Analyzing and interpretation of the satellite imagery lineaments to studying the tectonic framework of the Gulf of Aqaba area in Egypt

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Abstract

The present work is concerned with studying and analyzing the satellite imagery to extract and integrate lineament by using logic operator technique (Baridi J., 2000), in turn of lineaments analysis and interpretation to clarify the general structural framework of the south eastern part of Sinai which have complex tectonic. This study revealed that there is sort of tectonic rotation, affecting the area in clockwise direction. Accordingly the tectonic activity seaward is believed to be stronger than that landward, i.e. the stability in the zone behind the shore line is less than that in the land side. Since the tectonic activity in the study area comes from sea towards land, along an E-W direction, the Gulf of Suez tectonism is suggested to effect the study area, where the tectonic activity decrease from N to S. The surface activities i.e. (erosion) decrease toward the north, south and shore line of the Gulf basin more than that at its middle part. The tectonic activity in this study classified according to the lineaments thickness to reveal the shallow, intermediate and Deep seated tectonic.

Keywords: Lineaments, Lineaments analysis, Remote sensing, Gulf of Aqaba.

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تحليل المتجهات الخطية لصور الأقمار الصناعية وتفسيرها في دراسة الإطار التكتوني لمنطقة خليج العقبة بجمهورية مصر العربية

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الملخص

يركز البحث على دراسة صور الأقمار الصنعية وتحليلها من أجل استخلاص السِّمَات الخَطِّيَّة وتحليلها باستخدام تقنية المحاكاة المنطقية (بريدي، 2000) وصولاً إلى إعادة صياغة الإطار التكتوني وترتيبه العام في المنطقة المدروسة وتفسيرها بما يخدم التكتونيك في هذه المنطقة، تقع المنطقة المدروسة في جنوب شرق سيناء، وتملك هذه المنطقة نشاطاً تكتونياً معقداً ومركباً مع النشاط التكتوني لمنطقة خليج السويس، فرزت الدراسة النشاطات التكتونية المختلفة، وكشفت وجود تناوب لنشاط تكتوني باتجاه عقارب الساعة يؤثر في المنطقة، ويكون شديداً باتجاه الجانب البحري منها عنه في الجانب المتاخم لليابسة، مما عكس تأتي النشاط التكتوني من جهة البحر الشرقية إلى جهة اليابسة الغربية، كما ولوحظ تراكب للنشاط التكتوني المتأتي من خليج السويس مع النشاط التكتوني في المنطقة المدروسة، وذلك بتناقص حدة النشاط التكتوني من الشمال باتجاه الجنوب، أظهرت عمليات الفرز للنشاطات التكتونية المختلفة أن نشاط الفعاليات السطحية (كالحت) تتناقص باتجاه الجنوب وأيضاً تتناقص باتجاه خط الشاطئ عنها في المناطق الداخلية من المنطقة المدروسة، إذْ فُرزت في هذه الدراسة مختلف النشاطات التكتونية بناءً على ثخن السِّمَات الخَطِّيَّة إلى نشاط سطحي ومتوسط وعميق.

الكلمات المفتاحية: السِّمَات الخَطِّيَّة، تحليل السِّمَات الخَطِّيَّة، الاستشعار عن بعد، خليج العقبة.

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Introduction

The study area lies between the longitudes $34^0 10`$,$34^0 50`$E, and latitudes $28^0 10`$, $29^0 10`$N, (Egypt) in south eastern part of Sinai (Fig.1). The Sinai Peninsula is wedged between the African and Arabian plates where the boundaries of which are the Gulf of Suez and Gulf of Aqaba-Dead sea rift systems, from the east and west respectively. The Arabo-Nubian shield pre-Cambrian igneous and metamorphic rocks were exposed in the south of study area. The Field and petrographic evidences indicate that this shield consists of series of island arcs which were cratonized during the late Proterozoic-early Paleozoic (1200 to 500 my BP) Pan-African orogeny (Said, R. 1990). The peneplaned paleosurface of the shield dips gently northward with the overlying sediments ranging from Cambrian to Recent, and thickening north-ward. Also an east-west trending shear zone of dextral strike slip faults with a displacement up to 2.5 km has been recognized in central Sinai. The Syrian Arc structures attain a more northerly trend aligning themselves with the sinistral Dead Sea fault system and the Pelusium line, to the east and northeast of Sinai. In these regions, the folds appear to be reminiscent of fault plane drag. The folding was then reactivated throughout the Mesozoic and the deformation climaxed in the Oligocene (Agah, 1981).

The alternative theory is that the fold system is closely related to the compressional stresses created when the Tethys Sea, which was located between the Afro-Arabian and Eurasian land masses, began to close, as a result of northerly subduction, during the late Cretaceous (Senonian) period, in terms of reconstructing plate movements, the shifting of the Arabian plate by as much as 105 km in a right-lateral sense along the Dead Sea fault, coupled with a clockwise motion, necessitates and dictates a westerly and clockwise translation of the Sinai plate in order to avoid crowding and overlapping of the continental crust in the Dead Sea-Gulf of Aqaba shear zone. In turn, the bulk of the Sinai's gross westerly motion must then be taken up along and within the Gulf of Suez rift. This motion could be further resolved into two net components; one parallel (left-lateral) along, and the other normal (compression) to the rift trend. This sequence of plate motions can simulate compressional and left-lateral shear stresses capable of partially closing the Gulf of Suez. Thus the reverse sense of deformation, i.e. ductile extension of the crust (Mckenzie *et al.*, 1970; and Freund, 1970) and right-lateral strike-slip, since at least the late Oligocene time, could have caused the formation of the Gulf. The present work concerned with studying and analyzing the satellite imagery to extract and integrate lineament in tern of lineaments analysis and interpretation to clarify the general structural framework of the area under consideration. The extraction of lineaments from satellite imagery is very important for many purposes such as geological mapping (Rowan and Lathram 1980), and seismic and landslide risk assessment (Stefouli *et al.,* 1996). Lineaments may reflect geological structures or topographic features and usually extracted and interpreted from satellite imagery manually or automatically, many authors extract lineaments manually from satellite imagery (e.g., Arlegui and Soriano 1998; Leech *et al.*, 2003; Cortes *et al.,* 2003; Nama 2004), other authors interpreted the structural lineaments form the digital satellite imagery using the automatic extraction techniques (e.g., Casas *et al.*, 2000; Costa and Starkey 2001; Vassilas *et al.,* 2002 and Mostafa and Bishta 2005), in this study lineaments extract automatically by using the logic operator technique (Baridi J., 2000).

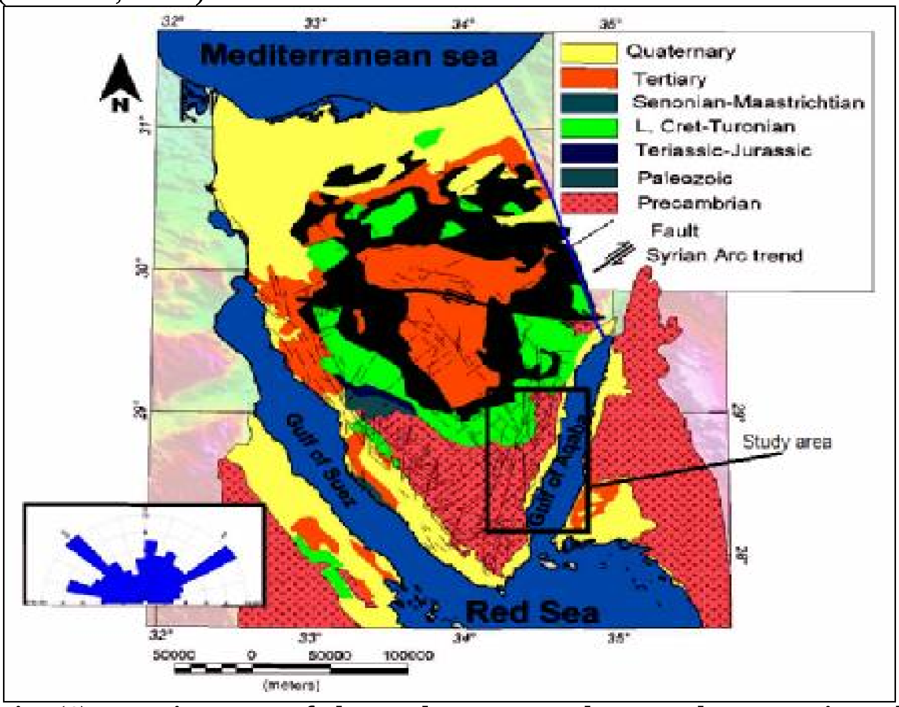

Fig. (1) Location map of the study area, overlaps on the Tectonic and Geologic map of the Sinai Peninsula (Ginzburg *et al.*, 1979; Neev, 1975).

Material and Methods

The data used in this study are topographic and geology map, as well as landsat-image Thematic Mapper, contains seven bands in digital form, which obtained from EROS data center (U.S.A.). These data were corrected, enhancement and processed by using (IDRSI Andes and ER Mapper), as the following:

The seven bands of landsat image raw data in uncorrected Thematic mapper are all grouped and subjected to Geometrical manipulation technique to change the geometrical properties from image grid system to original maps grid system (Anuta, 1973 and Schowengerdt R., A., 1983), which cover the study area. This process used polynomial equations to establish a rubber sheet transformation, as if one of the grids were placed on rubber and warped to original maps, after that the corrected images of the study area are obtained.

The landsat images of the study area are enhanced using contrast enhancement (stretching) technique (Goetz, A. F. H., *et al.*, 1975). This technique is used to increase the visual contrast in the landsat images of the study area in order to clarify the lineament components. Then the histogram equalization technique (Schowengerdt R., A., 1983) is applied to make a necessary balance of the gray level on the landsat images of the Gulf of Aqaba area.

The landsat image of the study area classified using principal component classification technique (Jenson and Waltz, 1979), which was applied on the multispectral image data of the Gulf of Aqaba area to correlate between features of images from channel to channel. The first principal component image (Fig. 2) “PCI” is just a weighted average image, while the remaining images are somewhat like pairwise differences between channels. This fact can be derived since the percentage of total variance (%Var) contributed by each eigenvalue is equal to 92.83% in the first principal component image, which means that, the first eigenvector account for 92.83% of variance in channels set, while the other remaining principal component images have 7.17% and the first principal components have the highest number of loading existing in all channels. This is true since the loading number of this image is equal to: 0.967, 0.989, 0.995, 0.993, 0.980, 0.828 and 0.977 corresponding to channels number: 1 to 7 respectively, while the remaining images have the smallest loading number. For that this image is then selected to study the lineaments since it has a higher number of structural features than principal component images of other orders.

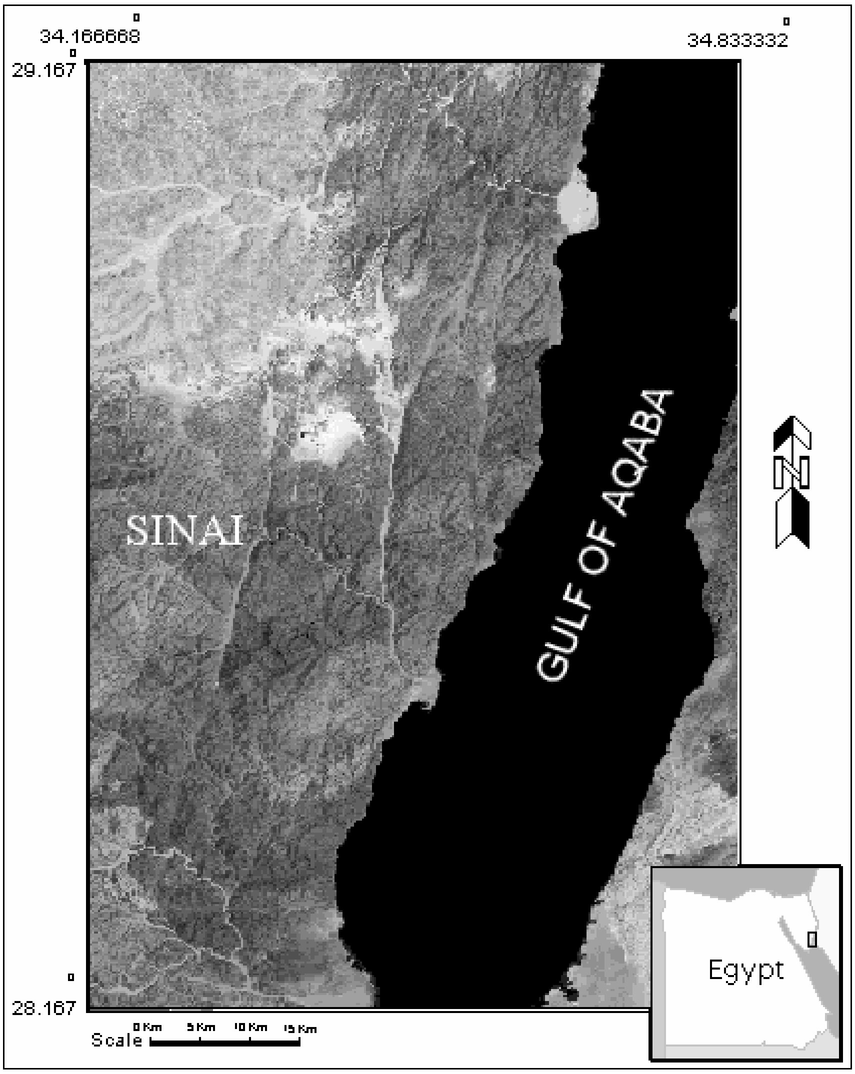

Fig. (2) First principal component image

The lineaments of the study area then extracted using first principal component image. This is carried out according to three major steps (the second and third steps are achieved by using special Fortran programs produced by the writer); the first of which is to clarify the data by using edge detection filtering technique (Barry S. Siegal, 1980). The second step is extract lineament information by using the logic operator technique (Baridi J., 2000), while the last step is to apply the classification technique (Baridi J., 2000) on the lineament data, where the study area is divided into 96 regular rectangles, each of which has an area of about 76.3888 Km2 and of sides 8.333 Km and 9.1666 Km. which extend along latitude and longitude directions respectively. In each rectangle the frequencies, the azimuth, and the thickness of each lineament are determined. The thickness of each lineament is classified into thick, mid-thick and thin, and the length of each lineament of these classes is measured. The output is then stored in 18 frequency data files in addition to 18 length data files for each class, where each file indicates the corresponding azimuth angle, from 0-10^0 NE to 0-10^0 NS. The resulting data base files number is 108 for all directions of different frequencies and lengths. In each azimuth deviation of 10^0, (from 0^0-180^0) east or west from the north direction, the distributed frequency, length, and types of lineaments are determined, according to the three orders of lineaments thickness. The obtained data values of each parameter (at each azimuth division) are presented in contour maps (54 maps for each type). Concerning any order of lineament thicknesses, there will be 18 maps for each type (frequency or length), 9 maps for 0^0-90^0 (east) and other 9 maps for 90^0-180^0 (west). The closures, in each of these maps, are determined, digitized by using on screen digitizing technic, and saved as vector files. These vector files are converted to raster images by interpolation process. The result of this processing was "9" images. These images have been in turn, processed in terms of number of their intersected closures using algebraic images, to produce a compiled intersection images. The idea of this technique is the overlaying of the "9" closures images to obtain the twelve compiled intersection images, each of which has many intersection areas which could be sorted and classified using color codes. The center of any of the homogeneous colors was defined and digitized in a separate vector file, which is contoured to produce twelve compiled distribution contour maps.

The subsurface structures could be found by the study of lineament features on the land surface. On one hand, the frequency lineament analysis gives rise to an indication about the origin of tectonism. As the frequency lineament becomes higher the origin of tectonism is seemed to be shallower. If the lineament frequency is low the origin of tectonism is deep, i.e. the overburden layers and sedimentary section masks a part of the effect of tectonic activity. On the other hand, the length of lineament gives an information about the intensity of tectonism. As the length of lineament increases, the intensity of tectonism is going high and when decreases, the intensity of tectonism is going low. Also the thickness of lineament, in conjunction with its azimuth direction gives information about the general structure framework of the study area. Thick lineaments give a criteria on the causative shallow range structure, medium lineaments show the causative intermediate range structure, while thin lineaments reflect the effect of a causative deep range structure. Accordingly the lineaments of the study area are classified into three classes (thin, mid-thick, and thick) according to its thicknesses. Another two classifications are made according to lineament azimuth "Eastward and Westward". Hence, concerning any lineament parameter (frequency or length), six images, or contour maps, are constructed.

Results and Discussion :

(i). Interpretation of the Azimuth-Frequency of thin lineaments (for deep seated tectonism):

- **Thin eastward lineaments:**

Figure (3) shows the compiled intersection image of azimuth frequency of the eastward lineaments of the study area. In this figure; from the tectonic point of view, the homogeneity of color is related to the same plate of relative movement while an increase of color darkness or lightness indicates a presence of highly active tectonic zone. For example, the blue color indicates a positive closures intersection while the darkness of this color indicates a high order positive closures intersection. The red color indicates negative closures intersection, while the yellow color surrounded by red color

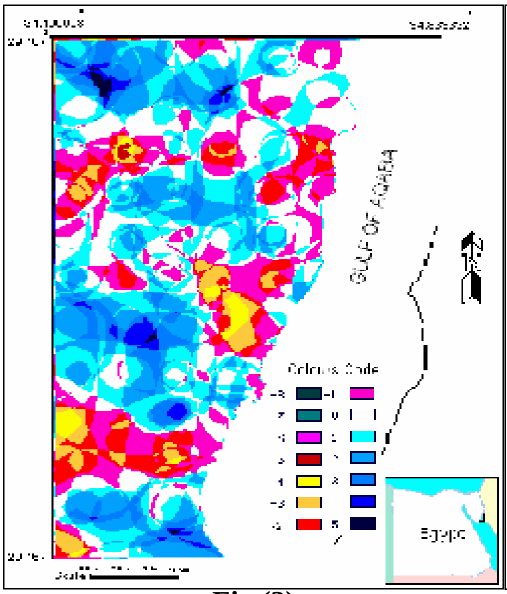

Fig.(3)
Image of the compiled closure intersection of azimuth- frequency of thin eastward lineaments.

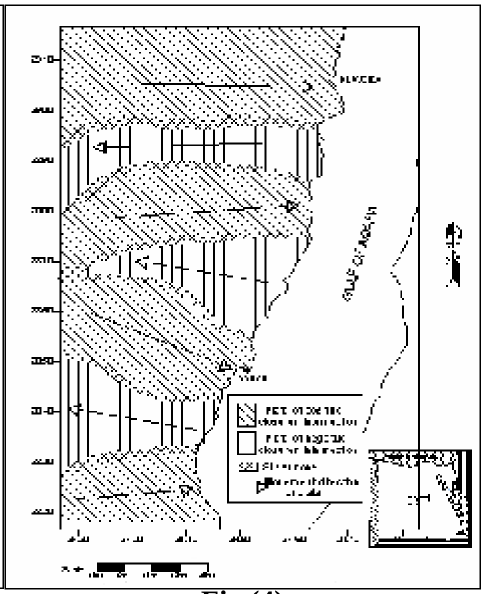

Fig.(4)
Structural map of deep seated as revealed from eastward lineaments.

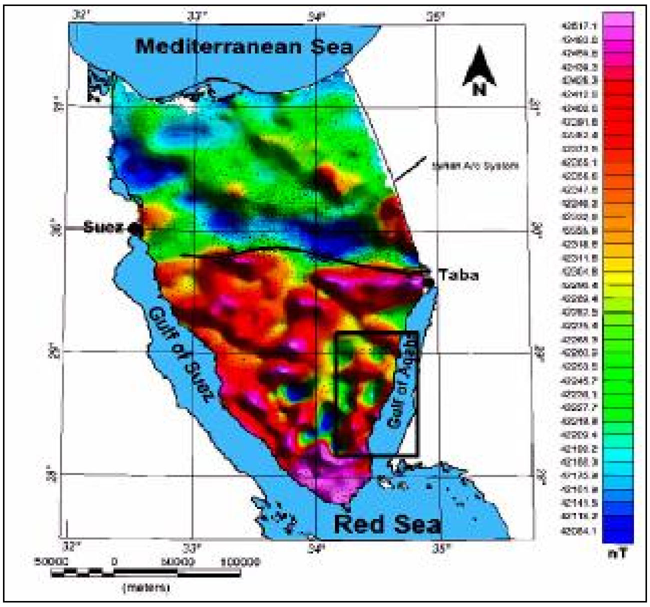

Fig. (5) Magnetic anomaly map of Sinai Peninsula (Aboud *et al.*, 2011).

Indicates high order of negative closure intersection. The first glance of this image shows four blue plates intervened with three red plates. All these plates together form a sandwich shape structure which intersects the shoreline. This may indicate a sort of strike-slip faults, which break the area and shore-line.

The different structural plates movements (positive or negative) were determined as shown in figure (4) where the movement directions of these plates are indicated by arrows taking the potential direction of closures intersection intensities between these plates. This may indicate the existence of shear zones of earthquakes foci in the study area. By comparing the results obtained from the proviso technique and the magnetic map figure (5), we can extract the same impression, that the magnetic map show good correlation between compiled closure intersection image and magnetic signatures. The southern part of the area also shows several circular magnetic anomalies that could be related to strike-slip movements of the Gulf of Aqaba area, while the northern part of the area is characterized by elongated magnetic anomalies trending in the E-W direction which could be related to a shear zone. Other circular anomalies are observed and could be interpreted as uplifting basement or intrusion of dibasic dykes.

The intersection image (Fig. 3), is interpreted to yield (Fig. 4). In this figure the different structural plates are determined and classified according to there rates of movement, which magnitudes reflect the activity of tectonism. The high tectonic activities are indicated by arrows number (1,3 and 8) while the low tectonic activities are indicated by arrows number (2,4,5,6 and 7) (Fig. 6). This may indicate a sort of tectonic rotation affecting in a clockwise direction. This rotation may be due to high tectonic

Activity (indicated by arrow number 8) which acts in the north of the area along an W-E direction, and its equivalent (arrow number 1) in the South along an E-W direction. In between the two arrows, the tectonic movement shows different directions but with low activity.

- **Thin westward lineaments :**

The azimuth frequency of thin class westward lineaments image of the study area, which indicate deep seated tectonic, is shown in (Fig.7). It has five homogeneous color zones, the two red ones indicate negative closure intersections while the three blue ones indicate positive closure intersections. The dark blue color indicates highly active zone, (where two epicenter active zones exist as illustrated in the figure), while the yellow color indicates a stable zone. The results of interpretation of this image is shown in (Fig. 8), where the different plates and their corresponding shearing zones are determined. The movement direction of these plates is indicated by arrows in clockwise direction. Accordingly the arrows of tectonic movements are classified as shown in (Fig. 9), where ten arrows could be determined. The arrows No. (1,5,7,10 and 11) indicate high tectonic activity movements while those of No. (3,6 and 9) indicate moderate ones and the rest of the arrows indicate low tectonic activity movements. The movement of the highest tectonic activity is indicated by arrow No. 1 which has a W-E direction and is existing in the northern part of the study area. The arrows No. (7 and 11) have an E-W direction and are existing in the southern part of the area. This may suggest a clockwise rotational motion of plate in the study area. Other arrows are of different directions which may indicate a sort of breaking in the area.

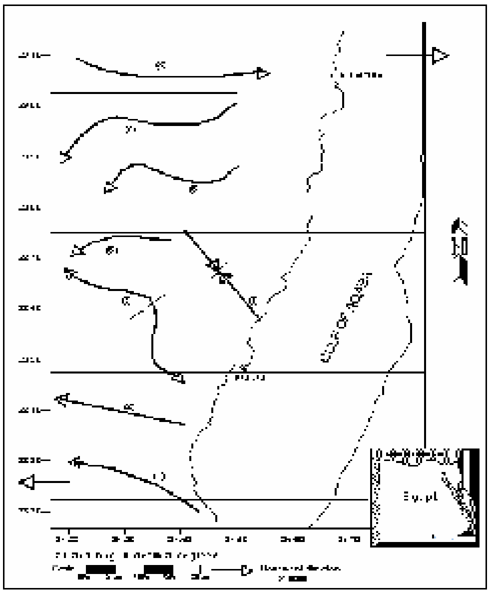

Fig. (6)
Deep seated tectonic movement, as revealed from contour intersection thin eastward lineaments.

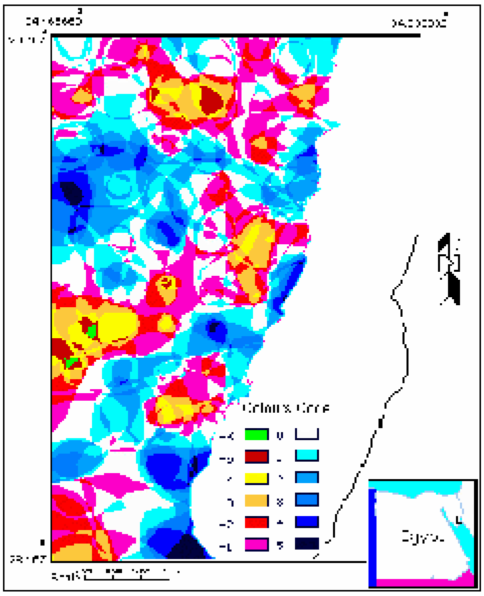

Fig. (7)
Image of the compiled closure intersection of azimuth- frequency of thin westward lineaments.

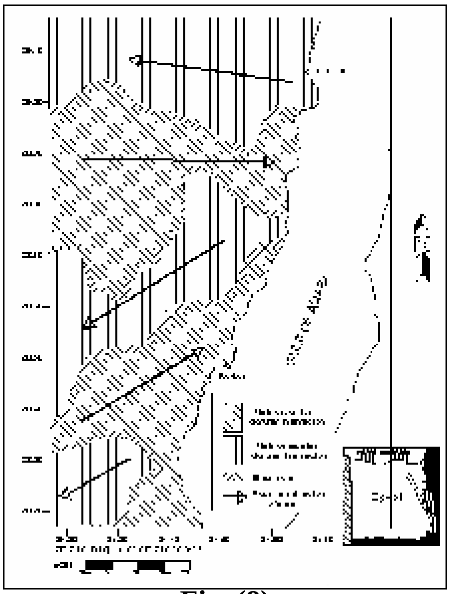

Fig. (8)
Structural map of deep seated as revealed

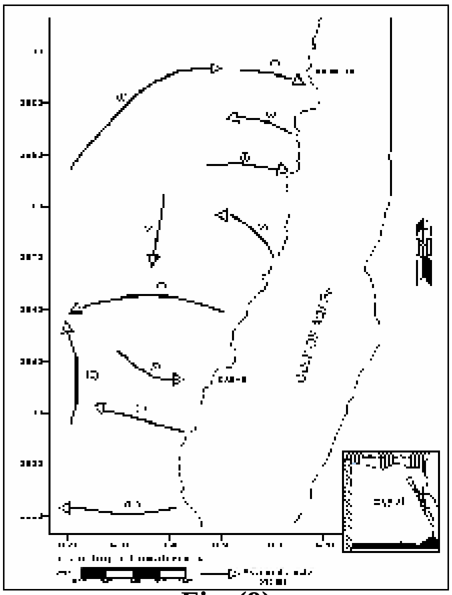

Fig. (9)
Deep seated tectonic movement, as revealed from contour intersection thin westward lineaments.

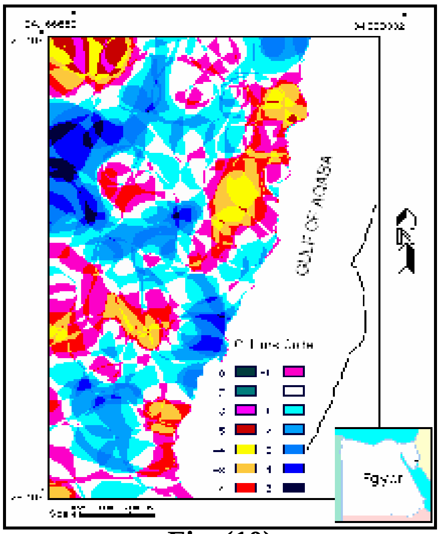

Fig. (10)
Image of the compiled closure intersection of azimuth- frequency of mid-thick eastward lineaments .

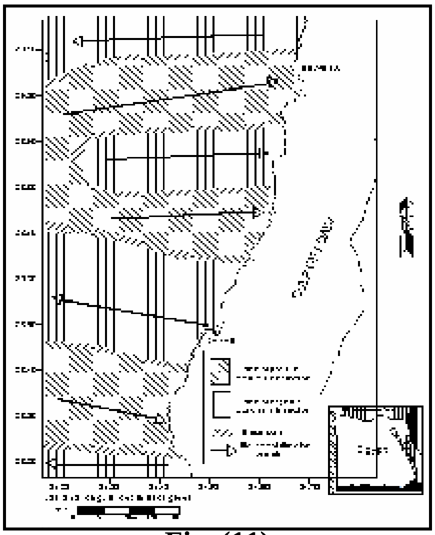

Fig. (11)
Structural map of subsurface plates at moderate depth as revealed from mid-thick eastward lineaments.

(ii).Interpretation of the azimuth-frequency of mid-thick lineaments:

This class of lineaments is concerned with tectonic activities of moderate depth, which consists of two types; east and west-wards lineaments:

- **Mid-thick eastward lineaments:**

Figure (10) shows the compiled closure intersection image of azimuth frequency of mid-thick eastward lineaments of the Gulf of Aqaba area. The color contrast is decreasing from the north toward the south, as well as the intensity of tectonic activity. (Fig.11) indicates different plate structures at moderate depth as existing in the area. The arrows indicate the movements of these plates which are separated by shearing zones, and which may generate in between strike slip faults, to break the area from north to south.

- **Mid-thick westward lineaments:**

Figure (12) represents the compiled closures intersection image of azimuth frequency of mid-thick westward lineaments of the Gulf of Aqaba area. Inspection of this figure shows that there are two energy epicenters of dark blue color. These epicenters may generate energy which is migrated to low tectonically active zones. Interpretations of figure (12) yield a structural map (Fig.13) of moderately deep plates in the study area. Inspection of figure (12) shows that there are two high energy active zones which in turn are included between low active belts.

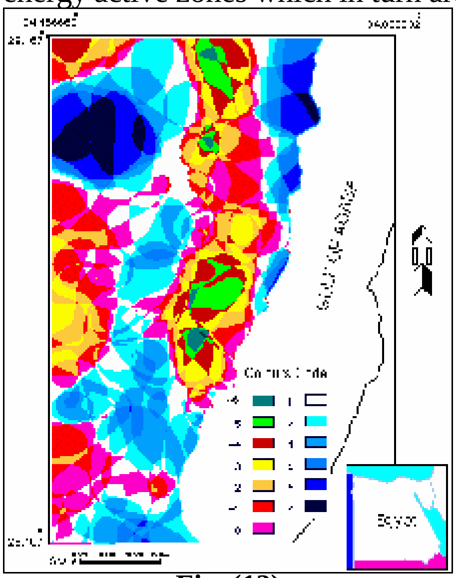

Fig. (12)
Image of the compiled closure intersection of azimuth- frequency of mid-thick westward lineaments.

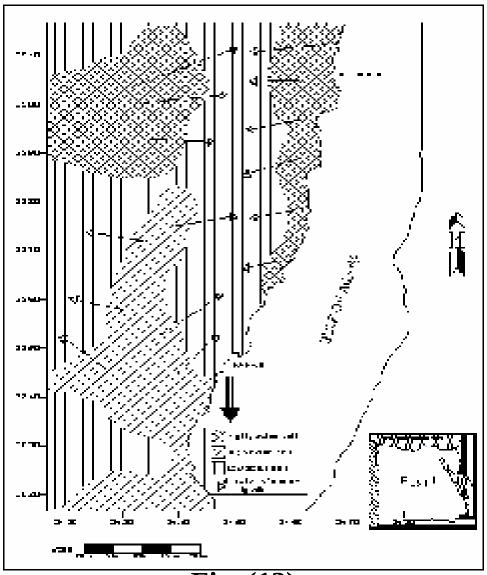

Fig. (13)
Structural map of moderate deep seated plates as revealed ***from mid-thick weastward lineaments***

(iii).Interpretation of the azimuth-frequency of thick lineaments:

As we have seen before thin and mid thick lineaments gave information about tectonic activities that come from deep seated origin, whereas thick lineaments give a criteria on the activity of causative structures of shallow and surface origins.

- **Eastward thick lineaments:**

Thick lineaments give good impression about surface dynamic activity. The flood drainage network and shallow tectonic activity complicate the resulted image and contour map. Figure (14) shows the compiled closure intersection image of azimuth frequency of the study area as revealed from thick eastward lineaments. From the interpretation of this image, it was possible to construct another map (Fig. 15) by which shows the surface activities in the study area as indicated by seven arrows. Arrow No. 2 explains the flood drainage which is flooding in the sea and is coming from a location at 5 Km to the south of Nuweiba city. Arrow No. 5 represents flood drainage at north of Dahab city while other arrows indicate flood drainage at some other locations inside the study area which are considered as rain water accumulation.

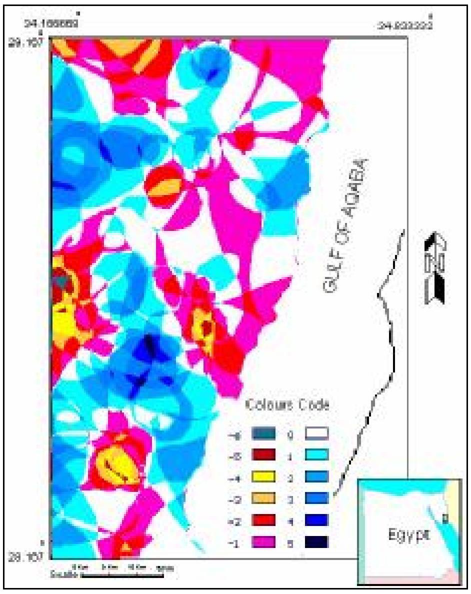

Fig. (14)
Image of the compiled closure intersection of azimuth- frequency of thick eastward lineaments.

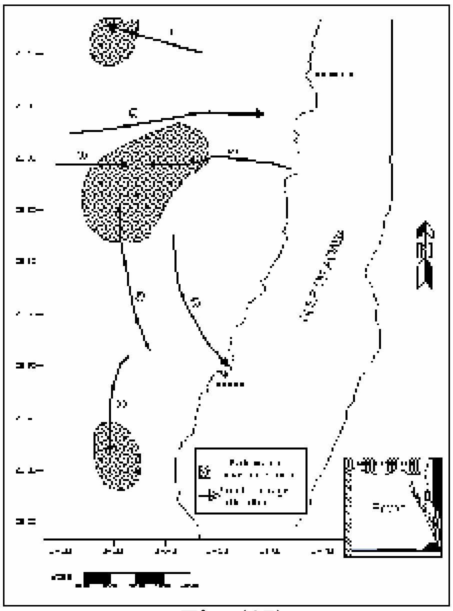

Fig. (15)
Surface activities, as revealed from thick eastward lineaments.

- **Westward thick lineaments :**

Figure (16) show the image and the correspond contour map of the compiled closures intersection of azimuth frequency of thick westward lineaments of the study area. Inspection of these figures show that tectonic activity is related in two belts, the lowest of which is shown in the image and the map, where a dark blue color represents the highest energy in the area and the green color indicates lowest energy. This image exhibits events of multi activity which when separated and interpreted two results area.

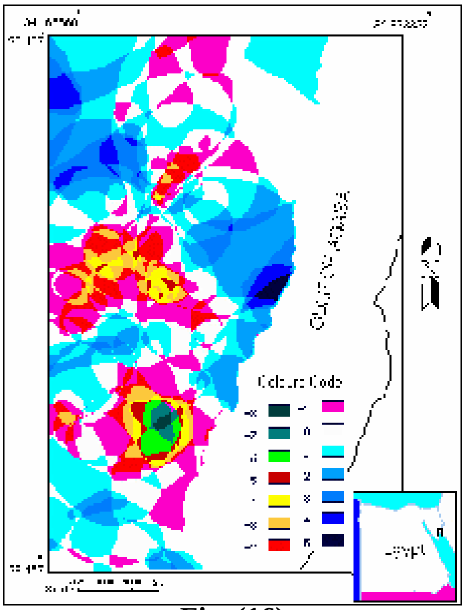

Fig. (16)
Image of the compiled closure intersection of azimuth- frequency of thick westward lineaments .

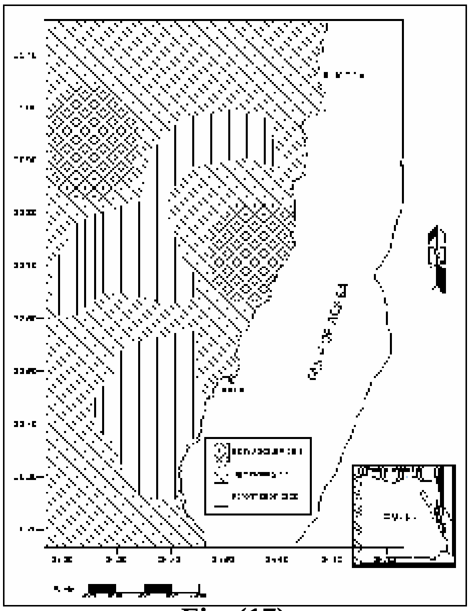

Fig. (17)
Surface structural activities, as revealed from thick weastward lineaments.

Obtained. The first one, from figure (17), gives a good impression to energy epicenter and deformation movement. The other one, from figure (18), indicates different belts of clockwise rotation which means that they have deep roots and that there movements seem to extend outside the study area.

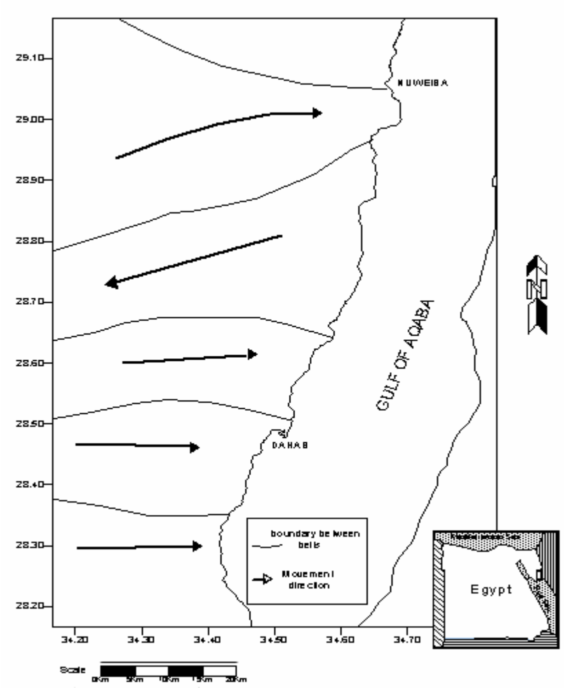

Fig. (18) Tectonic movements and boundaries between subsurface belts, as revealed from azimuth-frequency of thick westward lineaments.

CONCLUGIN:

- **Eastward lineaments :**

1-The compiled intersection image of azimuth frequency of the eastward thin lineaments, revealed that: (a). the low active plates intervened with the high active plates forming together a sandwich shape structure, which intersects the shoreline, and may indicate a sort of strike slip faults, that break the area and shoreline, (b). the movements direction of these plates indicate the existence of shear zones of earthquakes foci. (c). there is a sort of rotation, in tectonic manner, affecting in clockwise direction in the study area.

2-Tectonograms of the eastward thin lineaments (Fig.19), revealed that: (a). the tectonic activity seaward is stronger than that at landward, which means the stability zone behind shore line is narrower than that in the land side. (b). the tectonic activity comes from sea towards land along E-W direction. (c). the movement of tectonic activity in the study area appears as rotational motion along a clockwise direction.

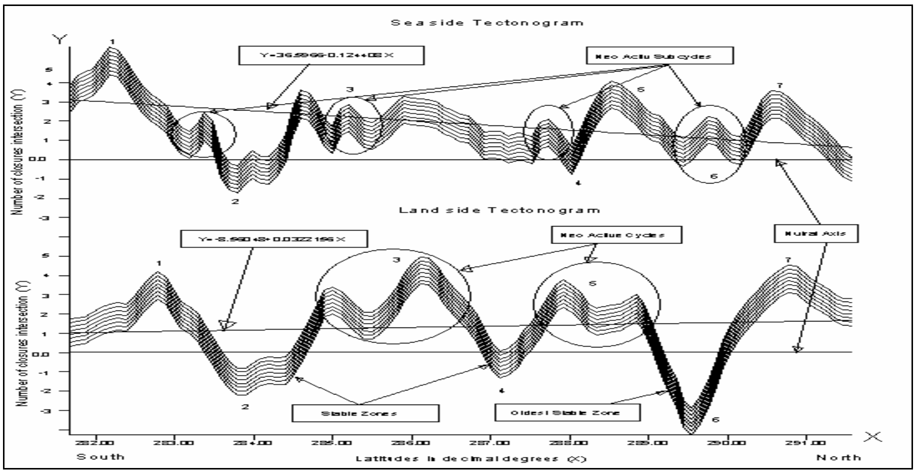

Fig. (19) N-S Tectonograms of deep seated tectonic movements; with corresponding trends' as revealed from azimuth-frequency of thin eastward lineaments.

- **Westward lineaments :**

1- The compiled intersection image of azimuth frequency of the westward thin lineaments revealed that: (a). there are two epicenters active zones in the study area (b). the study area is effected by clockwise rotational motion of plates.

2- The tectonograms of deep seated westward thin lineaments (Fig. 20) revealed that : (a). the tectonic events are shifted from south to north when we go from land to sea side, this may indicate tectonic events along an axis of about 45^0 NW-SE direction, which is congruent with the Gulf of Suez tectonism axis that affect the study area. (b). the tectonic activity associated with sea side is decreasing from south to north and is stronger than that associated with the land side, where the activity is decreasing from north to south in a gentle form.

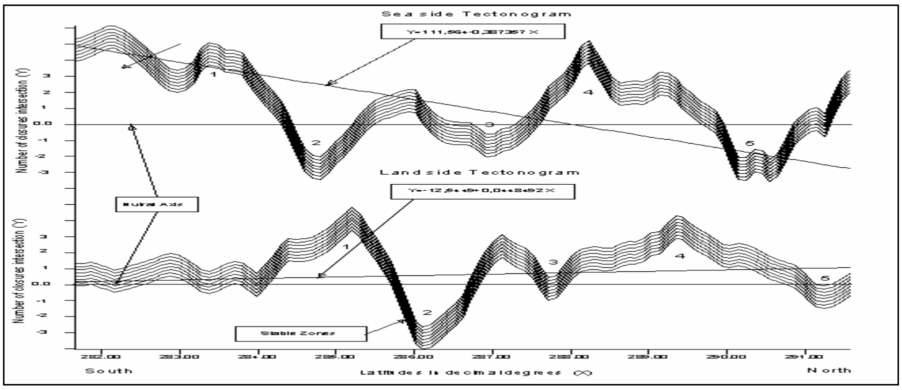

Fig. (20) N-S Tectonograms of deep seated tectonic movements; with corresponding trends' as revealed from azimuth-frequency of thin westward lineaments.

(ii). Moderate seated tectonism :

- **Eastward lineaments :**

1- The compiled intersection image and contour map in this case revealed that: (a). the intensity of tectonic activity is decreasing from north toward the south. (b). the different plates in the study area generated in between strike slip faults which break the area from north to south.

2- The tectonograms of this setting (Fig. 21) revealed that: (a). the tectonic activity decreases along N-S direction, with rapid changes along southward direction

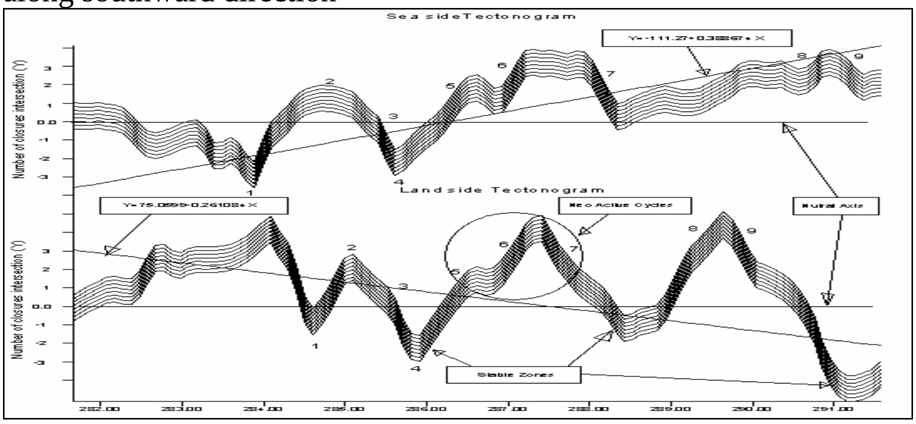

Fig. (21) N-S Tectonograms of moderately deep seated tectonic movements; with corresponding trends' as revealed from azimuth-frequency of mid-thick eastward lineaments.

(b). There is a high active zone lies behind shore line side, whereas low active zone lies on the land side (c). there are strike slip faults transmitted from sea to land sides and from land to sea sides respectively (d). the clockwise rotation and strike slip movement which come up from deep seated plates are not clear in the moderate seated.

- **Westward lineaments :**

1- The compiled closures intersection image in this case revealed that there are two energy epicenters may generate and migrate energy to low tectonic active zones.

2- The tectonograms of the westward mid-thick lineaments (Fig. 22) revealed that the deformation in this setting appears as elastic one when compared with the deep seated deformation.

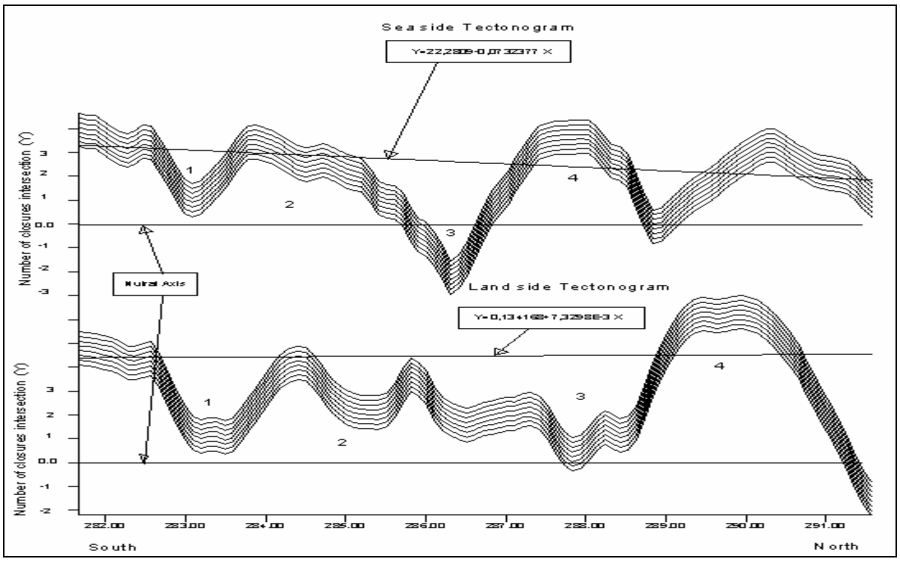

Fig.(22)N-S Tectonograms of moderately deep seated tectonic movements; with corresponding trends' as revealed from azimuth-frequency of mid-thick westward lineaments. (Number indicate to the same cycle)

(iii). Shallow seated and surface activities :

- **Eastward lineaments :**

1- The compiled closures intersection image revealed that the surface activities in the study area show some flood drainage flooding in the sea south of Nuwaibe by about 5 Km, and north of Dahab, while other drainage flood is existed inside the study area, the origin of these drainage are considered as due to rain water accumulation.

2- The tectonograms of the shallow and surface activity (Fig. 23) revealed that the land side is effected by surface and shallow tectonic activities more than sea side.

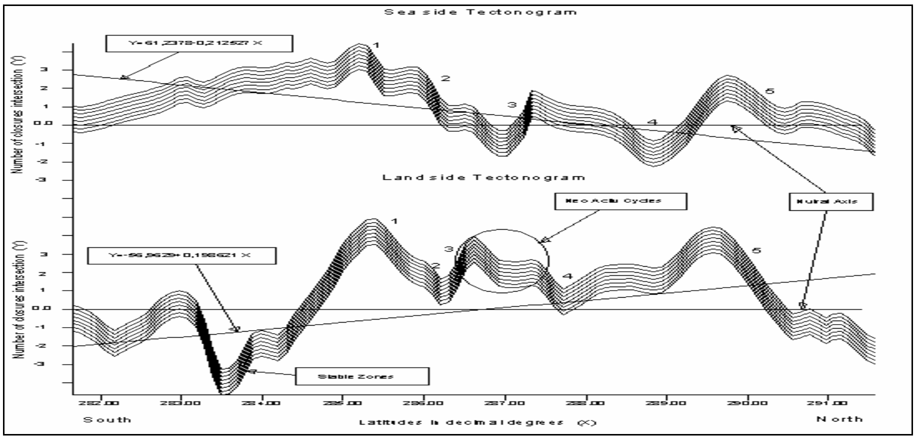

Fig.(23)N-S Tectonograms of surface activities;; with corresponding trends' as revealed from azimuth-frequency of thick eastward lineaments.

- **Westward lineaments :**

1- The compiled closures intersection image revealed that: (a). there are two energy epicenters and two deformation zones (b). the clockwise rotation of belts in shallow settings has a deep root and the tectonic movement extends outside the study area.

2- The tectonogram of this setting (Fig. 24) revealed that: (a). the shallow tectonic activity in the land side area is stronger than that in the sea side. (b). the clockwise rotation appears and extends more than that appeared in the deep rotation. (c). the deformation in this seated structure appears like plastic manner.

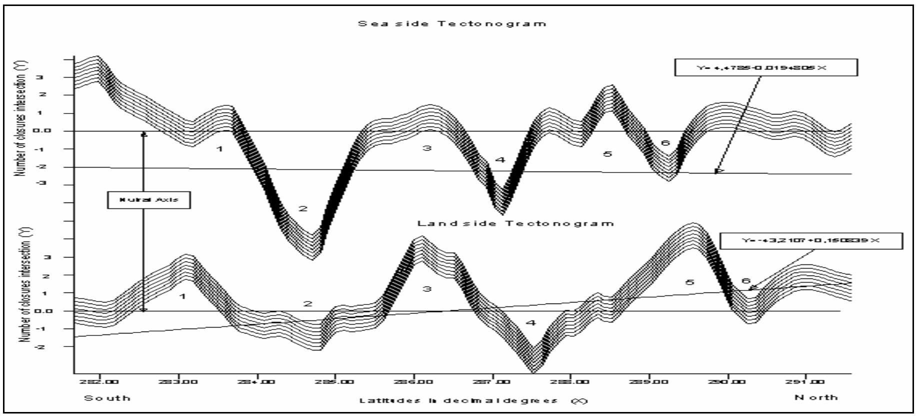

Fig.(24)N-S Tectonograms of shallow tectonic movements; with corresponding trends' as revealed from azimuth-frequency of thick westward lineaments.

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