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GROUND MAGNETOMETER SURVEY

OF THE

BIRCH LAKE AREA, NORTHWEST TERRITORIES

PERMITS 4569, 4570, 4571, 4572, 4575 and 4583

FOR

CHERMARC DEVELOPMENTS LTD

BY

RAYALTA PETROLEUM LTD

INDEX

GENERAL

Ground Magnetometer Survey was run with the helicopter to give magnetic coverage to the Birch Lake Area at ground level. The coverage was not intended to detail the area but rather to enhance the aerial Magnetometer portion of the work. When steep gradients were encountered during the ground Magnetometer operation, additional coverage was taken in the local area. Sixty stations were run in a random pattern over the entire area. These stations were then calculated and mapped in the field. From this mapping, areas of interest were selected and detailed Magnetometer profiles were run across the large magnetic features. This method is particularly helpful in defining and evaluating magnetic anomalies. The resultant map is one showing a detailed investigation of Basement sourced features that in conjunction with the aerial magnetometer map can be used to give a close approximation to the depth of Basement.

FIELD PROCEDURE

The magnetometer used was a vertical component reading instrument having a scale division of 10 gammas and an accuracy of ±2 gammas. Only days of stable diurnal magnetic change were used for metering. If consecutive base readings exhibited a widely fluctuating magnetic change, operations for that day were halted and for each day thereafter until the magnetic storm had subsided.

MAGNETIC METHODS

The theory behind the magnetic method has much in common with that of the gravitational method. Both are potential methods, having their fundamentals in potential theory. Just as the gravitational force in a given direction is the derivative or rate of change, in that direction of the gravitational potential, so also the magnetic force in a given direction is the derivative in that direction of the magnetic potential. However, an essential difference is that the magnetic case is inherently more complicated because there are two kinds of magnetic poles of opposite sign. Also, the positions of these poles determine a vector that may be in any direction. Thus, the magnetic state or magnetization of a body is defined by a magnitude and a direction rather than by a single magnitude (mass) as in the case of gravity. The quantity ordinarily measured in magnetic survey is a component of the intensity of the magnetic field at the surface of the earth. The most commonly considered unit is Oersted or Gauss. The ordinary c.g.s. unit used in magnetic survey is Gamma, which is defined as 1 gamma = 1/100,000 Oersted (or Gauss) or 0.00001 or 1×10^{-5} Oersted

The earth's normal magnetic field is about 0.60 Oersted or 60,000 gammas which is roughly equal to that of a dipole of moment 8×10^{25} emu. The exact internal cause of the geomagnetic field is still one of the great unsolved geophysical problems. The direction and magnitude of the geomagnetic field at any point in the earth's surface are represented by a vector or arrow parallel to the direction of the field (Figure 1) pointing to the direction of the force on a positive pole and having a length proportional to the strength of the field at that point. Picturing the earth as a uniformly polarized sphere, the magnetic lines are distributed on the earth. Near the poles the lines are close together, giving a relatively strong field, pointing in near the north geographic pole, out near the south geographic pole. Near the equator the field has about half its intensity at the poles, is parallel to the surface, and points north. As one goes north or south from the magnetic equator, the angle with the surface, or the magnetic "dip" increases rapidly until it is vertical (90°) at the magnetic poles. In ground magnetic survey either vertical

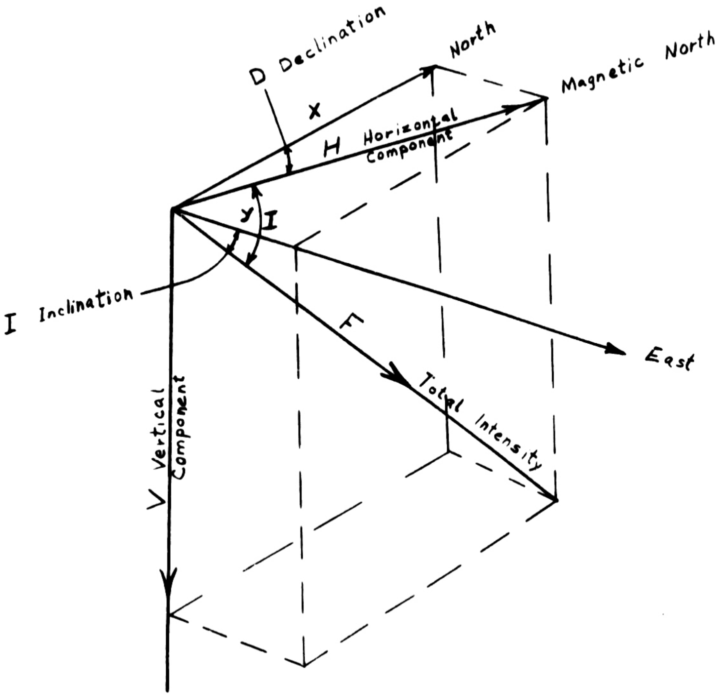

Fig. 1. Elements of the Geomagnetic Field, where.

$H = F \cos I$

$V = F \sin I = H \tan I$

$X = H \cos D \quad Y = H \sin D$

$X^2 + Y^2 = H^2 \quad X^2 + Y^2 + V^2 = H^2 + V^2 = F^2$

component or horizontal component is measured. The total magnetic field is measured by Airborne Magnetometer and other instruments.

There is an anomaly magnetic field of the earth which is cause by irregularities in the distribution of magnetized material in the outer crust of the earth. If this crust is uniform to a depth of some tens of miles, there would be no anomaly field. The fact that variations in the magnetic field exist which, from their nature and extent must have their source within the outer crust of the earth, indicates that the crust is not magnetically homogenous. Generally speaking, the contents of magnetic material in sedimentary rocks are very much lower than those for igneous rocks. Measurement of susceptibilities (the measurement of the number of elementary magnets per unit volume of the material and of their mobility or the ease with which they are oriented) of sediments, are no more satisfactory than those for igneous rocks, as nearly all have been made in fields many times greater than that of the earth.

The whole purpose of magnetic survey is to measure the anomaly field and attempt to interpret the magnetic inhomogenetics in terms of geological structures or magnetic ore bodies.

There are several ground magnetic instruments, the commonest one is the Schmidt type magnetometer which consists essentially of a pair of magnets mounted on a suspension, similar to that used in precision balance, comprised of a quartz knife edge reposing on quartz supports. The magnets are properly counter-balanced to remain in a horizontal position (for vertical magnetometer) when the magnetic field is normal. A microscope is used to read the deflections of the moving system - the deflections being proportional to the variations of the vertical component of the magnetic field. Modern Schmidt type ground magnetometers can adjust to make readings with a precision of about I gamma which corresponds to 1/50,000 of the total value of the magnetic field.

Because of the limitations of ground magnetometer operation in certain areas and under certain conditions, airborne magnetometer survey has been widely chosen during the past twenty years.

The common air-borne magnetometer is the flux-gate type - also known as the saturable reactor, and it makes use of a ferromagnetic element of such high permeability (it expresses the modification of the force of attraction or repulsion between two magnetic poles in a medium which is itself magnetic) that the earth's field can induce a magnetization that is a substantial proportion of the saturation value. If this field is superimposed upon a cyclic field induced by a sufficiently large alternating current in a coil around the magnet, the resultant field will saturate the core. The phase of each energizing cycle at which saturation is reached gives a measure of the earth's ambient field.

There are other new types of ground magnetometers being employed commercially. For instance, the Nuclear Precision meter can be easily operated for total magnetic field measurement. There is a new instrument which was developed in 1967 which is called the geomagnetic gradiometer. It measures directly the vertical gradient of the earth's magnetic field and the total field intensity. The system is composed of two simultaneous recordings optically pumped and monitored magnetometer sensors suspended from a helicopter. The sensors are separated vertically by a known distance so that the magnetic gradient can be determined from the difference in total magnetic intensity between the two sensors. Since the gradient is measured directly, the gradiometer allows geophysicists to make better use of Laplace's and Euler's equations. The gradiometer increases the value of magnetic prospecting by:

1. Greatly increasing resolving power;
2. Discriminating between intra-Basement and supra-Basement anomalies and
3. Eliminating problems caused by diurnal variations.

Like a gravimeter survey, corrections also must be applied to the field magnetic readings. Elevation of the station is not usually required in magnetic observation. However, the reading of a magnetometer is affected by the sum of all contributions to the magnetic field at the time and place of observation, in which the diurnal corrections and normal corrections are essential to magnetometer reading. Because the object of the survey is to map the magnetic expression of the "anomaly" part of the total magnetic field, it is necessary to remove all those parts of the total observed effect on the instrument which are extraneous to the final data desired. The magnetic expressions of geologic structures that may be economically important in the search for oil are often very weak. Therefore, careful correction of magnetometer readings is much more important in the application for oil prospecting than to the exploration for iron ore or igneous intrusions or contacts where the magnetic anomalies are much stronger and usually much more local and definite.

In general, magnetic corrections are:

1. Diurnal correction: This diurnal geomagnetic variation is caused by the solar magnetic field which changes somewhat erratically with time but is repeated (approximately) in daily cycles. The magnitude of the diurnal variation is from 10 to 100 gammas or more. Therefore, corrections must be made for its removal if the results of a magnetic survey are to be accurate to better than these magnitudes. Since the anomalies of interest in oil prospecting are commonly of lower relief than the magnitude of the daily variation, magnetic surveys for such a purpose must always include the measurement and removal of of the diurnal variation. This correction can be made by repeat observations in which the field instrument is returned within an interval of one hour during the day to the same arbitrary reference station. The readings at the same station would check if the magnetic intensities were constant.

The variations in these readings, therefore, are a measure of the magnetic variation during the day. For more accurate diurnal variation data, an instrument at base station is often used to make continuous readings (5 or 10 minute intervals).

2. Normal Correction: This is made to remove the normal variation of magnetic intensity over the earth's surface. It corresponds in a general way to the latitude correction of gravity values. However, no accurate mathematical expression is available by which normal magnetic effect may be calculated, and they must be determined empirically from magnetic charts, by which the north-south and east-west components of the normal rate of change of geomagnetic intensity may be estimated.

After the reduced magnetic readings are plotted and contoured, the techniques of interpretations are much like those employed in the gravitational method. Most magnetic interpretation involves only qualitative examination of the contour maps. In areas of sedimentary surface rocks, such maps often indicate the structure of the top surface of the igneous Basement. Major structural trends in some areas are often delineated very clearly on the magnetic map. However, even in qualitative interpretations it is necessary to be cautious, for a magnetic anomaly may signify either relief in the Basement surface or variation in the susceptibility changes of polarization in Basement rocks. Even at a depth of a mile or more, the latter may give rise to anomalies as high as several thousand gammas. At the same depth, structural features of the type important in oil prospecting would seldom produce anomalies much larger than 50 gammas. Moreover, it is important to state that a qualitative indication of the depth to the source of a magnetic anomaly is the sharpness of the anomaly itself. In general, like gravity anomalies, the broader the feature on the magnetic map or profile, the deeper the source. This principle is often invoked in eliminating the effect of shallow magnetized materials in petroleum surveying where only deep Basement features are of interest. It is also used to eliminate the effect of deep Basement irregularities in mining survey where only shallow magnetic bodies are sought. Quantitative analysis of magnetic data is generally difficult becuase of possible variations in susceptibility as well as the uncertainty which often exists as to the direction of the rock polarization, an uncertainty usually caused by a lack of information on the relative proportion of i nduced and permanent magnetization. An important phase of quantitative analysis of magnetic data is the estimation of the depth to the top of a magnetic body as this is a deciding factor for the subsequent development program whether in oil exploration or in mining. In the early days of magnetic exploration for ore bodies, the quantitative aspect of interpretation was not given much emphasis except for a casual estimate of the depth of the ore body. With the advent of oil exploration, the quantitative aspect of interpretation began to assume importance and has given rise to at least four well known methods, namely:

1. The doublet method -- Henderson & Zietz.
2. The Peter's half slope method.

3. The prismatic model method of Vacquier and others.

4. The two-dimensional model method of Talwani and others.

The different theories of magnetic interpretations fall fundamentally into two classes:

1. Those based on the concept of pole or poles with no assumption regarding the origin of the poles themselves in the magnetized body. The theory is thus valid for any strength and direction of magnetization regardless of origin.

2. Those based on the concept of magnetic induction where the anomalies are related to the strength and direction of the earth's field. Here the magnetization of the body is explicitly assumed to be only due to the induction in the earth's present field both in direction and magnitude.

The differences pointed out above are very fundamental as they introduce certain necessary assumptions in the various methods and any wide departure from these in practical cases has to be fully appreciated in deciding the suitability of the methods in individual cases.

Theoretically and practically, upward and downward continuation techniques can be applied to the interpretation of magnetic observations. However, the uses of continuation maps deviate in some particulars from their uses in gravity interpretation, such as:

1. Upward continuation is sometimes used in order to simplify the appearance of magnetic maps by suppressing local features. The proliferation of local magnetic anomalies often obscures the regional picture with an overabundance of detail. Upward continuation will smooth out these disturbances without impairing the main regional features.

2. Downward continuation is used for a purpose exactly opposite to upward continuation. It is to increase the resolution of weak anomalies. It has been proposed by Peters that if we can assume that the magnetic material is vertically polarized, downward continuation can also be used to determine the shapes of interfaces between uniformly but differently magnetized media. However, becuase of its inherent limitation to vertical field anomalies and to verti cal polarizations, Peter's method applies in principle only to the interpretation of ground magnetic surveys made in the higher magnetic latitudes. Since most magnetic surveys are made from aircraft using a total-field instrument, there is a much greater practical need for continuation methods which can be used with total-field measurements.

As mentioned previously, the aims of magnetometer surveys are often very much the same as those of gravity surveys, viz, to find from surface measurement the shapes or the volumes of formations whose susceptibilities or NRMS (natural remanent magnetization or the permanent magnetization) differs markedly from those of their surroundings. The models used to represent geological structures are similar to those used in gravity interpretations, but unfortunately the selection of suitable values for the susceptibility contrasts or NRMS is highly problematical on account of the wide variability of these properties, even within a single rock type. Since susceptibility or magnetization is mainly a function of the quantity of magnetic minerals in the rock, and inasmuch as these are usually present in small amounts, it is believed that the concentrations may vary widely. Therefore, methods of interpretation based upon the shapes, but not upon the amplitudes, of anomaly patterns, are generally used. In practice there are three well-recognized uses of magnetic methods. The first one is in direct exploration. By creating local anomalies in the natural field on the earth magnetic ores reveal their presence and provide us with a simple and effective tool for their discovery. The second application is in geological mapping in which the magnetization of a rock may give some information to its composites and provide a method for tracing the extent and shape of the formation. The third use is less direct, there being no intrinsic interest in the magnetized rocks whatsoever. A typical example is in the reconnaissance of sedimentary Basement with the airborne magnetometer, in which the depths of the magnetic rocks below the aircraft are calculated from the anomaly patterns. Also many geologic deformations or structures that form traps for oil accumulation are underlain by Basement uplifts. Further, even a rough estimate of Basement depth may be valuable for giving an indication of the available thickness of sedimentary section in which oil reservoirs may exist.

It should be remembered that the ambiguity of gravity interpretation holds equally well for magnetic data. The same laws of potential theory that explained why gravity data can never be accounted by a single unique interpretation apply also to the magnetic case. Therefore, independent geological information is necessary if one is to choose the most reasonable of an infinite number of subsurface pictures that might fit the magnetic observations equally well. Similarly, it is often impossible to differentiate between structure and density changes in the source of gravity anomaly. However, magnetic survey, like gravity, is one of the economic reconnaissance methods for oil and mineral prospecting, since few sedimentary rocks are appreciably magnetized, the magnetic method will generally give information only on igneous rocks or on ore deposits with magnetic constituents. In petroleum prospecting, magnetic methods are useful where structural features on the Basement surface, such as buried ridges, control overlying sedimentary structure. In mineral prospecting they are useful in locating magnetic, pyrrhotite, and similar magnetic minerals directly, as well as for exacting major structural trends in mining areas where the Basement is covered by aluminum, glacial till and other superficial material. In the mining district of Canada, where most of the geological formations are upturred and concealed by glacial deposits, the main use of the ground magnetometer is to outline geological structures and formation under the mantle of overburden. Because the structures that are associated with ore deposit are usually minor structures, they can seldom be discovered from an aero magnetic survey. Therefore it is usually the task of a ground magnetometer to locate the potentially ore-bearing minor geological structures.

- MAGNETIC INTERPRETATION -

GROUND MAGNETIC MAP

It is interesting to note that both the ground magnetics and airborne magnetics are amazingly similar to the Bouguer Gravity Map in major gravity highs and lows which are coincident with the position of the magnetic highs and lows. This evidence is another endorsement to the interpretation that both the gravity and magnetic anomalies are mainly caused by Basement topography.

The ground magnetic map also strongly reveals the existence of probable faults (makred in red) as indicated in the Bouguer Gravity Map. Geologically speaking, the Birch Lake area is covered by a section of sedimentary rocks of Middle Devonian, Ordovician and Older rocks.

They are mainly composed of carbonates and there is only a very small difference in magnetic susceptibility between these carbonates. Hence, the relatively higher susceptibility of Basement rocks play an important role to the magnetic anomalies. Faulting might be the principal tectonic factor to the variation of Basement topography. As a result, areas of depressed Basement topography have thicker sediments and show lower magnetic and gravity readings. On the other hand, uplifted Basement topography is overlain by thinner sediments which usually indicate higher magnetics and gravity. With this understanding in mind, we are in a better position to get a closer picture of the geological features.

Figure 1 and 2 are examples of the relationships between gravity and magnetic to the reefs. Figure 1 shows the reef built on a Basement relief and surrounded by clastic sediments. In this case we can expect both gravity and magnetic anomalies to be positive. Figure I is a good example to use magnetic surveys to define Basement reliefs or faults involving the Basement. If a reef is surrounded by shales having a higher magnetic susceptibility, (Fig. 2) the reef could be found directly and would correlate with a negative magnetic anomaly. This anomaly could be of sufficient amplitude to be recognized if the reef were situated no more than a mile deep and have a relief of several hundred feet. The gravity response would be positive.

AIRBORNE MAGNETIC MAP

The Airborne Magnetic Map is in close agreement with the Ground Magnetic Map as far as the locations, shapes and magnetude of the high and low magnetic anomalies are concerned. This is because of the higher magnetic latitudes involved in this area.

Strong evidence of Basement faulting in the Birch Lake area can be easily traced (marked by red lines) and are more or less in the same location as faults indicated on the ground magnetic and gravity maps.

Several distinct magnetic anomalies can be used for depth estimations and the results are marked in the respective anomalies. These depths are theoretically estimated and represent the maximum anomaly source depth. Obviously, these figures are different from the geological estimated depth. However, this difference is acceptable in view of the theoretical accuracy of the method used for this depth estimation. Further, the general half-slope or error-curve methods for depth calculation are restricted by the following assumptions. When certain magnetic profiles are chosen for this purpose. They should be:

(a) The anomalies would be "pure" that is, have least interference from other closely situated anomalies. The profile should be so chosen as to pass through rather equally-spaced sections of the contours and perfectly at right angles to the major axis and through the highest value of the anomaly.

(b) The anomaly should be caused by a mass having a uniform susceptibility different from other surrounding rocks.

(c) The mass is polarized only by induction in the earth's field and that this field has an almost negligible horizontal magnetic component. In other words, this method is really applicable only to masses in high magnetic latitudes.

(d) The anomaly producing body has infinite horizontal lengths This requirement is adequately fulfilled if its length is three times its width.

(e) The top surface of the anomalous mass does not stand in topographic relief above the surrounding rocks.

(f) The anomalous mass extends downwards to infinite depth. In practice, the vertical extent of the anomalous body can be no greater than the depth of burial of the body and the error in depth calculation which will still be within 20%.

(g) The contact between the anomalous mass and the surrounding rocks is vertical.

If the sides of the body slope outward, a greater than real depth will result from the calculations and converse for inward sloping sides. However, the sides can slope at an angle of up to 30degrees from the vertical and produce negligible error in the depth calculations.

Most of the expected violations of these assumptions will result in too great an estimate to the depth of an anomaly source. However, these methods can be considered as a reliable methods of calculating maximum probable depths. No attempt has been made to construct a contoured Basement map on the basis of magnetic data alone, because no initial information such as well logs, seismic data etc. are available at this time. However, these scattered depth figures do give valuable information to the overall picture of the Basement configuration in the Birch Lake area.

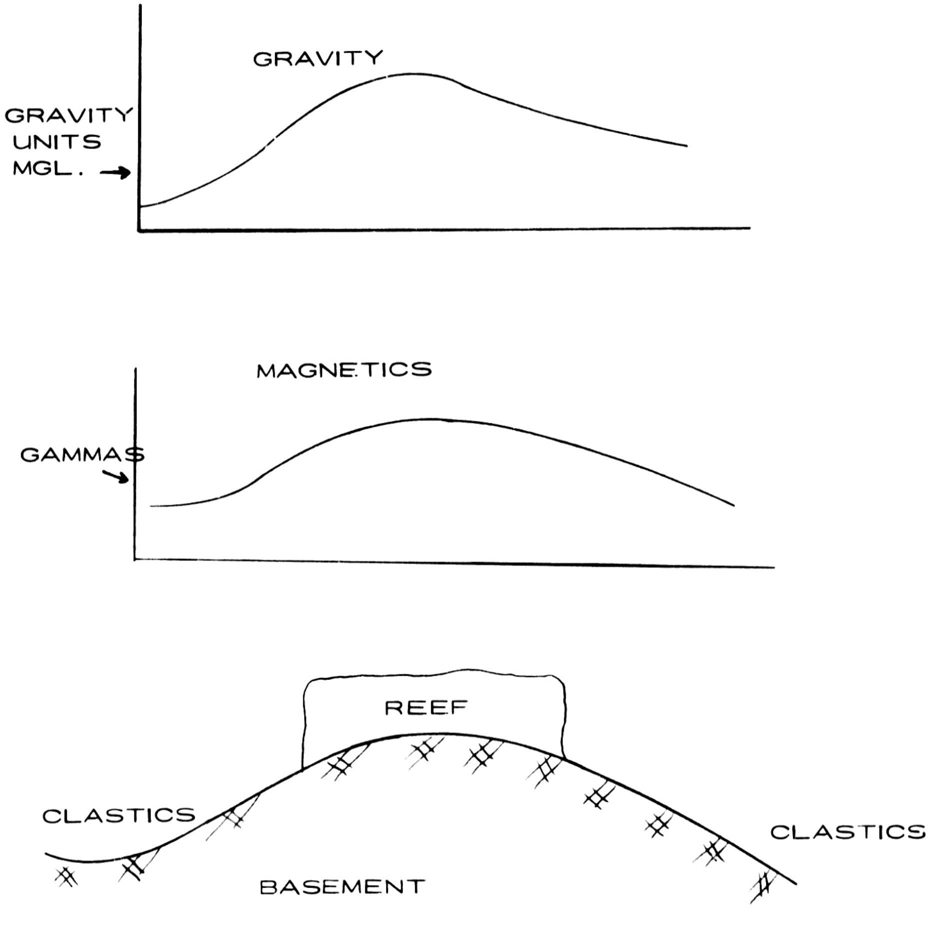

FIG. I

Reef or reef-trend overlying, and associated with Basement high may provide a positive anomaly on both gravity and magnetic surveys.

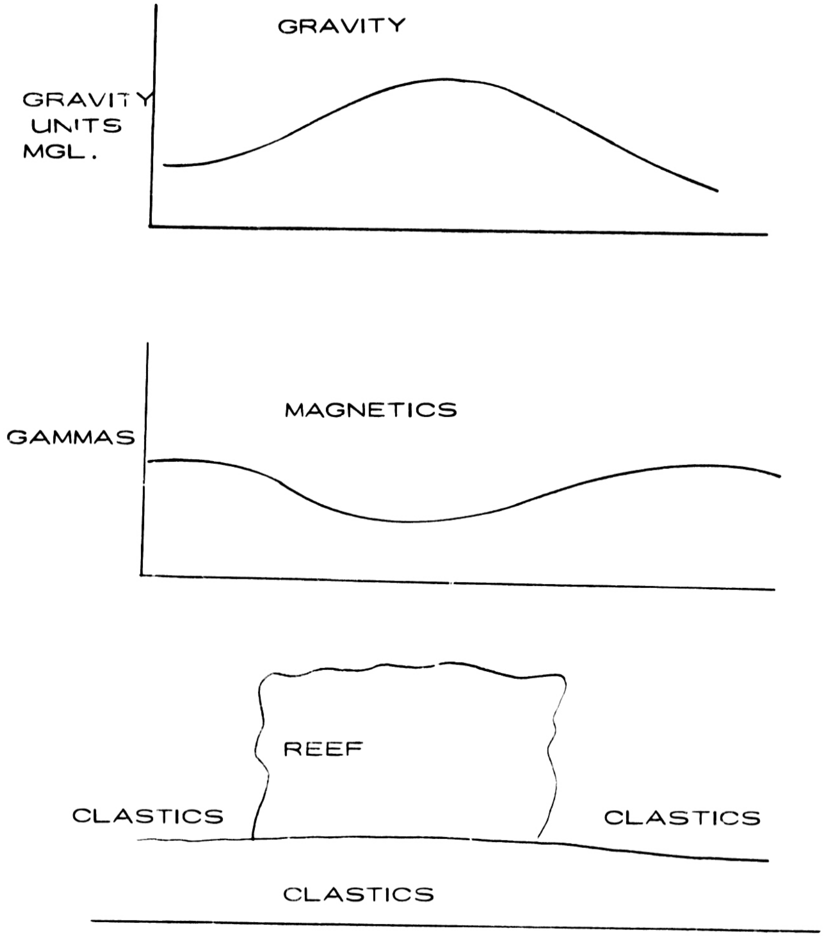

FIG. 2

Reef surrounded by formation having higher magnetic susceptibility but not associated with Basement high or other structional feature may show positive gravity but negative magnetic anomaly.

CONCLUSIONS

Several conclusions based on this preliminary analysis and interpretation of the gravity and magnetic data can be made:

(a) The density contrast and magnetic susceptibility contrasts between the different age carbonates in this area is essentially nil. Hence, the major sources of gravity and magnetic anomalies are from Basement, and Basement topography is a major cause of both gravity and magnetic anomalies. However, localized residual anomalies might be caused by reef-material build-up.

(b) The Basement configuration generally is in a monoclinal shape which dips gently to the south and southwest. However, local topographic changes are present and this topography variation may be due to tectonic events. In general, the Basement is situated at a depth ranging from 2,000 feet to ± 2,500 feet below surface.

(c) Faults can be expected in this area. They originate within the Basement and could cut most of the sedimentary section.

(d) No major geological features such as sizable anticlines, synclines etc. can be expected in this area. A cluster of isolated mass distributions along the faulting zones may indicate the possible existence of reef structures. If this is so then these reef structures may have a horizontal circular-like mass with one half to one and one half miles in radius, and from 150 feet to 300 feet in structural relief, at a burial depth ranging from ± 2,000 feet to ± 2,500 feet below the surface.

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