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# Statistical and tectonic trend analysis of the Bouguer gravity field of Egypt

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## ABSTRACT

The main tectonic trends present in Egypt are statistically identified and their tectonic significance studied. A graphical-numerical technique and the method of autocovariance analysis were applied to the Bouguer anomalies and their residual fields.

Seven principal tectonic trends were identified at different levels ranging between shallow sediments, basement surface and deep crust. The tectonic trends detected in Egypt suggest that the tectonic regime of the area has been influenced by two stress fields acting during different geologic epochs. The older one was probably a result of interaction between the African and the European plates, and the younger related to Red Sea rifting.

## INTRODUCTION

Bouguer gravity data are widely used in solving tectonic problems and have proved to be efficient, especially in studying the tectonics of the basement and overlying sedimentary consequences. Bouguer anomalies can be the result of one or more of the following factors: (1) Thickness of the Earth's crust and upper mantle, i.e. depth and relief of individual discontinuities; (2) Lithologic variations, gradual or abrupt, in the subsurface, and (3) Considerable dislocations in the subsurface.

Generally, it is possible to distinguish between anomalies that are due to tectonic dislocations on the basis of their form, shape and/or areal extension. For example, anomalies associated with faults are commonly linear. Faults controlling basement blocks may give rise to closed anomalies with considerable extension.

The present work deals with the application of several statistical techniques to the field of tectonics in order to study geologic dislocations and variation in their trends at the different depths. A graphical-numerical technique (Buchheim & Lauterbach 1954; Neuman 1954; Kaspar 1962; Affleck 1963; Mundt 1969; Riad 1977; Tealeb 1977, 1979a; Abdelhady & Tealeb 1985) and the method of the two-dimensional autocovariance analysis (Horton *et al.* 1964; Mundt 1969; Marcak 1973; Tealeb 1977, 1979b; Abdelhady & Tealeb 1985) have been applied to the gravity Bouguer anomalies of most of Egypt. Work done previously by the author and others in northern Egypt (Tealeb 1979a & b; Riad *et al.* 1981; Abdelhady &

Tealeb 1984, 1985; Tealeb & Abdelrahman 1985), is here extended to cover all of Egypt. The graphical-numerical method was directly applied to the anomaly maps in order to identify the extent of the major and minor trends, while two-dimensional autocovariance was employed on different residual fields to differentiate between trend directions of deep-seated and shallow-seated tectonics. For separation of the residual fields, techniques of trend elimination were used with polynomials of first and second orders (Zurmühl 1957; Tealeb 1977) and filter techniques (Kertz 1966; Tealeb 1977). In trend elimination, the method of least squares was used for the estimation of sets of polynomials of first and second orders, the elimination of regional (linear and quadratic) trends and the separation of residual fields. Numerical filters with zero-phase shift, which are built up with the help of displacement operators were also used for the separation of different regional and residual fields.

## DATA AQUISITION

Bouguer anomaly maps of Egypt, compiled by the General Petroleum Company (G.P.C.) of Egypt, were used in the present study. Maps at a scale of 1 : 500,000 and contour interval of 1 mgal are available for most of the areas north of Lat. 27° 00′N and for some areas to the south. Maps at scales of 1 : 500,000 and 1 : 1,000,000, and contour interval of 5 mgal, cover most of the area to the south of Lat. 27° 00′N and the Sinai Peninsula. The raw Bouguer maps are too bulky for inclusion in this paper. The regional Bouguer anomaly map of Egypt, compiled at a scale of 1 : 2,000,000 and contour interval of 10 mgal, is shown in Fig. 1.

Differences in scale and gravity contour interval between the maps constructed for various areas of Egypt north and south of Lat. 27° 00′N are due to the distribution of the data as well as to the general trend of roads and tracks along which the measurements were taken. They are also due to differences in the objectives of surveying. From the general shape and character of the Bouguer contours of Egypt it is obvious that anomalies in the southern areas reflect more the regional structure than the local one, whereas in the north both the regional and local structures are reflected. This variability in the character of the Bouguer anomaly constitutes a problem in making regional-residual separation and in the choice of the grid intervals used to make this separation. Also, it presents difficulties in the analysis of anomaly trends because of frequency differences between the various areas.

The raw data are bulky and are handled according to the following steps:

1. Analysis of the prevailing wavelengths was carried out in order to determine the minimum wavelength and to choose the grid intervals useful in regional-residual separation. For the purpose of regional-residual separation and application in autocovariance analysis, the original Bouguer anomaly maps were digitized using a grid interval of 5 km, which is sufficient to study both deep-seated and shallow-seated structures within the crust of Egypt. This interval represents one-half of the determined minimum wavelength of the gravity anomalies of Egypt.
2. Separation of the various regional and residual fields from Bouguer anomalies using the techniques already mentioned.
3. For the various regional and residual fields, depth estimations of subsurface density contrasts were made using the methods of autocorrelation and spectral analysis (Tealeb 1977; Tealeb 1979c, d & e; Tealeb 1985). Residual fields

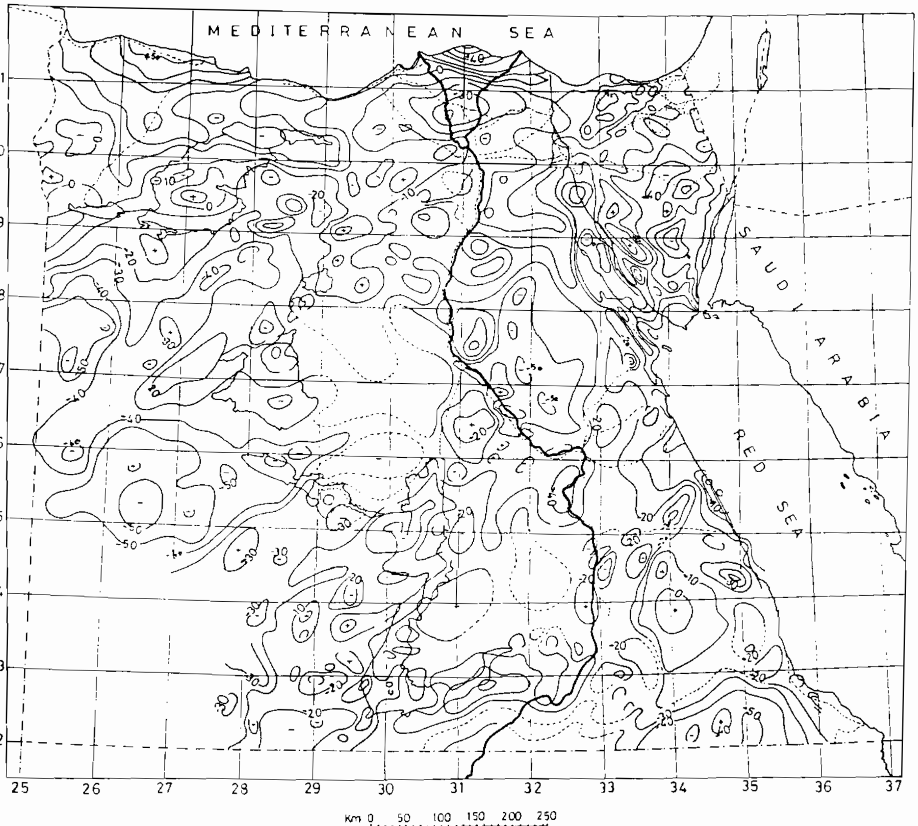


**Fig. 1.** Regional Bouguer anomaly map of Egypt.

representing shallow structures (basement surface) and regional fields of deep origin were chosen for the application of autocovariance analysis and estimation of predominant trends.

## REVIEW OF THE MAJOR STRUCTURES OF EGYPT

Egypt is a part of the north African craton which, during its geological history, underwent periodic marine transgressions from the ancient Tethys, situated to the north and northeast of the country.

Four major geological provinces (Fig. 2) have been distinguished (Said 1962; Smith 1984). These are the well defined Nubian-Arabian Shield, or massif, and the surrounding shelf areas which are subdivided into Stable Shelf, Unstable Shelf and Gulf of Suez-Red Sea Graben. The Nubian-Arabian Shield is exposed over large tracts in the Sinai Peninsula, Eastern Desert and in the extreme southern part of the Western Desert. It consists essentially of Pre-Cambrian rocks. The Stable Shelf embraces the area north and west of the Nubian-Arabian Shield. It exhibits a gentle tectonic deformation and relatively thin sedimentary sequence (400 m of sediments near to the Nubian-Arabian Shield area increasing to as much as 2500 m near the

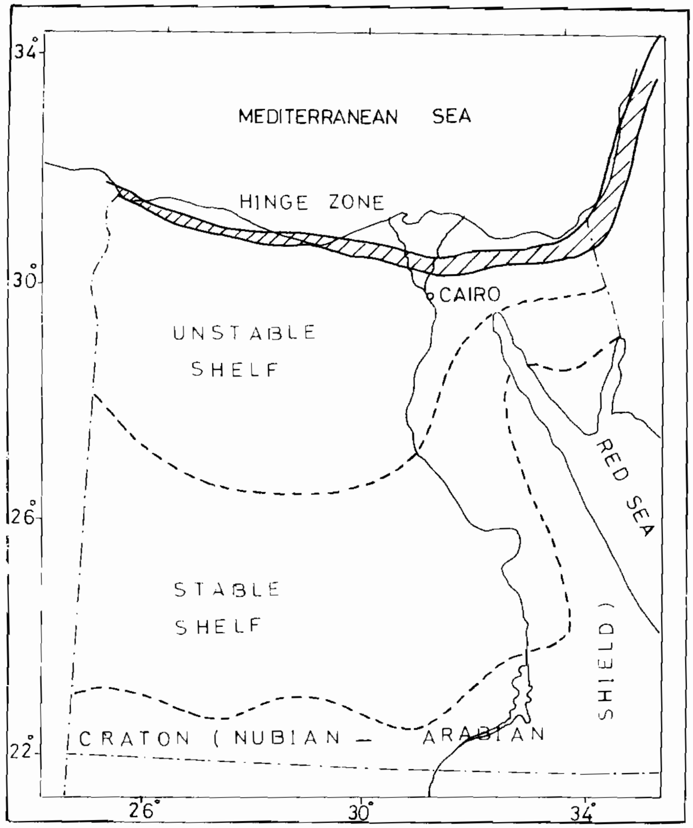


**Fig. 2.** Major tectonic provinces of Egypt.

transition into Unstable Shelf in the north). The Unstable Shelf lies north of the Stable Shelf and its sedimentary sequence is relatively thick. The formations here are gently folded around a northeast trend referred to as the "Syrian Arc". The Gulf of Suez-Red Sea Graben is an area of subsidence within the Stable Shelf and the northern part of the Nubian-Arabian Shield. Rifting of the Red Sea and Gulf of Suez is related to the great East African Rift System and relative motion of the Nubian, Arabian and Sinai plates has led to the opening of the Red Sea, Gulf of Suez and Gulf of Aqaba.

Based on surface and subsurface geology, Said (1962), Youssef (1968) and Moody (1973) classified the predominant structural trends of Egypt into Eritrean (NW–SE); Aualitic (NE–SW); East African (N–S) and Tethyan (E–W) patterns. Halsey & Gardner (1975), from their analysis of satellite photographs, identified two groups of tectonic trends: a group of three major and a group of four minor trends. The major trends are: the Suez trend (N35°W), which belongs to the Pre-Cambrian and was rejuvenated subsequently during Hercynian (Pre-Carboniferous), Laramide (Late Cretaceous) and Alpine (Late Tertiary) orogenies. The Aqaba trend (N15°E) belongs to the Late Tertiary orogeny, while the Qattara trend (N60°E) is considered as a Pre-Cambrian trend reactivated during Hercynian and Laramide orogenies. The minor trends are Aualitic (N40°E) related to the dynamic history of Qattara as

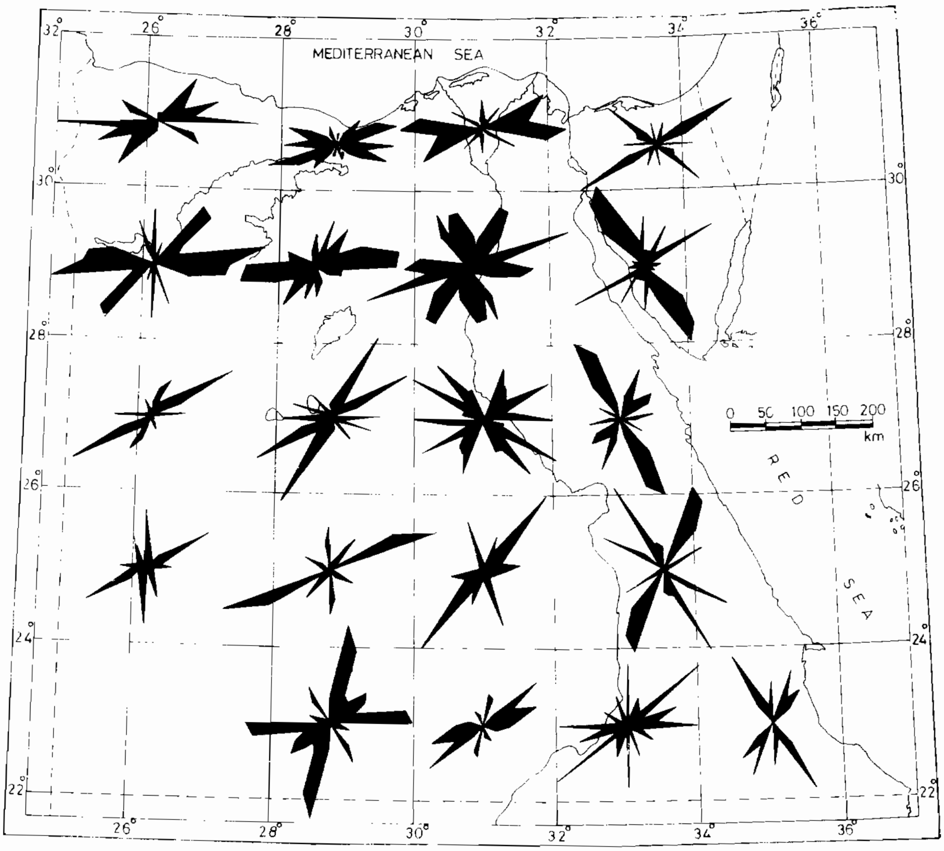


**Fig. 3.** Tectonic trends of the Bouguer anomaly of Egypt (estimated for 20 sectors).

a second-order basement-rooted system; East-African (N–S), considered as being of Late Tertiary age; Tethyan (E–W) trend related to the Pre-Cambrian and Late Tertiary compressions; and a N60°W trend, which was developed during Upper Jurassic–Lower Cretaceous.

Seven trend groups were recorded in northern Egypt from the analysis of Bouguer anomalies (Tealeb 1979a & b; Abdelhady *et al.* 1983; Abdelhady & Tealeb 1984, 1985; Tealeb & Abdelrahman 1985). These trends are in directions E–W, N60°E, N60°W, N30°W, N40°E, N–S and N20°E. Five of these trends (E–W, N60°E, N30°W, N40°E and N–S) have been picked up at different erosional levels ranging between the sedimentary successions, basement surface and deep basement. The other two trends (N60°W and N20°E) have been detected at shallow depth levels, within the sedimentary successions and basement surface. Similar trend groups were recorded by Riad *et al.* (1981) from the analysis of gravity data from northern Egypt and were believed to predominate at different levels between the basement surface and the overlying sediments. From analysis of magnetic data from northern Egypt, Meshref & El-Sheikh (1973) interpreted five trend groups (N85°E, N65°E, N35°E, N65°W, N35°W) affecting the basement complex and overlying sediments.

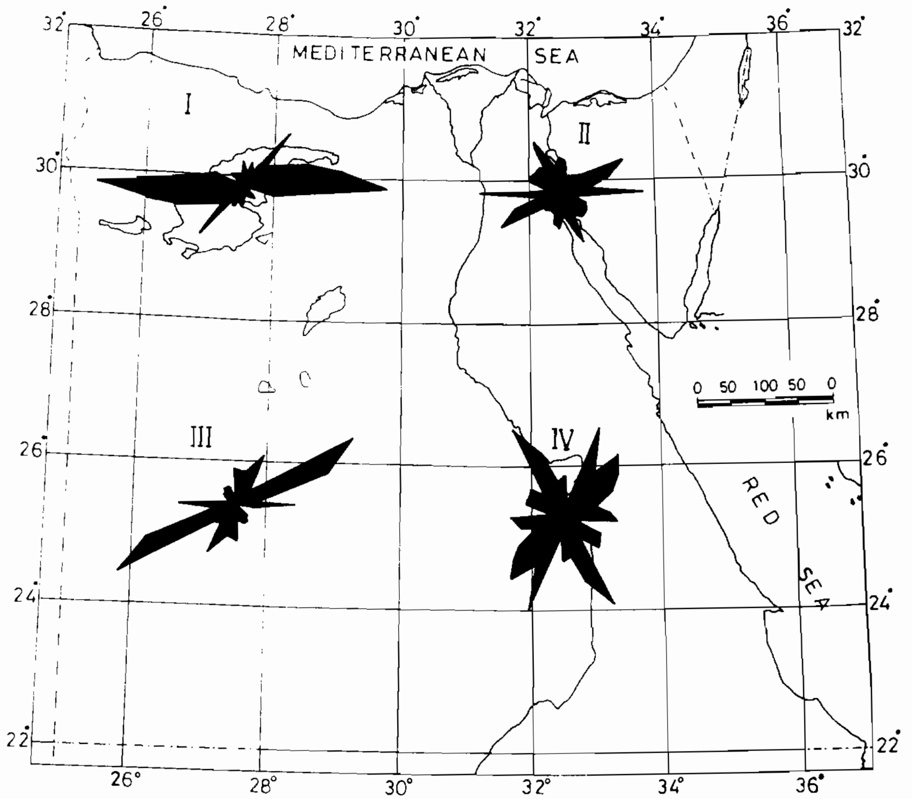


**Fig. 4.** Tectonic trends of the Bouguer anomaly of Egypt (summed up for four areas: northern Western Desert, southern Western Desert, Sinai Peninsula and Eastern Desert).

## METHODS AND TECHNIQUES USED FOR TREND ANALYSIS

### I. GRAPHICAL-NUMERICAL METHOD

This technique was applied directly to the Bouguer anomaly maps of Egypt. Based on anomaly maps and morphological characteristics, the study area was divided into twenty relatively homogeneous sectors. A simple graphical technique (Affleck 1963) was used: the axes of the anomalies, interpreted as dislocations beneath the earth's surface, were drawn visually on the anomaly maps. The lengths and directions of these axes were measured (azimuth measured clockwise from geodetic north) and then weighted to fixed azimuth intervals (10°) and summed up. From these data the relative frequency distributions were computed and plotted, for the twenty sectors, as rose-diagrams (Fig. 3). Peak frequencies of the rose-diagrams represent the predominant directional trends of the anomalies. These anomaly trends are believed to be related to tectonism, reflected in the measured gravity field.

The results given in Fig. 3 underscore the variability of the frequency distribution of tectonic trends among the twenty sectors. Each sector has its characteristic major trends, but overall there are seven trend groups. The trend patterns in Fig. 3 show differences in the dominant trends of four areas of Egypt: northern Western Desert (E–W and N60°E trends), southern Western Desert (N60°E and N40°E),

**Table 1.** Distribution of the Bouguer anomaly trends

| Trend direction | Reference name | Trend limits | Distribution of the anomaly lengths % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sector | | | | Area | | | | Total area of Egypt |
| | | | I | II | III | IV | North of Lat. 28°00′N | South of Lat. 28°00′N | West of Long. 32°00′E | East of Long. 32°00′E | |
| E–W | Tethyan | N80°E–N80°W | 33·6 | 19·0 | 13·0 | 9·7 | 26·3 | 11·4 | 23·6 | 13·4 | 18·7 |
| N60°E | Qattara | N70°E–N50°E | 24·8 | 23·4 | 40·9 | 12·4 | 24·1 | 26·6 | 32·6 | 16·7 | 25·1 |
| N30°W | Suez | N20°W–N40°W | 4·9 | 15·7 | 7·4 | 22·9 | 10·3 | 15·2 | 6·1 | 20·1 | 12·9 |
| N60°W | | N50°W–N70°W | 9·3 | 13·4 | 4·1 | 11·5 | 11·3 | 7·8 | 6·8 | 12·2 | 9·5 |
| N40°E | Aualitic | N50°E–N30°E | 15·7 | 10·2 | 7·8 | 17·0 | 13·0 | 12·4 | 11·9 | 14·3 | 12·9 |
| N–S | E. African | N10°E–N10°W | 6·4 | 11·5 | 12·1 | 9·2 | 9·0 | 10·6 | 9·2 | 10·1 | 9·7 |
| N20°E | Aqaba | N30°E–N10°E | 5·3 | 6·8 | 14·7 | 17·3 | 6·0 | 16·0 | 9·8 | 13·2 | 11·2 |

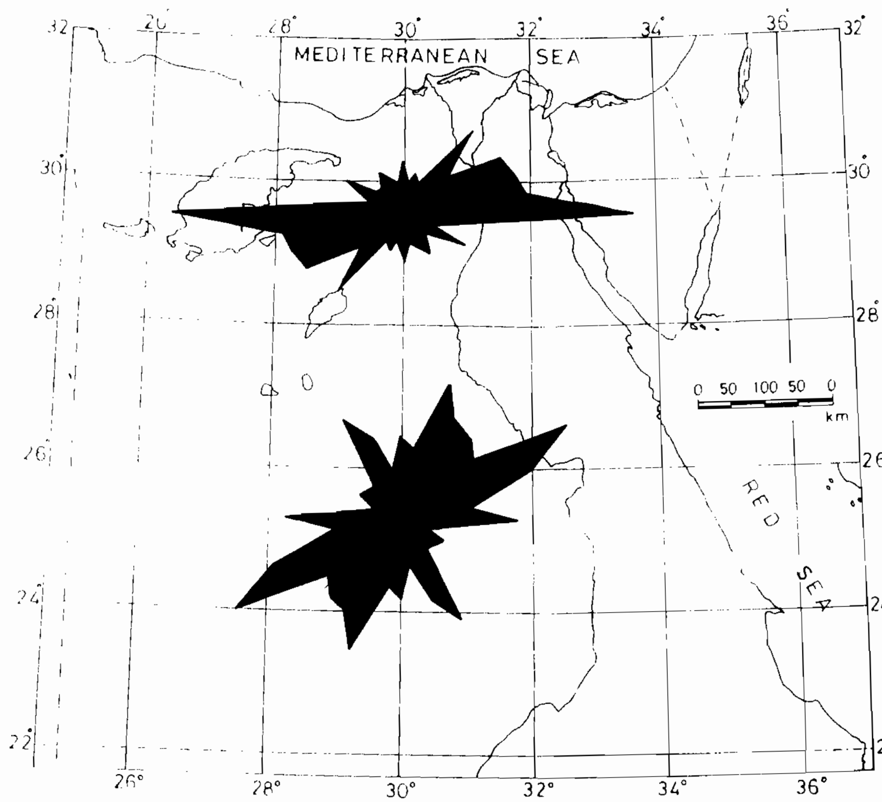


**Fig. 5.** Tectonic trends of the Bouguer anomaly of Egypt (summed up for: northern Egypt "Stable Shelf" and southern Egypt "Unstable Shelf").

Sinai Peninsula (N60°E and N30°W) and Eastern Desert (N30°W, N20°E and N60°E). The trends in these four areas are summarised in the form of rose-diagrams (Fig. 4) and in Table 1. The difference between tectonic trends dominant in northern Egypt (Stable Shelf) and in southern Egypt (Unstable Shelf) are also clear from the rose-diagrams in Fig. 5 and from the data in Table 1. In northern Egypt the dominant trends are the E–W, N60°E, N40°E and N–S directions, whereas in southern Egypt the dominant trends are in the N60°E, N20°E, N30°W and E–W directions. Fig. 6 and Table 1 show the tectonic trends predominant in eastern (N30°W, N60°E, N40°E, N20°E) and western (N60°N, E–W, N40°E)Egypt.

The overall picture appears in Fig. 7, and a summary of the frequency distribution of the anomaly trends is given in Table 1. Seven tectonic trends are dominant. According to their frequency distributions, these are the N60°E (Qattara), E–W (Tethyan), N30°W (Suez), N40°E (Aualitic), N20°E (Aqaba), N–S (East-African) and N30°W trend directions.

## II. TWO-DIMENSIONAL AUTOCOVARIANCE ANALYSIS

This technique was applied to the Bouguer values as well as to several residual and regional fields obtained from the low- and high-pass filtering of the Bouguer anom-

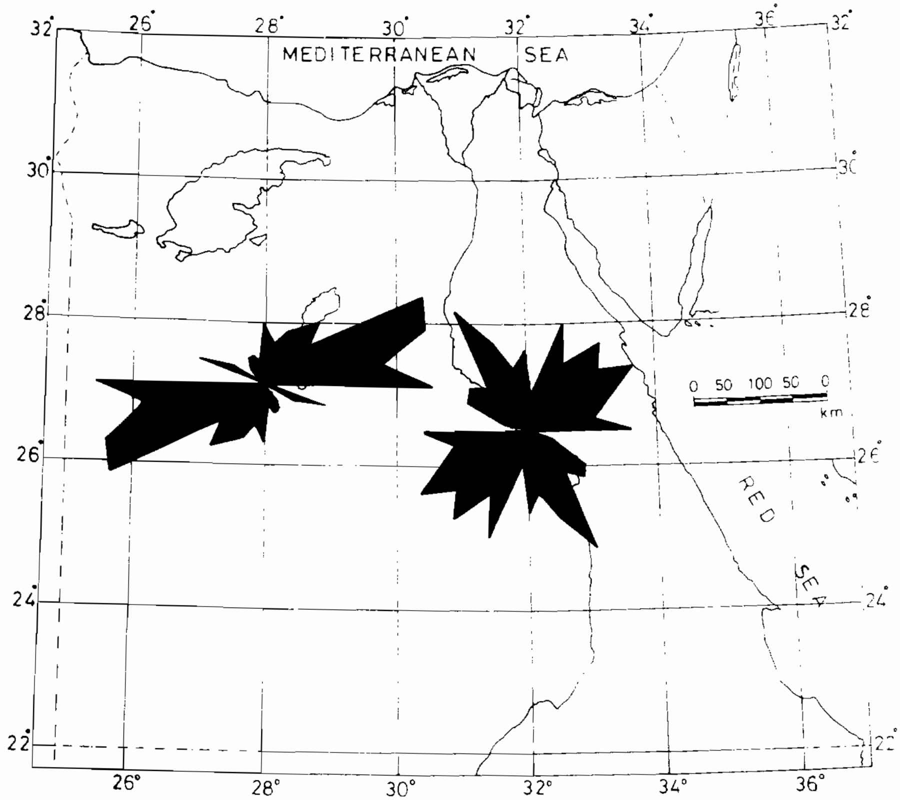


**Fig. 6.** Tectonic trends of the Bouguer anomaly of Egypt (summed up for the eastern and western regions of Egypt).

alies (Kertz 1966; Tealeb 1977) and after the elimination of linear and quadratic trends from the Bouguer anomalies and its filtered gang "smoothed field" (Agocs 1951; Zurmühl 1957; Tealeb 1977).

Before applying the autocovariance analysis on the separated regional and residual fields, different tests were carried out in order to study the character of these fields, including frequency analysis (Tealeb 1977, 1979e) and depth estimations of the different density contrasts within the subsurface (Tealeb 1977, 1979 c & d, 1985). Each reflects the gravity effects from one or two depth zones (density contrast) within the earth's crust. Some fields show depths within the basement complex (shallow origins) whereas others reflect deeper origins. These depth zones aid recognition and classification of trends dominant at shallow and deep levels.

Using this method, it is difficult to estimate that a given trend develops at a certain depth and dies out at a deeper level or the reverse, but it is possible to classify the predominant trends into shallow and deep trends. This difficulty is, of course, due to superimposition of anomalies from different sources, and none of the methods used are capable of distinguishing frequencies or wavelengths generated from sources presented at a definite level. It is also important to mention that the method of autocovariance is a statistical method which deals mainly with summing up of the prevailing frequencies and building mean values.

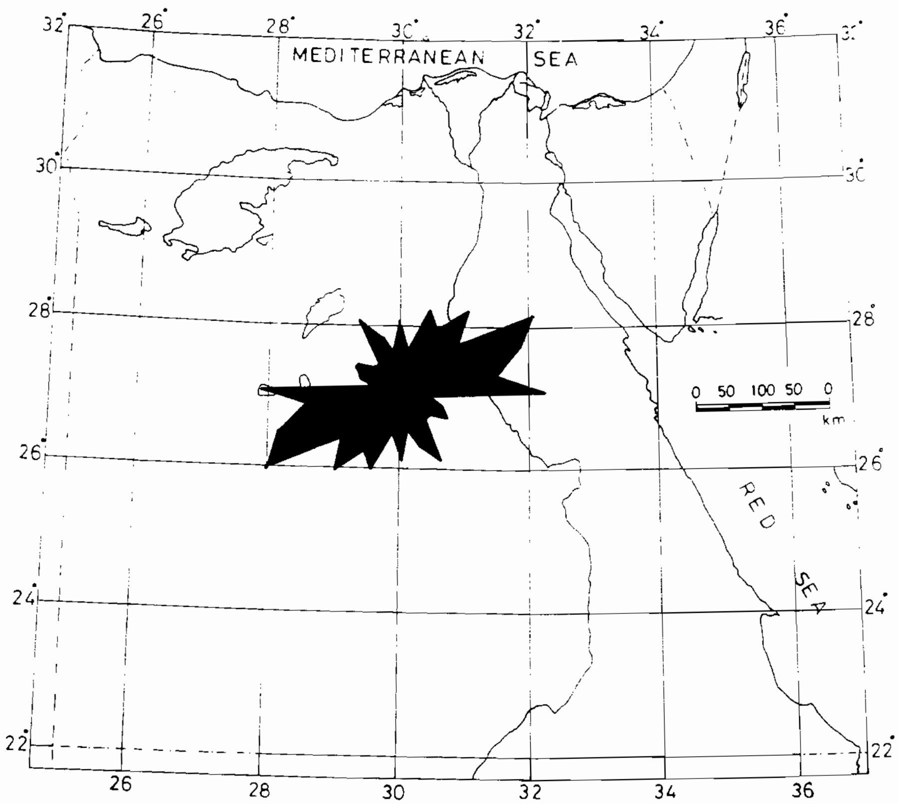


**Fig. 7.** Tectonic trends of the Bouguer anomaly of Egypt (summed up for the whole of Egypt).

Autocovariance analysis was carried out on gravity fields of 95 subareas covering most of Egypt. The analysis predicts the trend directions predominant in the shallow levels (sedimentary cover and basement surface) and underneath the basement surface, with respect to the mean depths of their sources.

For discrete samples $f(X, Y)$ in square grid at regular intervals, the autocovariance functions $R(r, s)$ and $R(r, -s)$ have been used according to the equations by Horton *et al.* (1964):

$$R(r, s) = \frac{1}{(N-r)(N-s)} \sum_{X=1}^{N-r} \sum_{Y=1}^{N-s} f(X, Y) f(X+r, Y+s),$$

$$R(r, -s) = \frac{1}{(N-r)(N-s)} \sum_{X=1}^{N-r} \sum_{Y=s+1}^{N} f(X, Y) f(X+r, Y-s),$$

$$r, s = 0, 1, 2, 3, \ldots, m,$$

where $r$ and $s$ are the possible displacements in the $X$ and $Y$ directions respectively, $N^2$ the number of samples and the maximum permissible pitch of correlation $(m \leqslant \frac{1}{5}N)$.

According to the symmetrical property of the autocovariance, the functions $R(-r, -s)$ and $R(-r, s)$ need not be computed, because $R(-r, -s) = R(r, s)$ and $R(-r, s) = R(r, -s)$.

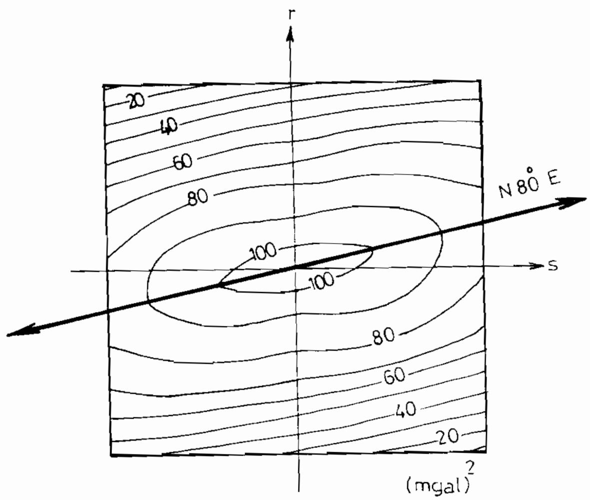


**Fig. 8.** Autocovariance diagram.

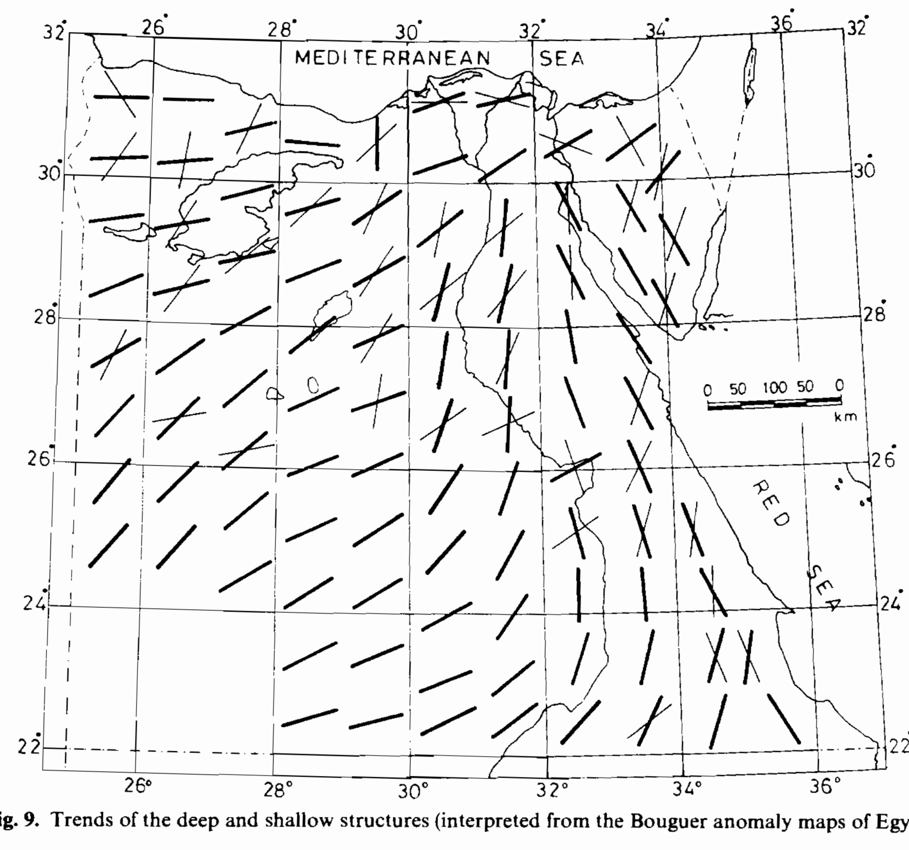


**Fig. 9.** Trends of the deep and shallow structures (interpreted from the Bouguer anomaly maps of Egypt).

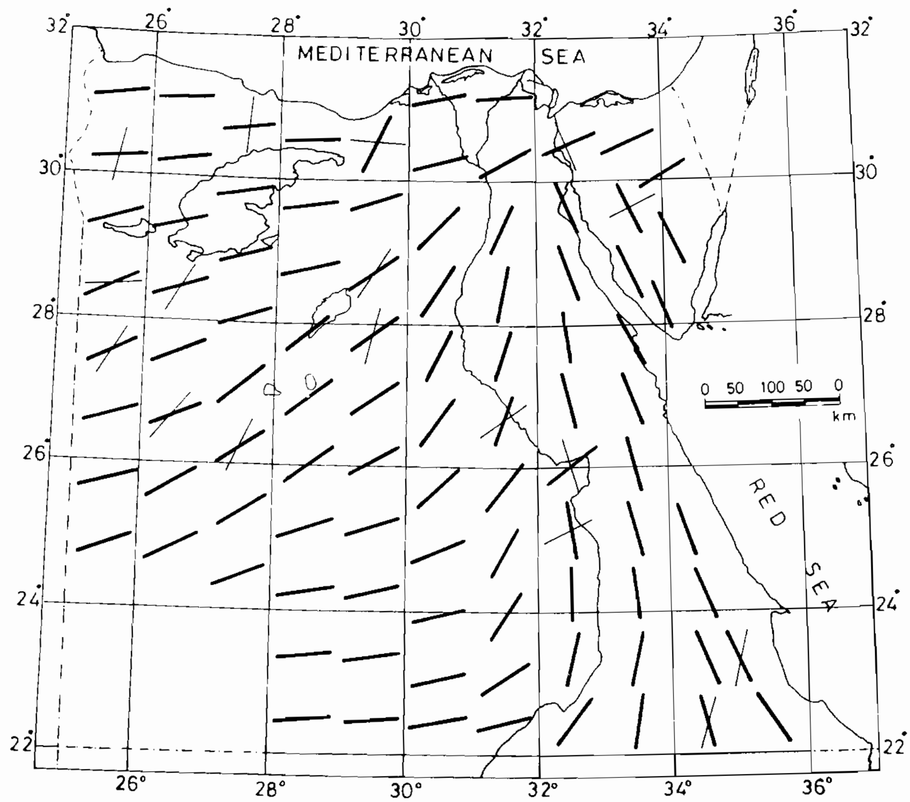


**Fig. 10.** Trends of the deep structures (interpreted from the regional gravity fields).

The calculated autocovariance values were plotted against the variable *r*, *s*. A contour map was then constructed from these values. The direction of maximum autocovariance (high correlation) represents the predominant trend direction of the analysed anomalies (Fig. 8).

The trends interpreted from the analysis of the Bouguer anomalies of the 95 subareas are shown in Fig. 9, and trend directions interpreted on the basis of the different regional and residual fields are given in Figs 10 and 11 respectively.

The trend directions in Fig. 9 are believed to have developed in relatively recent geologic times and affected both shallow (sedimentary sections) and deep (basement surface and deep basement) levels. In this figure, first and second order trends are represented by thick and thin bars respectively. The pattern in Fig. 9 shows that the E–W (Tethyan) trend is predominant in northern Egypt, whereas the N60°E (Qattara) and N40°E (Aualitic) trends are predominant in southwestern and central Egypt. Along the Nile Valley, the trends are directed mainly N40°E and N–S and show a pattern in close relation to the direction of the Valley itself. The N30°W (Suez) and N20°E (Aqaba) trends are mainly recorded in Sinai and along the Red Sea coast. The N20°E trend direction mainly appears as a second order trend. The N60°W is less well represented and mainly recorded in northern Egypt as a secondary trend direction.

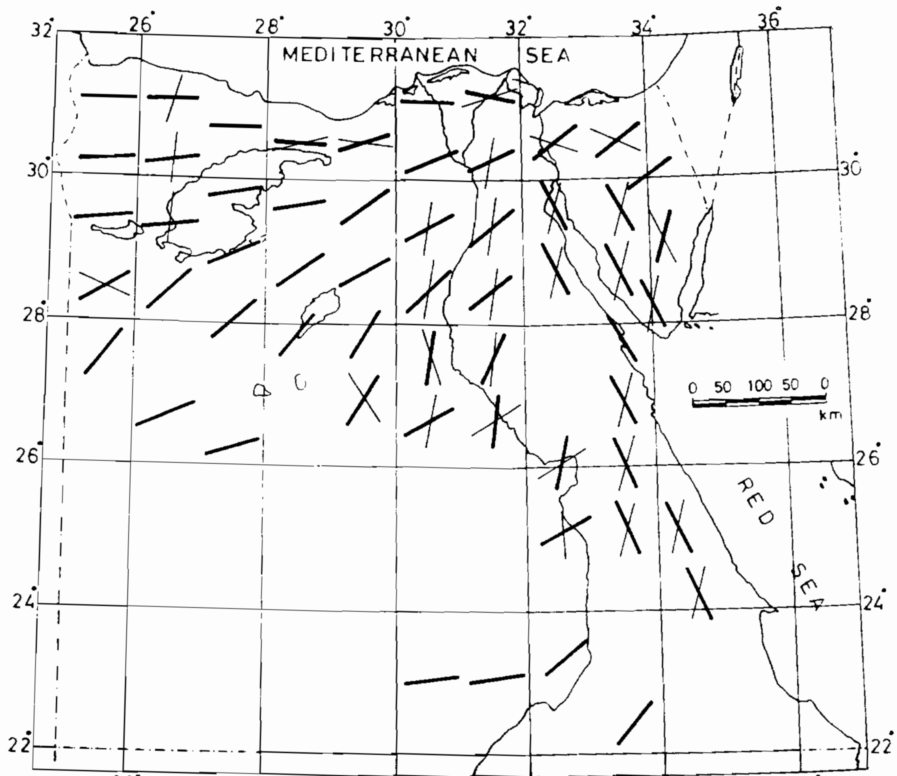


**Fig. 11.** Trends of the shallow structures (interpreted from the residual gravity fields).

In Fig. 10, trend patterns interpreted from regional fields of long wavelengths are given and represent tectonic trends of deep level. There is great similarity between the trends in Figs 9 and 10.

In Fig. 11, trend patterns interpreted from residual fields having short wavelengths are represented and indicate shallow trends. These trends are similar to those in Figs 9 and 10 for some areas and completely different for others.

On the basis of these results, seven tectonic trend groups are distinguished from analysis of the Bouguer anomalies of Egypt and from regional and residual fields. These trends are in the E–W, N60°E, N40°E, N30°W, N–S, N20°E and N60°W directions. Two trend groups (N20°E, N60°W) are present in shallow levels only (within the sediments), whereas five trends groups (E–W, N60°E, N40°E, N30°W, N–S) are detected in both shallow levels (sedimentary sections) and deep levels (basement surface and deep basement).

## TECTONIC SIGNIFICANCE OF THE TRENDS

The trends identified in the present study are in good correlation with established tectonic configuration of Egypt (Said 1962; Youssef 1968; Meshref & El-Sheikh 1973; Halsey & Gardner 1975; Riad 1977; Tealeb 1977, 1979a & b; Riad *et al.* 1981; Abdelhady *et al.* 1983; Abdelhady & Tealeb 1984, 1985; Tealeb & Abdelrahman 1985). Trend directions E–W, N60°E, N40°E, N30°W and N–S in both the deep and shallow levels are believed to be due to tectonic movements throughout the geological history. These structures were initiated in the Pre-Cambrian and rejuvenated in later geologic times, possibly during the Neogene. Other trends recorded in the N60°W and N20°E directions are thought to be due to tectonic movements which affected the area in the Neogene alone.

It is well known that areas of the Mediterranean region and adjacent parts of Africa, Europe and Asia were affected by several tectonic movements between the Paleozoic and late Tertiary times (McKenzie 1970; Dewey *et al.* 1973). Two main factors may have controlled evolution of the main tectonic trends in Egypt. These trends, as well as the shear zones present in northern Egypt, suggest that the region has been influenced by two main stress fields acting during different geologic epochs (Riad *et al.* 1981). The first was generated during the drifting of the African continent that eventually resulted in the collision between the African and European plates. This factor has probably been acting since the Pre-Cambrian, and due to it, a meridional (N–S) stress field was acting on the continent. The second stress field was due to rotation of the African continent. Accordingly, a modified equatorial (NE–SW) stress field acted since Oligocene times and is related to the spreading of the Red Sea. Riad *et al.* (1981) believed that the principal stress axis of this field is perpendicular to the axial trough of the Red Sea (N55°E). The tectonic trends related to these stress fields are shown in Fig. 12.

In the northwestern corner of Egypt, the tectonic trends show that the role of the Red Sea spreading is minimal. Over most of the Eastern Desert of Egypt, the trends show that the role of the meridional (N–S) stress field is very small. In other areas both stress fields have been acting with different intensities.

The Suez and Aqaba directions have been considered as two ideal fracture (shear) systems, which may have resulted from a northern horizontal compressive force oriented N10°W (Youssef 1968; Moody 1973; Halsey & Gardner 1975). This

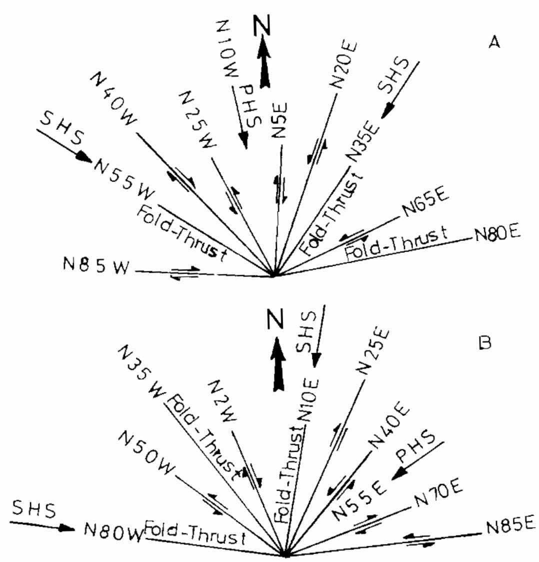


**Fig. 12.** Tectonic trends related to (A) Meridional wrench fault tectonics system. (B) Modified equatorial wrench fault tectonics system (after Riad *et al.* 1981).

concept was rejected by Abdel-Gawad (1969), Ben-Menahem *et al.* (1976) and Riad (1977). On the basis of the analysis of the Bouguer anomaly map, Riad (1977) concluded that the Suez trend is a right-lateral shear direction, due mainly to N–S compression, whereas the Aqaba trend is a left-lateral one (Abdel-Gawad 1969) as intepreted from surface lineaments. On the basis of earthquake analysis, Ben-Menahem *et al.* (1976) suggest a simple tectonic picture in which left-lateral motion with compression occurs along N–E trending faults including the Gulf of Aqaba and its extension through the Dead Sea, and a left-lateral motion with tension along a N–W trending branch of faulting including the Gulf of Suez and its extension.

The Aqaba and Suez trend directions may have resulted from a force oriented in N10°W direction as suggested by Youssef (1968) and Halsey & Gardner (1975). On the contrary, it is argued by Ben-Menahem *et al.* (1976) that two main types of forces caused the other movements. The trend predominant in the N30°W (Suez) direction was recorded in both the deep and shallow levels, whereas the trend in the N20°E (Aqaba) direction was recorded in the shallow levels only. These results indicate that the Suez trend direction is possibly older than the Aqaba trend direction. The Suez trend is possibly the result of a tensional force which started in the Pre-Cambrian and was rejuvenated during the late Tertiary, whereas the Aqaba trend may result from younger compressional force possibly initiated during the later Tertiary.

## CONCLUSIONS

Trend analysis of the Bouguer anomaly maps of Egypt, carried out by the graphical-numerical and the two-dimensional autocovariance methods, provides valuable information about tectonic trends and their developmental history. The interpretations in this paper are in harmony with the results of previous work. The graphical-numerical method gives the directions of major and minor extents, while the autocovariance analysis is helpful in studying trends at different depths. On the basis of these analyses, the following may be concluded:

(1) Tectonic movements have not been uniform all over the different regions of Egypt.
(2) Five principal tectonic trends: E–W (Tethyan), N60°E (Qattara), N40°E (Aualitic), N30°W (Suez) and N–S (East-African), were detected in deep and shallow levels.
(3) Two tectonic trends: N60°W and N20°E (Aqaba) were detected only in the shallow levels.
(4) The detected tectonic trends show that two stress fields may have been acting. The first is the meridional (N–S) stress field acting since early geologic times (Pre-Cambrian), and is believed to be related to drifting of the African continent and the collision between the African and European plates. The second is the modified equatorial (NE–SW) stress field acting since Oligocene times and related to Red Sea rifting.
(5) The effect of both stress fields is pronounced in all the areas of Egypt, but their intensities differ from one area to the other.
(6) Suez trend is strong at both deep and shallow levels whereas the Aqaba trend is present only at shallow levels. This suggests that the Gulf of Suez antedates formation of the Gulf of Aqaba.

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# تحليل إتجاهي إحصائي وتكتوني
# لمجال البوجير التثاقلي لمصر

على تعيلب
قسم التثاقلية الأرضية والجيوديسيا ،
المعهد القومي للبحوث الفلكية والجيوفيزيقية ،
حلوان ، مصر

## خلاصة

بنى البحث على التحليل الاحصائي لتحديد الاتجاهات التكتونية الرئيسية الموجودة في مجال البوجير التثاقلي لمصر ، لدراسة مدلولاتها التكتونية . أجرى البحث على مجال البوجير ومتبقيات المجال التثاقلي باستخدام طريقة عددية بيانية وطريقة التباين المشترك الذاتي .

أمكن تحديد سبعة إتجاهات تكتونية رئيسية تتواجد على أعماق مختلفة تتراوح فيما بين الرسوبيات الضحلة وسطح القاعدة وعمق القشرة . يلوح من الاتجاهات التكتونية التي تم التعرف عليها أن المنطقة قد تعرضت ، على إمتداد تاريخها التكتوني ، لمجالي قوتين أثرتا خلال أحقاب جيولوجية مختلفة ، الأقدم منها يحتمل حدوثها نتيجة للتفاعل بين طبقتي أفريقيا وأوربا ، أما الأحدث فتعزى إلى تفلّق البحر الأحمر . وقد استعان المؤلف بالجداول والخرائط العديدة لعرض النتائج .