IS THERE AN EXPLANATION FOR THE GRAVITY ANOMALIES ASSOCIATED WITH REEFS?

By

P. E. GRETENER*

Gravity anomalies associated with reefs have been discussed by Yungul (1961), Haye (1967) and Soukoreff (1968). The findings of these authors can be summarized as follows:

1. Almost all reefs have positive gravity anomalies associated with them.
2. The size of these anomalies is in the order of 0.3 to 0.6 milligals. A negative rim may or may not be present.
3. The depth of origin for these anomalies is shallower than the reef body.

Both Yungul (1961) and Haye (1967) have advanced explanations for these gravity anomalies. It is the purpose of this note to discuss their ideas and demonstrate that neither of them constitutes an acceptable mechanism.

Yungul (1961) suggests that the sand/shale ratio over a reef is higher than in the off reef section, leading to a positive density contrast for the sediments overlying the reef at shallow depth. For greater depth the contrast becomes negative. Yungul assumes that a reef creates a positive topographic expression on the sea floor even after it is buried at great depth. The mechanism, illustrated in his Figure 1, however, is in error. He predicts that a reef resting on a shale body will at first sink into this body under its own weight. This is correct. However, he states that under a large overburden the reef base will eventually rise above the top of the basal shale. To quote Yungul (1961): "This process is equivalent to that in which the reef is uplifted like a salt dome." This is incorrect. The reef base will eventually be level with the top of the basal shale. Under a large overburden the load on the basal shale will be equal on- and off reef. The thickness of the basal shale will, therefore, be uniform on- and off reef. This constitutes a terminal condition and a salt dome effect does not exist. Draping does occur, however, in the beds overlying the reef due to differential compaction in the reef - off reef interval. Differential compaction occurs in response to the load provided by the overburden. Draping in a given horizon does, therefore, not exist at the time of deposition of the particular horizon but is developed later as the horizon is loaded by continued deposition (Labute and Gretener, 1969). Thus initial sea floor topography as suggested by Yungul (1961) must be confined to the beds immediately overlying the reef where initial dip may be postulated, but it cannot be assumed to exist in the section high above the reef. Thus Yungul's suggestion that sediments over reefs should be characterized by higher sand/shale ratios and, therefore, different densities is unacceptable. Draping of beds overlying reefs, however, is a fact and its gravitational effect will be considered later.

Haye (1967) has suggested that sediments overlying reefs have a higher than normal density due to increased compaction. In his Figure 4 he shows a model where a stack of coins is embedded in foam rubber. A book is placed on the foam rubber and a load is applied to the book. Under these conditions the foam rubber over the stack of coins is more highly compressed than that on either side. This is taken to demonstrate that sediments over rigid reefs (stack of coins) are subject to increased compaction. Unfortunately the model is unrealistic. The overburden, consisting of the youngest and weakest sediments does not behave like a rigid book. These sediments will deform, as proven by the draping, and the effect postulated by Haye is mechanically unacceptable.

What then can be expected to occur around reefs? The draping effect as mentioned by Yungul (1961) and Haye (1967) is real and must be considered in computing the gravity effect of a reef. Labute and Gretener (1969) have recently given some quantitative data on the amount of draping observed over a Leduc reef in Central Alberta. The situation above a pinnacle reef, approximated by a vertical cylinder, is shown schematically in Figure 1. The beds over the reef will drape due to differential compaction at the reef level. The compaction structure (Δh) will be a maximum at the top of the reef and it will diminish systematically upwards. It will always be zero at the depositional surface and it may become zero at a level below the surface (z_0, Fig. 1), indicating that differential compaction was essentially complete under this load ($z_1 - z_0$, Fig. 1).

In order to evaluate the gravitational effect of such a geological configuration it will be necessary not only to consider the geometry and the density contrast of the reef body proper but also the compaction structures developed over the reef. Every draping boundary separates layers of different densities. Density is generally increasing with depth ($\rho_4 > \rho_3 > \rho_2 > \ldots$) and each deformed boundary (compaction structure of Fig. 1) will thus cause a small positive gravity anomaly. The total effect may be obtained by summing the contributions of all compaction structures from z_1 to z_0.

To arrive at a numerical result one may proceed as follows. The individual and increasing densities ρ_0, ρ_1, . . . of Figure 1 are replaced by a density-depth function such as given in Figure 2a. One then forms the first derivative of this curve as shown in Figure 2b. Next the compaction structure (Δh) is given as a function of depth (Figure 2c, schematic after Labute and Gretener, 1969). Multiplying $\Delta\rho/\Delta z$ by Δh (Fig. 2d) will lead to the variable density contrast of the "compaction cylinder" overlying the pinnacle reef. Since all the numerical values given in Figure 2 are only approximate it seems permissible to replace the "compaction cylinder" with its variable density contrast with three cylinders with a fixed density contrast such as shown in Figures 2d and 3.

To find the maximum gravity effect one must now sum the effect of the reef and the three overlying cylinders representing the compaction structures. This leads to:

$$\Delta g_{max} = \Delta g_{rmax} + \Sigma\ \Delta g_{cmax}$$

where Δg_{max} is the maximum total gravity effect

Δg_{rmax} is the maximum gravity effect due to the reef body

$\Sigma \Delta g_{cmax}$ is the maximum gravity effect due to the compaction structures

For the numerical example presented in Figure 3, i.e. bottom reef 2200 m, top reef 2000 m, diameter of circular reef 2000 m, density contrast reef - off reef +0.15 g/cm^3, density contrast of the three cylinders representing the compaction structures as given in Figures 2d and 3, we obtain:

$$\Delta g_{max} = 0.13 + 0.01 = 0.14 \text{ mgl}$$

It can be seen that the observed gravity anomalies of 0.3 to 0.6 milligal cannot be explained in this manner. Furthermore, the gravitational effect of the compaction structures overlying the reefs can be termed negligible.

In conclusion one can make the following statement, provided the reported gravity anomalies associated with reefs are real: Insofar as a sound mechanism to increase the density of the sediments overlying reefs has not yet been proposed, these gravity anomalies still present an enigma.

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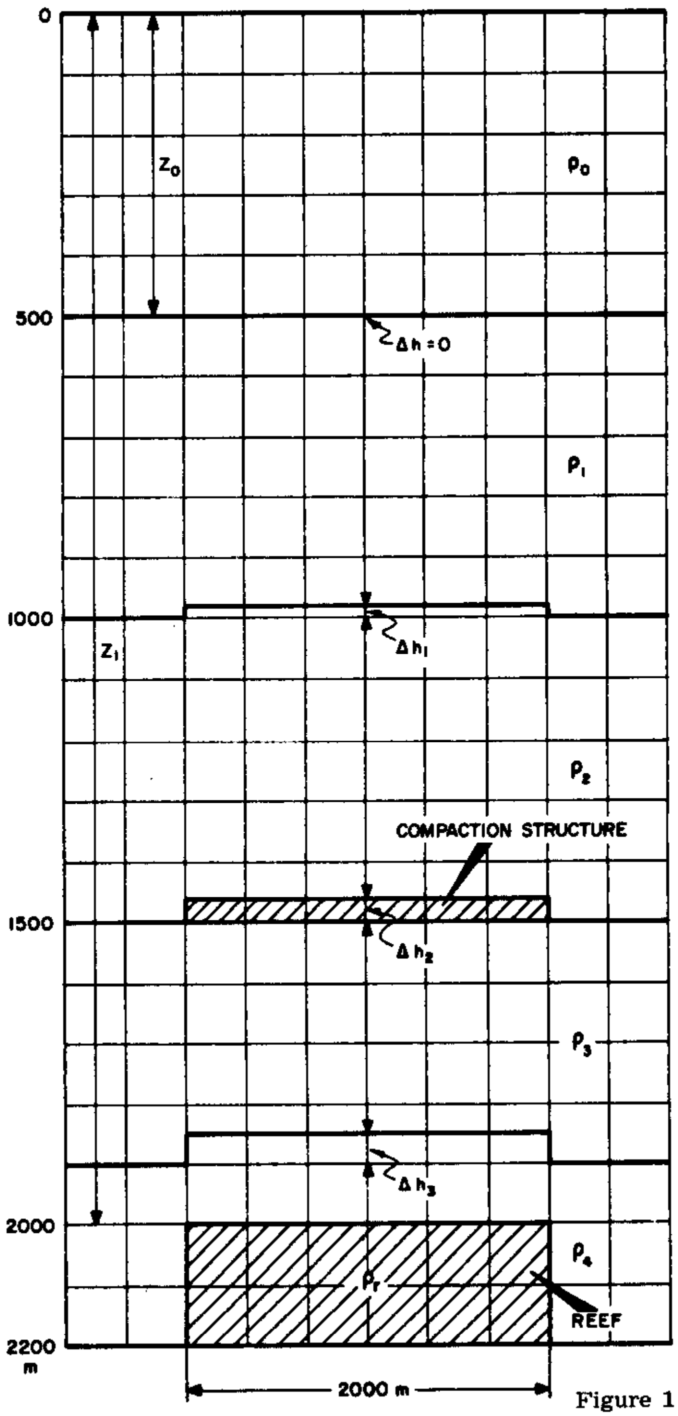
0
500
1000
1500
2000
2200
m
Z_0
Z_1
ρ_0
ρ_1
ρ_2
ρ_3
ρ_4
ρ_r
$\Delta h = 0$
Δh_1
Δh_2
Δh_3
COMPACTION STRUCTURE
REEF
2000 m

Figure 1

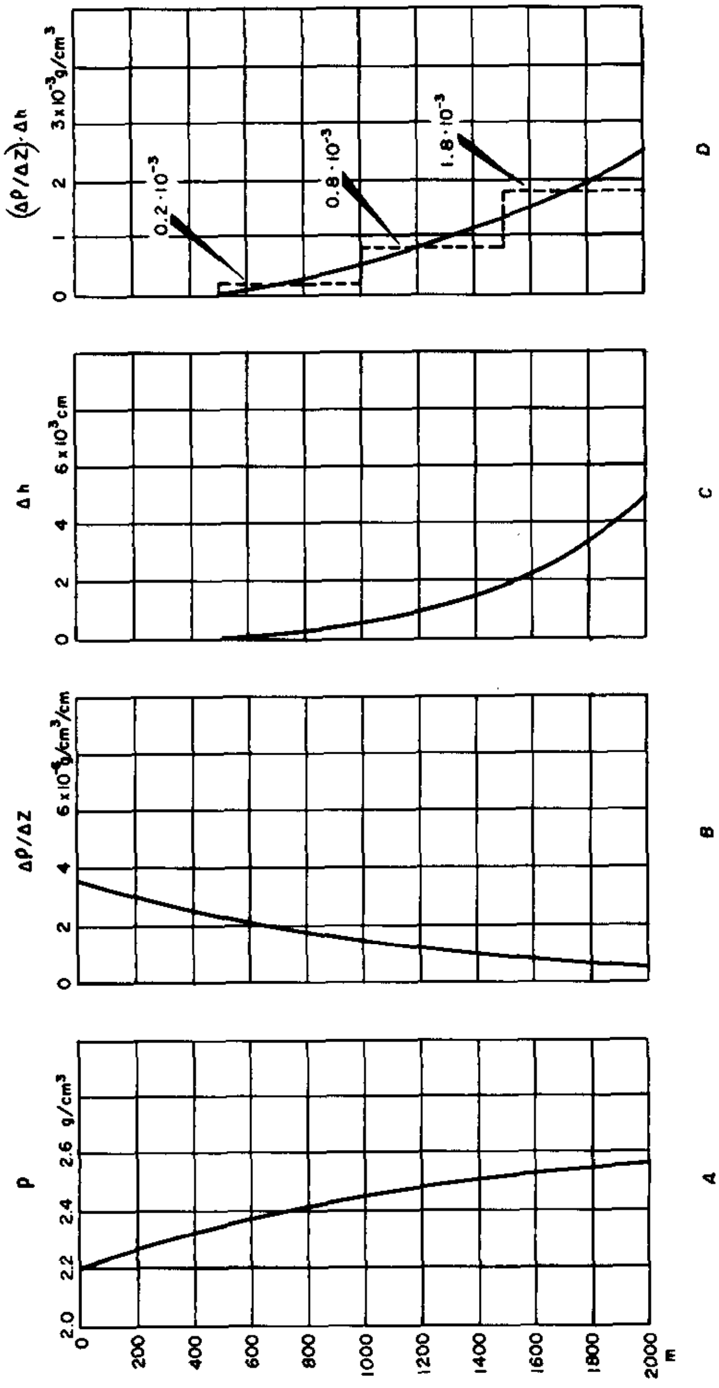
(Δρ/ΔZ)·Δh
3×10⁻³ g/cm³
2
1
0
0.2·10⁻³
0.8·10⁻³
1.8·10⁻³
D
Δh
6×10⁻³ cm
4
2
0
C
Δρ/ΔZ
6×10⁻⁶ g/cm³/cm
4
2
0
B
ρ
2.6 g/cm³
2.4
2.2
2.0
A
0
200
400
600
800
1000
1200
1400
1600
1800
2000
m

Figure 2

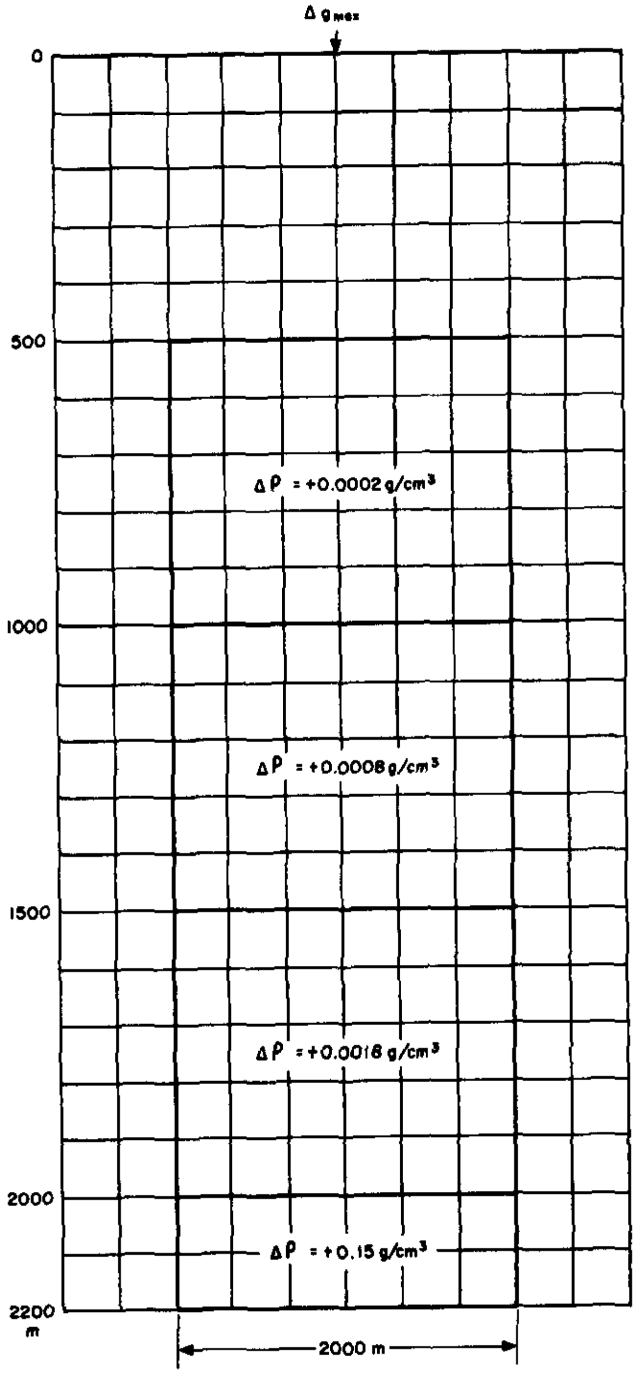
Δ g max
0
500
1000
1500
2000
2200 m
Δρ = +0.0002 g/cm³
Δρ = +0.0008 g/cm³
Δρ = +0.0018 g/cm³
Δρ = +0.15 g/cm³
2000 m

Figure 3

ANSWER TO DISCUSSION BY DR. P. E. GRETENER ENTITLED "IS THERE AN EXPLANATION FOR GRAVITY ANOMALIES ASSOCIATING WITH REEFS?"

By

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In answer to Dr. Gretener's discussion in which he finds exception both to Yungul's and my own explanation for the gravity anomalies associated with reefs, I, too, question Yungul's explanation of an increase in sand content vertically over the reef due to the winnowing action of waves, etc. My questioning of that explanation was the reason for offering another idea, although in some cases Yungul's explanation could be correct. I believe that as a single article, Yungul's casts more light upon the subject than any other I have read.

As I see it, Dr. Gretener has simply restated the problem, the fact that it is difficult to explain the source of the shallow positive anomalies which often occur in coincidence with pinnacle reefs. As he has demonstrated, the anomaly resulting from the reef mass itself, and from the anticlinal draping above the reef, does not fulfil the anomalies measured in the field. My own efforts have been directed toward explaining the cause of the observed anomaly.

From Dr. Gretener's discussion, it appears that he does not recognize the presence of denser rock vertically over a reef in the sense that a change in density might occur laterally within stratigraphic time units. I am convinced that this does occur. My basis for thinking this is the report by Pohley, 1953, (quoted by Yungul) to the effect that "dip shown for the beds above reefs on seismic maps are often greater than those encountered in drilling." He further states that "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." I have spoken to numerous geophysicists who verify this velocity phenomena. I believe that the increase in velocity, and density, may be the cause of the unexplained anomaly amplitude. In my mind, what causes the lateral increase in density above the reefs is the pertinent issue. Obviously, an anomalous mass exists for there to be an anomaly.

Dr. Gretener criticizes my analogy of coins surrounded by foam rubbed with a book on top, to demonstrate the greater compaction above the reef; the book representing the rigidity of the shallower beds and their resistance to bending. Rigidity here will cause an increase in density laterally. It must be remembered that an infinitesimal increase in compaction and density (1%) is all that is required to provide the observed anomaly.

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