LATERAL DENSITY CONTRAST*—KEY TO FINDING REEFS WITH GRAVITY

by

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Reef hunters desiring to reduce their seismic costs can do so in many areas by utilizing specially designed gravity programs. Many explorationists have noted the correlation between narrow, shallow-sourced, low amplitude gravity anomalies and underlying deep structures, particularly pinnacle-type reefs.

Fig. 1 is an example of an anomaly associated with a Missisippian reef field in West Central Texas.

In one area, statistics have been quoted to the effect that three out of four reef fields displayed positive gravity anomalies of this type.

This relationship has not been universally recognized, primarily because of the lack of detailed gravity coverage specifically designed to map shallow anomalies. In many instances where the anomaly was mapped it was interpreted to result from "shallow effects" unrelated to the deeper structure.

The fact remains that some workers have appreciated the relationship and used detailed gravity to make discoveries even though the geological explanation for the anomaly sources has remained obscure and frequently misunderstood. The following is an explanation of the source of the shallow anomalies and their relationship to the underlying structure. In addition to the shallow gravity effects, some reefs, such as those in the Rainbow Lake Area of Canada (0.6-1.0 mgls) and some in Saskatchewan, display anomalies suggestive of additional deeper influence.

Studying the gravity anomaly relationship to pinnacle reefs offers the best place to gain an understanding of the geological cause of the shallow anomalies. One of the best articles published on reefs and gravity is "Gravity Prospecting for Reefs" by S. H. Yungul, Geophysics, Vol. XXVI, No. 1, February, 1961. Modern detailed gravity surveys designed to map shallow anomalies have substantiated most of Yungul's findings. Below is a recapitulation of the results of Yungul's literature search taken directly from Geophysics, and referenced numerically as per his article.

1) Reefs frequently show recognizable gravity anomalies which may be (a) a simple high, (b) a high with a negative rim around it, (c) a low with a positive tendency in the center,or(d) a simple low. Most

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*To mean changes in density in a horizontal direction.

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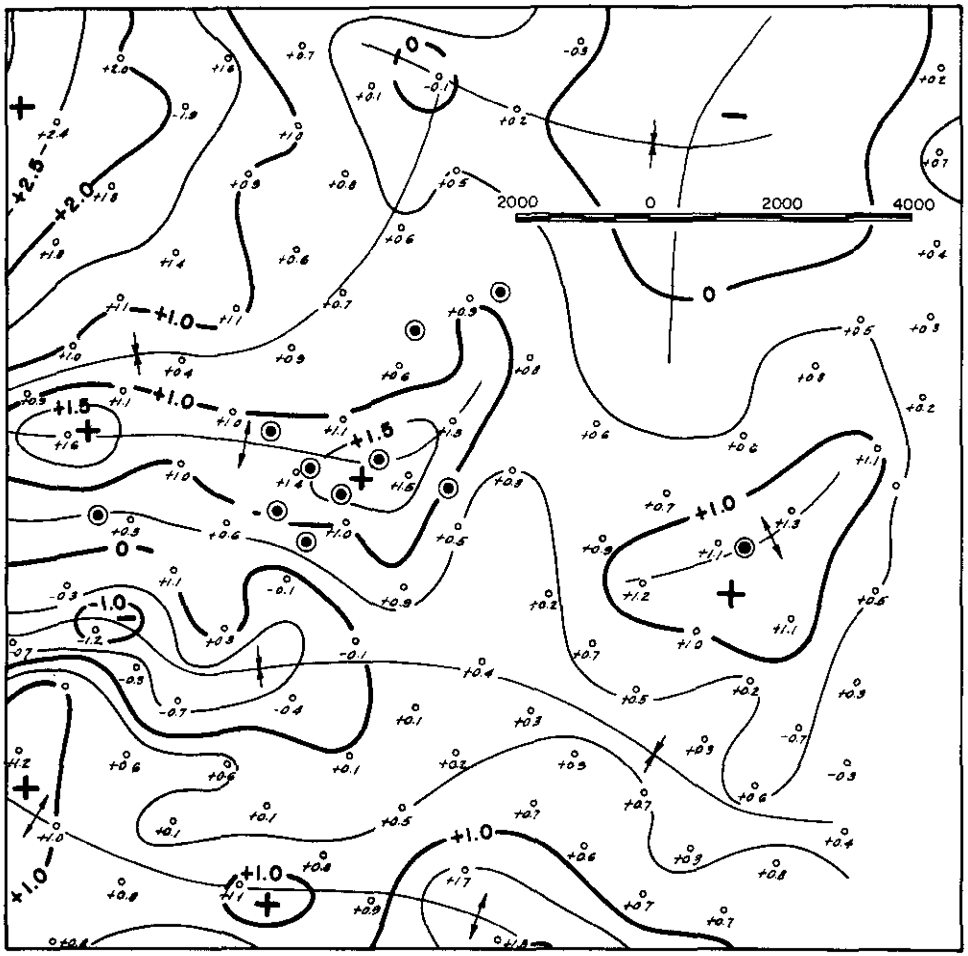

FIG. 1.—Residual gravity of Mississippian reef field in West Central Texas.

frequently it is a high with a negative rim around it, like a "sombrero." (This author has never seen a reef indicated by a negative anomaly.)

2) When the anomaly is of the sombrero type or a simple high, its intensity is of the order of +0.5 mg. This is greater than an allowable density contrast between the reef mass and the enclosing sediments could produce. What is more, a gravity high may be present even when the reef density is less than that of the enclosing sediments. Clayton (1951) reports that at North Snyder the cores show the reef is less dense than the surrounding shales. Yet the anomaly is +0.6 mg.

4) The gravity highs are too narrow to be generated by masses at specified reef depths.

5) When the anomaly is of the sombrero type, the width of the positive is of the order of the width of the reef, irrespective of the reef depth.

9) Pohly (1953) reports that the dips shown for the beds above the reefs on seismic maps are often greater than those encountered in drilling. This may be considered as indirect evidence of a lateral increase in density over reefs, because a velocity increase is usually accompanied by a density increase.

13) In view of the wide ranges of the observed reef geometries and anomaly types, it seems, at present, that there is no direct evident relation between the reef mass specification (depth, height, extent, density) and the gravity anomaly specifications (type, intensity, extent). Consequently, certain factors other than the reef mass play the major role.

From these results it is apparent that an anomaly is generated above the reef and that higher-density material has been developed vertically over the reef and is responsible for the shallow anomaly.

What is the geologic cause of the increase in rock density over the reef? Obviously, it is not related to tectonic movement since there is often none associated with reefing. Yungul states that he believes it to be related to an increase in sand content over the reefs due to the winnowing action of wave motion during deposition.

This explanation could have some application in specific instances. However, there is reason to believe that the increase in density is not from this cause. Frequently, no lithologic changes can be detected above the reef in wells on and off the reef. Many reefs are thought to have been buried in shales deposited below wave base. Also, the anomaly relationship with the reef is often too intimate to rely upon depositional factors. With the anomaly source as much as 4,000 ft. above the reef, ancient sea-bottom physiographic features unrelated to the reef should occur. Such things as currents and source relationships would prohibit a vertical relationship of the accuracy observed.

If the increased density over the reef is not tectonic and not depositional, then what is its cause? Almost by elimination the cause must be compaction. Remember that differential compaction occurs vertically.

In West Texas, for example, the Permian rocks on the surface have a density of approximately 2.3 gm/c.c. To reach this density the originally deposited muds must have been subjected to overburden that has since been removed. Here then are the basic constituts for differential compaction to occur, the overburden, the reef and the surrounding shales. The reef is more resistant to compaction than the shales. In fact, stratigraphic markers just above the reef are always draped downward off the reef. The amount of draping is primarily an indication of the amount of compaction rather than depositional thinning.

Fig. 2 shows what happens in over simplification.

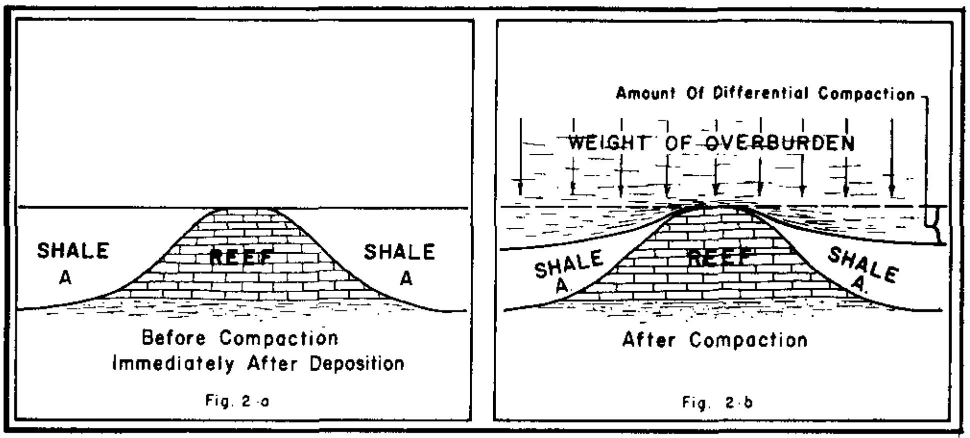

FIG. 2.—Draping amount shows amount of compaction rather than depositional thinning.

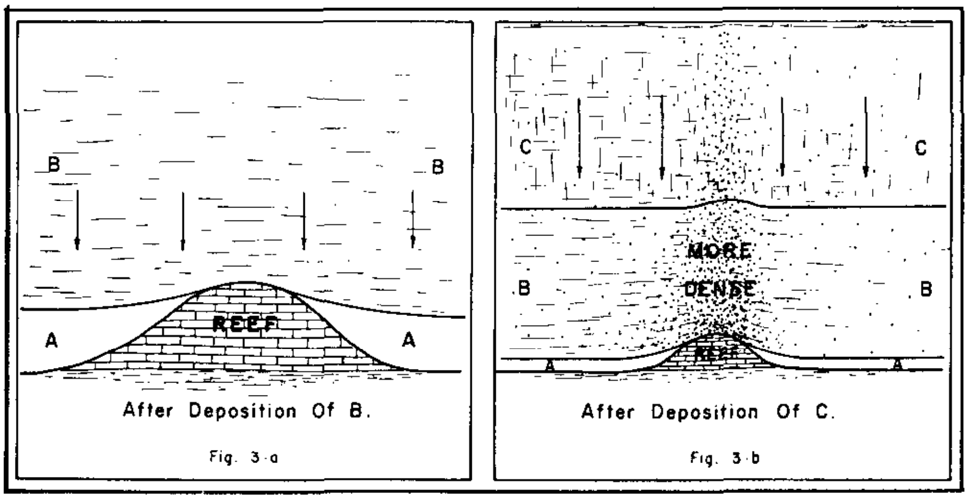

FIG. 3.—Note what happens when overburden is applied.

Note what happens to the rocks stratigraphically above the top of the reef when overburden is applied (Fig. 3).

Notice that formation "B," which had equal thickness on and off the reef, when subjected to the weight of overburden "C," has a greater thickness off the reef than over it. The difference in thickness of "B" on and off the reef (not considering depositional differences) is proportional to the density of "B" on and off the reef. In other words, a vertical column of slightly more compacted rock is developed above the reef.

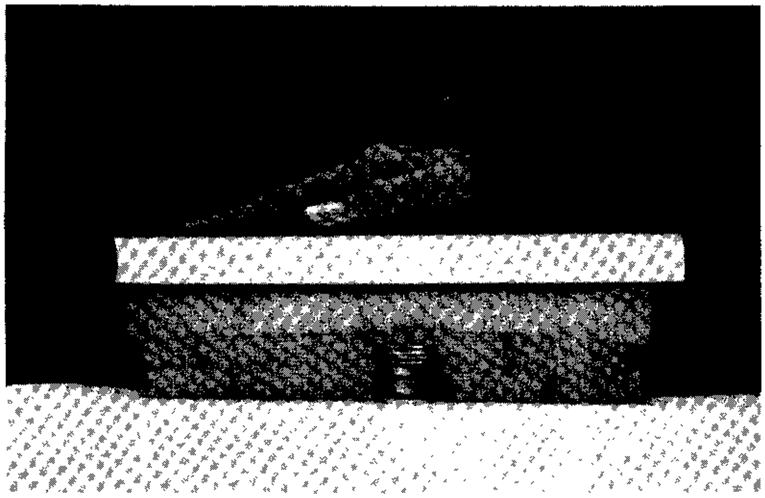

FIG. 4.

In the model (Fig. 4) notice how the sponge is compressed over the noncompactible coins when pressure is applied from above. This is analogous to the reef situation, the sponge representing the surrounding shales, the coins the reef. The hand is the weight of overburden and the rigidity of the book represents the rigidity of rock and its resistance to bending.

There are many indications that differential compaction reaches the surface thousands of feet above the reef. Photogeologic geomorphologic evidence can be seen associated with many reefs. Subdued shallow structure can be mapped over most reefs when well control is adequate. Surface indications can be seen over many reefs in Canada where shallow structure is difficult to map.

With vertical density contrasts reaching to the surface, how much density contrast is needed to produce a recognizable gravity anomaly? If it is assumed that the vertical column of denser material has a diameter of 3,000 feet and extends from the surface downward, the density contrast required to produce a three-gravity unit anomaly (0.3 mg.) is less than 0.025 gm/cc.

A 0.025 density contrast is far too small to be measured by any of today's density logging tools. It represents a volume reduction or thinning due to differential compaction of approximately only 1%. In other words, using an average density of 2.5 and a lateral density change of 0.025, a volume reduction or thinning by compaction of 1% is all that is needed.

As an example, if a reef is at 6,000 ft. and the weight of the overburden has been such that the rocks stratigraphically above the reef are 60 ft. thinner than off the reef, due to compaction, then a 1% volume reduction has occurred.

This will cause a density increase of 0.025 over the reef. If the vertical column of increased density has a diameter of 3,000 ft., an anomaly in excess of three gravity units (0.3 mgl) will result. This lateral density effect, plus that caused by drape structure of bedded density contrasts over the reef, will often provide sufficient anomaly for detection.

A theoretical explanation for the source of the anomaly has now been established, in addition to the seismic evidence cited and the empirical gravity anomaly relationship observed.

Recognition that differential compaction is the key to many reef anomalies requires appreciation of two phenomena:

1) That with overburden, buried topography will affect the densities above it. In other words, with overburden, differential compaction below the level of the top of the reef will cause density changes above the reef.

2) Very minor changes in sedimentary thickness due to compaction will cause recognizable gravity anomalies when they extend to shallow depths.

It should be noted that except for larger reefs and those having strong density changes at the reef level (i.e. salt displacement), the anomalies have small areal extent. Normal reconnaissance gravity traverses usually will not map them effectively. Also, as Yungul points out, the derivative or gridded residual procedures are not detailed enough to map the smaller reef type anomalies. The curvature characteristics of the derivative methods are also confusing.

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The compaction phenomena causing lateral density contrasts should exist over tectonic structure as well as reefs. On tectonic structures, it would be even more difficult to separate that portion of the gravity anomaly caused by shallow anticlinal structure of bedded density contrasts and that caused by a lateral density contrast.

The contribution of the lateral density contrasts could account, in part, for the shallow maximum-depth indices measured on many anomalies associated with deeper tectonic structures. This may also explain why model studies using only bedded density contrasts are usually quite inaccurate with the exception of salt domes. Often the anomaly found in the field exceeds the amplitude that could result from bedded density contrasts associated with known structural amplitudes.

For predicting the ability of gravity to map structure many geophysicists do not consider the presence of lateral density contrasts; only those related to bedding. Some have hesitated to use gravity because of a lack of identifiable density contrasts. Frequently, they are surprised to learn of anomalies associated with the structures where density contrasts cannot be detected.

Because lateral density contrasts are difficult to confirm, field tests across known structures are the best criteria for judging the effectiveness of gravity. They are far better criteria than theoretical computation of anomalies based only on known bedded density contrasts.

CONCLUSIONS

Shallow gravity anomalies are often associated with deeper structures. The anomalies are produced by vertically extending density increases caused by differential compaction over underlying buried topography, such as reefs.

Because of the inability of reconnaissance type gravity surveys to map these anomalies, they have not been fully appreciated and used, and the gravity effects from this source have often been overlooked in planning gravity field programs.

In many areas, recognition and usage of gravity anomalies caused by compaction above reef offers the explorationist an opportunity to localize unfound fields with specially designed field surveys. Because of the low cost compared to seismic surveys, particularly the tightly gridded type necessary for thorough reef reconnaissance, the detailed gravity approach offers a searching mechanism to localize prospects at approximately 5% of seismic costs.

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