J KAU: Earth Sci., vol. 5, pp. 123-137 (1412 A.H./1992 A.D.)

A Gravity and Magnetic Study of the Arba'at Area, Red Sea Hills, Sudan

WARIS E.K. WARSI*, DAVID C. ALMOND** and ABDULAZIZ A. OSMAN***
*Department of Earth Sciences, Sultan Qaboos University, Muscat, Oman,
**Institute of Fundamental Studies, Kandy, Sri Lanka and
***Department of Geology, University of Kuwait, Safat, Kuwait

ABSTRACT. Detailed gravity and magnetic measurements made in Khor Arba'at and the adjoining coastal plain region provide a better definition of the near surface geological features. The Nakasib Shear Zone (NSZ), which represents a reworked suture between two island arcs, is characterized by a gravity low and exhibits a lack of magnetic anomaly. The edges of NSZ, however, display magnetic anomaly associations where the shear zone rocks present a substantial magnetic susceptibility contrast with the surrounding rocks, such as ophiolites. The post-tectonic intrusion of the Arba'at granite has a well defined gravity low which suggests a westward extension of the granite body into the shear zone rocks. The main Arba'at intrusion is estimated to be about 6 km thick. The coastal plain basin containing Mid-Tertiary and younger sediments appear to be laterally segmented by the subsurface relief of the Proterozoic basement. Gravity data suggest a local thickening of sediments in the southern part of the area. Evidence for a regional subsurface fault offsetting the Cenozoic sediments beneath the Recent sediments of the coastal plain is lacking.

Introduction

Regional studies in the Red Sea Hills have outlined the regional characteristics of this important segment of the Red Sea continental margin. Among others, a notable integrated study was carried out in the 1970s under the Soviet-Sudanese Red Sea Hills Project, with extensive gravity and magnetic mapping of the region (e.g. Isaev *et al.* 1974). Although geophysical studies of the Red Sea Hills, particularly gravity, have been useful in mapping the large scale structures (Qureshi 1971, Isaev *et al.* 1974), they often do not provide information on smaller features, apparently due to large station spacings used in field surveys. For example, the regional gravity map of Red Sea Hills prepared from the data of Soviet-Sudanese Project, shows a lack of anomaly over the Arba'at granite (Isaev *et al.* 1974). In this area, the field measurements were made with a station interval of about 8-10 km. However, the traverse of Sadig *et al.* (1987) made with smaller station intervals revealed, for the first time, a gravity low associated with the Arba'at granite.

The area of Khor Arba'at and adjoining coastal plain, located to the north/northwest of Port Sudan (Fig. 1), is the focus of an integrated study under a research prog-

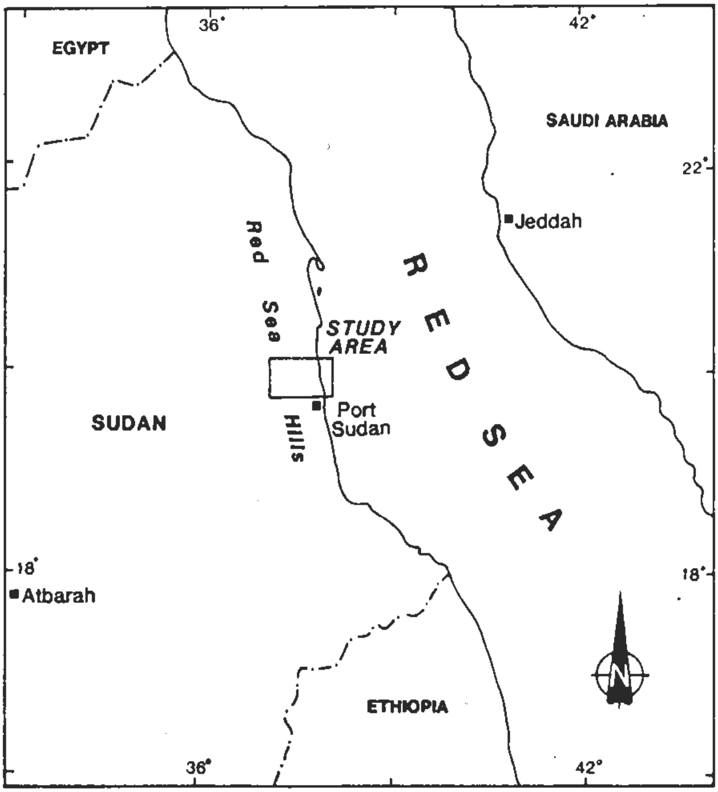

FIG. 1. Location map.

ramme funded by the University of Kuwait. As part of this project, a detailed gravity and magnetic survey with closely-spaced stations was carried out in the area. The main objectives of the survey were to examine the shallow crustal structure and to compliment the geological investigations. In addition to confirming the earlier findings, this study provides new information on the Arba'at granite, Nakasib Shear Zone, and the coastal plain.

Geology of the Area

The Red Sea margin in Sudan is a young passive continental margin. The geologically complex Late Proterozoic terranes of the Arabian-Nubian Shield which compose this region are believed to have evolved by accretion of island arcs (Vail 1985) and were subsequently overprinted by Cenozoic trends related to opening of the Red Sea. A generalized geological map is given in Fig. 2. Late Proterozoic rocks occupy

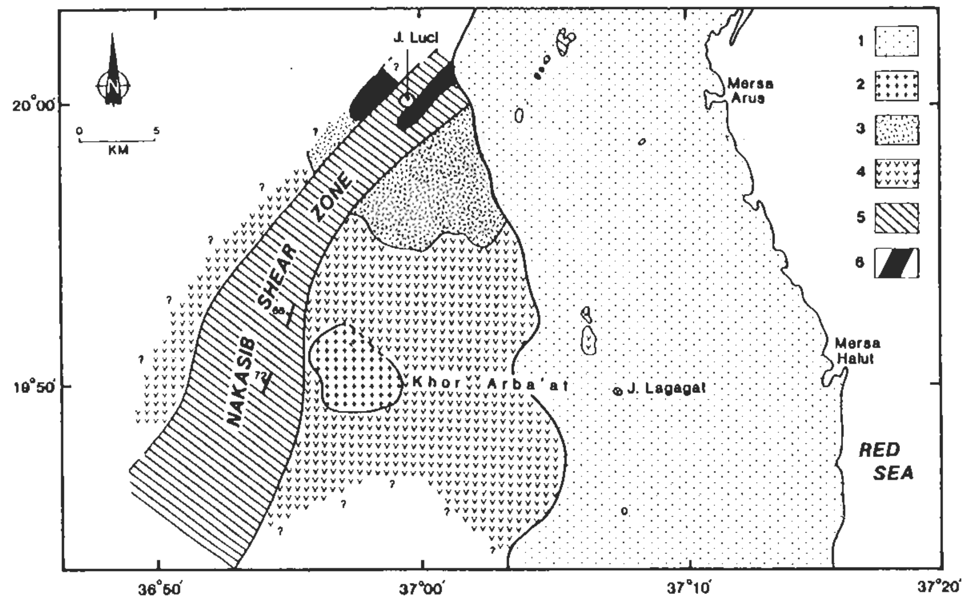

FIG. 2. A generalised geological map of the study area. 1-coastal plain sedimentary cover, 2-Arba'at granite, 3-batholithic granite, 4-volcanics (basic to acidic) and related sediments, 5-mylonitized volcano-sedimentary and intrusive rocks of the NSZ. Northeasterly trend and subvertical nature of the NSZ can be noted from the dips and strikes shown. Several inliers of Proterozoic basement are observed in the coastal plain.

most of the area, but along the coastal strip they are covered by sediments of Mid-Tertiary and younger ages.

The oldest group of rocks is a volcano-sedimentary sequence flanking the NSZ. These are island arc generated calc-alkaline rocks varying in composition from basic to acidic but predominantly of intermediate composition. They have been subjected to weak greenschist facies regional metamorphism but are little deformed. The volcano-sedimentary suite is intruded by syn- to late-tectonic batholithic granitoid rocks containing numerous dykes.

The NSZ marks the line of a reworked suture between two accreted arcs and is associated with lenses of ultramafic and mafic rocks, suspected to be dismembered ophiolite complexes. Severe deformation by folding and shearing characterizes the

NSZ, but this deformation was completed before 700 Ma (Almond *et al.* 1990). Much younger than the shearing is the prominent post-tectonic intrusion of the Arba'at granite, which has been dated at about 552 Ma (Almond *et al.* 1990).

The eastern part of the area is a 20 km wide coastal strip forming a low relief plain underlain in part by Tertiary sediments, but mainly composed of unconsolidated Recent deposits. These rocks rest with strong unconformity on the Proterozoic basement. Apparently, the basement lies at shallow depths beneath the coastal plain, as evidenced by small inliers of Proterozoic rocks, such as Jebel Lagagat (Fig. 2). The Tertiary sediments are largely of Miocene age and are dominated by clastic marine limestones and evaporites. They outcrop around Khor Eit (20°10'N; 37°10'E), near the northern limit of the area, and in a series of small hills which exhibit north-south alignment and low seaward dips. These features probably indicate fault control (Gass 1960). An appreciable thickness of these sediments may underlie parts of the coastal plain, bounded on the west by a fault, or faults related to extension within the Red Sea basin.

Field Survey and Reduction of Data

Regional gravity and magnetic measurements were made in the Arba'at area during January, 1989, and a total of 69 stations were established with spacings of 1-2 km. Gravity observations were made using a Master Model Worden gravimeter (Serial No. 111) with a dial constant of 0.0925 mgal/division. The calibration of the gravimeter was checked and confirmed in Kuwait prior to measurements in Sudan (Warsi 1989). The stations were located on 1:100,000 topographical maps. Elevations were determined using two Pauline precision altimeters and were referred to bench-marks available in the area.

Gravimeter observations were reduced by applying corrections for the lunar and solar tides (Longman 1959) and for instrumental drift. Gravity values were computed in the IGSN71 system by using "Port Sudan K" base station value of 978,625.99 ± 0.026 mgal (Morelli *et al.* 1974). A maximum error of ± 0.20 mgal is estimated in the observed gravity. Average accuracy of altimeter observation is of the order of ± 3.0 m. Maximum station location errors are estimated to be ± 250 m.

Gravity anomalies have been computed with reference to the International Gravity Formula 1967 (IGSN 1971). Bouguer anomalies (BA) are based on a slab density of 2.67 g/cm^3. No corrections have been applied for the terrain and curvature of the earth. An overall accuracy of ± 0.30 mgal is estimated for the Bouguer anomalies.

Magnetic measurements were made using a Scintrex proton precession magnetometer. Total field magnetic anomalies are based on the geomagnetic reference field model IGRF85 (IAGA 1988). No diurnal correction has been applied. Repeat observations during the field work suggested the diurnal variations of less than 25nT.

Regional Geophysics and Geological Correlations

In the compilation of the Bouguer anomaly map (Fig. 3), the newly acquired data were supplemented with data from the Soviet-Sudanese Project. Notice that the BA

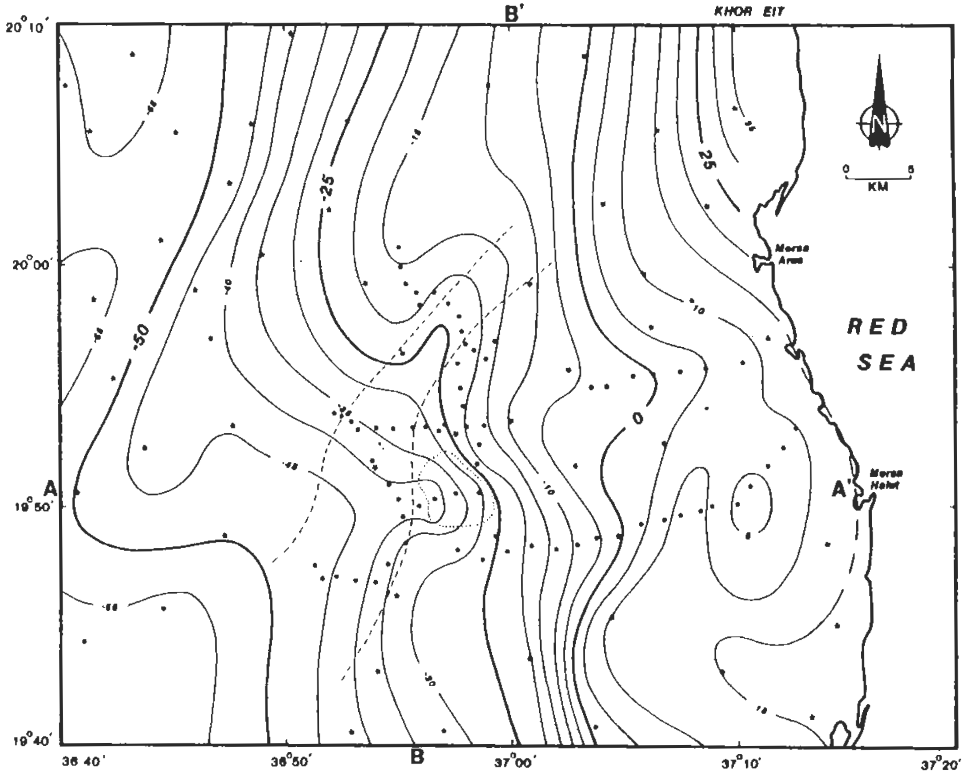

FIG. 3. Bouguer anomaly map of the area. Station control is shown as dots (present study) and stars (Isaev *et al.* 1974). Contour interval is 5 mgal. NSZ boundaries are shown as dashed lines. Arba'at granite outcrop is shown by dotted line. A strong E-W regional gradient dominates the anomalous field. Notice gravity low associations with the NSZ and Arba'at body. A local sedimentary thickening is indicated by the low west of Mersa Halut.

map covers a slightly larger area than the magnetic map (Fig. 4). Anomalies range between + 35 and – 55 mgal, with positive BA values along the coast and negative values in the western part of the area. The BA map exhibits a simple pattern of north-south trending contours and displays a continuous westward decrease of the gravity field. Although there are not many significant closures on the map, presence of several shallower anomalous masses is indicated as "nosings" in the contour pattern.

A total intensity magnetic anomaly map of the area is shown in Fig. 4. The map is based exclusively on the data of the present survey. Notice that the magnetic map covers a slightly smaller area than the BA map. A large anomaly with a relief of over 2000 nT is observed in the northwestern part of the area, in the vicinity of 20°N latitude. Another significant positive closure of 500 nT is located to the southwest of the Arba'at granite. The rest of the area is characterized by relatively low amplitude anomalies. The central part of the area is marked by a broad east-west trending low.

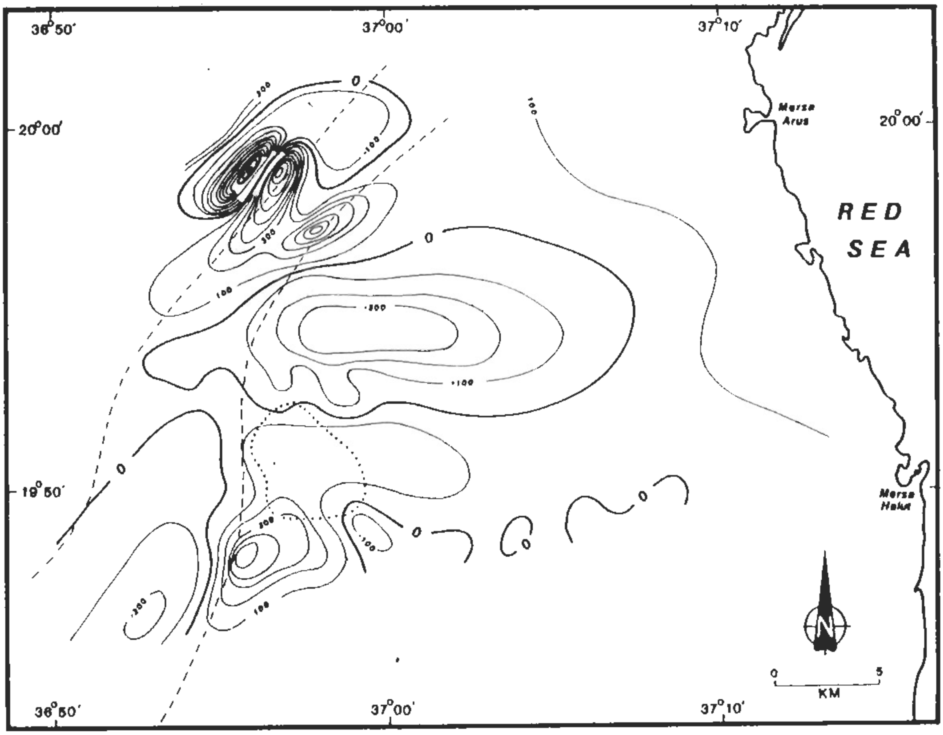

FIG. 4. Total intensity magnetic anomaly map of the area. Contour interval is 100 nT. The map s prepared from data of the present survey (dots in Fig. 3). No significant magnetic anomalies are found associated with the Arba'at body or NSZ. Notice presence of magnetic anomalies along the edges of the NSZ. The large dipolar anomaly is located over an ophiolite lens.

The general westward decrease of Bouguer anomalies is characterized by steep gradients of 2.5-2.75 mgal/km. The steepest decrease occurs over a distance of 10-15 km westward of the coastal plain. The north-south trending linear contours are, in fact, a part of the regional pattern which is typical of the entire Red Sea coastal region in Sudan (Isaev *et al.* 1974). The regional gradient in large part represents the deeper effect associated with Moho and has been explained as being due to a seaward thinning of the continental crust (e.g., Phillips *et al.* 1969, Qureshi 1971, Izzeldin 1987). In this paper we focus our attention on the effects of shallower, near surface anomalous sources. In order to remove the regional field, a least squares polynomial surface was fit to the Bouguer anomalies using the algorithm of Balch and Thompson (1989). The BA map (Fig. 3) was digitized with a grid spacing of 1I minute. Several fits of degrees 2-4 were tested, essentially yielding similar results in the central part of the area. A residual anomaly map (Fig. 5) has been prepared by subtracting the third

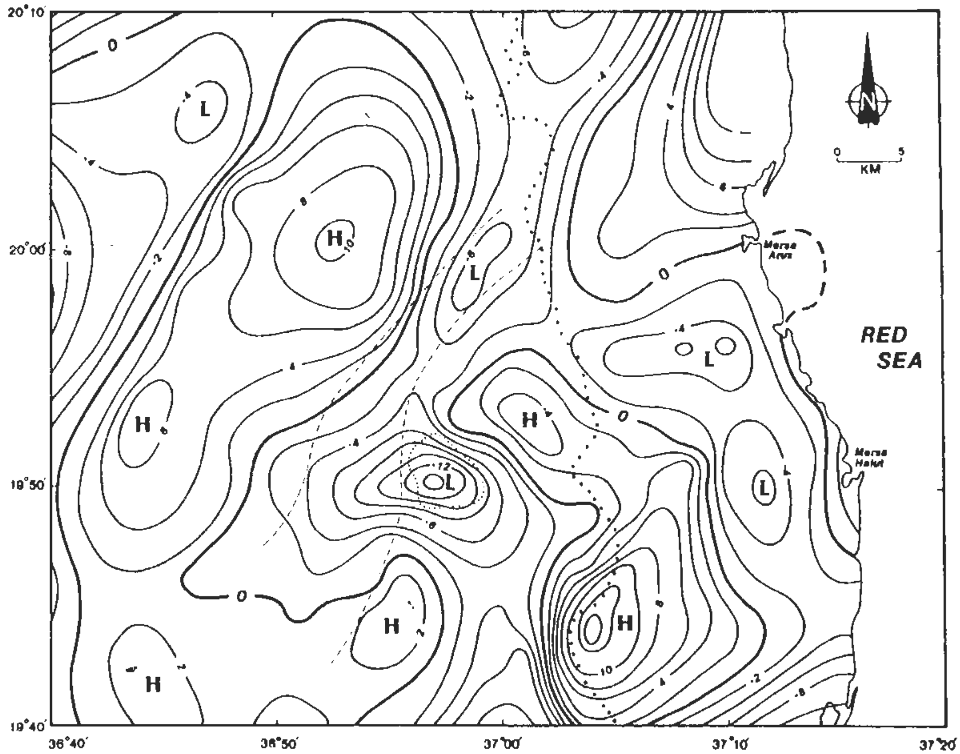

FIG. 5. Residual gravity anomaly map of the area derived by fitting a polynomial surface of degree 3. Contour interval is 2 mgal. "H" and "L" indicate gravity highs and lows respectively. The line with large dots indicates western limit of the coastal plain. The NSZ is marked by a linear gravity low. A prominent gravity low is centered over the Arba'at body which appears to extend westward into the NSZ rocks.

degree surface from the BA map. Additionally, two profiles AA' and BB' have been constructed to display the correlations of anomalies with the surface geology (Fig. 6). Profile AA' runs in an eastwest direction and is roughly perpendicular to the regional tectonic strike. Regional gravity anomalies show several positive and negative closures reflecting the effects of near surface bodies. In the following sections we discuss the gravity and magnetic fields and their correlations with upper crustal geological features.

Arba'at Granite

The Arba'at granite, located to the east of the NSZ, is a post-tectonic intrusion. It has an oblate outcrop 5-6 km in diameter and rises over 500 m above sea level. Although a gravity low over the granite body is apparent in the BA map, it is highly subdued by the steep regional gradient (Fig. 3; Fig. 6, Profile AA'). The residual map (Fig. 5) shows a prominent gravity low closure over the granite body with a minimum of – 14 mgal. A slightly larger residual of – 20 mgal estimated by Sadig *et al.* (1987)

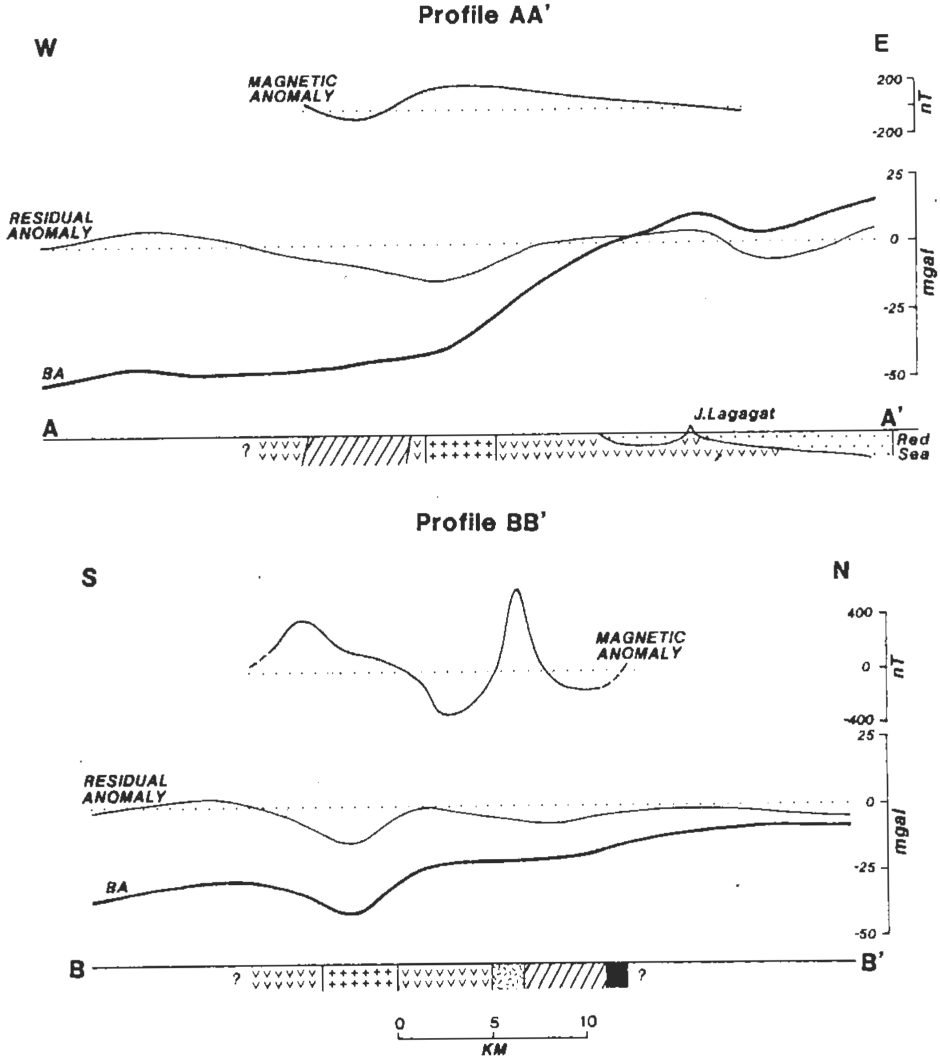

FIG. 6. Gravity and magnetic profiles. Locations are shown in Fig. 3. For geology refer to Fig. 2. The steep regional BA gradient is noted on profile AA' which runs normal to the regional geological strike. Gravity lows over the Arba'at granite, NSZ and coastal plain can be seen clearly on the residual anomaly profile.

for this body can be attributed to their graphical fitting of the regional field. We believe that our value more closely represents the effect of the Arba'at body as it is based on a denser data coverage and a two dimensional computation of the regional field. The disposition of the gravity low clearly suggests the thickest part of the body to be located under the outcrop. Closely-spaced contours along the northeastern edge of the outcrop indicate a steeper contact. The low exhibits an E-W orientation and suggests a westward extension of the Arba'at granite into the NSZ rocks, possibly across the entire width of the shear zone. Such an extension is also supported by westward dipping contacts mapped in the field.

Residual anomaly over the Arba'at granite has been modeled using the technique of Talwani *et al.* (1959) and the main intrusion is assumed to be cylindrical in shape. A density contrast of – 0.10 g/cm^3 was assumed in our computations. This value is similar to the one used by Sadig *et al.* (1987) for the Arba'at granite. Such a small contrast is reasonable as densities of the surrounding volcano-sedimentary rocks are only marginally higher than the granite. Densities of a number of representative rock samples from various units in Arba'at area measured in laboratory (Table 1) also

TABLE 1. Densities of individual rock samples measured in laboratory.

Sample no.	Rock type	Location	Density (g/cm^3)
84	Siltstone	NSZ	2.73
86	Siltstone	NSZ	2.66
87	Siltstone	NSZ	2.59
57	Talc carbonate	NSZ	2.72
96	Andesite	S of Arba'at	2.87
99	Andesite	S of Arba'at	2.81
110	Older granitoid	NE of Arba'at	2.82
113	Older granitoid	NE of Arba'at	2.67
260	Biotite granite	Arba'at	2.57
319	Biotite granite	Arba'at	2.61
320	Granite	Arba'at	2.56
451	Biotite granite	Arba'at	2.57
452	Biotite granite	Arba'at	2.62

lend support to the assumed density contrast. The intrusive body is intepreted to be 5-6 km in diameter extending to similar depths below sea level (Fig. 7). The two dimensional models presented here are not the best representations of the body because of its equidimensional shape. Nevertheless, this modeling exercise provides a general estimate of thickness and shape of the body. A computation of the maximum gravity effect of the Arba'at body was also made assuming a three-dimensional vertical cylinder (Telford *et al.* 1976). A wide cylinder (diameter 5 km, length 6 km) with an average density contrast of – 0.108 g/cm^3 yields a value of – 14 mgal and, thus, supports the general validity of the models in Fig. 7.

Several models with a single density contrast were attempted but a much better fit could be obtained by including a 1.5-2.0 km wide lighter density (contrast: – 0.15 g/cm^3) core. Gravity modeling by Sadig *et al.* (1987) also suggests a lighter density core for the Arba'at body. There is some geological evidence for lateral density variations within the body. The variations possibly result from contamination of the granitic magma near the outer margins by the basic host rocks. Preliminary petrographic work indicates radial mineral composition and textural variations, possibly gradational in nature.

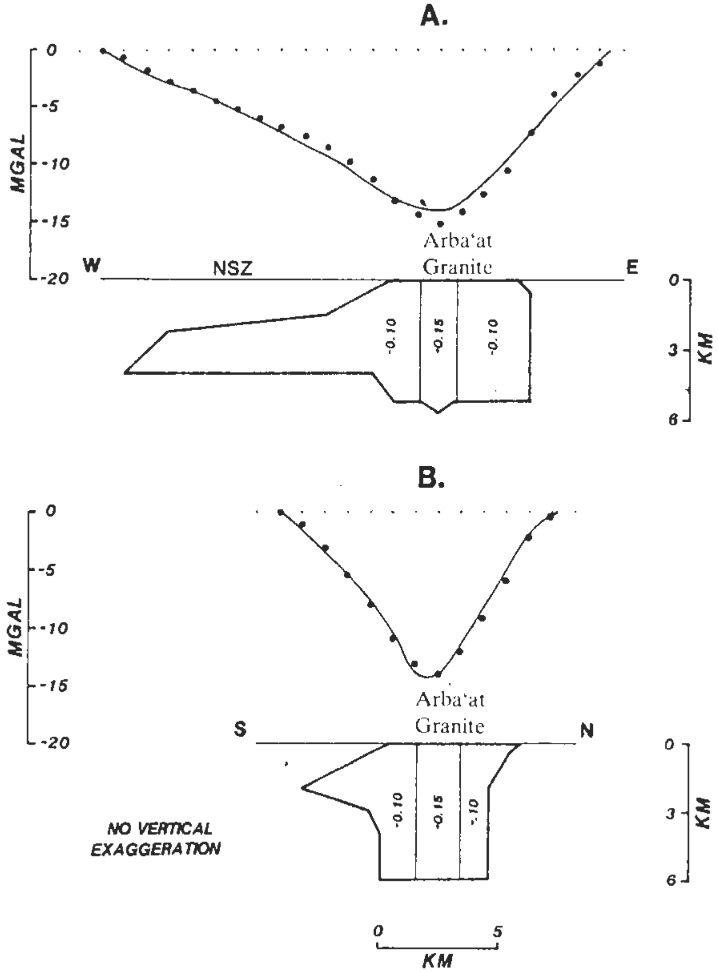

FIG. 7. Two-dimensional gravity models for the Arba'at granite body. The models were constructed from residual anomalies along sections of profiles AA' (A) and BB' (B). For details refer to Figs. 3 and 6. Numbers inside polygons indicate density contrasts. Computed gravity effect of models is shown as large dots. A central lighter core within the main intrusion provides a better fit to the data. A westward extension of the Arba'at granite into the NSZ is suggested (A).

The gravity data suggest extension of the Arba'at granite into the NSZ rocks. The granite body apparently extends some 10 km westward of the main intrusion. The extension has been modeled as a 2 km thick laccolithic tongue with its base at a depth of 4 km (Fig. 7). Such intrusions with a combination of shapes are not uncommmon. Bott *et al.* (1958) have computed a similar shape for the Dartmoor granite body in Devonshire and attributed it to a forcible intrusion with stoping. It is likely that during emplacement of the Arba'at granite, the NSZ rocks provided a zone of weakness, allowing the magma to intrude laterally. At the present level of erosion the granite body lies outside the NSZ, but at depth it may have been channelled within or along the margin of zone.

The granite body does not produce any significant magnetic anomaly possibly due to low susceptibility contrast of the granite with the volcanics of shear zone rocks (Fig. 4). A positive anomaly of about 500 nT amplitude is observed to the SW of the Arba'at body, near the eastern edge of NSZ. It is not correlatable with exposed geology and must arise from a subsurface body of basic composition, possibly in contact with the granite. It is interesting to note that this magnetic anomaly is located in a region of low amplitude gravity high (Fig. 5).

Nakasib Shear Zone

The Nakasib Shear Zone is a 5-10 km wide zone which gradually narrows from south to north and apparently extends under the sedimentary cover of the coastal plain (Fig. 2). It is a major tectonic lineament in the region and represents a reworked suture between two collided arcs (Vail 1985). The deformation in the NSZ is ductile and has a dextral sense of displacement (Almond and Ahmed 1987). Significance of the gravity and magnetic characteristics of the NSZ have been discussed by Warsi and Almond (1992).

The BA contours to the west of NSZ display a distinct northeast trend whereas, to the east, a north-south orientation is dominant (Fig. 3). The shear zone is characterized by negative gravity values and an elongate minimum of – 6 mgal is indicated on the residual map, in the vicinity of 20°N latitude (Fig. 5). The negative effect is obviously due to low density rocks such as pyroclastics dominantly found in the NSZ. For example, a siltstone sample from NSZ yields a low value of 2.59 g/cm^3 (Table 1). Moreover, the deformation of these rocks by shearing has further contributed to the lowering of density. Gravity control outside the surveyed area is limited but suggests a northeastward extension of the NSZ below the sedimentary cover of the coastal plain. The extension is also indicated by a series of inliers of NSZ rocks in the vicinity of 20°01'N and 37°05'E (Fig. 1). A subdued expression of the negative gravity effect of the shear zone is observed to the SW but is modulated by the Arba'at low. It must be mentioned that a highly mafic intrusion of Tertiary age at Jebel Luci is located within the NSZ, north of the batholithic granite contact (20°N; 37'E) (Fig. 2). Such masses will produce gravity and magnetic anomalies but of local significance.

A prominent gravity high with a maximum relief of 10 mgal is observed to the west of the NSZ. Our observations in the vicinity of 20°N latitude suggest a rather sharp contact between the low density shear zone rocks and denser rocks to the NW. It is in this region that Sadig *et al.* (1987) recorded a gravity high and attributed it to an ophiolite body. Field mapping in this area shows occurrence of pillow lavas, serpentinized peridotics and gabbros, possibly representing a slice of obducted seafloor. Ultramafic/mafic lenses of ophiolitic affinities are commonly associated with suture/ shear zones in the Red Sea Hills (Vail 1985, Almond *et al.* 1990). It is, therefore, likely that the broad gravity high is due to a significant proportion of accreted ophiolitic masses in the region. The causative body for the high may be 15-20 km wide and several tens of km long. Additional geological as well as geophysical data will be needed to resolve the nature of this zone.

The available magnetic data suggest an absence of large magnetic anomalies within the NSZ (Fig. 4). A small magnetic low with NE orientation is suggested in the southern part of the area. Low amplitude variable polarity anomalies are consistent with the shear zone lithology. Significant magnetic anomalies are, however, associated with the edges of the NSZ. A large dipolar anomaly with a peak to peak amplitude of 2000 nT is observed along the western edge, over the implied ophiolite body. Sadig *et al.* (1987) attributed this anomaly to an increase in susceptibilities due to serpentinization. Clearly, ophiolitic rocks have large magnetic susceptibilities and present a sharp contrast with the NSZ rocks. Occurrences of isolated magnetic anomalies along the shear zone margins rather than a continuous linear edge effect can be explained in terms of an intensely reworked (sliced and laterally slid) nature of the ophiolites within the NSZ. Where ophiolite lenses are absent or highly altered, the greenschist mylonites of the NSZ produce little magnetic effect.

Coastal Plain

The coastal plain, a strip parallel to the Red Sea coastline, is a zone of seaward thinning of the continental crust and it displays north-south trending BA contours (Fig. 3). Gravity effects of shallower masses are superimposed upon this regional trend and can be seen more clearly in the residual anomaly field (Fig. 5). As mentioned earlier, Miocene sediments of the Red Sea basin are exposed along the coast. In Khor Eit area, Gass (1960) estimates a sedimentary thickness of about 2 km above the basement. A question arises if these deposits are also preserved in a down faulted basin below the Recent sedimentary cover. Two traverses were run to examine the presence of a buried fault. There is no evidence of a regional scale north-south faulting in the gravity or magnetic data. The basement erosional surface appears to dip gently towards the east beneath the coastal plain sedimentary cover and its shallowness and irregular relief is indicated by inliers within the coastal plain (Fig. 2). Sadig *et al.* (1987) also suggest that any fault contact between sediments and basement is local in nature rather than regional. Gass (1960) favours differential compaction of evaporites as a possible cause of small scale north-south faulting in the Khor Eit area, and suggests a major fault offsetting sediments to be located seaward of the coastline.

The new measurements define a gravity low to the west of Mersa Halut which may represent local thickening of sediments including the Mid-Tertiary sequence (Fig. 3). This low is marked by a closure of – 6 mgal (Fig. 5). The gravity low abuts against a high in the vicinity of Mersa Arus suggesting a laterally segmented basement relief underneath the coastal plain. A pronounced high with a 14 mgal closure and a steep western flank is observed westward of the coastal plain gravity low (Fig. 5). The northern part of the high is located over Jebel Lagagat. As the sedimentary cover is thin in the area, this anomaly must be attributed to sources within the basement.

Concluding Remarks

The study has brought out several new details in addition to confirming the finding of previous studies in the Red Sea Hills region. The effect of rapid seaward thinning of the continental crust is observed in the Khor Arba'at region as a steep gravity gradient (2.5-2.75 mgal/km) along a 30-35 km strip including the entire coastal plain and adjoining basement terrane (Qureshi 1971). The basement apparently gradually dips seaward underneath the coastal plain and there is no evidence of a regional north-south faulting offsetting Cenozoic sediments.

We have examined a section of the Nakasib Suture Zone and found it to be associated with a negative gravity field and a lack of magnetic anomaly except along its edges. These signatures may be typical of suture zones, at least in the Red Sea Hills setting as the reworked rocks of the suture zones will always have lower density and magnetic susceptibility as compared to the surrounding rock units. Along the western edge, the large amplitude magnetic anomaly correlates well with an ophiolite lens.

The gravity low over the Arba'at granite reported by Sadig *et al.* (1987) has been mapped in more detail. The granite body is estimated to be 5-6 km thick with a possible westward extension into the Nakasib Shear Zone.

In general, the Red Sea Hills region in Sudan is poorly studied as compared to Red Sea margins elsewhere. Additional detailed geophysical work is needed in this region. Our results reported here could be useful in future geological studies. It will be interesting to see if the geophysical signatures of the Nakasib Shear Zone can be used to characterize other sutures in the region.

Acknowledgement

We wish to thank the Geological Research Authority of the Sudan (GRAS) and University of Khartoum for their support. Valuable support in the field work was received from the GRAS Office in Port Sudan and Prof. F. Ahmed of the Department of Geology, University of Khartoum. Mr. Z.A.K. Khurram helped with the geophysical measurements. Financial support for this study was through the University of Kuwait research grant No. SG020.

References

Almond, D.C. and **Ahmed, F.** (1987) Ductile shear zones in the northern Red Sea Hills of Sudan and their implications for crustal collision, *in:* **Bowen, P.** and **Kinnairds, J.A. (eds.)** African Geology Reviews, *Geological Journal* **22:** 175-184.

Almond, D.C., Darbyshire, D.P.F. and **Ahmed, F.** (1990) Age limits for major shearing episodes in the Nubian shield of NE Sudan, *J. Afr. Earth Sci.* **8:** 489-496.

Balch, S.J. and **Thompson, G.T.** (1989) An efficient algorithm for polynomial surface fitting, *Computer & Geosciences* **15:** 107-119.

Bott, M.H.P., Day, A.A. and **Masson-Smith, D.** (1958) The geological interpretation of gravity and magnetic surveys in Devon and Cornwall, *Phil. Trans. Roy. Soc.*, **A251:** 161-191.

Gass, I.G. (1960) *The Geology of the Sudan coastal province,* a report prepared for Gen. Expl. Co. of Calif., Hunting Tech. Serv. Ltd., 10 p.

IAGA (1988) International Geomagnetic Reference Field Revision 1987, *Geophys. Jour.,* **93:** 187-189.

IGSN (1971) Geodetic reference system 1967, Spec. Publ. 3, *Bull. Geodesique,* International Union of Geodesy and Geophysics, Paris, 116 p.

Isaev, E., Saveliev, Y., Rusjanov, Y. and **Pukhtinov, A.** (1974) *Bouguer anomaly maps, Scale 1:500,000, Appendix: Results of complex geophysical investigations of the Red Sea Hills,* Vol. 7, Technoexport, Moscow (Unpubl. Rep.).

Izzeldin, A.Y. (1987) Seismic, gravity and magnetic surveys in the central part of the Red Sea: their interpretation and implications for the structure and evolution of the Red Sea, *Tectonophysics,* **183:** 269-306.

Longman, I.M. (1959) Formulas for computing the tidal acceleration due to Moon and Sun, *J. Geophys. Res.,* **64:** 2351-2355.

Morelli, C., Gantar, C., Honkasalo, T., McConnel, R.K., Tanner, I.G., Szabo, B., Uotilla, V. and **Whalen, C.T.** (1974) *The International Gravity Standardisation Net 1971 (IGSN71),* Spec. Publ. 4, International Union of Geodesy and Geophysics, Paris, 116 p.

Qureshi, I.R. (1971) Gravity measurements in the north-eastern Sudan and crustal structure of the Red Sea, *Geophys. J. Roy. Astr. Soc.* **24:** 119-135.

Phillips, J.D., Woodside, J. and **Bowin, C.O.** (1969) Magnetic and gravity anomalies in the central Red Sea, *in:* **Degens, E.T.** and **Ross, D.A. (eds.),** *Hot Brines and Heavy Metal Deposits in the Red Sea,* Springer, New York, pp. 98-113.

Sadig, A.A., Almond, D.C. and **Ahmed, F.** (1987) A gravity and magnetic traverse from Port Sudan to Abu Hamed, NE Sudan, *J. Afr. Earth Sci.* **6:** 823-832.

Talwani, M., Worzel, J.L. and **Landisman, M.** (1959) Rapid gravity computation for two dimensional bodies with application to the Mendocino fracture zone, *J. Geophys. Res.* **64:** 49-59.

Telford, W.M., Geldart, L.P., Sheriff, R.E. and **Keys, D.E.** (1976) *Applied Geophysics,* Cambridge Univ. Press, 860 p.

Vail, J.R. (1985) Pan-African (late Precambrian) tectonic terrains and the reconstruction of the Arabian-Nubian shield, *Geology* **16:** 839-842.

Warsi, W.E.K. (1989) Gravity bases in the State of Kuwait, *J. Univ. of Kuwait (Sci.)* **16:** 433-447.

Warsi, W.E.K. and **Almond, D.C.** (1992) Gravity and magnetic signatures of a reworked suture zone: an example from the Red Sea Hills, Sudan, *J. Afr. Earth Sci.* **14:** 361-363.

دراسـة جاذبيـة ومغنطيسيـة الأرض لمنطقـة أربعات بجبال البحر الأحمر ، السودان

وارث إ . ك . وارثي * ، ديفيد ك . ألموند ** و عبد العزيز أ . عثمان *

*قسم علوم الأرض ، جامعـة السلطان قابـوس ، مسقط ، عُمان ، **معهـد الدراسات الأساسية ، كاندي ، سريلانـكا ، و ***قسم الجيولوجيا ، جامعة الكويت ، الصفـاة ، الكويت**

المستخلص . أوجـدت القياسـات الجـاذبية والمغنـطيسية لخور أربعات ومنطقة السهل الساحلي المجاور تفسيرًا أفضل للظواهر الجيولوجية القريبة من السطح . أظهر نطاق جز « ناكسيب » والذي يعتبر خط التحام معرى بين قوسي جزر ، أظهر وجود شذوذ منخفض في الجـاذبية وانعـدام شاذة مغنـطيسية . غير أن حافة نطاق « الجز » أظهرت وجود شاذة مغنطيسية حيث أثبتت صخور هذا النطاق وجود قابلية مغنطيسية ملحوظة وذلك مقارنة بصخور الأفيوليت المجاورة .

أظهر دخول الصخور النارية بعد الحركات الأرضية في جرانيت أربعات شذوذ منخفض في الجاذبية والتي أسس عليها افتراضًا أن الجسم الجرانيتي ممتد في اتجاه الغرب داخل صخور نطاق « الجز » .

يتضـح من الـدراسـة أيضًـا أن سمـك متـداخل أربعات الجرانيتي يبلغ حوالي ستة كيلومـترات ؟ وأن الحوض الساحلي الرسوبي ؟ والذي يشتمل على صخور أوسط الثلاثي والـرسـوبيات الأحدث ، يبدو مجزأ جانبيًا والتضاريس تحت السطحية لصخور القاعدة الأسـاسية ذات العمـر البروتوزوي . وتقترح دراسة الجاذبية وجود ازدياد محلي في سمك الرواسب في الجزء الجنوبي من منطقة البحث ولا يستدل من نتائج الدراسة على وجود صدع تحت سطح رسوبيات العصر السينوزوي الواقعة تحت الرواسب الحالية للسهل الساحلي .