3- The surficial waters of arctic regions contain more phosphorus than those of tropical regions. (Thompson and Robinson, 1932).

Dietz and his associates (1942) consider that the maximum amount of PO_4 radical that can be present in sea water is 2.6×10^{-9} mols per lt, and that "sea water deeper than a few hundred meters is essentially saturated with tricalcium phosphate". In other words they conclude that surficial waters are undersaturated and deeper waters become supersaturated.

Distribution of Phosphate Deposits in the Geologic Column:

Phosphatic deposits of the type of the Nodular Shale have been described from many localities and from several portions of the Geologic Column. Dawson (1876) ascribes the Precambrian Laurentian apatite deposits to metamorphosed phosphate deposits. The Phosphoria of the Permian of the Rocky Mountain region is perhaps the outstanding example of phosphatic nodular deposition. Complete summaries of the occurrences of phosphate deposits have been published by Blackwelder

(1916), and Mansfield (1927).

Numerous phosphate nodular deposits have been reported from California Tertiary rocks. These have been described by Galliher (1931), and others.

In the last 50 years phosphatic nodules have been dredged from recent sediments of the present seas (1). The classic locality

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(1) Collet (1908) mentions several of these localities, as does Twenhofel (1926).

---

for nodules of this type is the Agulhas Bank, off the coast of South Africa, where they were first found by the Challenger Expedition. (Murray and Reynard, 1891). The most Recent locality to be described is off the coast of Southern California (Dietz, Emory and Shepard, 1942).

The depths at which phosphatic nodules have been found vary from 240 feet (Shepard, oral communication) to over 10,000 feet.

<u>Theories of the precipitation of Phosphorus as Phosphates:</u>

1- <u>Murray and Reynard (1891)</u>:- The general hypothesis of Murray and Reynard (1891) for phosphate deposition of the nodular type has been pretty well accepted since its inception, but difficulties are present. Their general thesis is that the phosphatic nodules are due to a "mass killing" of a fauna and that the individual remains form centres of deposition. This theory is accepted by Collet (1908) who considers the chemical actions involved to be as follows:-

> "Organic matter decomposing on the ocean bottom produces ammonia, which reacts with the calcium phosphate in solution, producing ammonium phosphate. It is the reaction of the ammonium phosphate on the calcium carbonate of calcareous shells, which seems to be the first stage in the formation of these nodules. This reaction is a pseudomorphosis"(p. 209). (1)

---

(1) The writer's translation.

The equation of the reaction is as follows:-

$$2(NH_4)_3PO_4 + 3CaCO_3 = Ca_3(PO_4)_2 + 3(NH_4)_2CO_3.$$

Collet considers that the calcium phosphate thus precipitated will attract further molecules of calcium phosphate, due perhaps to a series of reactions between the ammonium carbonate and the calcium carbonate of the sea water.

2- <u>Blackwelder (1916)</u>- Blackwelder (1916) stated that the dissolved quantity of phosphorus in sea water expressed as P_2O_5, amounted to about .18% of the total amount of dissolved salts (p. 288). This amount is sufficient to form the largest known phosphate bed in a few thousand years (p. 291). Reviewing conditions of phosphatic deposition he concludes that anaerobic conditions are necessary for the deposition of phosphates. However he recognizes that the lack of phosphate deposition in the Black Sea, where all his postulated conditions occur, militates against his theory. To the Black Sea data, should be added the recent work of Størm, (1938) who fails to report nodules from the fiords of Norway, where similar anaerobic conditions exist.

Blackwelder concludes in part:-

> "There is excellent reason to think that the immediately controlling conditions (for phosphatic depositions) are chemical or biochemical".....

and that the question is "a room for which a key is yet to be found".

After working on the Phosphoria formation of Idaho, Mansfield (1927) concludes that this deposit was laid down in an isolated basin in which there was a large amount of organic material. Nodules from this formation contained nuclei of animal remains. Mansfield thought that the conditions under which the Phosphoria was depostied were anaerobic, similar to conditions postulated by Blackwelder.

3- Mansfield (1940) - Recent work by Jacob, Reynolds, and Marshall, (quoted in Mansfield, 1940) has shown that " all types of commercial phosphate produced throughout the world contain fluorine". The quantities range from 0.4% to 4.2%. Mansfield draws attention to the rather close association of phosphatic deposits to volcanic activity in North America, assuming that volcanic activity affords the most ready source of fluorine. The action of the fluorine is that it combines with the calcium phosphate and renders the latter more insoluble.

4- Dietz, Emory and Shepard (1942)- Phosphate nodules from dredged samples off the coast of Southern California have been studied recently by these authors at the Scripp's Institute of Oceanography. The interesting points in their findings are that the nodules contain large quantities of fluorine (over 4%), and that they occur in localities very deficient in organic matter, and under aerobic conditions. It is impossible to go into their theory as to the origin of these nodules, but they are rather close to Mansfield's (1940); the conditions appear to be specialized.

Primary Origin of Nodules:

The presence of the Nodules on the ocean floors of to-day, seems to indicate that the nodules in rocks are of primary origin. That is they are formed on the ocean floor before burial and before lithification of the enclosing rock takes place. This is in contrast to concretions, which are thought to form after burial and even after lithification, that is ~~are~~ concretions are of secondary origin.

This view of primary origin of the nodules is substantiated by the character of the nodules in the Nodular Shale, where they lie flattened parallel to the bedding, and in some cases laminae seem to curl around them. In no case has the author seen these small laminae to have been interrupted by a nodule.

DISCUSSION OF PHOSPHATIC DEPOSITION WITH REFERENCE TO THE ORIGIN OF THE NODULAR SHALE

The first three theories outlined in the previous section, all find points of confirmation in the Nodular Shale. For example, general faunal evidence, derived from studies of fish faunas by David (oral communication) shows that there was a marked cooling of the ocean with the initiation of the Mohnian stage. This could account for such a "mass killing" of a fauna which would provide for this type of deposit. Anaerobic conditions seem to be indicated for the northern area of Nodular deposition, as evidenced by the high organic content of the Nodular Shale. The presence of Fluorine in the nodules, together with the bentonite beds in the Nodular Shale substantiate Mansfield's theory of the Association of volcanic activity as a source of the fluorine, which is thought to cause phosphatic deposition.

One apparent difficulty appears with the theory of Murray and Reynard, and that is the problem of obtaining a section of rock nearly 160 feet thick, such as the Nodular Shale exhibits in portions of Playa Del Rey, containing nodules, with an initial extermination of a fauna. In this connection, it should be remembered that Bradley (Quoted in Hoots, 1935) considers that laminations present in the Nodular Shale represented seasonal variations, saying "that the layers rich in organic matter was formed in summer", due to the enormous increase of pelagic organisms. If this is so, then there is every reason to suspect an annual supply of dead organisms with which to generate new nodules. These conditions, are very similar to those noticed by Murray in 1898, when he remarked that recent nodules seem to have been dredged from those localities which show large deviations of annual temperatures in the surficial waters, a condition which causes the death of a large number of animals (Collet, 1908, p. 195).

The role of fluorine in the deposition of the Nodular Shale is not clear, if the above conditions are ture. It can only be said that it may have aided in the precipitation.

The favoring of the hypothesis of Murray and Reynard by the author is based on the fact that no massive phosphate deposits are known to occur in the Nodular Shale. The Fluorine Hypothesis of Mansfield requires mass deposition of phosphates and fails to explain fully the occurrence of phosphatic deposits in nodular form.

THE RELATIONSHIP OF THE NODULAR SHALE TO THE ORIGIN OF OIL

INTRODUCTION:-

The work of Hoots (1935) on the Nodular Shale in the Playa Del Rey field attempted to prove, and with some success, that the Nodular Shale of that area

> "has been the source of much, if not all, of the Playa Del Rey oil" (p. 181).

The evidence cited by these workers is summarized as follows:- (p. 181)

1- The character of the oil produced at Playa Del Rey and the close relation which exits between the known distribution in the Los Angeles Basin of this unusual type of oil and the Nodular Shale.

2- The close stratigraphic relationship between the Nodular Shale and the producing oil zones.

3- The presence of free oil in this shale, and its radically different character from that of the crude being produced.

4- The high kerogen content and the increase of the free oil-kerogen ration downward in the supposed direction of migration.

5- The microscopic character and significance of the organic and phosphatic material.

6- The high carbon ratio of this oil shale, indicating that oil-formation has occurred.

Since the publication of these results, the El Segundo Oil Field has been discovered, and the presence in that field of the Nodular Shale and a heavy oil is further ~~suggests~~ proff of the above statements. Herold (1941, p. 45) cites El Segundo as an example of downward migration of oil.

In the Torrance area, oil shows below the Nodular Shale are known from only three wells: The D & B Oil Company Dawn No. 2 (Sec. 25, T4S,R15W), the Loma Verde Well (Sec. 18, T4S,R15W) and the Hunter-Delvin Well, (Sec. 17, T4S,R15W) (Hunter, oral communication). These all occur well to the south of the Torrance anticlinal axis. The general lack of oil below the Nodular Shale in this area may be attributed to a decrease in the organic content of the Nodular Shale in this region, and to the presence, in part of the area, to an impervious tight shale at the base of the Nodular Shale.

Oil seeps from the Palos Verdes Hills region are mentioned by Schultz (1937), from excavations for the Whites Point Outfall Sewer Tunnel. Several wells have been drilled in the Palos Verdes Hills, but to the author's knowledge none have been producers.

Catalysts in the formation of Oil:

Gester (1941) and others have drawn attention to possible catalysts, such as some of the metals, whose presence is thought necessary for oil formation. In the spectrographic analysis of the Nodular Shale some of these suspected catalysts were found to be present. Their distribution is tabulated in Table 11:

TABLE 11 (1)

Element	Areal variation
Nickel	Increases northward
Vanadium	No change
Lead	Not found
Molybdenum	No change
Chromium	Little change
Copper	Increases northward

---

(1) See Table I for relative abundance.

Analogous area:

It is of interest to note that oil has been obtained from samples of the Phosphoria formation of Idaho (Heald, 1921); the Phosphoria has been traced into the Lander district of Wyoming (Thomas, 1934), where it is known as the Embar formation; this formation produces the oil in the district mentioned. The oil has a low gravity (22), an asphaltic base and carries sulphur, a description that resembles the oils of Playa Del Rey and El Segundo.

Conclusions:

From the evidence presented, it is the author's opinion that much of the petroleum in the Playa Del Rey area owes its origin to the organic matter that was deposited with the Nodular Shale. By analogy it seems plausible that the Oil at El Segundo was derived from the Nodular Shale of that area, and that much of the Oil at Inglewood is derived from the Nodular Shale of that area.

Objections to the Nodular Shale as a source for the petroleum are based on the fact that the Nodular Shale has such a low permeability, that it would be difficult for petroleum generated in it to escape. The author agrees with Hoots (1935) in that faulting would provide avenues of escape. The folding that the sediments have undergone could conceivably squeeze the petroleum out of the sediments along even small fault planes.

Possible fuyture areas for petroleum discovery:

Three possible future oil prospects seem to be indicated as a result of the author's study of the Nodular Shale:-

(1)- The possibility of stratigraphic traps occurring by the overlapping of Middle Miocene rocks by the Nodular Shale almost anywhere in the central portion of the area studied by the author. This possibility will be governed somewhat by the stratigraphy encountered in the Union Oil Company Callendar 79 in the Dominguez Oil Field.

(2)- The Nodular Shale almost certainly underlies the Lawndale Oil Field, and accumulation below the Nodular might be expected in that area. However, the small size of the area, and the depth to which drilling would have to be undertaken, might make this region economically prohibitive.

(3)- The north slope of the Palos Verdes Hills region. Here there is a possbility of finding an accumulation against the northeast side of the falt in a trap which is formed by the fault which may seal beds dipping away from it. The possibilities of this area are supported by the shows of oil in the conglomerate cored in the Hunter Delvin, Loma Verde, and Dawn 2 wells previously mentioned.

C O N C L U S I O N

The following broad conclusions seem justified from this investigation:-

(1)- The origin of the irregularities of the Schist surface under the western portion of the Los Angeles Basin, is not entirely erosional, but is due in part to tectonic deformation, the schist having suffered deformation to the same extent as the overlying Nodular Shale.

(2)- The Nodular Shale represents an area of relatively slow accumulation of sediments, under a neritic environment, taking place in an embayment of the Mohnian seas as they gradually submerged the Schist basement. This embayment was in all probability bordered on the north by an ancestral Santa Monica Mountains.

(3)- There is no erosional unconformity between the Nodular Shale and the underlying Schist Conglomerate.

(4)- The nodules in the Nodular Shale, are thought to owe their origin to seasonal variations in the temperature of the Middle and Upper Miocene seas, which would have the effect of killing off a large enough proportion of the fauna to provide sufficient materials to be available for the reactions of Collet (1908) to take place, with the result of phosphatic nodular deposition.

(5)- The Nodular Shale is responsible for a major portion of the oil generated in Playa Del Rey Oil Field and by inference in the El Segundo Oil Field too.

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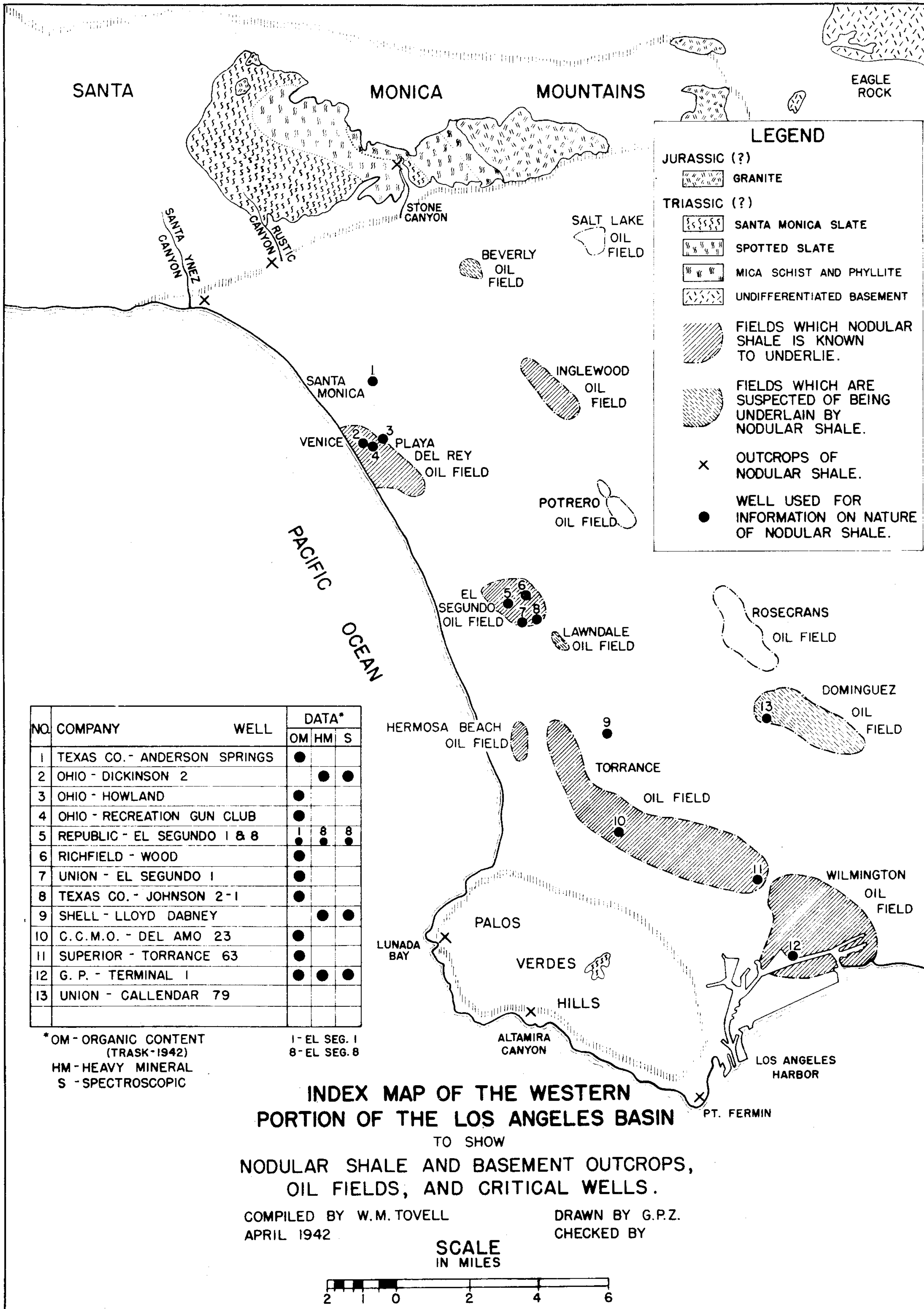
Fig. 1- Index map of the Western Portion of the Los Angeles Basin, Showing locations of Schist and Basement outcrops, Nodular Shale outcrops, Oil Fields, and critical wells.



NO.	COMPANY	WELL	DATA* OM	HM	S
1	TEXAS CO. -	ANDERSON SPRINGS	●		
2	OHIO -	DICKINSON 2		●	●
3	OHIO -	HOWLAND	●		
4	OHIO -	RECREATION GUN CLUB	●		
5	REPUBLIC -	EL SEGUNDO 1 & 8	1 ●	8 ●	8 ●
6	RICHFIELD -	WOOD	●		
7	UNION -	EL SEGUNDO 1	●		
8	TEXAS CO. -	JOHNSON 2-1	●		
9	SHELL -	LLOYD DABNEY		●	●
10	C.C.M.O. -	DEL AMO 23	●		
11	SUPERIOR -	TORRANCE 63	●		
12	G. P. -	TERMINAL 1	●	●	●
13	UNION -	CALLENDAR 79			

*OM - ORGANIC CONTENT (TRASK-1942)
HM - HEAVY MINERAL
S - SPECTROSCOPIC

1 - EL SEG. 1
8 - EL SEG. 8

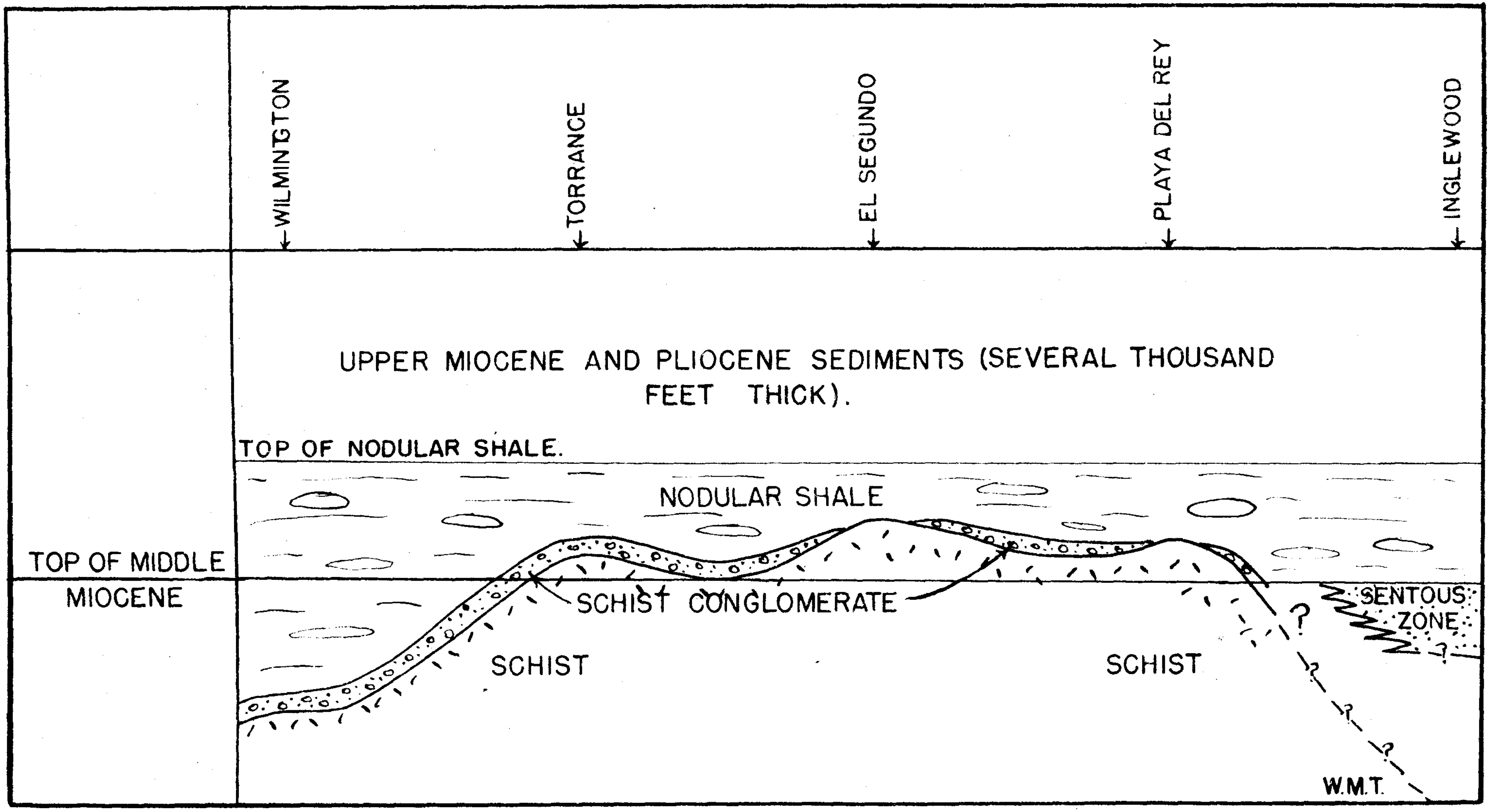
INDEX MAP OF THE WESTERN PORTION OF THE LOS ANGELES BASIN TO SHOW NODULAR SHALE AND BASEMENT OUTCROPS, OIL FIELDS, AND CRITICAL WELLS.

COMPILED BY W. M. TOVELL
APRIL 1942

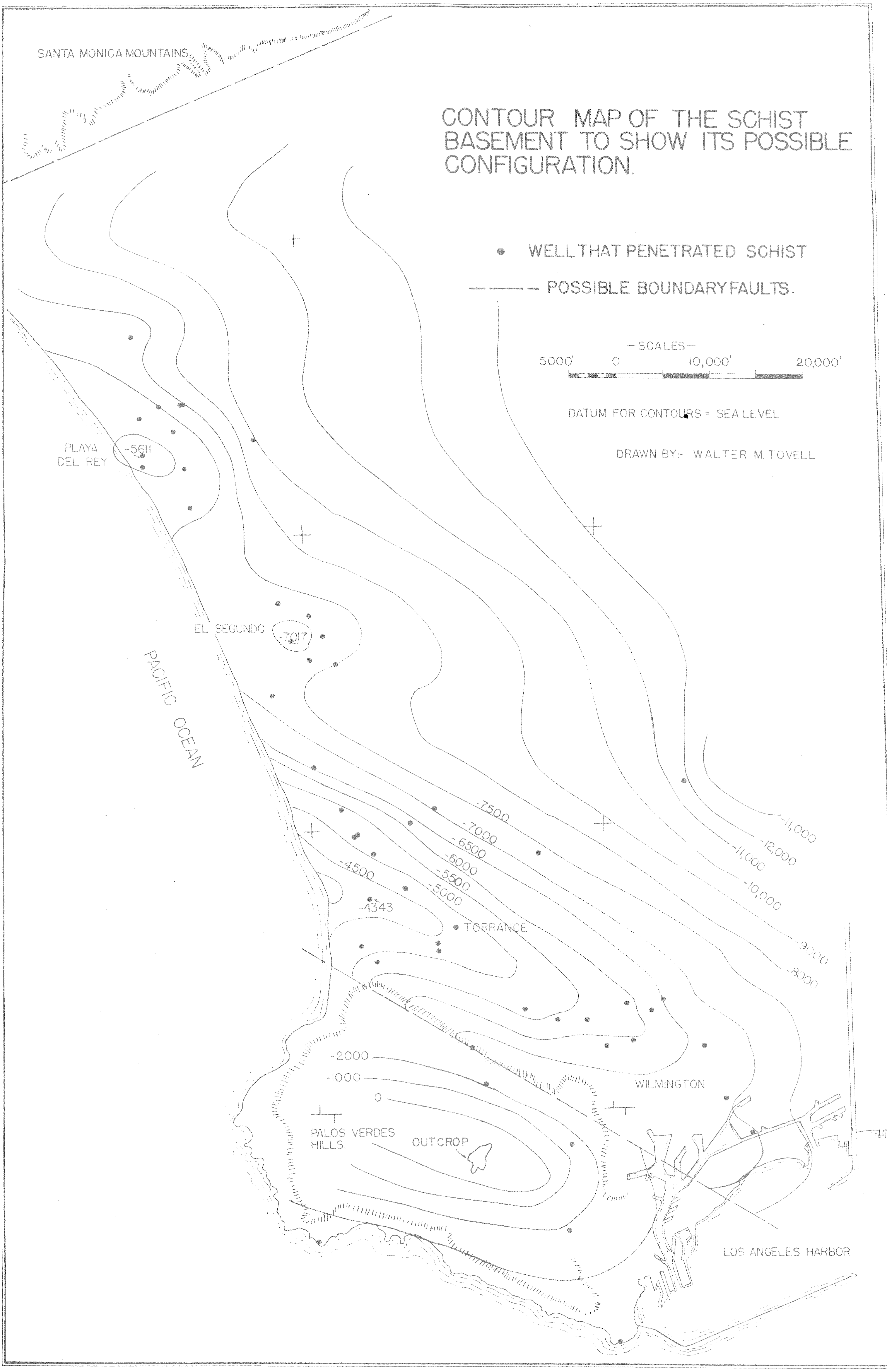
DRAWN BY G.P.Z.
CHECKED BY

Fig. 2- Diagram to show the relations of the Schist, Schist Conglomerate, and Nodular Shale in The Western Los Angeles Basin. The diagram is to no scale. The line of section is from Wilmington north through Terrance and El Segundo, to Playa Del Rey and then East to Inglewood.

FIGURE 2


WILMINGTON
TORRANCE
EL SEGUNDO
PLAYA DEL REY
INGLEWOOD
UPPER MIOCENE AND PLIOCENE SEDIMENTS (SEVERAL THOUSAND FEET THICK).
TOP OF NODULAR SHALE.
NODULAR SHALE
TOP OF MIDDLE MIOCENE
SCHIST CONGLOMERATE
SCHIST
SCHIST
SENTOUS ZONE
W.M.T.

Map 1- Structural contour map of the Schist Basement to show its possible configuration. All contours outside of the oil field areas should be considered as conjectural.


SANTA MONICA MOUNTAINS
CONTOUR MAP OF THE SCHIST BASEMENT TO SHOW ITS POSSIBLE CONFIGURATION.
WELL THAT PENETRATED SCHIST
POSSIBLE BOUNDARY FAULTS.
—SCALES—
5000' 0 10,000' 20,000'
DATUM FOR CONTOURS = SEA LEVEL
DRAWN BY:- WALTER M. TOVELL
PLAYA DEL REY
-5611
EL SEGUNDO
-7017
PACIFIC OCEAN
-7500
-7000
-6500
-6000
-5500
-5000
-4500
-4343
TORRANCE
-11,000
-12,000
-11,000
-10,000
-9000
-8000
WILMINGTON
-2000
-1000
0
PALOS VERDES HILLS.
OUTCROP
LOS ANGELES HARBOR

Map 2- Structural contour map of the Schist surface at the El Segundo Oil Field, to show its possible configuration.

Map 2a- Structural Contour Map of top of the Nodular Shale at the El Segundo Oil Field.

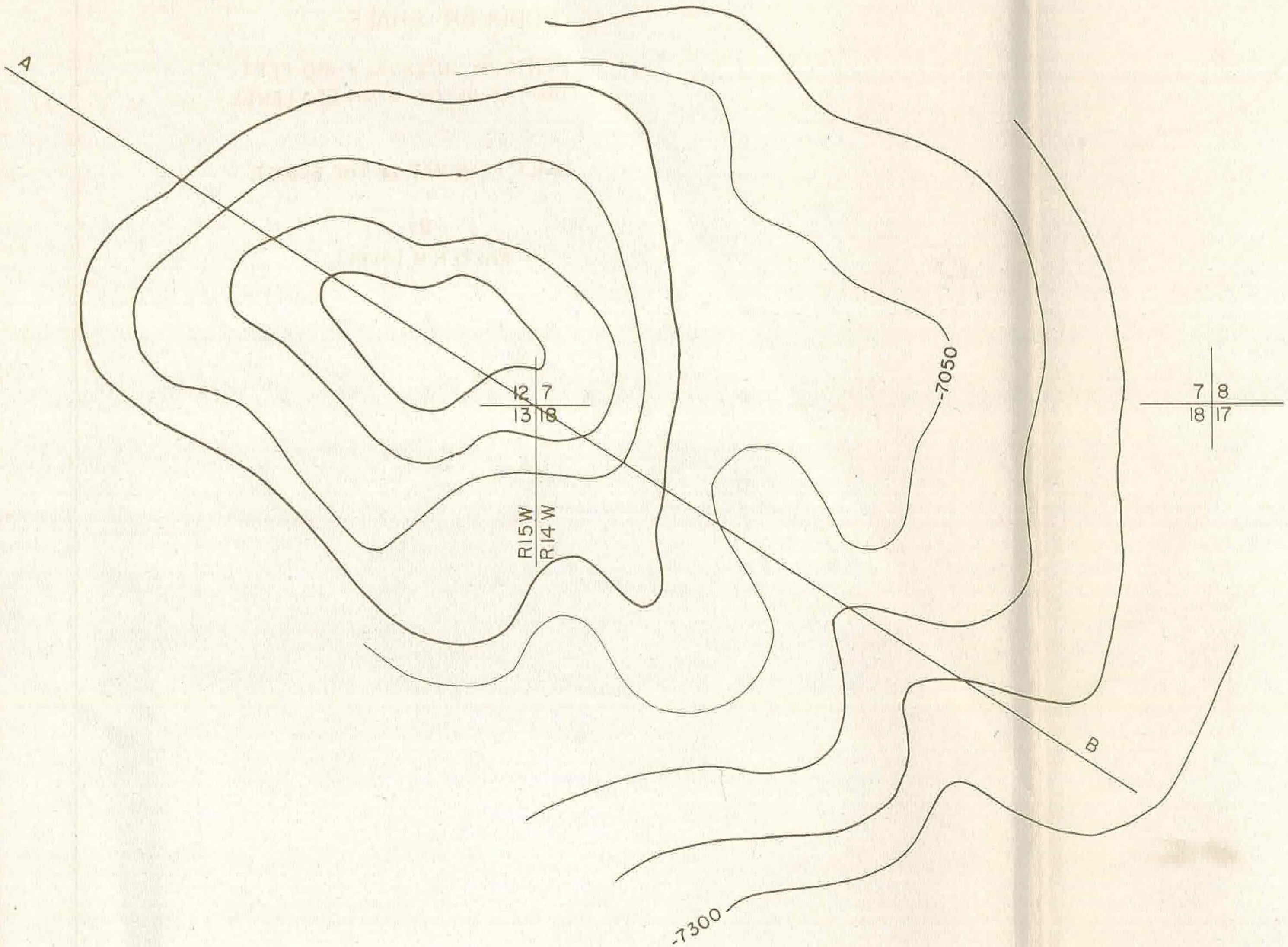
EL SEGUNDO OIL FIELD

STRUCTURAL CONTOURS ON THE TOP OF THE NODULAR SHALE.

CONTOUR INTERVAL = 100 FEET
DEPTHS BELOW MEAN SEA LEVEL

SCALE AS IN MAP OF THE SCHIST.

BY-
WALTER M. TOVELL.



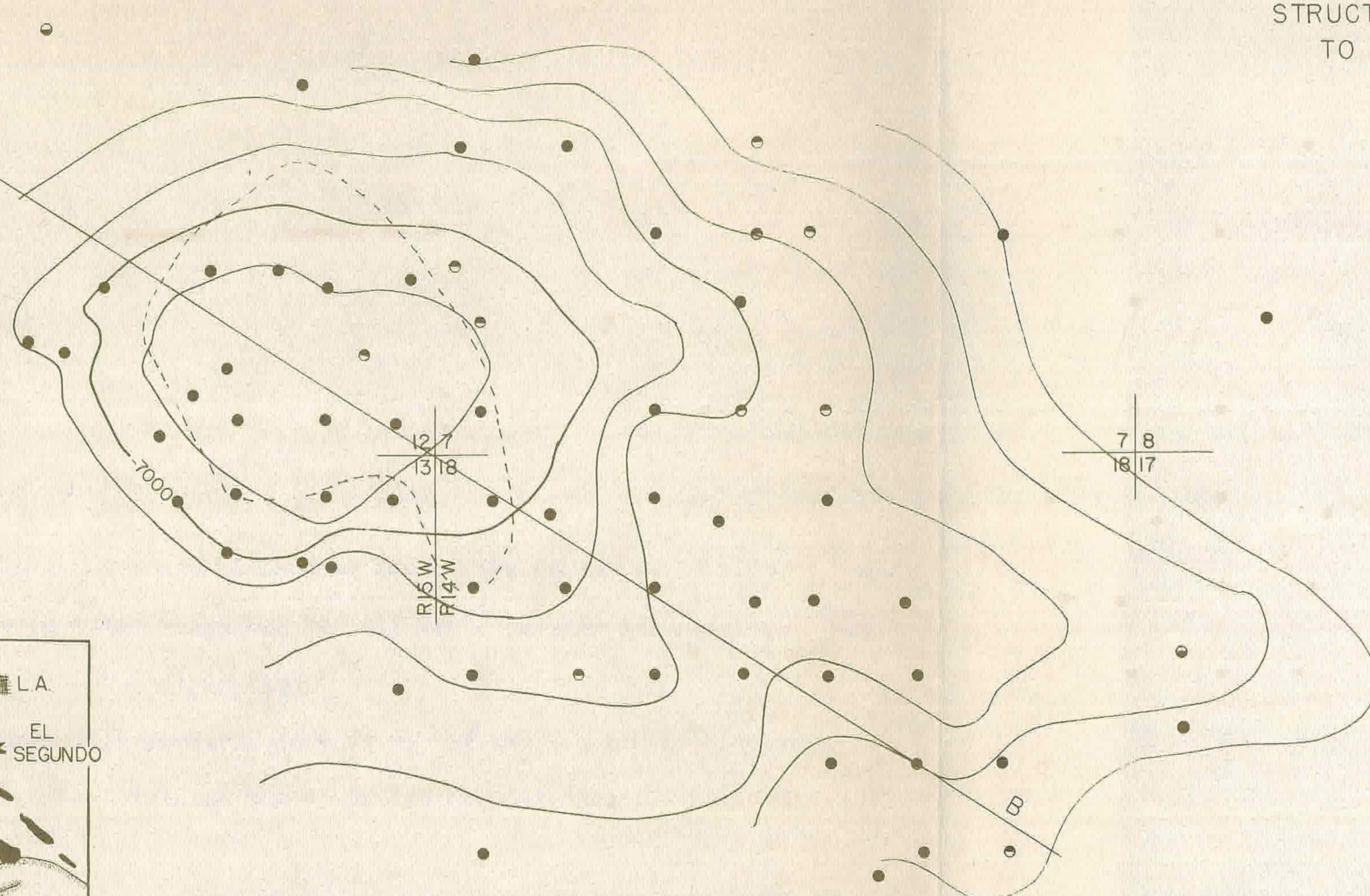
EL SEGUNDO OIL FIELD
LOS ANGELES COUNTY, CALIFORNIA

STRUCTURAL CONTOURS ON SCHIST SURFACE TO SHOW ITS POSSIBLE CONFIGURATION

CONTOUR INTERVAL = 100 FEET
DEPTHS BELOW MEAN SEA LEVEL

SCALE.
600' 300' 0 600' 1200' 1800'

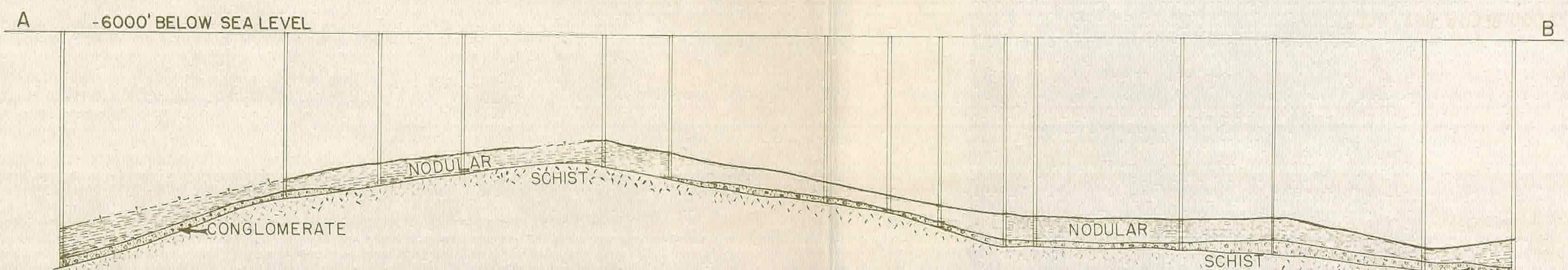
BY-
WALTER M. TOVELL.



INDEX MAP

- ● WELL WITH COMPLETE DATA
- WELL WITH TOP OF SCHIST ONLY REPORTED
- WELL WITH TOP OF NODULAR SHALE REPORTED
- WELL WITH SCHIST AND TOP OF CONGLOMERATE REPORTED
- WELL WITH TOPS OF NODULAR SHALE AND CONGLOMERATE REPORTED
- ----- POSSIBLE ZERO ISOPACH OF THE CONGLOMERATE

DRAWN BY:- W.M.T.
CHECKED BY:- F.D.B.
DATE:- MAR. 12, 1942
REVISED:-



CROSS-SECTION A-B TO SHOW THE RELATIONSHIPS OF THE NODULAR SHALE, CONGLOMERATE, AND SCHIST AT EL SEGUNDO

SCALES
400' 200' 0 400' 800' 1200'
HORIZONTAL
VERTICAL

Map 3- Structural contour map of the Schist surface at the Playa Del Rey Oil Field to show its possible configuration.

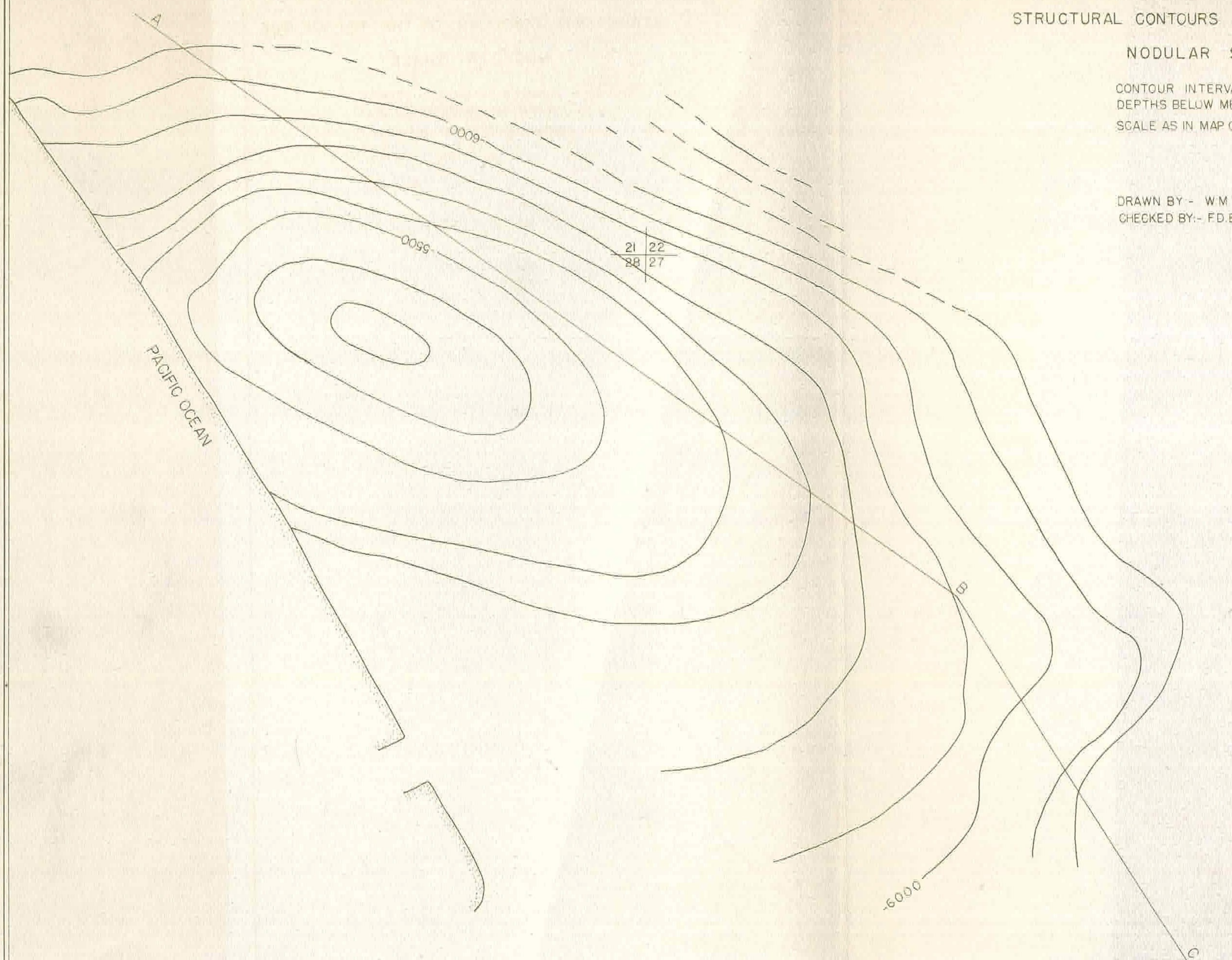
Map 3a- Structural contour map of the Top of the Nodular Shale at the Playa Del Rey Oil Field.

PLAYA DEL REY OIL FIELD

STRUCTURAL CONTOURS ON THE TOP OF THE NODULAR SHALE

CONTOUR INTERVAL = 100 FEET
DEPTHS BELOW MEAN SEA LEVEL
SCALE AS IN MAP OF THE SCHIST

DRAWN BY:- W.M.T.
CHECKED BY:- F.D.B.



PLAYA DEL REY OIL FIELD
LOS ANGELES COUNTY, CALIFORNIA

STRUCTURAL CONTOURS ON SCHIST SURFACE.
TO SHOW ITS POSSIBLE CONFIGURATION

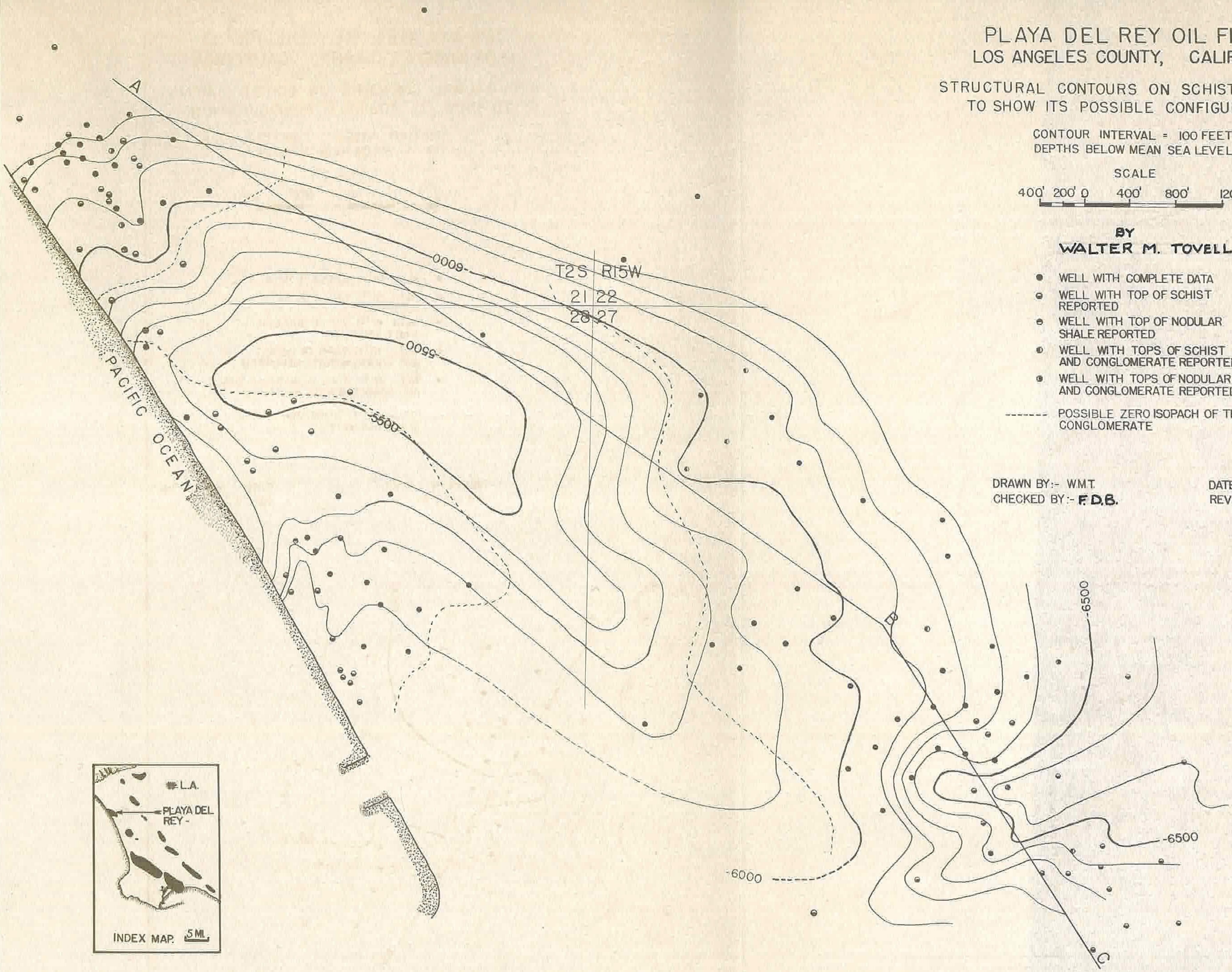
CONTOUR INTERVAL = 100 FEET
DEPTHS BELOW MEAN SEA LEVEL

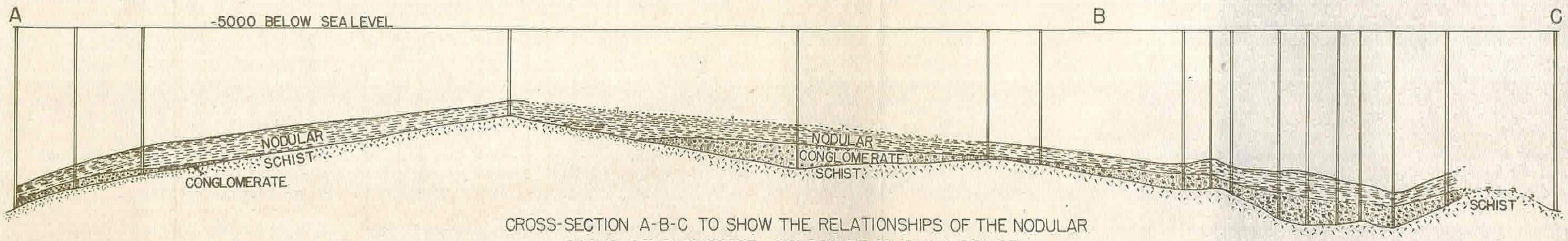
SCALE
400' 200' 0 400' 800' 1200'

BY
WALTER M. TOVELL

- WELL WITH COMPLETE DATA
- WELL WITH TOP OF SCHIST REPORTED
- WELL WITH TOP OF NODULAR SHALE REPORTED
- WELL WITH TOPS OF SCHIST AND CONGLOMERATE REPORTED
- WELL WITH TOPS OF NODULAR SHALE AND CONGLOMERATE REPORTED
- ------- POSSIBLE ZERO ISOPACH OF THE CONGLOMERATE

DRAWN BY:- W.M.T. DATE:- MAR. 12, 1942
CHECKED BY:- F.D.B. REVISED:-





CROSS-SECTION A-B-C TO SHOW THE RELATIONSHIPS OF THE NODULAR SHALE, CONGLOMERATE, AND SCHIST AT PLAYA DEL REY

SCALES
400' 200' 0 400' 800' 1200'
HORIZONTAL
1000' 750' 500' 250' 0 500' 1000'
VERTICAL