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HEAVY MINERAL ZONES IN THE MODELO FORMATION OF THE SANTA MONICA MOUNTAINS, CALIFORNIA

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ABSTRACT

A detailed heavy mineral study was made of a portion of the Modelo formation in the Santa Monica Mountains, near Los Angeles. It was found that the heavy minerals varied both vertically in the formation and laterally within single lithologic units. Four distinct mineral zones were recognized. These zones transect the lithologic boundaries and the structure of the formation. The cause of the peculiar boundary relations between the mineral zones and the rock units is not clear. Whether or not the mineral zone boundaries are surfaces of contemporaneous deposition remains a moot question.

The purpose of this investigation was to ascertain the degree of lateral and vertical mineral variation that occurs in some Tertiary formations of California. Such information is fundamentally important for determining the usefulness of minerals as criteria for correlation. Reed had carried out an analogous examination in the Tertiary formations of the Coalinga district. He sampled a stratum two feet thick for a distance of two miles and showed that there was in general "a gratifying degree of similarity in the heavy mineral assemblages of the various samples" (13).

A section of the Modelo formation, on the north flank of the Santa Monica Mountains, was selected for this inquiry. This district lies about 18 miles northwest of Los Angeles, is readily accessible, and a good geologic map of the area is available (8).

At this locality, the lower member of the Modelo formation, to which this investigation was confined, consists, with the exception of the basal greywacke, of several thick alternating units of fine-grained sandstone and shale. A dark greywacke, composed of angular slate fragments, generally occurs at the base of the Modelo where it directly overlies the Santa Monica slate. The sandstone units are dun colored and moderately indurated. The shale is grey and commonly sandy, becoming more siliceous toward the top of the formation. These lithologic units may be traced on the surface for several miles.

Except for the basal greywacke, the texture of the sandstone units in the Modelo of this locality is remarkably uniform, ranging from medium- to fine-grained. Screen analyses failed to show any definite textural trend laterally or vertically in the formation. The transition from sandstone to shale units is marked by a series

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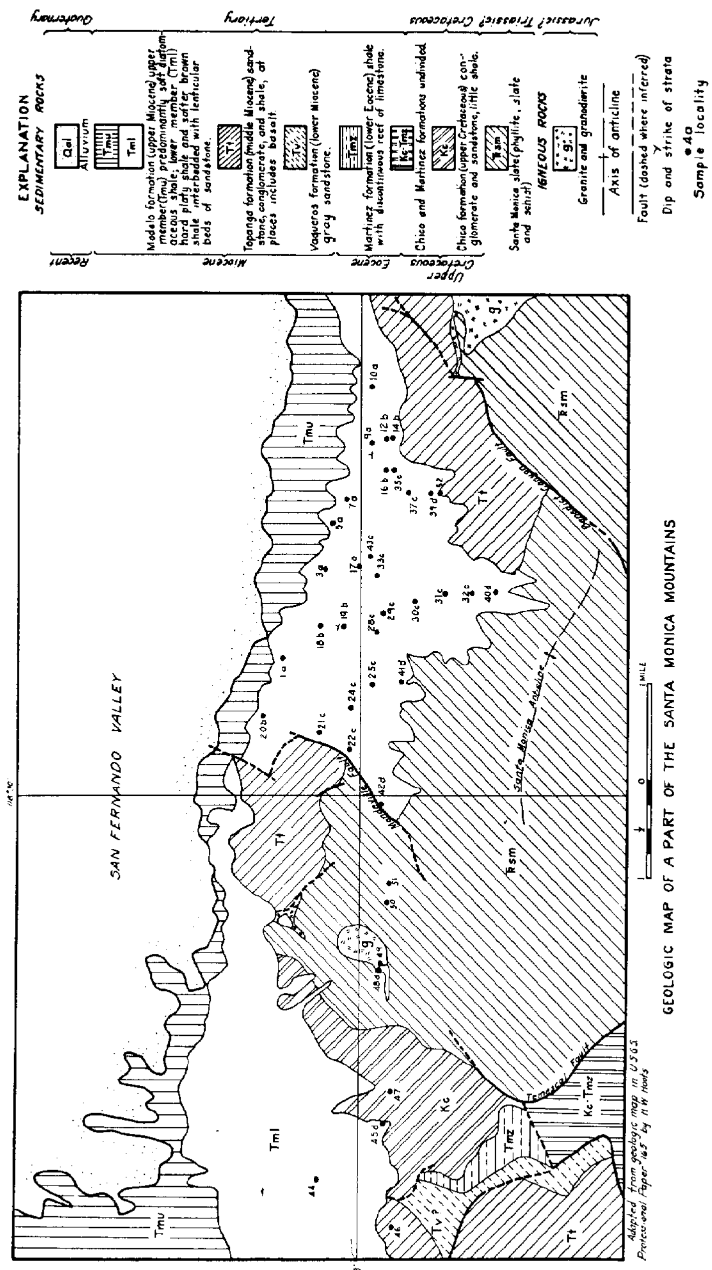

GEOLOGIC MAP OF A PART OF THE SANTA MONICA MOUNTAINS

FIG. 1

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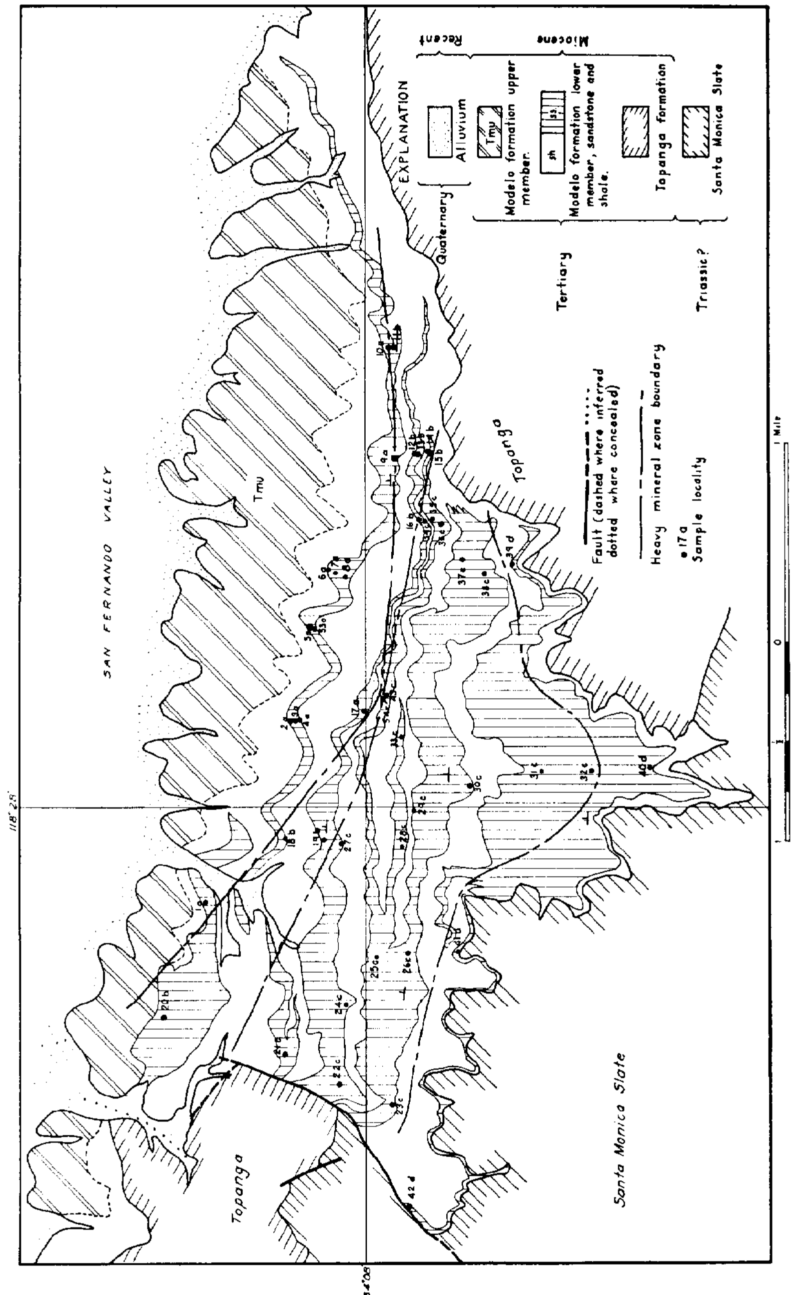

MAP OF THE HEAVY MINERAL ZONES OF THE MODELO FORMATION

FIG. 2

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FIG. 3. Cut-crop of a shale member in the Modelo formation along Beverly Glen Boulevard near locality 53 a.

of alternating thin strata of sandstone and shale, and not by a gradual change in texture. Crossbedding occurs occasionally. The formation is well stratified and appears to have been deposited in comparatively still water.

In common with many California Recent sediments, the Modelo sandstone is arkosic and its grains are angular (14). Particles as large as 2 mm. in diameter show only slightly the rounding effects of abrasion. Since grains as small as 0.05 mm. may be rounded by stream transportation (7; 19), it is apparent that the material composing the sediments has not been transported a very great dis-

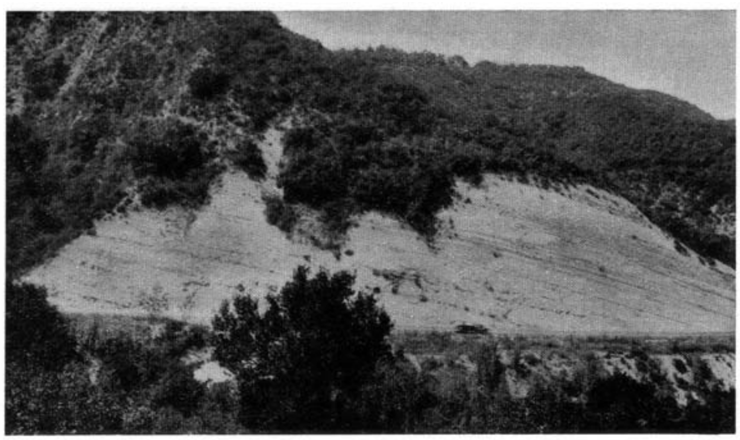

FIG. 4. Cut-crop of a sandstone member in the Modelo formation along Beverly Glen Boulevard near locality 53 a.

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tance nor has it been reworked many times prior to its deposition as Modelo (1). The presence of feldspar in the Modelo formation is not particularly significant either as an indicator of paleoclimatic conditions or of distance from source. Feldspar is known to have been transported a distance of 600 miles under the adverse conditions of a warm and humid climate (11). Recent work by the writer has shown that in the southern California region, sands that have been transported by an intermittent stream a distance of 50 miles are still angular and very arkosic. Feldspar apparently is more resistant to chemical decomposition and to abrasion than is generally believed.

The heavy mineral separations were made in the laboratory, using the method described by Milner (12). Observations and comparisons were confined exclusively to material of one grade-size (one-fourth to one-eighth mm.). The advantages of using material of the same grade-size when comparing heavy mineral concentrates have been noted by Dryden and by the writer (2; 4). After identifying the minerals by optical methods, counts were made under the binocular microscope. This procedure was practicable because the various minerals could be distinguished by color, cleavage, shape and magnetic properties. With a few exceptions, the number of grains counted for each sample exceeded 300, which is generally sufficient to insure reasona-

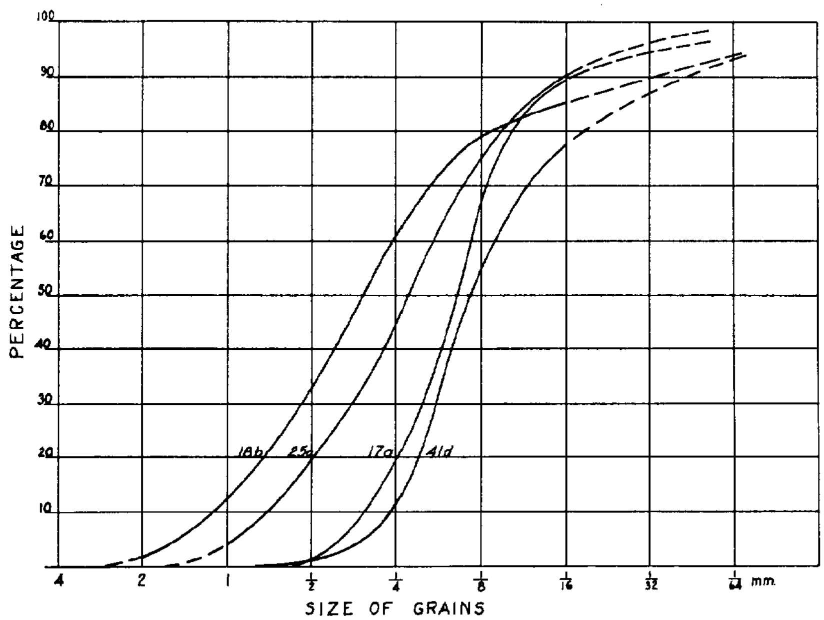

FIG. 5. Cumulative curves, each showing the texture of a sample from a different mineral zone, 17a from zone A, 18b from zone B, 25c from zone C, and 41d from zone D.

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ble accuracy of the mineral percentages (3).

Two histograms have been used to represent the quantitative mineralogical characteristics of each sample. One indicates the relative abundance of each mineral species. The other shows the number of grains of each species that is present in one gram of sand. The latter data are secured by

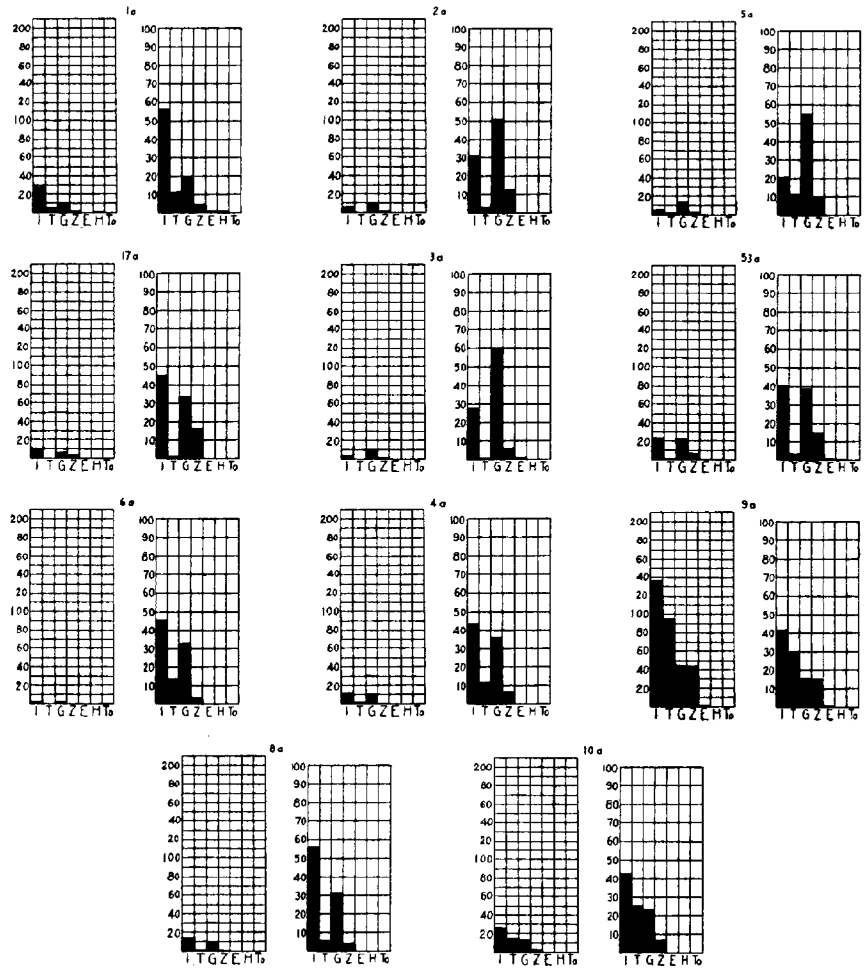

FIG. 6. Zone A., Explanation: I = ilmenite, T = titanite, G = garnet, Z = zircon, E = epidote, H = hornblende, To = tourmaline. The right histogram of each sample indicates the percentage, by number of grains, of each mineral species in the size fraction between one-fourth and one-eighth mm. The left histogram of each sample indicates the actual number of grains of any mineral species in one gram of the size fraction between one-fourth and one-eighth mm. Zone A. Epidote, hornblende, and tourmaline are absent or present in only negligible quantity. Ilmenite and garnet are generally more abundant than titanite. (9 a and 10 a are transition samples between zone A and zone B.)

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simple calculations.[1] This combination of histograms presents graphically the quantitative relations between the heavy and light mineral fractions as well as between the various species of the heavy residue. A knowledge of the absolute abundance of heavy minerals in a sediment is helpful to a proper interpretation of its geologic history.

The following heavy minerals have been found in the Modelo formation: ilmenite, magnetite, titanite, garnet, epidote, hornblende, tourmaline, zircon, muscovite, biotite, and barite. Little attention was devoted to the barite and the micas because of the authigenic character of the former and the ubiquitous nature of the latter. Ilmenite, as such, was identified on the basis of a positive reaction to a chemical test for titanium and its strong magnetic susceptibility. Mag-

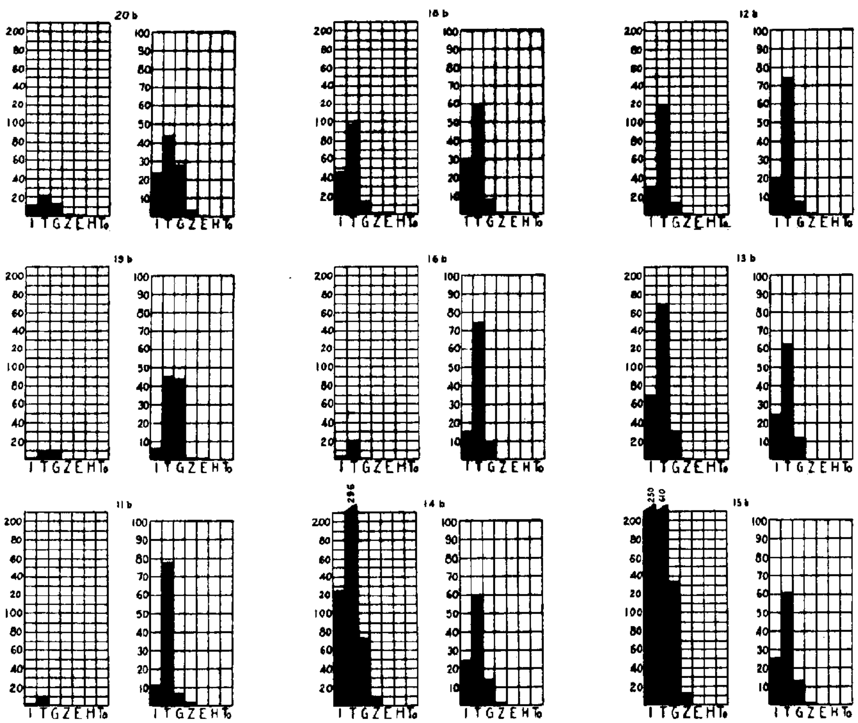

FIG. 7. Zone B. Epidote, hornblende, and tourmaline are absent, or present only in negligible quantity. Titanite is more abundant than either ilmenite or garnet.

[1] Let p = no. of grains of any mineral species per gram of undifferentiated sand ($\frac{1}{4}$–$\frac{1}{8}$ mm.).
f = fraction of total heavy concentrate used for mineral count. (Secured by means of sample splitter.)
n = no. of grains of any mineral species counted.
w = wt. in grams of undifferentiated sand from which heavy concentrate was separated.
Then $p = n/fw$

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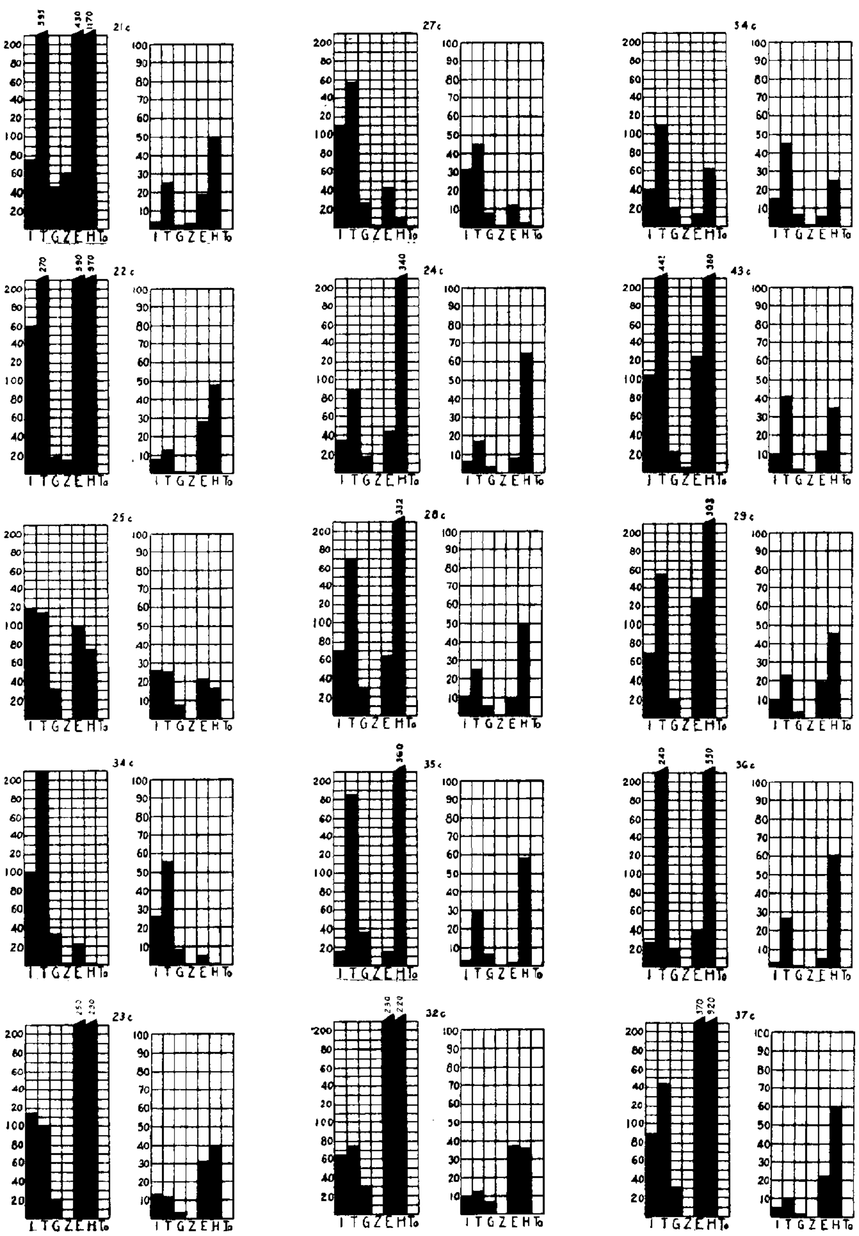

FIG. 8*a* (*see opposite page for legend*)

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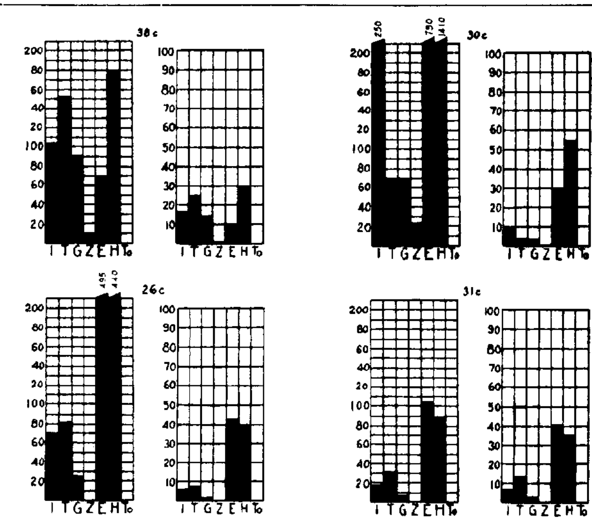
netite was recognized by its exceptionally strong magnetic properties and its octahedral habit. It is not unreasonable to suspect that much of what has been called ilmenite may be titaniferous magnetite.

Ilmenite, titanite, garnet, epidote, hornblende, tourmaline, and zircon are the heavy minerals that were used to zone the Modelo formation. From qualitative and quantitative considerations of the distribution of these minerals, it is possible to definitely distinguish four zones in the lower member of the Modelo formation. This in itself is not unusual. It is remarkable however, that these zones should transect the lithologic boundaries and the structure. This is a feature of utmost significance to those using heavy minerals for the determination of subsurface structures.

The zones were determined in two ways: (1) by the presence or absence of mineral species, (2) by the relative proportions of the various mineral species.

Zone D, the lowest in the Modelo formation, is the least uniform in its mineral content. It is distinguished as a zone largely because it lies between the definitely identifiable zone C above and a non-conformity below. It is characterized in its western part by the presence of tourmaline which is absent or exceedingly rare in the overlying zones and in its eastern part by the ilmenite-titanite-garnet proportions which are distinctly different from those of zone C above. Heavy minerals are not abundant in this zone.

Zone C is distinguished by the presence of hornblende and epidote and the relative proportions of il-



(*See opposite page for first part of figure*)

FIG. 8*a*, *b*. Zone C. Epidote and hornblende are present: very abundant at the base of this zone and diminishing in abundance toward the top. Tourmaline is absent. Titanite is normally more abundant than either ilmenite or garnet.

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menite, titanite, and garnet. Heavy minerals are comparatively abundant here.

Hornblende and epidote are absent from zone B but it possesses the same ilmenite-titanite-garnet proportions characteristic of the underlying zone C. The heavy mineral content of the sediments is small.

Hornblende and epidote are also absent from zone A but it may be distinguished from the contiguous zone B by its ilmenite-titanite-garnet proportions. Heavy minerals are scarce, forming less then one-half of one per cent of the sediment.

Descriptions of heavy mineral zones are not uncommon and their usefulness for correlation, especially where fossils are rare or lacking, has been repeatedly pointed out by sedimentary petrologists (5; 12), but to the writer's knowledge there have been no descriptions heretofore of mineral zones transecting lithologic units.

Many paleontologists are aware that faunal zones sometimes cut across rock units (16; 17). The paleontologist assumes that the character of the included faunal assemblage indicates conclusively the age of the sediments (10). A faunal zone, therefore, consists of material accumulated during an interval of contemporaneous time and a zonal boundary is the equivalent of an isochronal surface. H. G. Schenck, appreciating the full significance of faunal zones transecting lithologic boundaries, stated in a recent article, "No accurate correlations will be possible until time and rock units are separated in the investigator's mind and words, . . ." (16, p. 534).

Faunal zones crossing rock units are easily explained as the conse-

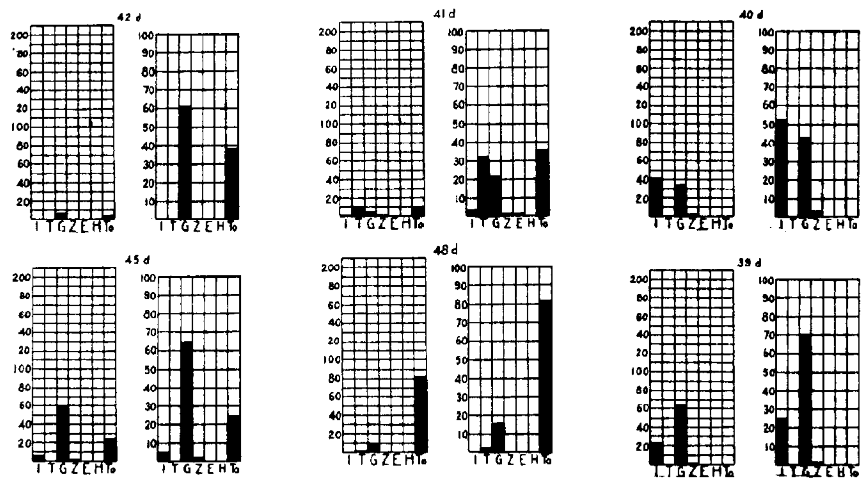

FIG. 9. Zone D. Epidote and hornblende are absent, or present only in negligible quantity. Tourmaline is present in the western part of this zone. Titanite is rare. Garnet is always present and ilmenite is usually present.

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quences of transgressing or regressing seas. Consider as an illustration a basal conglomerate or sandstone being formed by a slowly transgressing sea. It will vary in age from place to place, being younger in the localities where the land has been submerged more recently. If conditions are suitable for the development of a fauna and if the fauna is short-lived com-

It cannot always be justifiably assumed that mineral zone boundaries are surfaces of contemporaneous deposition. Only when there has been uniform distribution of the sediment carried into a basin is it likely that a mineral zone boundary may represent the locus of points of concurrent deposition.

It is easy to understand why min-

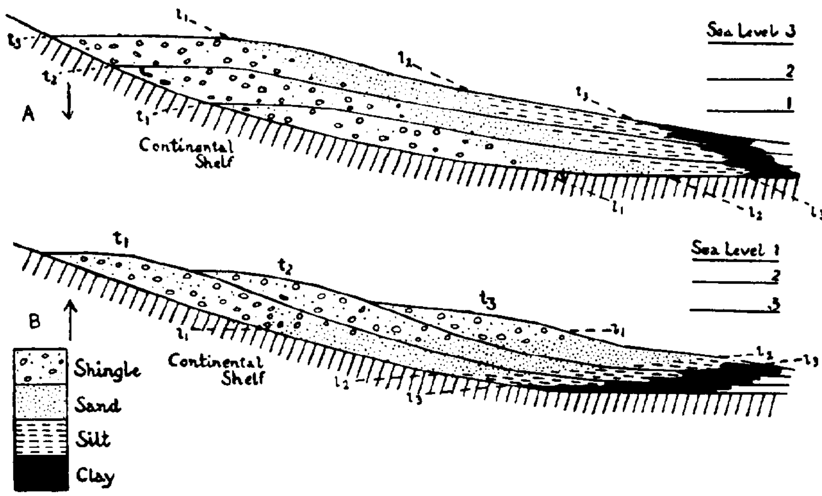

FIG. 10. Diagram to illustrate Transgression of Chronological (t_1-t_3) and Lithological (l_1-l_3) planes: A, Subsiding floor, B Rising floor. (Adapted by the author from the original drawing by Prof. P. G. H. Boswell, *op. cit.*, p. 8.) (From Milner, H. B., Sedimentary Petrography, D. Van Nostrand Co., N. Y., 1929.)

pared to the velocity of the landward moving sea, the faunal zones will cross the lithologic boundaries. Figure 10 illustrates the consequences of both transgressing and regressing seas when several strata are involved. It should be observed that for any one lithologic unit, the age becomes progressively younger toward the periphery of the basin if it has been deposited by a transgressing sea, and older toward the periphery when deposited by a regressing sea.

eral zones may cross chronologic surfaces. Consider a basin receiving sediments from two provinces of widely differing rock types. Currents are too weak to thoroughly mix and distribute the sediments uniformly. As a consequence, the stratum being deposited will not be distinguished by one homogeneous heavy mineral suite but rather by two suites as illustrated by Figure 11, and the mineral zone boundary will be neither parallel nor coincident with the chrono-

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logic surfaces. Increasing the number of sources of sediment and the range in composition of the provenance rocks will increase the complexity of the relations between the mineral zone boundaries and the time surfaces.

In early Modelo time the sea in this district was spreading (8, p. 104). Figure 2 shows each stratigraphically higher sandstone unit overlapping its predecessor. It was to be expected, therefore, that the chronologic surfaces would cut the sandstone units in the same manner as illustrated in Figure 10 for a transgressing sea, and that the mineral zone boundaries, if they represented surfaces of contemporaneous deposition, would do likewise. A careful study of the mineral zone map shows that as the margins of the trough are approached, each successive mineral zone that cuts across a sandstone unit is usually stratigraphically lower than the one preceding. If the mineral zone boundaries are identical to chronologic surfaces, then the sequence of the transections in the Modelo is like that resulting from a regressing sea as illustrated in Figure 10. Since structural evidence points to a spreading sea during early Modelo time, the boundary relations that exist here between the lithologic units and the mineral zones present an anomaly. Whether or not the mineral zone boundaries are loci of points of concurrent deposition and therefore chronologic surfaces remains a moot question.

This investigation shows that there are distinct variations of the heavy minerals both vertically and laterally in the Modelo formation of this district. Although vertical variations

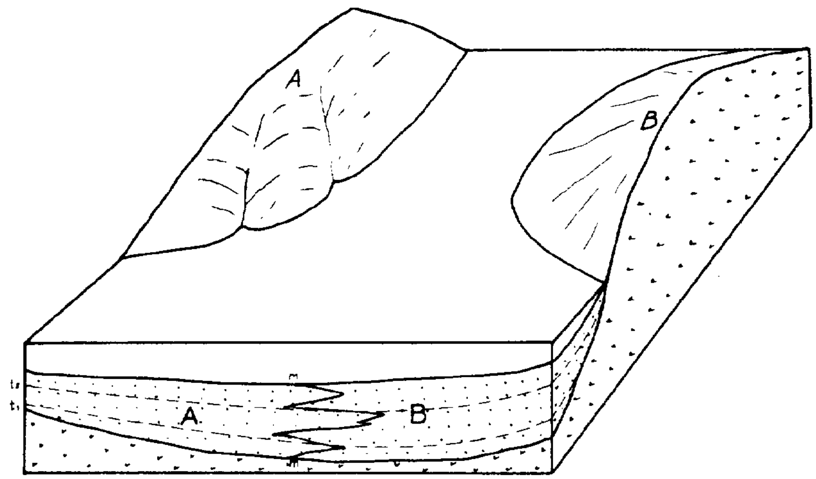

FIG. 11. Illustrating a mineral zone boundary *m–m* transecting chronologic planes t_1, t_2. This type of boundary relation may occur where detritus from two different rock provinces is being swept into a basin where the currents are too weak to thoroughly mix the incoming detritus.

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were anticipated and are desirable for zoning purposes, the rapid lateral variations within some of the sandstone units were entirely unexpected.

The value of this investigation lies in the fact that data have been gathered which disclose some of the difficulties that may be encountered when heavy minerals are employed for zoning and structural determinations. The writer is not of the opinion that heavy minerals are invariably useless for correlation. In basins where currents have produced a uniform mixture and distribution of the incoming detritus, the likelihood of securing useful data from heavy mineral studies is good. No better argument favoring the use of heavy minerals as criteria for correlation can be given than the fact that they have been employed with success in the oil fields of the Mid-Continent, in Texas, and in other regions (6; 9; 15; 18). More work of a detailed nature will have to be done in California before their usefulness in this section can be adequately judged.

The writer is grateful to Dr. Ian Campbell of the California Institute of Technology for the encouragement and helpful suggestions tendered during the progress of this investigation and the writing of this report.

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