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Geophysical and Structural Aspects of the Central Red Sea Rift Valley

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Geophysical and structural aspects of the central Red Sea rift valley

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Eight aeromagnetic traverses were flown recently across the Red Sea at the latitude of about 21°. The data showed a high-amplitude axial trough anomaly trending northeasterly that terminated near the northern edge of the survey area. A second high-amplitude anomaly was observed to trend northwesterly beginning immediately west of the 1000 m bathymetric contour. Depth estimates to the upper surface of the very magnetic rock units was estimated to be about 2 km. The three deep hot brine areas seemed to be related to the steep gradients of the large axial trough anomaly. A third low-amplitude anomaly trending northwest into the Red Sea from the land area south of Jeddah appeared to have a much deeper source. This anomaly possesses the same trend as numerous dykes, faults, and magnetic trends observed in the Arabian shield rocks.

Introduction

Eight aeromagnetic profiles covering a 42 km wide belt were flown across the Red Sea at the latitude of Jiddah. The data is here reviewed in the light of present knowledge, especially along the eastern side of the Red Sea.

Summary of structural geology

The eastern shore of the Red Sea is underlain by Pleistocene coral reefs underneath which is a thick series of evaporite-derived rocks mostly halite. These deposits were discovered near Jeddah in 1938, when wells were drilled in a search for drinking water. A short distance east of Jeddah, 10 km east of the shore, the crystalline rocks of the Afro-Arabian shield crop out in low foot hills and extend eastward for 200 km. Mainly of younger Precambrian age, the shield is none the less cratonized and crystalline; and its bifurcation formed the Red Sea rift valley. The crystalline rocks were bevelled at the end of the Pan African event, then exhumed and bevelled further, the last time during mid-Tertiary and continuing up to the present. The Red Sea was formed during the Miocene and at which time the crystalline rocks as well as younger Phanerozoic sediments and lava flows were ramped up. The ramping occurred along old Precambrian wrench faults as the *en échelon* blocks were tilted in a simple hinge action with very little actual displacement.

Within the Red Sea trough the exposed rocks west of the shield are Tertiary, chiefly Miocene, with a fringe of younger Pleistocene coral reefs (see figure 1). Some upper Jurassic (Bathonian to Kimmeridgian) limestone is broken off into the rift at the Yemen–Saudi Arabian border. In the south the Miocene rocks have been called the Baid formation because they are mostly non-marine and are exposed in Wadi Baid where they were first studied.

Farther north at the latitude of Yenbo and beyond the marine aspects predominate and we use the term Ragama from Jebel Ragama on the eastern shore of the Gulf of Aqaba where the marine clastics as well as evaporties and limestone are best exposed (see figure 2).

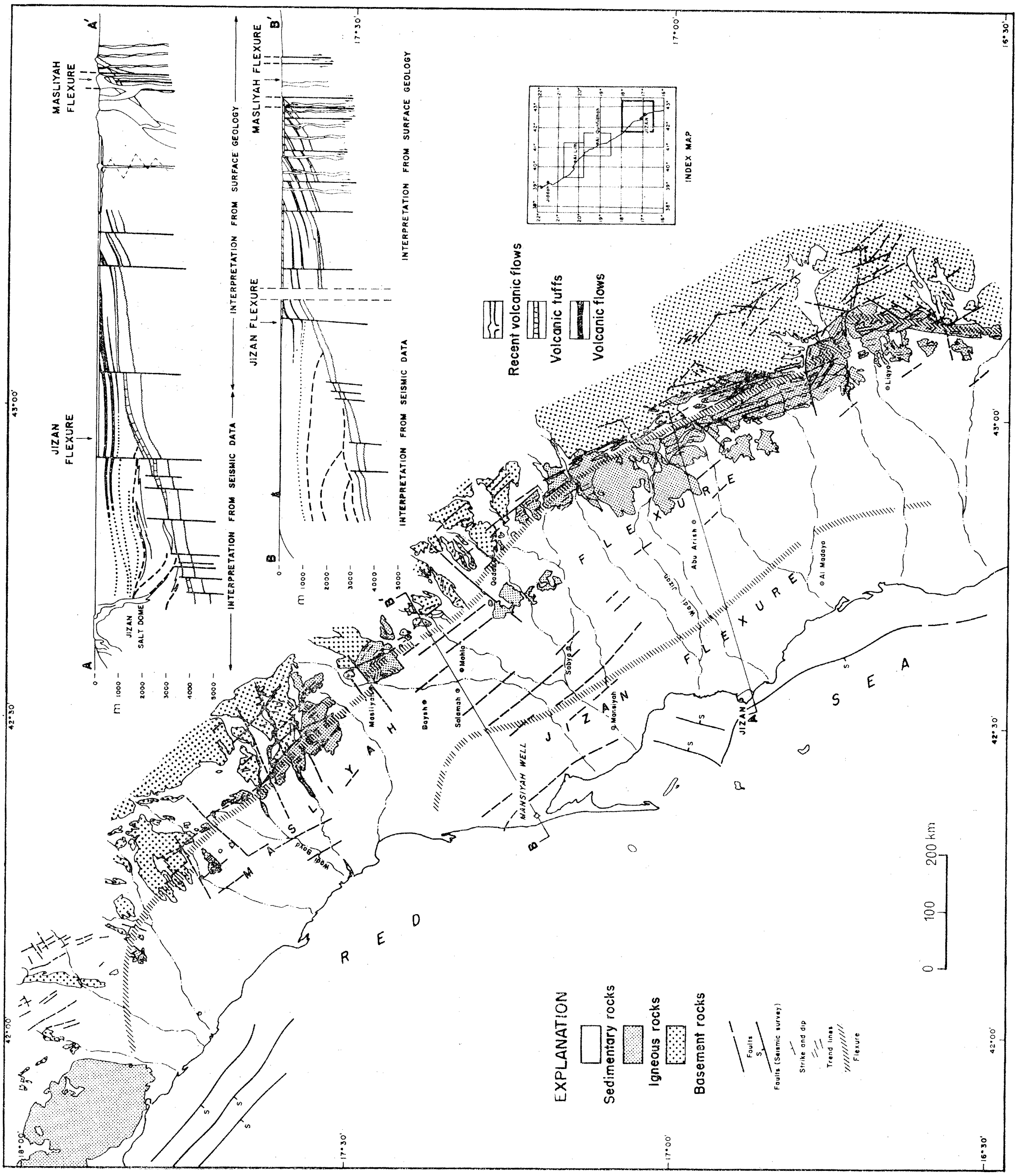

FIGURE 1. Structural map of the Jizan coastal plain (after Michel Gillman, Aramco.)

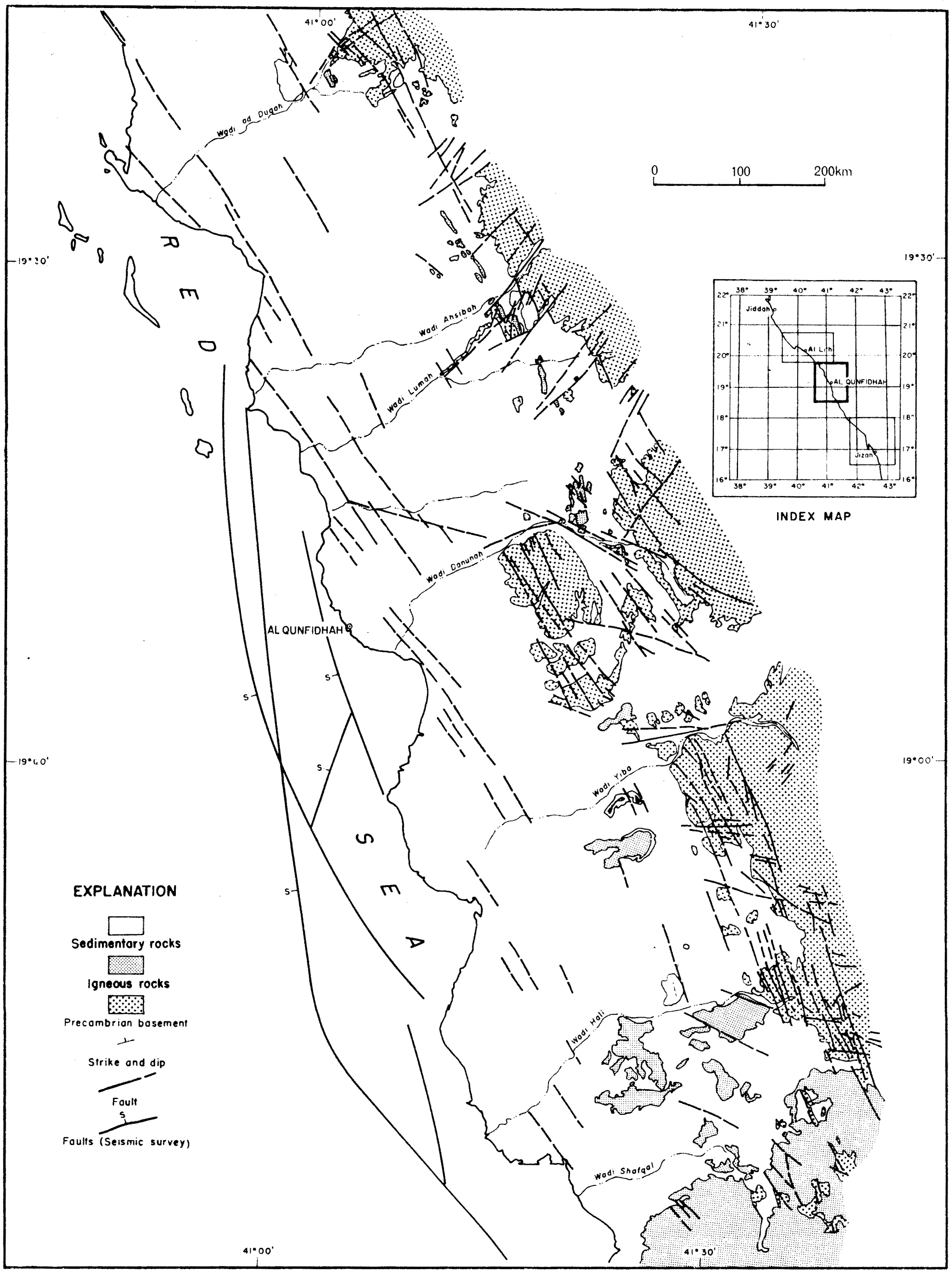

Figure 2. Structural map of the Al Qunfidhah coast (after Michel Gillman, Auxerap).

Aeromagnetic survey

It is well known that total intensity magnetic data is a most useful tool for the geologist in the shield areas. The magnetic lineations often provide, for example, a reliable means of tracing faulting through areas masked by a thin veneer of alluvium. Similarly, dyke systems may be delineated by their magnetic characteristics as well as volcanic flows, ring dykes, and igneous intrusives. Figure 3 shows the linear trends of magnetic anomalies, mapped by the airborne

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magnetometer in the Saudi Arabian shield. One may observe at least four categories of magnetic anomaly trends: (1) The Najd fault system (N 50° W), (2) The Red Sea fault system (N 30° W), (3) The north–south system, and (4) The northeast system. We would, therefore, expect to see in the magnetic data of the Red Sea patterns characteristic of faulting and igneous intrusions as we see directly over the exposed Shield rocks.

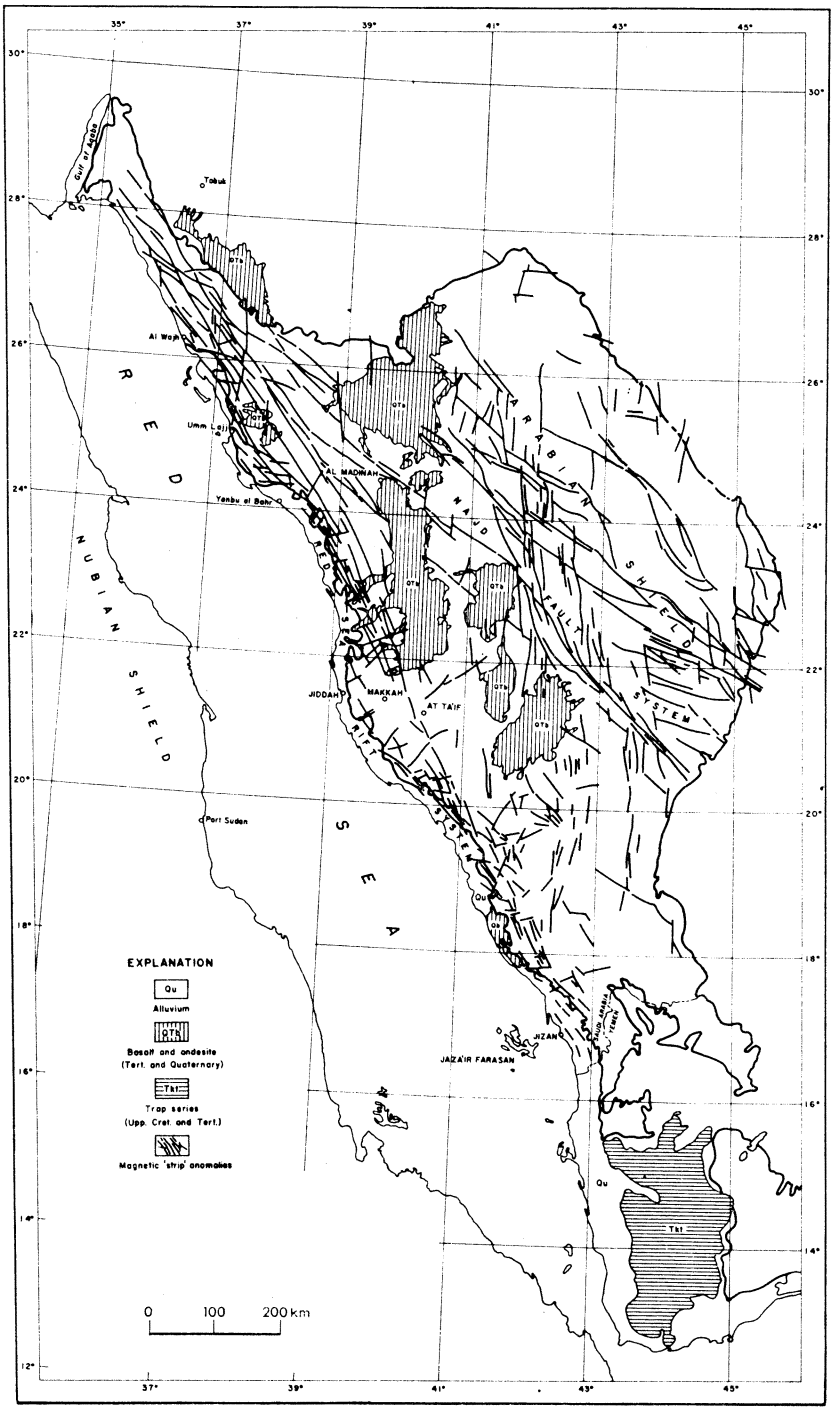

FIGURE 3. Linear magnetic anomalies of the Arabian Shield (after D. Hase, U.S.G.S.).

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During January 1969, an aeromagnetic survey of the central Red Sea rift valley was made. It was expected that the resulting data would extend the knowledge of the shield rocks to the water-covered areas beneath the Red Sea. It was especially desirable to extend the traverses from the Precambrian crystalline rocks on the African continent across the rift valley to the shield rocks of the Arabian peninsula. A further purpose of the survey was to investigate the relation, if any, between the hot brine 'deeps' and the magnetic field.

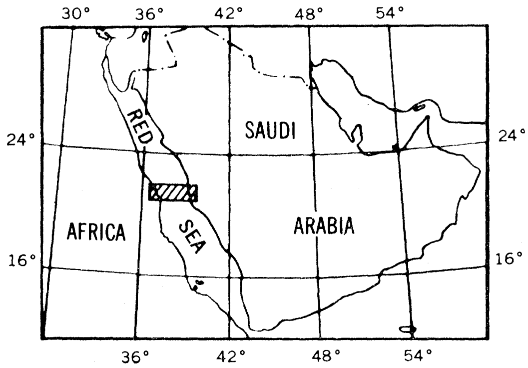

FIGURE 4. Index map showing location of aeromagnetic survey.

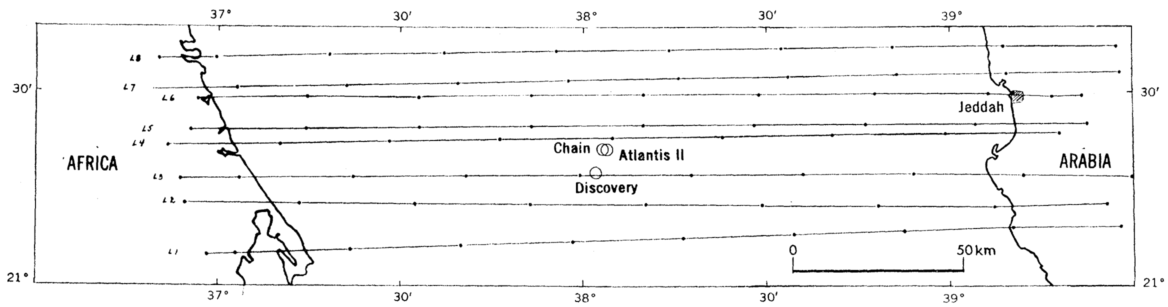

FIGURE 5. Flight line location map of area. ○, location of 'deeps'.

The location of the present survey area is shown in figure 4. Eight traverses, spaced approximately 7 km apart, were flown at a flight elevation of 300 m. The survey was made by A.R.G.A.S under contract to the U.S. Geological Survey and the Ministry of Petroleum and Mineral Resources project. The magnetic data, were obtained from a caesium-vapour magnetometer aboad a converted B-17 aircraft. A doppler navigation system was used for pilot guidance. Since documentation points exist only over land areas, the doppler navigator must rely on memory for most of the traverse. Further, sea state is directly related to effectiveness of the navigation system: a smooth sea, means a greatly reduced return signal and poorer positioning. For these reasons the flight path may be in error by perhaps 1 km or more.

Figure 5 shows the location of the eight traverses. It may be noted that the traverses are essentially in an east–west direction, between the latitudes of 21° and 21° 40′ N. The circles in the centre of the survey area denote the locations of *Chain*, *Atlantis* and *Discovery* 'deeps'. Only one traverse (L 3) is shown to cross the *Discovery* deep.

The eight aeromagnetic profiles are shown in figure 6. These profiles are nested north to south and are referred to a common relative datum. The vertical scale, in nT (gammas), is shown along either edge of the illustration. The African and Arabian coast lines are indicated on each profile by an arrow. Longitude 38° E was chosen as a reference and the 1000 m bathymetric contour is indicated on each profile by the inverted arrow.

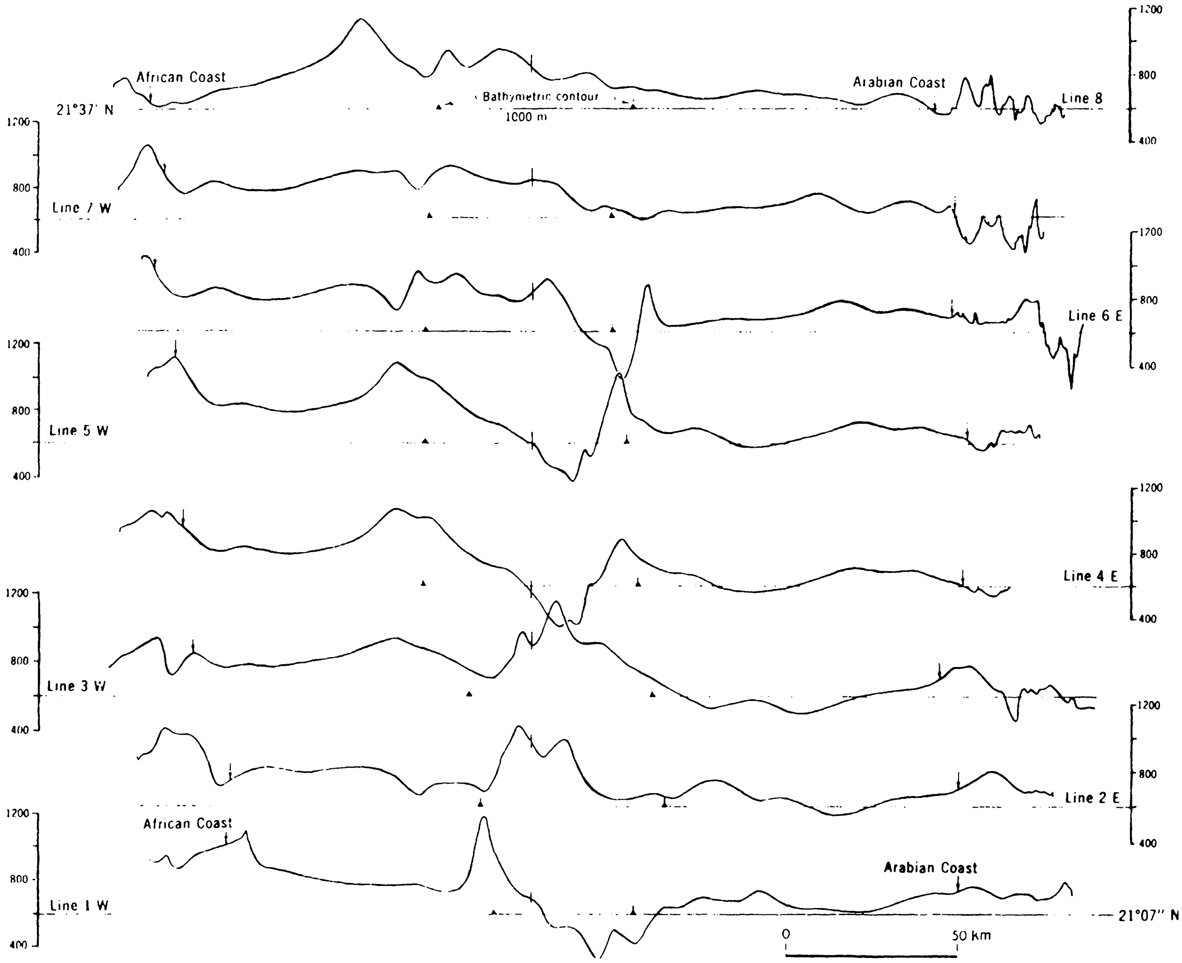

FIGURE 6. Aeromagnetic profiles across the Red Sea. The flight elevation was 300 m. The units are nanoteslas (gammas).

MAGNETIC FEATURES

The total intensity magnetic profiles show a number of significant anomalies, many of which may be correlated from line to line. The axial trough anomaly, a dominant feature near the centre of the survey area, appears on lines 1 to 6. It is seen to have a northeasterly trend that seems to cut across the 1000 m bounds of the trough. The average amplitude is approximately 700 nT. The anomaly has little or no expression in the upper two lines (L 7, L 8), so that one may conclude that the source terminates near line 7.

Another large-scale magnetic anomaly can be followed from line 3 to line 8 just west of the 1000 m contour, though the character changes somewhat on lines 6 and 7. This prominent magnetic feature was not anticipated.

The character of the magnetic pattern from the Arabian coast inland is noticeably different. The relatively high frequency, lower amplitude anomalies are characteristic of the exposed shield rocks in this area. These high-frequency anomalies terminate abruptly at or near the edge of the exposed shield rocks. On the African side an anomaly of approximately 300 nT with a northerly trend is observed about at the coastline. This anomaly can be followed on all flight traverses and is, in general, of larger amplitude than the anomalies over the Arabian shield rocks.

Returning to the Arabian side, a smaller, but very interesting anomaly trend may be seen, beginning inland south of Jeddah at least on line 2 and trending northwesterly to at least line 7, though it is somewhat obscure on line 4. Finally, the magnetically flat areas, on either side of the central anomalies seem to be characteristic of large north-trending areas beneath the sea. But, though both areas have 'smooth' magnetic features, they nevertheless differ from one another: the Arabian side is noticeably more magnetic.

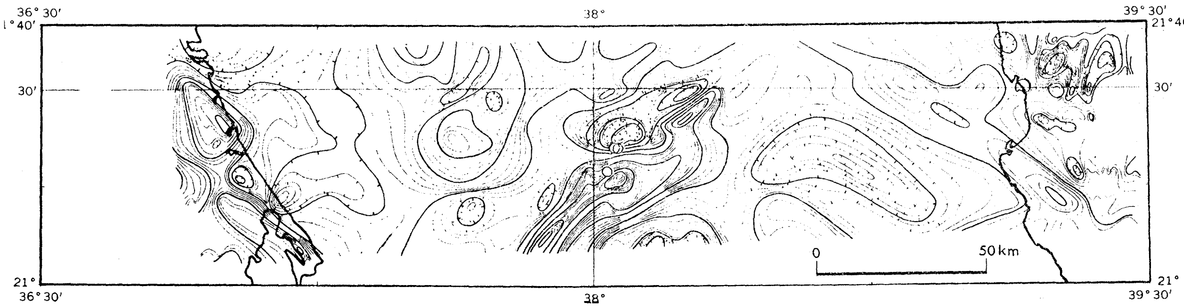

Figure 7. Preliminary total magnetic intensity map of the Red Sea area. ○, location of 'deeps'; contour intervals 20 and 100 nT.

The several magnetic features that appear on these profiles are more apparent when contoured. Figure 7 shows such a contour map. The contour interval is 20 nT and the index contours are 100 nT. The main axial trough anomaly, clearly trends northeasterly. Again, the circles denote the location of the 'deeps' and are seen to be positioned beneath the magnetic gradients. However, as previously mentioned, errors in flight line locations may alter this relation somewhat. The second largest magnetic feature trends in a north-northwesterly direction immediately west of 38° E longitude. The African coast anomaly, is well defined as are the high-frequency anomalies characteristic of the shield in the northeast of the map in Saudi Arabia.

One of the more interesting magnetic features that was evident on the nested profiles is clearly seen to trend northwesterly from the southeast corner of the survey area.

Interpretation of anomalies

The main axial trough anomaly has been observed and discussed by several investigators, including Allan, Charnock & Morelli (1964), Drake & Girdler (1964), Knott, Bunce & Chase (1965), and Vine (1967). This anomaly is generally believed to be produced by basic intrusives of high magnetic susceptibility along the main axial trough. The anomaly apparently does not extend north of 24° latitude according to Girdler. The recent survey shows the trend of this anomaly to be nearly northeasterly, and, further, that it does not appear to parallel the main axial trough. In addition, this anomaly whose source is calculated to be approximately 2000 m below sea level terminates near the northern boundary of the survey area about 21° 37′ N latitude. It seems significant that another magnetic anomaly located immediately to the west of 38° E longitude and having amplitudes only slightly less than the main axial trough anomaly trends north-northwesterly, apparently on the shallow side of the 1000 m contour. Depth calculations here place the upper surface also at a depth of roughly 2000 m. A rather basic intrusive block very likely is producing this anomaly.

As previously pointed out, the high-frequency anomalies observed over the Arabian shield rock units terminate abruptly very near the edge of this exposure. It must be concluded that these anomaly-producing rocks are either absent immediately to the west or have been down-faulted so that they are now covered by a considerable thickness of essentially non-magnetic sedimentary rocks. The Mansiyah well no. 1, drilled 600 km south of Jeddah to the depth of 3931.6 m terminated in infra evaporite series composed of shale containing conglomerate, silt, and sandstone. An unknown thickness of these sediments overlying the Precambrian, thus places the top of the Precambrian certainly in excess of a depth of 4 km. Depth estimates to the upper surface of the disturbing body based on several magnetic profile gradients suggest that the Precambrian rocks in the survey area may be buried as much as 4 to 6 km.

Returning once again to the west side of the Survey area, the African coast magnetic anomaly is interpreted to be caused by a disturbing mass present under a rather thin cover of sedimentary rocks. Only the southernmost lines reached the outcrops of Precambrian igneous and metamorphic rocks. However, these shield rocks are very likely deeply buried immediately east of the outcrop area. A well drilled at Ras Abu Shagara encountered Precambrian rocks at about 2000 m, according to Carella & Scarpa (1962). About 40 km to the north along the coast (near midway of the Survey area) small outcrops of basalt are mapped. There seems little doubt that the African coast magnetic anomaly is produced by an extensive zone of basalt that is mostly obscured by a thin cover of sedimentary rocks.

In the Arabian shield area southeast of Jeddah numerous dykes trending northwesterly have been mapped by Brown and others. The magnetic anomaly that possesses this same trend from the southeast corner of the map area might represent an extension of one or more dykes out into the Red Sea. It is quite evident that the body producing the anomaly is deeply buried beneath the coastal plain south of Jeddah and even more deeply buried beneath its extension into the Red Sea.

Conclusion

These few magnetic traverses across the central Red Sea rift valley have provided a truly considerably amount of data. It is especially helpful to have complete and continuous magnetic profiles from shield to shield along fairly closely spaced flight lines so that the many trends relating to the tectonic structure of the Red Sea rift valley may be delineated. It is entirely possible that other 'deeps' may be discovered along the trends of the large amplitude, steep-gradients magnetic anomalies that are characteristic of the axial trough.

The usefulness of magnetic data in crustal studies has been well demonstrated in both continental and oceanic areas. Unquestionably an aeromagnetic survey of the entire Red Sea rift valley would be most valuable.

It has been said that an abundance of magnetic data already exists and there is little value in gathering more. It appears from this survey that it will be more enlightening to have the present aeromagnetic survey extended both north and south at the same flight line spacing as far as practical; extending the traverses across the entire Red Sea rift valley.

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