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GEOPHYSICAL INVESTIGATIONS OF A GEOTHERMAL ANOMALY AT WADI GHADIR, EASTERN EGYPT

by

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ABSTRACT

During regional heat flow studies a geothermal anomaly has been discovered approximately 2 km from the Red Sea coast at Wadi Ghadir, in the Red Sea Hills of Eastern Egypt. A temperature gradient of 55 degC/km was measured in a 150 m drillhole at this location, indicating a heat flow of approximately 175 mW m^{-2}, approximately four times the regional background heat flow for Egypt. Temperature data from three additional drillholes to the west of the first hole indicate that the anomaly dies away rapidly from the coast, to values approximately twice the regional background. Gravity and magnetic data have been collected along Wadi Ghadir, and combined with offshore gravity data, to investigate the source of the thermal anomaly. Magnetic anomalies in the profile do not coincide with the thermal anomaly, but were observed to correlate with outcrops of basic rocks. There is a sharp negative gradient in the Bouguer gravity anomaly data along Wadi Ghadir, immediately to the east of the high heat flow drillhole. This gradient indicates a rapid increase in the thickness of sediments to the east of the Red Sea Hills at Wadi Ghadir, possibly fault controlled, and the combined effects of thermal refraction across the fault and water circulation up the fault could be the local source of the thermal anomaly. Other regional heat flow and gravity data indicate that the transition from continental to oceanic type lithosphere occurs close to the Red Sea margin, and that the regional thermal anomaly is possibly related to the formation of the Red Sea.

INTRODUCTION

In a cooperative programme sponsored by the U.S. National Science Foundation, earth scientists from the Egyptian Geological Survey and Mining Authority and various U.S. institutions have been collecting heat flow, gravity and microearthquake data to study the transition between the stable African shield and the Red Sea trough in eastern Egypt (Morgan et al., 1981; Boulos et al., 1981; Daggett et al., 1981). Heat flow measurements have been made in boreholes drilled for other purposes, mostly mineral exploration, and in specially drilled boreholes. These data indicate high heat flow, approximately twice the regional background heat flow for Egypt, in a zone at least 30 km wide along the Red Sea margin (Morgan et al., 1981). In one of these special drillholes, approximately 2 km from the Red Sea coast at Wadi Ghadir in the Red Sea Hills of eastern Egypt, a significant local thermal anomaly was discovered, with a heat flow approximately twice the coastal high heat flow, and approximately four times the regional background heat flow for Egypt. In order to study the local and regional significance of this local thermal anomaly, three additional temperature test boreholes have been drilled in Wadi Ghadir, and gravity and magnetic data have been collected in the wadi along a profile approximately perpendicular to the coast. The study has been extended offshore to the east using oil exploration geophysical survey data, kindly made available to us by the Egypt General Petroleum Co. The purpose of this paper is to present the new geophysical data that we have collected from Wadi Ghadir, together with preliminary qualitative interpretations of the data, and some speculations on the source of the geothermal anomaly.

THERMAL GRADIENT DATA

Regional heat flow studies indicate that geothermal gradients of 19 to 29 degC/km are typical in the granitic outcrops of the Red Sea Hills in a zone extending 30 km or more from the Red Sea coast, decreasing to gradients of 12 to 18 degC/km in the granitic outcrops further from the coast (Morgan et al., 1981). One borehole, Q1 (Figure 1), was drilled near the exit of Wadi Ghadir from the Red Sea Hills, approximately 2 km from the Red Sea coast, to determine the heat flow in the Precambrian Basement as close to the Red Sea margin as possible. The temperature data from this drillhole do not fit into the regional pattern, as below 20 m they define a good linear gradient of 55 degC/km. To investigate this anomaly further, three additional temperature test boreholes, Q5, Q6 and Q7 (Figure 1), were drilled at 4 to 6 km intervals along the wadi. The geothermal gradient was found to decrease rapidly at first along the wadi, from 55 to 30 degC/km between Q1 and Q5, and then decrease more slowly as the wadi continues to the west, with a value of 27 degC/km at Q6, and 24 degC/km at Q7. This decrease in gradient along the wadi is shown in Figure 1, and the temperature data from all the Wadi Ghadir boreholes are plotted in Figure 2. The general decrease in gradient to the west has been observed in data from other boreholes in eastern Egypt (Morgan et al., 1981), and the data from Wadi Ghadir therefore indicate that the geothermal anomaly observed in the Q1 data is very limited in extent to the west, and appears to be localised in the immediate vicinity of Q1.

MAGNETIC DATA

In order to investigate possible structural control over the source of the

Wadi Ghadir geothermal anomaly, ground magnetic data were collected along the wadi, starting at the coastline, and extending approximately 3 km past drillhole Q7. These data were collected using a proton precession magnetometer with a precision of 1 gamma, and a station spacing of 500 m. Station locations are shown in Figure 3, and the observed data, corrected for diurnal drift of the magnetic field, are plotted in Figure 4. Local magnetic anomalies, up to a few hundred gammas in amplitude and 2 km in width were observed at several locations along the profile. While the data were being collected it was observed that these anomalies correlated with outcrops of basic rocks within the granitic host rock of this section of Wadi Ghadir. No significant magnetic anomaly was observed at the eastern end of the profile corresponding with the geothermal anomaly, in fact the magnetic field appears to flatten in this region. Similarly towards the western end of the profile the anomalies decrease as the profile extends from the granitic Basement rocks to a melange unit (see El-Sharkawy and El-Bayoumi, 1981). The magnetic data do not therefore provide any direct evidence on the source of the geothermal anomaly.

GRAVITY DATA

The only published gravity data from the vicinity of Wadi Ghadir are in the form of a profile along the Red Sea coast running from Port Sudan to Safaga (Brown et al., 1980). These data indicate that the coastal zone is characterised by Bouguer gravity anomalies within the range -10 to 20 mgal. Boulos et al. (1981) present gravity data from an east-west profile along the Marsa Alam to Idfu road, approximately 30 km north of Wadi Ghadir, and these data indicate a relatively positive simple Bouguer anomaly as the coast is approached. These data are presented relative to a Luxor base station, and when they are converted to absolute Bouguer anomaly values, the coastal positive anomaly remains, with a value of approximately 20 mgal at the coastline.

New gravity data were collected along Wadi Ghadir using a LaCoste & Romberg temperature stabilized Model G gravimeter, and tied into the study reported by Boulos et al. (1981) at a Marsa Alam base station. Gravity values were measured at the same station locations used in the magnetic survey (Figure 3), and the gravimeter readings were corrected for instrument calibration and drift, and converted to absolute anomaly values using the anomaly value at Marsa Alam. Elevation control along the Wadi Ghadir gravity profile was measured with a pair of aneroid altimeters, and from the internal consistency of the data is estimated to be good to within $\pm$ 3.3 m. This gives an estimated uncertainty in the resulting gravity anomaly data of a little less than $\pm$ 1 mgal. Four density values were tested for reduction of the gravity anomalies to simple Bouguer anomalies, as shown in Figure 5. The density which gives the least correlation between Bouguer anomaly and elevation along the main section of granitic rock outcrop along the wadi is 2.67 g cm^{-3}, which is the same reduction density used by Boulos et al. (1981). Simple Bouguer anomaly values along Wadi Ghadir calculated using this reduction density are shown in Figure 4. Also shown in Figure 4 is the seaward extension of the gravity profile taken from an offshore petroleum exploration survey by Union Oil, and used in the present study by the courtesy of the Egypt General Petroleum Co. For the offshore survey a reduction density of 2.3 g cm^{-3} was used, which effectively replaces the sea water by sediment.

Three features are clearly apparent on the Wadi Ghadir Bouguer gravity profile and its seaward extension: i) a small positive gradient, 1 mgal/km, in the anomaly going west over the contact between the granitic rocks and the melange in Wadi Ghadir at the western end of the profile. This is clearly related to the transition from less dense granitic rocks to more dense rocks of the melange unit (see Figure 4). ii) a sharp negative gradient, over 3 mgal/km, starting at the eastern margin of the Red Sea Hills, and leading to an inferred minimum in the gravity anomaly of -30 to -34 mgal approximately 5 km offshore. This feature is closely spatially related to the geothermal anomaly. iii) a gentle positive gradient, approximately 2 mgal/km, extending from approximately 6 to 27 km offshore. The cause of this positive gradient is not immediately apparent as it shows no correlation with the sedimentary wedge on the Red Sea margin, shown beneath the anomaly plot in Figure 4, which would be expected to give a strong negative anomaly. Feature i) does not appear to bear any relationship to the source of the geothermal anomaly and will not be discussed further. Both features ii) and iii) are thought to relate to the local and regional sources of the geothermal anomaly, however, and are discussed below.

INTERPRETATION AND SPECULATION ABOUT THE SOURCE OF THE GEOTHERMAL ANOMALY

The sharp negative gravity gradient at the eastern margin of the Red Sea Hills is closely spatially related to the geothermal anomaly observed in drillhole Q1. The most probable cause of the negative gradient is a steeply dipping fault bounding the eastern margin of the Red Sea Hills, downdropping the crystalline Basement to the east, and allowing a fill of low density sediments adjacent to the outcropping Precambrian rocks. An estimate of the thickness of this fill can be obtained from the relative magnitude of the negative anomaly, an inferred 20 to 24 mgal. Assuming densities of 2.3 and 2.67 g cm^{-3} for the sediments and Precambrian rocks respectively, a 20 to 24 mgal negative anomaly would be given by an infinite slab of sediments 1.29 to 1.55 km in thickness. These estimates are in reasonably good agreement with the depth to crystalline basement estimated from aeromagnetic data approximately 6 km offshore, as shown in Figure 4. We conclude therefore that the eastern margin of the Red Sea Hills at Wadi Ghadir is bounded by a fault, probably a normal fault, close to the contact between the sediments and Basement, and that the sediment thickens rapidly away from the Red Sea Hills to up to 1.5 km 5 km offshore, and that probably most of this increase occurs on the range bounding fault.

There are two possible mechanisms by which the fault, indicated by the gravity data, could be the local source of the geothermal anomaly. The first mechanism is thermal refraction: the low density sediments are expected to have a themal conductivity approximately half that of the crystalline basement, and this has the effect of lowering the heat flow on the sediment side of the fault, and increasing the heat flow on the Basement side. This effect has been modelled using numerical techniques by Blackwell and Chapman (1977), the results of which are shown in Figure 6A. It can be seen that this mechanism is capable of increasing the heat flow, and correspondingly the temperature gradient, by approximately 30% on the Basement side of the fault. The second mechanism is the ascent of hot water in the fault zone convecting heat to the surface. This mechanism has also been numerically modelled by Blackwell and Chapman (op. cit.), the results of which are shown in Figure 6B. The rising hot water model is capable of producing a very large surface heat flow anomaly, 6.5 times the regional heat flow in the example given by Blackwell and Chapman (op. cit.) The maximum value of the anomaly is controlled primarily by the temperature of the ascending water, and the level to which it rises.

It is clear that the proximity of the junction between the sediments and the Basement to drillhole Q1 must result in some significant increase in the gradient at Q1 by thermal refraction. From the models of Blackwell and Chapman (1977), however, this increase is only likely to be on the order of 20 to 30%, which, assuming a background gradient of 30 degC/km (the value from the adjacent borehole, Q5), is only capable of explaining a gradient of 36 to 39 degC/km at the Q1 site, significantly lower than the 55 degC/km actually measured. Thermal refraction effects alone, therefore, are not thought to be capable of explaining the magnitude of the geothermal anomaly.

Without any direct information concerning groundwater movements in the coastal zone, we can only speculate about the thermal effects of groundwater convection in the sediments and the Basement rocks. Thermal springs occur further north along the margins of the Gulf of Suez (e.g. Ain Sukhna and Hamman Pharaoun), and perhaps a similar system exists in the eastern part of Wadi Ghadir, not reaching the surface because of the depth of the water table in this area. We speculate that this is the most likely primary local source of the Wadi Ghadir geothermal anomaly.

A third possible source of the Wadi Ghadir geothermal anomaly is a still-cooling igneous intrusion in the upper crust beneath the area of the anomaly, and possibly with an associated hydrothermal convection system above the intrusion. We cannot completely discount this hypothesis, but merely state that there are no data to support it: there are no gravity or magnetic anomalies directly spatially related to the thermal anomaly indicating an intrusion beneath it, and regional microearthquake studies (Daggett et al., 1981) do not report any microearthquake activity in this area, as would be expected from a still cooling intrusion in the upper crust. From the existing data, therfore, we believe the intrusion hypothesis to be highly unlikely.

On a broader scale, two features of the Wadi Ghadir geophysical data remain to be explained. The first is the general decrease in geothermal gradient along the wadi to the west. This is a general feature in the geothermal gradients in eastern Egypt (Morgan et al., 1981). The second unexplained feature is the moderate positive gradient in the Bouguer gravity data between 6 and 27 km offshore, which shows no correlation with the expected anomaly from the offshore sedimentary section. We believe that these two features have a common explanation.

The coastal gravity anomaly profile of Brown et al. (1980) shows dominantly positive gravity anomalies along the coast, typically 2 to 20 mgal in amplitude. The present study has shown that Wadi Ghadir has an approximately -10 mgal anomaly at the coast, but this is easily reconciled by the observation that the Basement rocks at the eastern end of Wadi Ghadir are granitic in character, and would be expected to be lower in density than the more basic Basement rocks that surround them. Anomalies of up to -30 mgal have been measured over granitic outcrops in other areas of eastern Egypt (Boulos et al., 1981), so the difference between the typical coastal anomaly and the Wadi Ghadir anomaly is thought to be of only local significance. Regional gravity anomaly data indicate that the coastal zone is characterised by positive gravity anomalies which increase in magnitude towards the coast over the Precambrian outcrops, then decrease rapidly over the sediments and out to sea, reaching a low of typically -30 mgal 5 to 10 km offshore. After this low the anomaly values rise again with a gradient on the order of 2 mgal/km, showing no apparent correlation with sediment thickness (e.g. see Figure 4).

The positive gravity gradients to the east must be caused by a dramatic increase in density to the east in the lithosphere. This could be caused by a rapid thinning of the continental crust eastwards, less dense crust being replaced by more dense mantle rocks, and/or a dramatic increase in the density of the crust, perhaps most easily explained by a transition from continental to oceanic type crust close to the Red Sea margin. Models of this type of transition have been tested by Gettings (1977) using gravity data from the Saudi Arabian margin of the Red Sea, and he concludes that the positive seaward gravity trends are caused by oceanic type lithosphere extending across the full width of the Red Sea, upon which variable thicknesses of sediments, including highly variable thicknesses of evaporites, superimpose local negative gravity anomalies. The sharp negative anomaly at the Red Sea margin is caused by the rapid increase in the thickness on sediments at this boundary. The gravity anomaly profiles across the Egyptian Red Sea margin are a mirror image of the profiles presented by Gettings (op. cit.) for the Saudi Arabian Red Sea margin, and we believe that the model of a transition from continental to oceanic type lithosphere close to the Red Sea margin best explains both sets of data.

The additional advantage of the continent/ocean transition model is that it provides a source for the moderately high geothermal gradients in the coastal zone of eastern Egypt (e.g. gradients from drillholes Q5, Q6, and Q7, above, and see Morgan et. al., 1981). These high gradients could be caused by residual heat from the initial rifting and opening of the Red Sea during mid-Tertiary time. At the present time there are insufficient data to confirm or disprove this hypothesis, but it is consistent with the available information. In addition, this residual heat may in part be driving the local geothermal system responsible for the Wadi Ghadir geothermal anomaly, and such hidden geothermal systems may be common along the Red Sea coastal zone.

CONCLUSIONS

New borehole temperature data from Wadi Ghadir indicate that the geothermal anomaly previously discovered at the eastern end of the wadi is very limited in lateral extent. Magnetic data from the wadi show no correlation between the geothermal anomaly and the magnetic field, but appear to correlate with outcrops of basic rocks. New gravity data from the wadi, combined with offshore gravity data, indicate a fault at the contact between the sediments and the Basement in eastern Wadi Ghadir, and the combined effects of thermal refraction across the fault and hydrothermal circulation up the fault are thought to be the local source of the geothermal anomaly. The regional heat flow and gravity data are thought to indicate a transition from continental to oceanic type crust close to the Red Sea margin. This transition is responsible for the high heat flow along the Red Sea margin, and the positive gravity gradients out to sea, upon which are superimposed negative gravity anomalies caused by the coastal sedimentary fill. It is possible that other geothermal anomalies, similar to the Wadi Ghadir anomaly, remain to be discovered in the Red Sea coastal zone.

ACKNOWLEDGEMENTS

We are deeply grateful for the help, before his untimely death, of Mr. Galal A. Moustafa, Chairman of the the Egyptian Geological Survey and Mining Authority. We also acknowledge Mr. M. A. Zaatout, Mr. M. F. El-Ramly, and Mr. M. H. Hermina for their valuable advice in the organisation and execution of this study. The assistance given to us by Dr. Hussein Kamel to obtain the offshore geophysical data from the Egypt General Petroleum Co. is deeply appreciated. Funding was provided primarily by the U.S. National Science Foundation through grant numbers EAR77-23354 and INT78-16649 from the Earth Sciences Program and the Office of International Programs respectively. A portion of this research was performed while one of the authors (PM) was a Staff Scientist at the Lunar and Planetary Institute which is operated by the Universities Space Research Association under Contract No. NASW-3389 with the National Aeronautics and Space Administration. This paper is the Lunar and Planetary Institute Contribution No. 446.

REFERENCES

Blackwell, D. D. and D. S. Chapman, Interpretation of geothermal gradient and heat flow data for Basin and Range geothermal systems, Geothermal Resources Council, Transactions, v.1, p.19-20, 1977.

Boulos, F. K., P. Morgan, S. F. Hennin, A. A. El-Sayed and Y. S. Melek, The tectonic structure of northeast Africa from gravity data, Annals Geological Survey Egypt, in press, 1981.

Brown, C., R. W. Girdler and R. G. B. Renner, A gravity traverse across northern Africa, J. geophys. Res., v.85, p.6436-6442, 1980.

El-Sharkawy, M. A. , and R. M. El-Bayoumi, The ophiolites of Wadi Ghadir area Eastern Desert, Egypt, Annals Geological Survey Egypt, v.9, p.124-134, 1981.

Daggett, P. H., P. Morgan, F. K. Boulos, S. F. Hennin, A. A. El-Sherif and Y. S. Melek, Microearthquake studies of the northeastern margin of the African plate, Annals Geological Survey Egypt, in press, 1981.

Gettings, M. E., Delineation of the continental margin in the southern Red Sea region from new gravity evidence, Saudi Arabian Mineral Research Bulletin 22-K, 1977.

Morgan, P., C. A. Swanberg, F. K. Boulos, S. F. Hennin, A. A. El-Sayed and N. Z. Basta, Geothermal studies in northeast Africa, Annals Geological

Survey Egypt, in press, 1981.

FIGURE CAPTIONS

Figure 1. Location map for the four temperature test boreholes (Q1, Q5, Q6 and Q7) drilled in Wadi Ghadir. The inset map in the upper right shows the approximate location of Wadi Ghadir. Geothermal gradients determined in the drillholes are plotted above the wadi map to show the increasing gradient towards the Red Sea coast.

Figure 2. Temperature data plotted as a function of depth for the four temperature test boreholes drilled in Wadi Ghadir. Borehole locations are shown in Figure 1.

Figure 3. Location map of Wadi Ghadir showing the positions of the gravity and magnetic measurement stations (small closed circles). Stations are numbered consecutively from 0 to 44 starting at the Red Sea coast. Drillhole sites from Figure 1 are shown by open circles.

Figure 4. Simple Bouguer gravity anomaly, magnetic anomaly and elevation data from Wadi Ghadir plotted as a function of station number on the left of the figure: marine Bouguer gravity anomaly, seismic travel time to the base of the evaporites and depth to crystalline basement based on airborne magnetic data for the eastern extension of Wadi Ghadir along latitude 24 deg 50 min on the right of the figure (offshore data from Union Oil maps). Onshore locations of temperature test drillholes are shown (Q1, Q5, Q6 and Q7) together with the contacts along the wadi between the melange unit (M), the granitic rocks (G) and the sediments (S). Structural features interpreted

from airborne magnetic survey for Union Oil are as follows: a. interpreted syncline, b. interpreted normal fault, downthrown to east, c. structural disturbance, d. interpreted normal fault, downthrown to east, e. interpreted fault, sense of displacement unknown.

Figure 5. Bouguer gravity anomaly data with different reduction densities plotted with elevation as a function of station number. Basic geology is shown on the elevation profile.

Figure 6. A. Effect of thermal refraction across a normal fault which brings low thermal conductivity (1.45 W/m/K) sediment (Fill) into lateral contact with high conductivity (2.9 W/m/K) bedrock. B. As A. but with water at 100 degC circulating up the fault. (Figures adapted from Blackwell and Chapman, 1977).

FIG 1

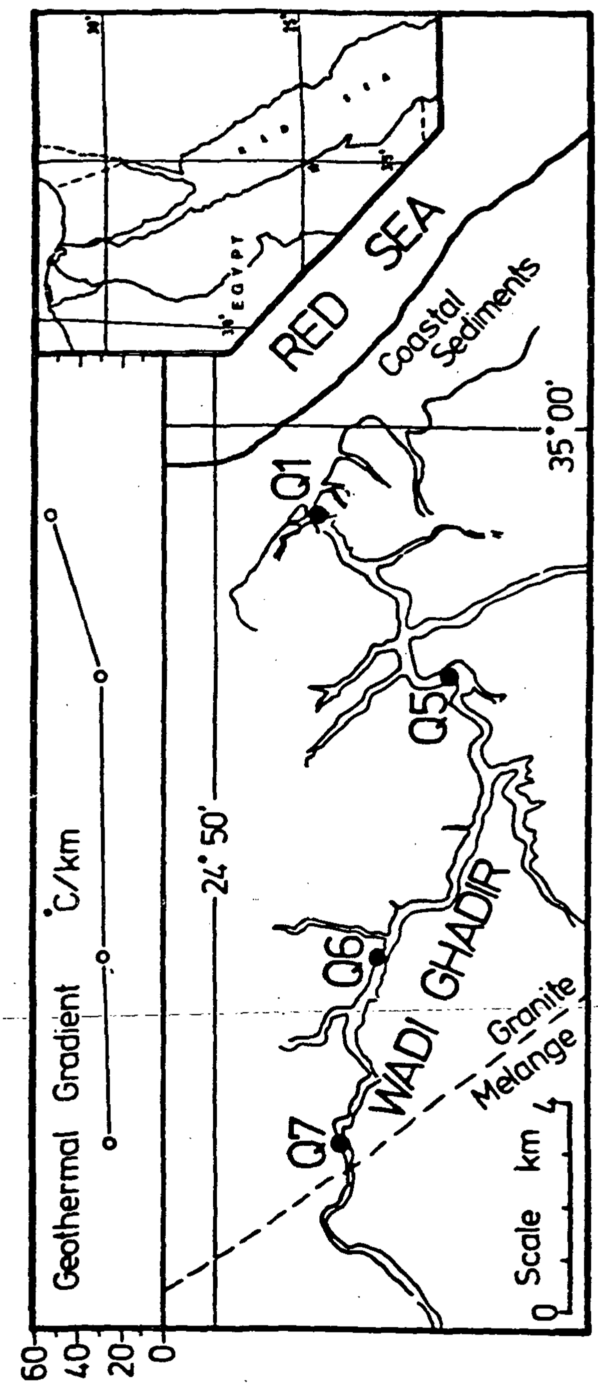

RED SEA
Coastal Sediments
35°00'
24°50'
Q1
Q5
Q6
Q7
WADI GHADIR
Granite
Melange
Scale km
0
4
Geothermal Gradient °C/km
60
40
20
0
EGYPT

FIG 2

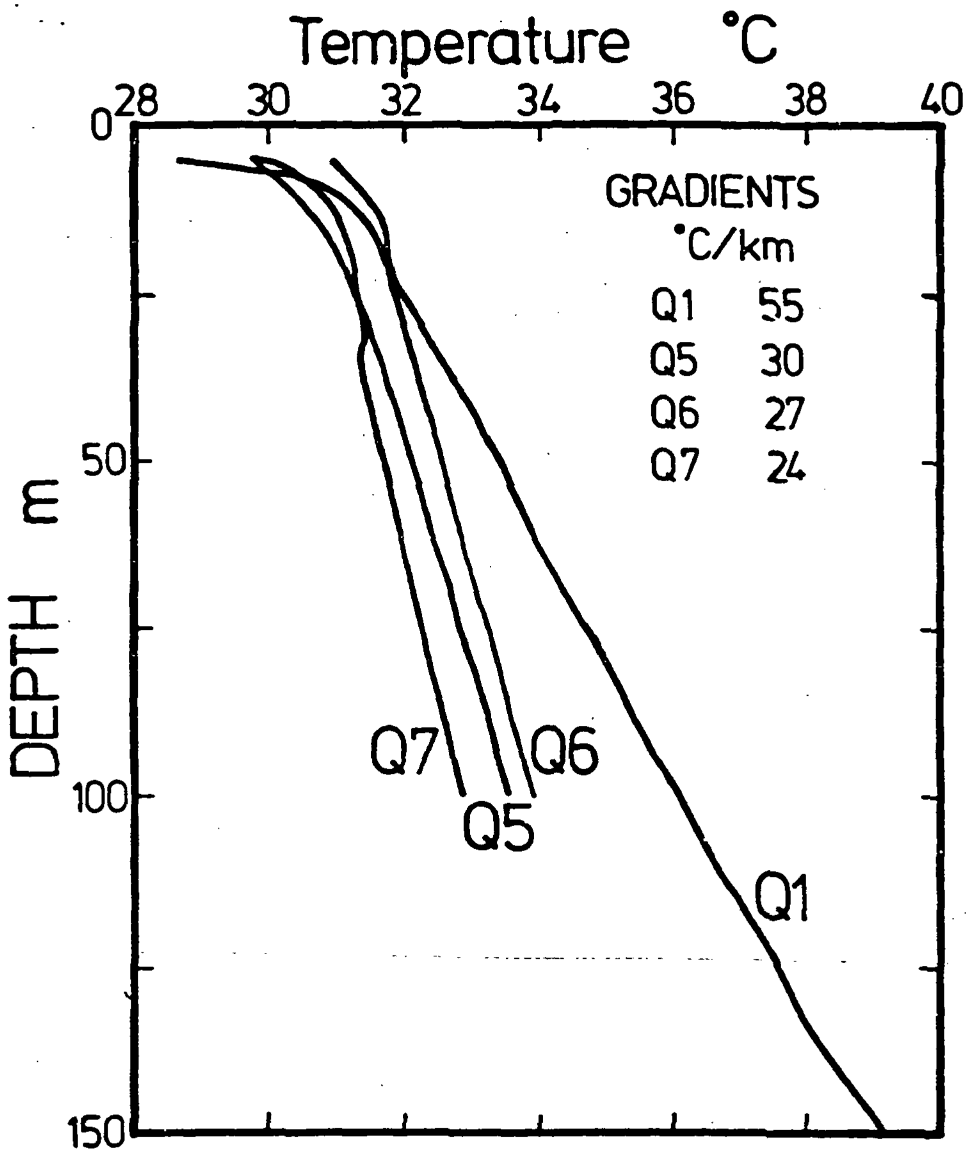
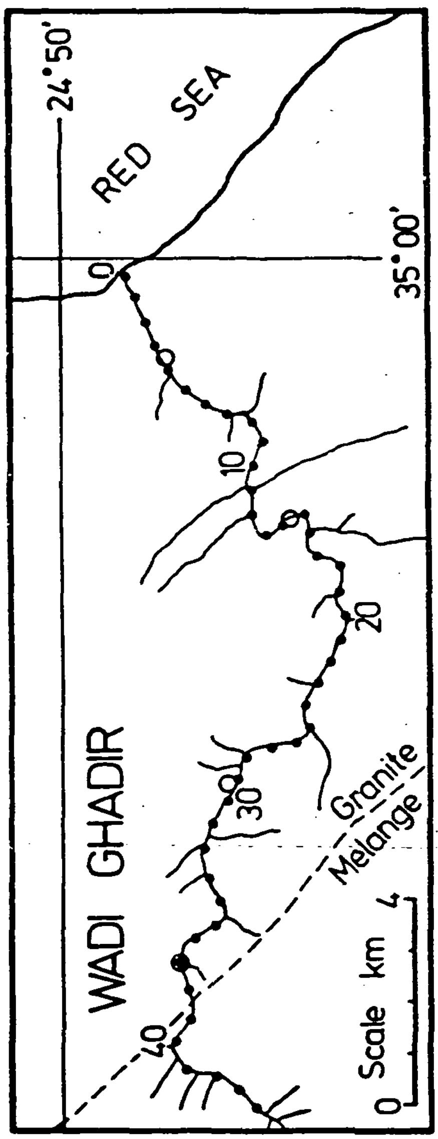

Temperature °C
28
30
32
34
36
38
40
0
50
100
150
DEPTH m
GRADIENTS
°C/km
Q1 55
Q5 30
Q6 27
Q7 24
Q7
Q6
Q5
Q1

FIG 3


WADI GHADIR
RED SEA
24°50'
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Melange
Scale km
0
4

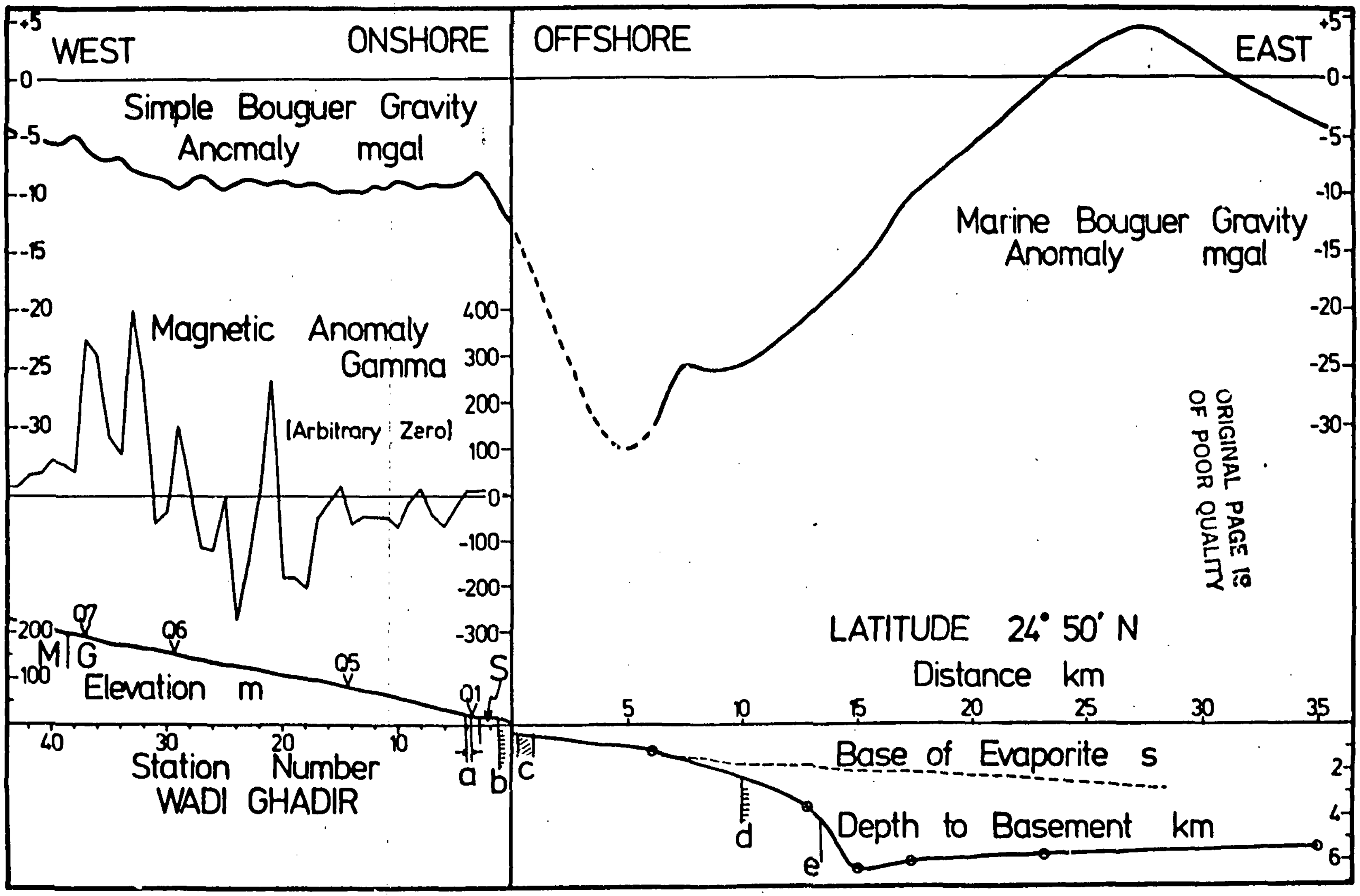
WEST
ONSHORE
OFFSHORE
EAST
Simple Bouguer Gravity Ancmaly mgal
Marine Bouguer Gravity Anomaly mgal
Magnetic Anomaly Gamma
(Arbitrary Zero)
M G
Q7
Q6
Q5
Q1
S
Elevation m
Station Number
WADI GHADIR
a
b
c
d
e
LATITUDE 24° 50′ N
Distance km
Base of Evaporite s
Depth to Basement km

FIG 4

FIG 5

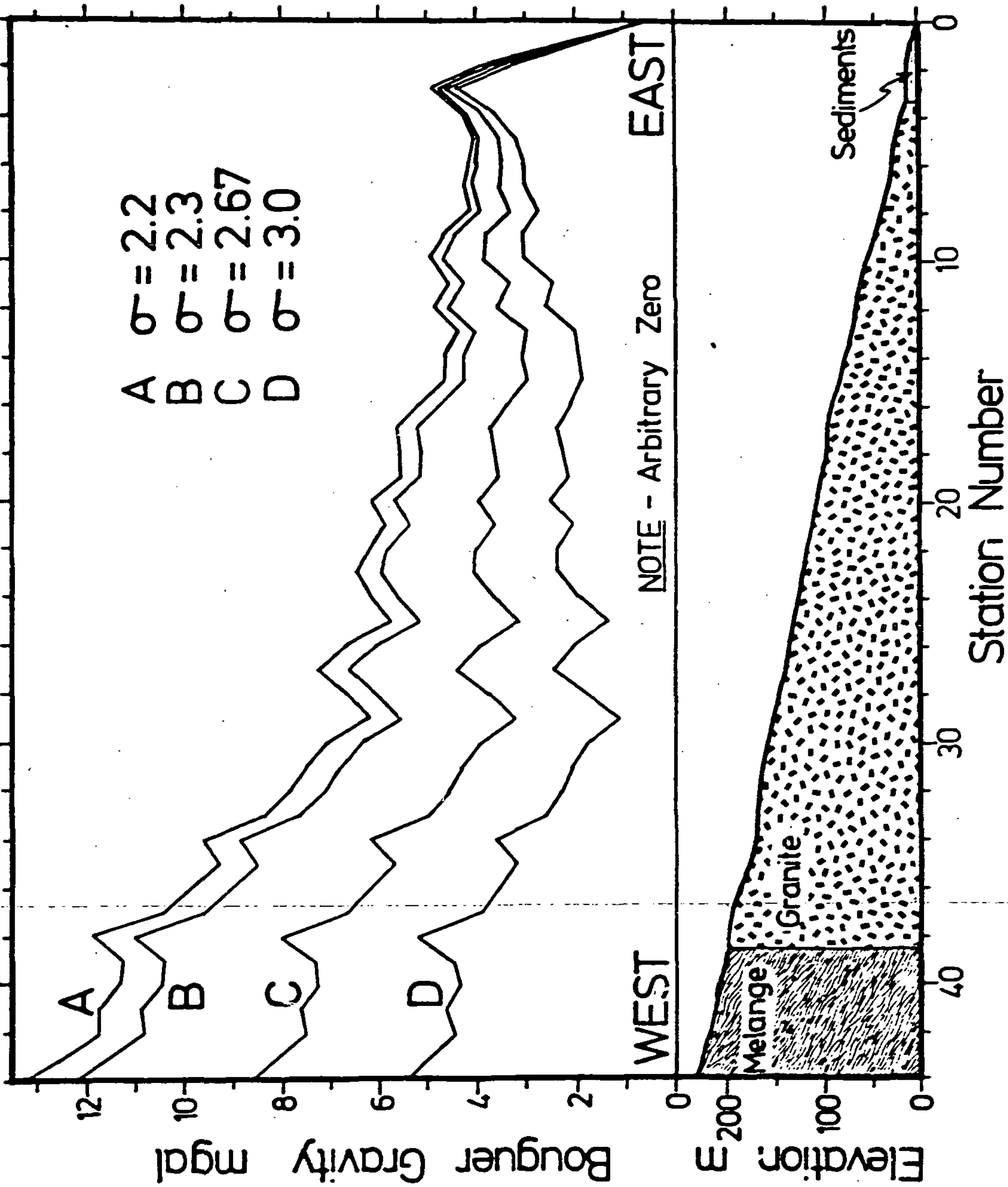
A σ = 2.2
B σ = 2.3
C σ = 2.67
D σ = 3.0
A
B
C
D
WEST
EAST
NOTE - Arbitrary Zero
Melange
Granite
Sediments
Bouguer Gravity mgal
Elevation m
Station Number
0
10
20
30
40
2
4
6
8
10
12
0
100
200

FIG 6

ORIGINAL PAGE IS
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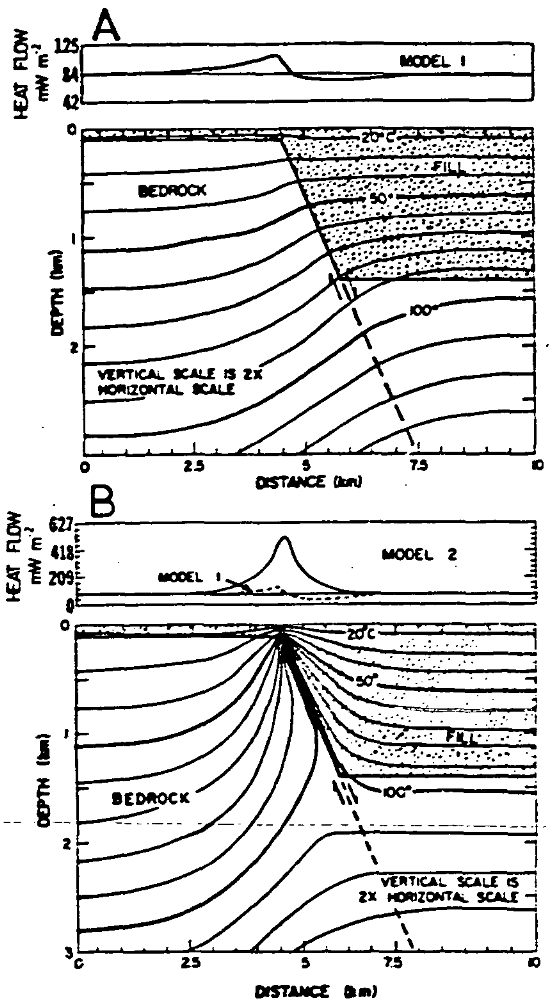

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STRUCTURE MODELS OF THE LOWER VERE PLAINS, JAMAICA

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Abstract

The results of a gravity survey from Harris Savannah to Portland Ridge have been used in conjunction with borehole information to construct models of the geological structure across the South Coast Fault Zone. Two models are presented here. The first explains the negative gravity anomaly across the Lower Vere Plains solely in terms of alluvium with a graben ($\sim$ 650 m required). The second model has a thinner alluvial layer ($\sim$ 100 m) within a graben with a total relief of about 2.5 km on the northern side and about 1.2 km on the southern side.

During 1977-78 thirty-nine new gravity stations were occupied in eastern Clarendon using the more widely spaced stations of the Andrew (1979) survey as reference stations. The object of this work was to provide data on the gravity anomaly that was thought might be associated with the South Coast Fault System which runs through the Lower Vere Plains. We present here an interpretation of the structure of this area that is consistent with these gravity data and the known geology.

GRAVITY MEASUREMENTS

The new measurements (Table 1) were made with a Worden gravimeter (Prospector Model 112). Station location uncertainties are very low; the area is covered with 1:12500 topographic maps with good photogrammetric control and most stations were sited at easily identifiable roadside features such as irrigation canals and crossroads where spot-heights (checked with a Paulin Terra altimeter) were available. The area is of very low relief and the terrain corrections were negligible for most stations.

ANOMALY MAPS

Both Free Air and Bouguer anomaly values were calculated. Figure 1, shows the Free Air anomaly map with the station numbers, whilst Figure 2, shows the Bouguer anomaly map. Datum for the Bouguer and terrain corrections is sea-level and a standard specific gravity of 2670 kg m^{-3} is assumed for all stations in contrast to Andrew who assumed local values for each station. In Table 1 we have corrected these stations to a standard S.G. for compatibility of these with the new data in the anomaly maps. The Free Air anomaly map shows that the general southerly gradient of gravity which dominates the southern side of the whole island of Jamaica (Andrew, 1969) is interrupted by the Lower Vere Plain gravity minimum. Because of the low topographic relief this pattern is little changed in the Bouguer anomaly map, which is very different from the Bouguer anomaly map for this region drawn by Andrew (1969). Andrew's map is drawn with a NE-SW gradient, but as can be seen from the new data this is incorrect. The ano-

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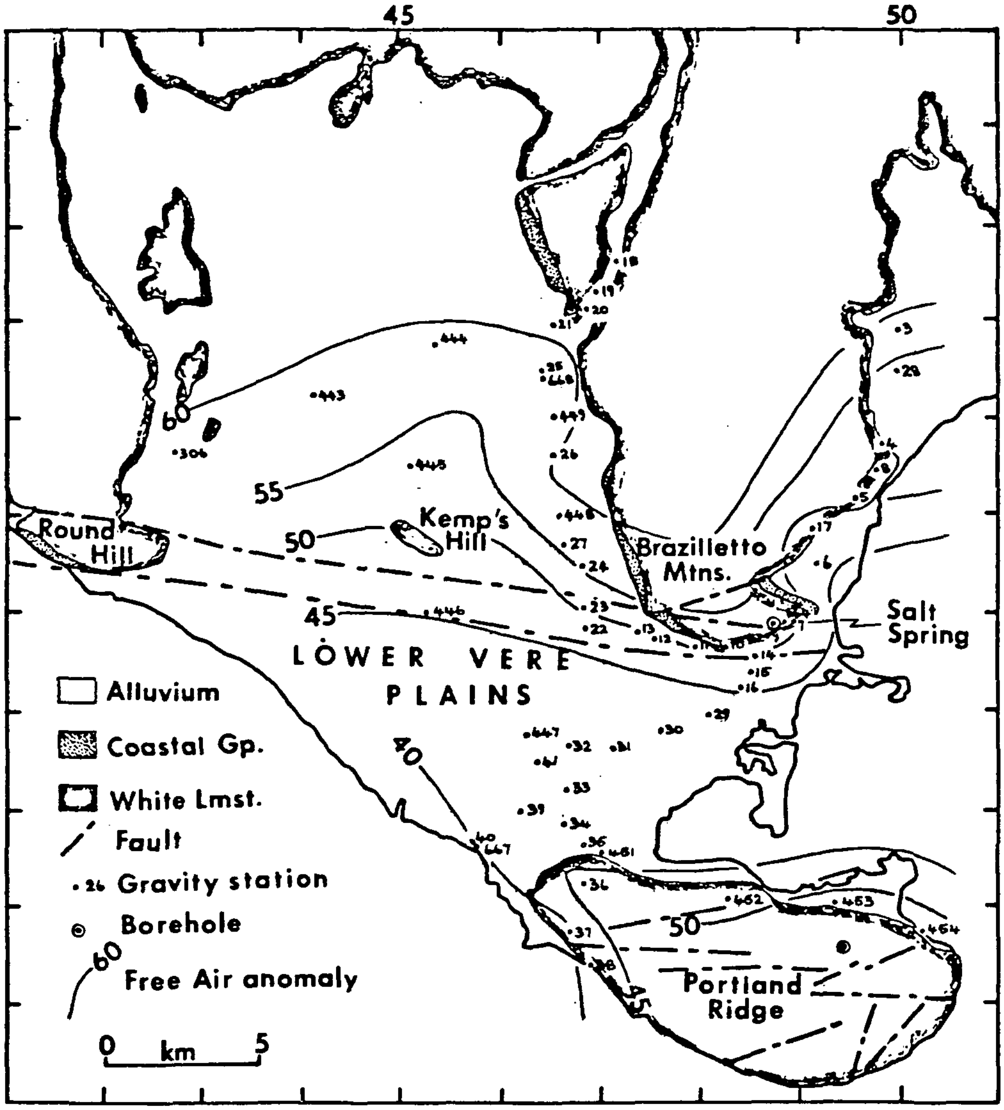

Fig. 1 Simplified geological map of the Vere plains of southern Jamaica with Free Air gravity anomalies contoured at intervals of 5 mgal. Faults are shown only for the southern half of the area.

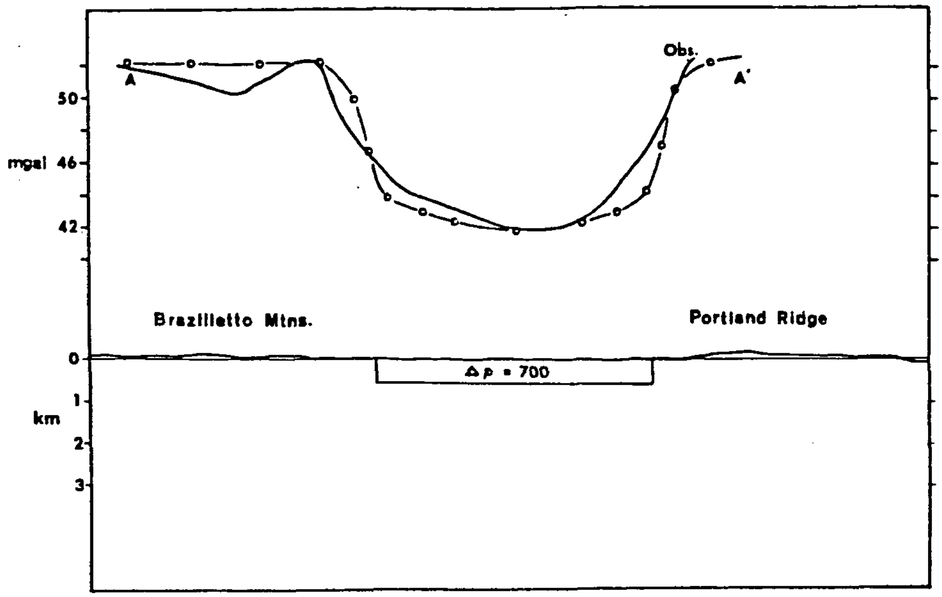

Fig. 3 Structure model corresponding to Bouguer anomaly profile A-A'.

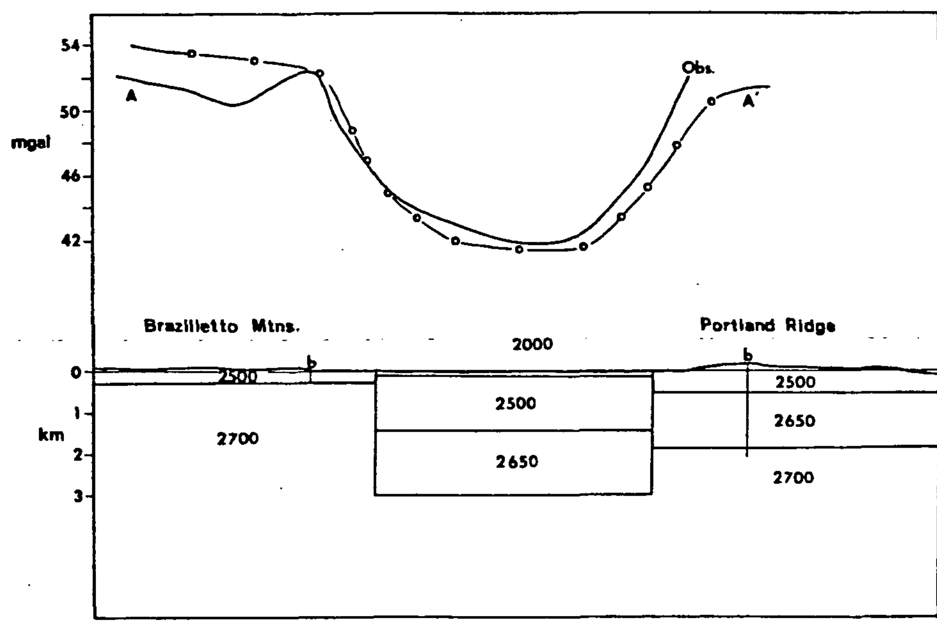

Fig. 4 Structure model corresponding to Bouguer anomaly profile A-A'. Specific gravities are in units of kg m^{-3}, b indicates Salt River and Portland Ridge boreholes.

TABLE 1. GRAVITY READINGS IN SOUTHEASTERN CLARENDON, JAMAICA

Station	Grid Ref.	Height (ft.a.s.l.)	Observed Gravity (mgal)	Free Air Anomaly (mgal)	Bouguer Anomal (mgal)
UWI 3	4999 3688	37	978589.8	56.9	55.7
UWI 4	4984 3566	39	978583.8	52.9	51.7
UWI 5	4951 3512	20	978582.6	50.6	50.4
UWI 6	4918 3444	6	978577.8	45.4	45.3
UWI 7	4891 3389	10	978581.6	50.3	50.8
UWI 8	4973 3541	20	978584.8	52.3	51.8
UWI 9	4863 3372	15	978584.0	53.4	53.3
UWI 10	4826 3362	32	978579.6	50.8	50.2
UWI 11	4793 3361	51	978576.8	49.8	48.4
UWI 12	4751 3367	39	978576.3	48.1	47.0
UWI 13	4725 3371	43	978575.7	47.8	46.5
UWI 14	4851 3349	11	978579.8	49.2	49.0
UWI 15	4845 3335	11	978577.6	47.2	46.9
UWI 16	4834 3319	10	978576.1	45.8	45.5
UWI 17	4910 3482	9	978582.3	49.6	48.8
UWI 18	4709 3705	220	978585.4	68.8	61.4
UWI 19	4645 3722	199	978585.2	67.1	60.4
UWI 20	4679 3702	215	978582.9	66.5	59.3
UWI 21	4649 3690	183	978581.3	62.1	55.9
UWI 22	4633 3373	50	978574.8	47.5	45.8

447*	4625 3275	30	978571.2	43.6	42.6
448*	4657 3494	104	978583.0	59.2	55.7
449*	4649 3601	138	978580.2	58.0	53.4
451*	4702 3155	6	978570.5	42.4	42.2
452*	4821 3105	9	978573.4	46.3	46.4
453*	4932 3104	6	978579.5	52.1	52.5
454*	5021 3077	2	978578.6	51.2	51.4
664*	4883 3388	6	978583.5	52.0	52.4
667*	4572 3163	147	978568.8	40.2	40.1
668*	4642 3634	2	978579.6	57.8	52.8

* Andrew (1969) station

TABLE 2. SPECIFIC GRAVITY DETERMINATIONS OF ROCKS FROM SOUTHEASTERN CLARENDON

Rock type	S.G. (kg m^{-3})	No. of samples
Alluvium	1700	2
Coastal Group	2410	2
Newport Fm.	2490	3
Partly dolomitised Newport Fm.	2520	3
Totally dolomitised Newport Fm.	2600	1
Tertiary Limestones (Andrew,1969)	2610 (2510-2670)	10