Investigating the Behaviour of the Earth's Crust in Sinai Peninsula after the Earthquake of 1995

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تعتبر مراقبة تحركات القشرة الأرضية من أهم المهام التى تواجة الجيوديسيين وذلك لما لها من تأثير واضح على أمن الانسان وسلامة نجزاتة المدنيـــة والاقتصادية. بدأت دراسة هذه التحركات فى مصر منذ فترة من الزمن فمثلا أنشأت شبكة لدراسة حركة القشرة الأرضية حول بحـــيرة ناصـــر عام ١٩٨٣ . أنشأت أيضا شبكات لدراسة الحركة فى أجزاء مهمة من الجمهورية تغطى القاهرة الكبرى وخليج السويس وشـــبه جزيـــرة سيناء. فى هذا السياق تم انشاء شبكة جيوديسية مكونة من ١١ نقطة لدراسة الحركة حول خليج السويس ومنطقة شبه جزيرة سيناء وذلك عام ١٩٩٤ ورصدت فى ذلك العام. جدير بالذكر أنه حدث زلزال بقوة ٧ ريختر عام ١٩٩٥ بمنطقة نويبع ورصدت الشـــبكة المذكورة أعوام ١٩٩٦ و١٩٩٨ و١٩٩٩ وذلك باستخدام أجهزة GPS. تم حساب الانفعال الحادث بالمنطقة وذلك بمقارنة خطوط القواعد من مرات الرصد المتكررة وأيضا باستخدام أسلوب أخر يعتمد على حساب قيم التشويه فى المنطقة ككل. فى هذا البحث تم عرض وشرح لهذه الشبكة والطرق المذكورة لاكتشاف الحركة وكذلك دراسة سلوك القشرة الأرضية فى المنطقة بعد حدوث الزلزال

Abstract

Sinai Peninsula is an important part in Egypt, economically, historically, securitally and strategically. Therefore, the development of Sinai is one of the main aims for the Egyptians. The development of Sinai requires a lot of money, efforts, and time while Sinai Peninsula lies in unstable area, from the seismic point of view. So, following the Crustal movement of that area, is an important matter, for planning, construction, security of the projects and inhabitants. A geodetic network was initiated in Sinai in 1994 consisting of 12 stations. An Earthquake occurred in Sinai in 1995. The network was successively observed in the years 1994, 1996, 1998, and 1999. This research is made for studying the effect of the earthquake on the crust and its behaviour, along four years after the occurrence of the earthquake. GPS dual frequency receivers were used in

observing the network. The results showed considerable horizontal and vertical movements at some places in Sinai because of the earthquake. The results showed also that, the crust was retaining to its former position with time.

1- Introduction

After long time. Egyptian started to develop desert areas away from the Nile Valley. Large projects as in Sinai in the north-east and Toshka in the south are planned and they are in execution already. The Crustal movement is a main factor affecting the development process specially in unstable areas like Sinai Peninsula. A GPS network was established in Sinai to study the Crustal movement. Static GPS technique is used in many similar cases because of its accuracy which matches the nature and the required accuracy of such applications, the reader could refer to i.g.(Seeber, 1989). An earthquake occurred after initiating the network, So, the behaviour of the Crust along the years after the earthquake occurrence is investigated here. The network was observed once before the earthquake and three times after the earthquake. In the next sections, the GPS network, in and around, Sinai is illustrated and the processing of the data and the results are explained. Strain analysis is also explained in two different ways.

2- Design of the GPS Network and its Monumentation

In order to monitor the Crustal movement in Sinai Peninsula and around the Suez Gulf, a GPS Network consisting of 12 stations was established, in 1994. First, the GPS stations have been chosen on topographic and geological maps, then field trips to the area were started to choose the places for the network stations. These places were chosen to fulfil the following requirements (Fujii, 1997) :

i- The stations are well distributed around and through the area under consideration in order to detect the movement of its geological structure. .

ii- GPS static survey needs clear view with no obstructions above an elevation angle of 15° to 20°. It was difficult to find suitable places for Kathrine and Dahab points especially from the point of free site over 20° elevation angle. But finally, after hard work, two suitable places for these two stations were selected.

iii- The stations must be away from any electromagnetic sources, and metal structures in order to avoid the multipath effect.

iv- All the network stations were constructed in bedrock, in order to have high stability for the network stations.

v- The accessibility of the stations, by cars and instruments are considered

3- GPS Surveying Campaign Data

Using GPS, the network stations were defined in WGS84 with high accuracy to avoid the uncertainties in the old Egyptian datum, namely "Helmert 1906". Sinai network was observed four times since 1994 till 1999 for the purpose o f detecting the Crustal movement in Sinai Peninsula and around the Gulf of Suez. Table (1) summarises the campaign information. The shortest session, in the first campaign, was 6 hours and the last campaign was almost 24 hours. The session times were enough for such base lines. The satellites under 15° elevation angle are not used. Number of used satellites was 6 or more along the whole period of any session. The values of GDOP were never more than 8 during the observations. Precise ephemeries are used in processing the observations. These factors are considered to obtain the required accuracy of detecting the crustal movement.

4- Data processing

Bernese Software version 4.0 was used, (Bernese Software Manual, 1996). Processing part of Bernese GPS software consists of more than 80 FORTRAN programs, Bernese GPS Software was developed as a tool for highest accuracy requirements.

The software is particularly well suited for a rapid processing of small-size single and dual frequency surveys, permanent network processing, ambiguity resolution on long baselines (up to 2000 km using high accuracy orbits), ionosphere and troposphere modelling, combination of different receiver types (antenna phase center calibrations), simulation studies, orbit determination and earth rotation parameters estimation and generation of so-called free network solutions.

The row GPS data of the epoch 1994 were loaded into the GPSurvey. The precise ephemeries were added also in the orbital part of GPSurvey. Then base lines were calculated in one of the GPSurvey subprograms (Trimble, 1998). The obtained results were treated in order to depict the adjusted coordinates for all the network stations, free network adjustment was used. These adjusted coordinated were considered to be the apriori coordinates for all the observation epochs.

The software creates the single differences and stores them in files and it produces also an ambiguity free L3 solution. No final results are taken from this run but to check the data quality. The gained apostriori RMS error of this step must be less than 3mm. During the processing of any baseline, during the separately processing mode, one station used to be fixed. So the common station in most of the sessions were fixed. Saastamoinen model was used for the troposphere while no apriori ionosphere model was used. Till here, 80% of the ambiguities were resolved.

Consequently, all baselines were processed together using the ionosphere free L3 linear combination. In this step, no stations considered to be fixed and the ambiguities which have been resolved in the previously runs are used as known parameters. The output of this step is the network adjusted coordinates and their variance covariance matrix.

5- Strain Analysis from Baselines Data

As a first approach to evaluate the rates of strain accumulation in Sinai Peninsula and Gulf of Suez area, the baseline vectors were used as strain markers, to estimate how these lines deformed between the different epochs. Baseline vectors give precise relative positions for all pairs of sites in the network. Hence, precise strain rates can be estimated from successive sets of baseline vector measurements and then it may be used to quantify the components of the lithospheric strain rates (Ramsay, 1967).

All available baselines (all combination baselines) in the network were calculated from the adjusted coordinates. The changes in baselines lengths, along with the strain occurred in them, were detected. This was done, in order to recognise which of these baselines were elongated and which were shortened. Table (2) and Figures (1), (2), (3) represent the displacement of all network stations, which will be used in strain analysis using network deformation method. Table (3) shows the change of stations heights in terms of ellipsoidal form.

6- Strain Analysis from Network Deformation Data

The analysis of repeated GPS observations has become an important tool for investigating Crustal movements. It is common in Crustal movement studies to represent the deformation in terms of strain parameters. The theory of infinitesimal strain in two dimensions has been applied for the strain analysis of the area under investigation, considering that the area is homogenous and the resulting strain is small in the x and y directions. For the explanation of that theory, the reader could refer to e.g. Schneider, 1982; Caspary, 1987 and Vyskocil, 1989.

If the following notations will be considered;

U&V are the displacement of point p within the considered area.

T_x, T_Y are the translation of the whole body in the axis direction.

d: is the vector of displacement (U,V).

r: is the vector of coordinates (x,y).

T: is the vector of translation of the whole body (T_x, T_y).

So;

$$\begin{vmatrix} U \\ V \end{vmatrix} = \begin{vmatrix} x & 0 & y & -y & 1 & 0 \\ 0 & y & x & -x & 0 & 1 \end{vmatrix} \begin{vmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \\ \omega_{xy} \\ T_x \\ T_y \end{vmatrix} \quad (1)$$

Where ε_x and ε_y are the components of strain along x-axis and y-axis respectively, ε_{xy} is the shear strain and ω_{xy} is the component of rotation. All these parameters are called the elements of deformation tensor and rotation. On the other hand T_x, and T_y are the translation of the whole block in x and y directions, respectively. The calculations of these unknown parameters help in determination of the main parameters of deformation. Which are:

$\delta = 0.5\ (\varepsilon_x + \varepsilon_y)$ (dilation or average extension) (2)

$\omega = 0.5\ (\varepsilon_{xy} - \varepsilon_{yx})$ (average differential rotation) (3)

$\tau = 0.5\ (\varepsilon_x - \varepsilon_y)$

Tensor shear components (4)

$\nu = 0.5\ (\varepsilon_{xy} + \varepsilon_{yx})$

$\gamma = (\tau^2 + \nu^2)^{1/2}$ Total shear (5)

The deformation principle axes are:

$e1 = 0.5\ (\delta + \gamma)$, $e2 = 0.5\ (\delta - \gamma)$, and $\alpha = \text{Arctan}\ 0.5(\nu / \tau)$ (6)

Where, α is the angle between the x axis and the main principal strain e1. The above mentioned strain parameters are expressed in the deformed body center of gravity.

The area under investigation was divided into three main blocks from the analysis point of view, taking into consideration the global geological structure of the area. These main blocks are Sinai main block, west of the Gulf of Suez main block and Gulf of Suez main block. Each main block was divided into some minor blocks as follows, Figure (4):

- Sinai main block was divided into 1bl, 2bl, 3bl, 4bl, 5bl and 6bl.
- The west of the Gulf of Suez main block is composed of one minor block due to the lack of points in this side after the destroying of some points, which were previously observed in epochs 1994 and 1996, such as Ismailia and Geneva.
- Gulf of Suez main block was divided into 5 minor blocks, I b3, 2b3, 3b3, 4b3 and 5b3, Figure (4).

The above-mentioned minor blocks are the network triangles themselves and the strain was calculated, for each of them, in its center of gravity.

Two programs were developed in order to get the strain in this area. The first program is used for computing the strain in the main blocks center of gravity and also for computing the translation T_x and T_y of these main blocks.

In the area under investigation, one considers that, there are two blocks have two different translation vectors, namely Sinai and west of Suez Gulf main blocks. These two different translation vectors affect the third block namely Gulf of Suez main block. So, for stations 4, 5, 6, 7, 8, 9 and 10 we considered them to have the same translation vector (Tx, Ty) of Sinai main block. On the other hand, for points 1, 2, and 3 they have the translation vector (T_x, T_y) of the West of the Gulf of Suez main block.

The second program was used for computing the strain in triangles, minor blocks, center of gravity where the translation vector (T_x, T_y) for these minor blocks considered to be known. The required input data for the 1st program are:

n: is the number of years between the reference and the considered epochs.

m: is the number of network stations.

X,Y, Z: are the Cartesian coordinates of the reference epoch network stations.

ϕ, λ: the Geographic coordinates of the reference epoch network stations.

To determine the nominated parameters of strain, and due to the system of observation equation (Equation 1) being over determined, Least squares adjustment was applied and, the following equations were resulted:

$$u = (b^T\, p\, b)^{-1}\, b^T\, p\, d \tag{7}$$

Where

$$u = \begin{vmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \\ \omega_{xy} \\ T_x \\ T_y \end{vmatrix} \tag{8}$$

u is considered as the unknown vector, strain parameters and the translation vector component.

$$d = \begin{vmatrix} x_1 - x_o \\ y_1 - y_o \\ . \\ . \\ . \\ . \\ x_i - x_o \\ y_i - y_o \end{vmatrix} \qquad (9)$$

d is the vector of station displacement, where x_i, y_i are the coordinates of the considered epoch stations while x_o, y_o are the coordinate of reference epoch stations.

P is the unit weight matrix, where it is assumed that the observations have the same weight and no correlation between the observables.

b is the coefficient matrix of the observation equation.

After executing the first program, the main output results are T_x and T_y which are considered to be known in the second program. Therefore, the input data for the second program will be the triangle terminal coordinates and the translation components of the main block that includes this triangle. Taking in consideration the above modulation in equation (1) and applying the least squares adjustment on the equation system, one can get:

$$u = (b^T p\, b)^{-1} b^T \; p \; d$$

Where

$$u = \begin{vmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \\ \omega_{xy} \end{vmatrix} \qquad (10)$$

Which is the vector of unknown strain parameters.

$$
d = \begin{vmatrix} x_1 - x_o - T_x \\ y_1 - y_o - T_y \\ . \\ . \\ . \\ . \\ x_i - x_{oi} - T_x \\ y_i - y_{oi} - T_y \end{vmatrix} \qquad (11)
$$

7- Interpretation of results and Discussions

Two methods were used for detecting the strain accumulation in the area, namely strain accumulation from base line data, and strain accumulation from network deformation analysis.

7-1 Estimating the Strain Accumulation From Baseline Date

Here, in order to estimate the strain accumulation from the baselines, epoch 1994 was considered as a reference epoch. Concerning the results of 1996 analysis with respect to 1994 as a reference epoch, Table (4) demonstrates the computed strain of all baselines. The maximum change in base line length was computed in the base line that connecting points 1 and 9 with a value of -0.144m. On the other hand, table (5) shows the maximum annual strain in the baseline between points 6 and 9 with a value of -0.811 μ St/y, where the negative sign indicates contraction. In order to simplify the interpretation of the results obtained from baselines, all combination were used.

Figure (5) reveals that most of the displacement occurred in the direction of baseline connecting stations 6 and 9 is resulted from 1995 earthquake occurrence. That is completely confirmed by investigating the reported damages associated with the 1995 earthquake where most of the reported damages took place in the specified direction, while there was no damage reported in other directions. In addition, the contraction of point 9 toward point 6 has caused tensile action in the north side of the network, namely the baseline connecting stations 4 and 10.

Concerning the analysis of 1998 with respect 1994 as a reference epoch, the maximum change was recognised in the baseline that connects point 1 to point 9, with a value equals (-0.164 m). The maximum contraction was stated in Table (5) for the baseline 6-9 which equals (-0.415 μ St/y). To clarify the strain mechanism in the 1998 epoch with reference to 1994 epoch, figure (6) demonstrates the overall view of the annual strain that occurred along Sinai network. As shown in Figures (5) and (6), the annual rate of strain has been reduced to approximately its half values. This confirms that there is an energy release in the area near by the epicenter of 1995 earthquake and the area has the tendency to return back to its normal situation.

For the final observation epoch, namely 1999, the change in baselines length and the strain analysis with respect to 1994 as a reference epoch were computed. The results were drawn in Figure (7) and outlined in Table (5). The maximum change in base line length is found also in the baseline 1-9. The maximum annual strain has been reduced to (-0.31 μ St/y) in baseline 6-9. For simplicity, the above results were drawn along the baselines of Sinai network in Figure (7). As it is shown in Figure (6) and in Figure (7) one can easily see that the reduction process of the strain values was continued as in baselines 6-9 and 6-8 . On the other hand, the extension in baseline connecting points 6 and 8 has the tendency to increase. Which is confirming again the tendency of the area to return to its normal situation.

Unfortunately, no observations have been done before 1995 earthquake except 1994 observation, so one could not estimate the 1995 pre-seismic activity. However, one can easily clarify from the above mentioned figures that the post seismic activity were represented in the compression occurrence for the baselines connected to point 9, which has the nearest location to the earthquake epicenter. In other words, one can say that, the energy release can be detected in the area. This is clear from the reduction occurred in the contraction values in the baselines connected to station 9. Also, this is simply recognised from the remarkable reduction in the contraction values where the maximum contraction has been reduced from (-0.81μ St/y) in 1996 to (-0.31μ St/y) in 1999.

Finally, referring to Figures (5, 6 and 7), one can easily distinct two different movement mechanisms in the Sinai sub-plate. The first movement mechanism is related to the upper part of Sinai enclosed between Gulf of Aqaba and Gulf of Suez represented mainly by points 4 and 10 of the network. The second one is related to the rest of Sinai Peninsula. As it is clearly indicated in Figures (5 and 6) and partially in Figure (7), that is due to the destroy of station 10, two different mechanisms can be detected which approve that the area in between has already had a fault.

7-2 Estimating Strain accumulation from Network deformation analysis

Recall that the area under investigation was divided into three main blocks, and these main blocks were divided into minor blocks, as mentioned before and in Figure (4), where two programs were writen for the purpose of detecting the deformation in the area. The first one has been applied to the area of Sinai network to compute the translation parameters of the three main blocks. The translation parameters obtained from that program showed a remarkable local movement of Sinai sub-plate in the south west direction. The depicted movement ranging from (2mm/y) to (4mm/y). On the other hand, the maximum detected translation was (12mm/y), this high translation value is due to 1995 earthquake and detected throughout the analysis of epoch 1996 with respect to 1994 as a reference epoch.

On the other hand, the translation parameters have been utilised in the second program to compute the strain components in all minor blocks that demonstrated in Figure (4). In order to reach the best interpretation of the geodynamics of the area under investigation, Figures (5), (6), (7) and Table (5) are interpreted. The strain components from the analysis of 1996 with respect to 1994 show that the maximum contraction occurred in blocks (4b1) and (5b1) which are the nearest blocks to the epicenter of 1995 earthquake and lie in the direction. that has the most damages occurred. The dilatation values in these two blocks are (-1.8 μ St/y) and (-1.65 μ St/y) respectively. On the other hand, the maximum tensile strain took place in the area to the north of Suez Gulf.

The strain components resulted from the analysis of 1998 epoch with respect to 1994 as a reference epoch show that the two blocks (4b1) and (5b1) are still have the maximum values of dilatation, their values were reduced to (-1.39 μ St/y) and (-0.241 μ St/y). On the other hand, block (3bl) is characterised with maximum tensile strain, though it was in the last epoch very stable (approximately zero strain). This confirms that there is an energy release in the area near by the epicenter of 1995 earthquake. In addition, the earth's crust starts to restore its natural dynamics.

The above interpretation was confirmed again through the different strain components of the analysis of 1999 epoch with respect to 1994 as a reference epoch. One can observe that the maximum contraction is still in block (4b1), with dilatation of magnitude (-1.584 μ St/y). Additionally, the maximum tensile strain is also in block (3bl) with magnitude (1.62 μ St/y) and in the northern part of the Gulf of Suez. Also, the maximum Shear strain was detected in 3b 1 and I b2, which is an extension of 1998 results.

As a closing remark for this section, the results of 1996, 1998 and 1999 indicate the presence of dynamical forces considered in the block (3b1) and minor blocks of Gulf of Suez. Due to the presence of these forces in the minor blocks of Suez Gulf and the nature of the tensile strain across those blocks, which resulted from these forces, the Gulf of Suez is considered to be opening. The rate and direction of this opening need more observation epochs to be determined precisely.

7-3 Vertical Movement

On the other hand, Table (3) is made in order to have an indicator for the vertical movement in the area. From this table, one can easily notice the following:

- Stations 1 and 2 go down in most of the considered epochs while station 3 rises up in those epochs, these stations are lying in the western part of the Gulf of Suez, which means that the change in the ellipsoidal height affected by the pressure from east to west.

- There is a remarkable increase in the ellipsoidal height of stations 10, 9, while the maximum increase in the ellipsoidal height was at station 5. These stations are lying in the eastern and middle part of Sinai sub-plate, which means that the uplift occurred in middle and eastern parts of Sinai.
- The direction of movement in stations 7 and 8 is not clear but in most of the epochs they go down.

Throughout the above mentioned results, one can easily observe that the western and southern parts of Sinai Sub-plate go down while the middle and eastern parts are uplifted. Regarding the tectonic settings of the northern African Region and the above results, namely the local movement of Sinai sub-plate, which indicated the opening of the northern part of the Gulf of Suez, the right lateral movement of the front lane of the Syrian arc and the movement of the Gulf of Aqaba, a preliminary geodynamic model was depicted (Figure 7). Comparing the results from the horizontal movements and the vertical movements, it is clear that, both movements are in the same harmony and they can be explained by the Preliminary geodyñimcal model (Figure 7), which shows that the horizontal movements is in accordance with the vertical movement.

8- Conclusions and Recommendations

In the light of the analysis of the collected GPS data for 4 study epochs in 4 years, over the established GPS network for studying the crustal movements in Sinai region, the following conclusions can be drawn:

1- The deformation occurred in most baselines connected to station 9 (which is laying between Dahab and Newabaa) are due to 1995 earthquake and the maximum recorded contraction was in the line connecting station 9 and station 1 (Hurgada) with a magnitude 0.081 µSt/y in the epoch 1996 with respect to epoch 1994 as a reference epoch, while the contraction release in the subsequent epochs (1998 and 1999 with respect to 1994 as a reference epoch).
2- The tendency of the area to return to its normal nature is clear from the remarkable strain reduction in all baselines connected to station 9, which is depicted from 1998 and 1999 results.

3- The local movement of Sinai Peninsula is in the south-west direction, was found to range (2mm/y) to (4mm/y).

4- There is a remarkable opining in the Gulf of Suez. It reaches 5mm/a.

5- Regarding the vertical movement, western and southern parts of Sinai Sub-plate go down, while the middle and eastern parts are uplifted.

6- Regarding to the northern African region tectonics, and the above mentioned results, a preliminary geodynamic model was established for the Sinai region.

Hence, based on the above conclusions, the following recommendations can be drawn:

1- Newabaa area and southern Sinai, should generally have special code for construction, due to the relatively high crustal movement, which is recorded there as (-1.8 μ St/y).

2- Sinai network should be connected with some GPS permanent stations (which are away from Sinai sub-plate), in order to detect the whole sub-plate movement, and also in determining the plate boundary. This can be made in conjunction with some other geophysical methods.

3- Continuation of the observation in the area is a must in order to get a complete geodynamical model, which needs a larger number of observation epochs.

4- It is also recommended to have several local precise networks, to detect the activity of the Sinai faults.

5- Finally, it is highly recommend to start as soon as possible the proposed program designed by (Tealeb, 1995) for monitoring recent crustal movements in the Gulf of Aqaba with the co-operation of the surrounding countries.

9- References

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Table (1) Campaign Information

	1st campaign	2nd campaign	3rd campaign	4th campaign
start date	6 May, 1994	18 April, 1996	15 Feb. 1998	5 May 1999
End date	12 May 1994	24 April, 1996	27 Feb.1998	7 May, 1999
No. of sessions/ day	2	1	1	1
Obs. Period	6 h	9 h	8 h	23 h 30 m
No. of used receivers	3	4	3	9
Types of receivers	4000sse	4000sse	4000sse	4000ssi

Table (2) Point displacement for the different epochs

Point		Ref. Coord. From 1994 m	Pt. dis. 1996 mm(1996-1994)	Pt. dis. 1998 mm(1998-1994)	Pt. dis. 1999 mm(1999-1994)
1	X	4719518.289	-19	-40	-17
	Y	3138837.068	11	12	8
	Z	2915115.861	9	14	20
2	X	4705289.215	4	-9	0
	Y	3034782.948	9	6	11
	Z	3044479.454	16	5	8
3	X	4687850.821	9	58	12
	Y	2994041.259	37	69	49
	Z	3110554.673	9	41	21

4	X	4643927.627	-33	-37	-45
	Y	3000769.187	27	20	18
	Z	3169580.683	15	5	2
5	X	4670465.756	57	73	18
	Y	3044908.220	94	104	71
	Z	3087652.141	52	60	23
6	X	4652796.240	-4	9	0
	Y	3113620.750	-9	-6	-11
	Z	3047399.877	-16	-5	-8
7	X	4682682.156	27	9	-4
	Y	3110728.442	9	2	-9
	Z	3002886.486	19	9	5
8	X	4668877.245	0	-7	-3
	Y	3171025.070	-5	9	19
	Z	2961578.657	-7	-6	-4
9	X	4614302.454	117	142	121
	Y	3167434.597	-53	-45	-51
	Z	3049704.757	-57	-45	-49
10	X	4598942.738	-16	4	-----
	Y	3072099.872	58	77	-----
	Z	3167150.784	27	37	-----

Table (3) Ellipsoidal heights and their changes along the different epochs with respect to 1994 as a reference epoch

Station	h (1994) m	dh(1996-1994) mm	dh(1998-1994) mm	dh(1999-1994) mm
1	54.196	-5	-17	0
2	27.034	15	-1	9
3	27.846	29	95	42
4	313.007	-4	-17	-23

5	151.351	112	132	59
6	920.240	-15	1	-9
7	126.237	32	11	-5
8	254.041	-6	-3	6
9	562.290	31	59	38
10	461.117	30	59	----

Table (4) changes in base lines along the different epochs, 1994 is a reference

Points		Baselines from 1994		1996 -1994		1998-1994		1999-1994	
from	to	L m	RMS mm	diff mm	RMS mm	diff mm	RMS Mm	diff mm	RMS mm
1	2	166627.325	5	4	5.8	-6	5.8	-11	5.1
1	3	245285.515	7	-19	7.6	-15	7.6	-26	7.3
1	4	299214.026	7	1	8.1	-18	7.6	-12	7.3
1	5	202478.511	7	-20	7.6	-31	7.6	-33	7.3
1	6	150288.906	6	-15	6.7	-35	6.7	-28	6.3
1	7	99250.581	6	-7	6.7	-19	6.7	-13	6.3
1	8	75890.541	7	-30	8.1	-35	7.6	-21	7.6
1	9	173211.898	8	-144	8.9	-165	8.5	-147	8.2
1	10	287252.361	8	4	8.9	-13	8.5	-----	-----
2	3	79560.778	6	-21	6.7	-17	6.7	-12	6.1
2	4	143431.161	6	11	6.7	-1	6.3	12	6.3
2	5	56383.290	6	10	6.3	8	6.3	12	6.3
2	6	94759.909	4	-12	4.5	-11	4.5	-19	4.1
2	7	89491.743	5	-9	5.4	-10	5.4	-14	5.4
2	8	163585.725	4	1	5	8	5	14	4.5
2	9	160942.084	7	-118	7.6	-129	7.6	-121	7.1
2	10	166584.456	7	32	7.6	31	7.6	-----	----
3	4	73882.216	8	29	8.9	12	8.9	17	8.2
3	5	58431.278	8	18	8.5	19	8.5	16	8.2

3	6	139701.849	7	-25	7.6	-31	7.6	-35	7.1
3	7	158855.445	7	-29	7.6	-26	7.6	-31	7.3
3	8	232114.453	6	-21	6.7	-10	6.7	-6	6.3
3	9	197932.626	9	-99	9.8	-105	9.5	-107	9.2
3	10	131152.255	10	37	10.8	40	10.4	-----	----
4	5	96771.961	7	24	7.6	15	7.6	23	7.3
4	6	166560.130	5	-1	5.6	-11	5.4	-10	5.4
4	7	203420.518	6	-3	6.7	-10	6.7	-9	6.3
4	8	269952.574	6	0	6.7	1	6.3	8	6.3
4	9	207425.281	8	-44	8.5	-48	8.2	-50	8.2
4	10	84365.936	9	17	9.5	33	9.5	----	----
5	6	81571.247	6	-41	6.3	-47	6.3	-49	6.1
5	7	108012.770	6	-30	6.3	-30	6.3	-35	6.3
5	8	178332.573	6	-27	6.7	-20	6.3	-17	6.3
5	9	140025.117	9	-123	9.5	-29	9.2	-128	9.1
5	10	110340.211	9	20	9.5	21	9.5	-----	-----
6	7	53693.348	5	-12	5.8	-13	5.4	-13	5.4
6	8	104494.672	4	-4	4.5	7	4.5	13	4.5
6	9	66204.336	7	-107	7.6	-110	7.3	-104	7.1
6	10	137711.520	7	21	7.6	13	7.3	----	----
7	8	74381.420	5	10	5.8	18	5.4	27	5.4
7	9	100415.748	8	-130	8.9	-141	8.5	-133	8.2
7	10	188380.510	7	16	7.3	11	7.6	----	----

Table (5) Strain in all baselines considering 1994 as reference epoch

		1994	Strain96	Strain98	Strain99	Remarks
From	To	L in meter				
1	2	166627.3	1.35032E-08	-8.4485E-09	-1.2914E-08	
1	3	245285.5	-3.79435E-08	-2.5178E-08	-2.1119E-08	
1	4	299214	2.31106E-09	-1.5069E-081	-7.7630E-09	

1	5	202478.5	-4.96497E-08	-3.8403E-08	-3.2765E-08
1	6	150288.9	-8.19488E-08	-5.8496E-08	-3.8044E-08
1	7	99250.58	-3.53046E-08	-4.831 E-08	-2.6380E-08
1	8	75890.54	-1.92336E-07	-1.150E-07	-5.3435E-08
1	9	173211.9	-4.15887E-07	-2.381 E-07	-1.699E-07
1	10	287252.4	6.90334E-09	-1.1541E-08	------- 10 was destroyed
2	3	79560.78	-1.30020E-07	-5.4502E-08	-2.9854E-08
2	4	143431.2	3.76662E-08	-1.438E-09	1.73519E-08
2	5	56383.29	8.9601 E-08	3.68593E-08	4.16187E-08
2	6	94759.91	-6.41041 E-08	-5.4377E-08	-3.8702E-08
2	7	89491.74	-5.29323E-08	-2.8508E-08	-3.1 1 09E-08
2	8	163585.7	1.33264E-09	1.18715E-08	1.63437E-08
2	9	160942.1	-3.66094E-07	-2.0017E-07	-1.5043E-07
2	10	166584.5	9.56212E-08	4.58386E-08	------ 10 was destroyed
3	4	73882.22	1.91562E-07	4.11906E-08	4.59678E-08
3	5	58431.28	1.57518E-07	8.13049E-08	5.57544E-OE
3	6	139701.8	-9.07826E-08	-5.5477E-08	-4.9999E-08
3	7	158855.4	-9.24457E-08	-4.1338E-08	-3.8886E-08
3	8	232114.5	-4.51415E-08	-1.0842E-08	-5.2285E-09
3	9	197932.6	-2.50206E-07	-1.3151E-07	-1.0762E-07
3	10	131152.3	1.39948E-07	7.58127E-08	------- 10 was destroyed
4	5	96771.96	1.23367E-07	3.95647E-08	4.74766E-08
4	6	166560.1	-2.04731 E-09	-1.695E-08	-1. 1 912E-08
4	7	203420.5	-6.55047E-09	-1.235E-08	-8.5714E-09
4	8	269952.6	-3.09314E-10	6.88084E-10	6.36556E-09
4	9	207425.3	-1.06904E-07	-5.8483E-08	-4.8528E-08
4	10	84365.94	9.90092E-08	9.74623E-08	-------- 10 was destroyed

5	6	81571.25	-2.48372E-07	-1.4429E-07	-1.2049E-07
5	7	108012.8	-1.41307E-07	-6.9841E-08	-6.6376E-08
5	8	178332.6	-7.79302E-08	-2.8171E-08	-1.9311E-08
5	9	140025.1	-4.40582E-07	-2.3116E-07	-1.8329E-07
5	10	110340.2	9.27087E-08	4.89463E-08	------- 10 was destroyed
6	7	53693.35	-1.12239E-07	-5.726E-08	-4.6877E-08
6	8	104494.7	-1.90058E-08	1.5929E-08	2.33064E-08
6	9	662040.34	-8.11254E-07	-4.1508E-07	-3.151E-07
6	10	137711.5	7.82251E-08	2.41538E-08	-0.19999996
7	8	74381.42	6.60246E-08	5.87949E-08	7.19373E-08
7	9	100415.8	-6.48778E-07	-3.5297E-07	-2.6582E-07
7	10	188380.5	4.22496E-08	1.43062E-08	-------- 10 was destroyed
8	9	103718.4	-4.91962E-07	-2.6369E-07	-1.946E-07
8	10	238614.6	1.70128E-08	5.77081E-09	------- 10 was destroyed
9	10	152046.7	2.84288E-08	1.12301E-09	--------10 was destroyed

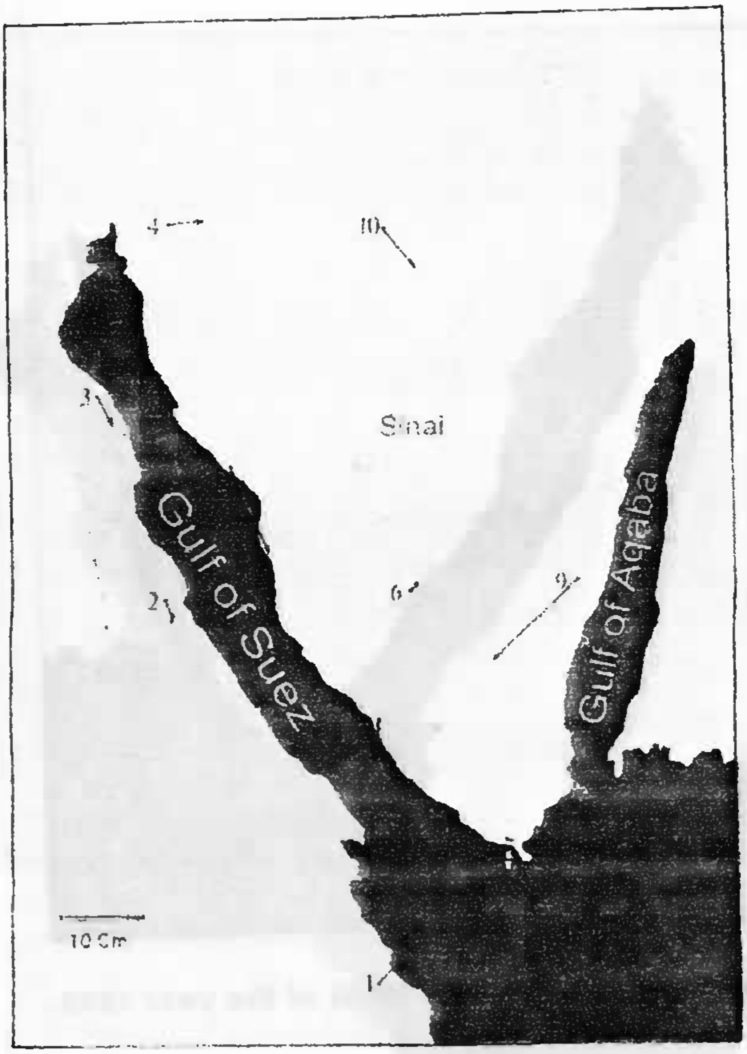

Fig. (1) point Displacement of the year 1996.

with respect to the year 1994 as a reference epoch

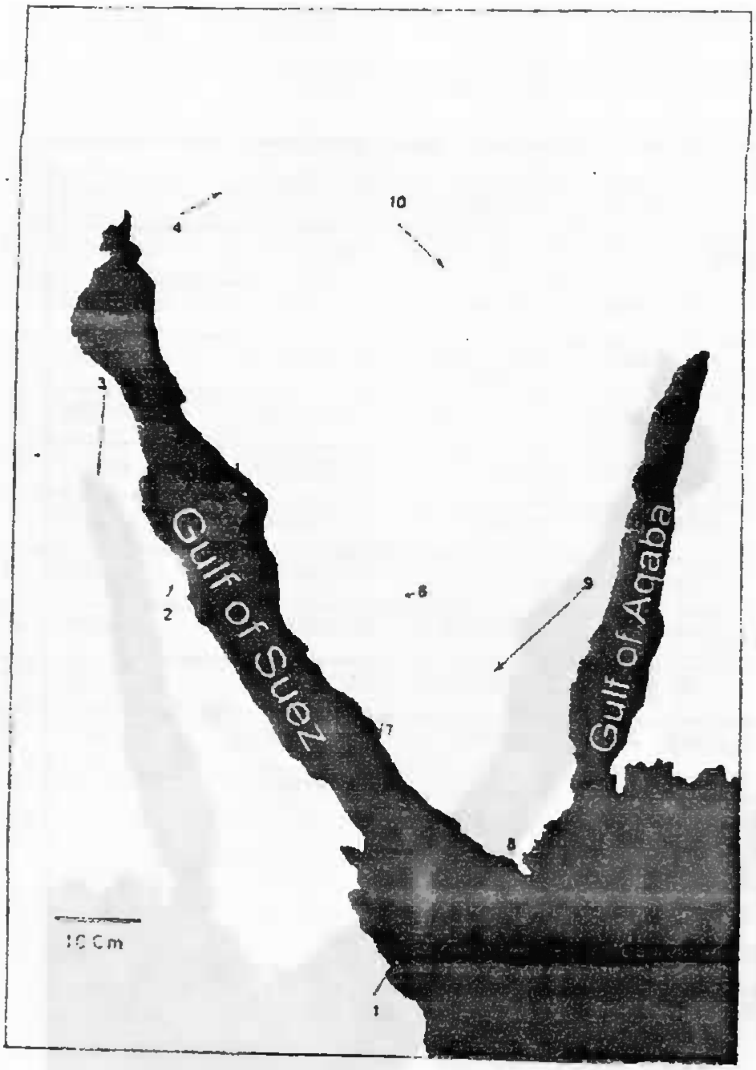

Fig. (2) point Displacement of the year 1998.

with respect to the year 1994 as a reference epoch

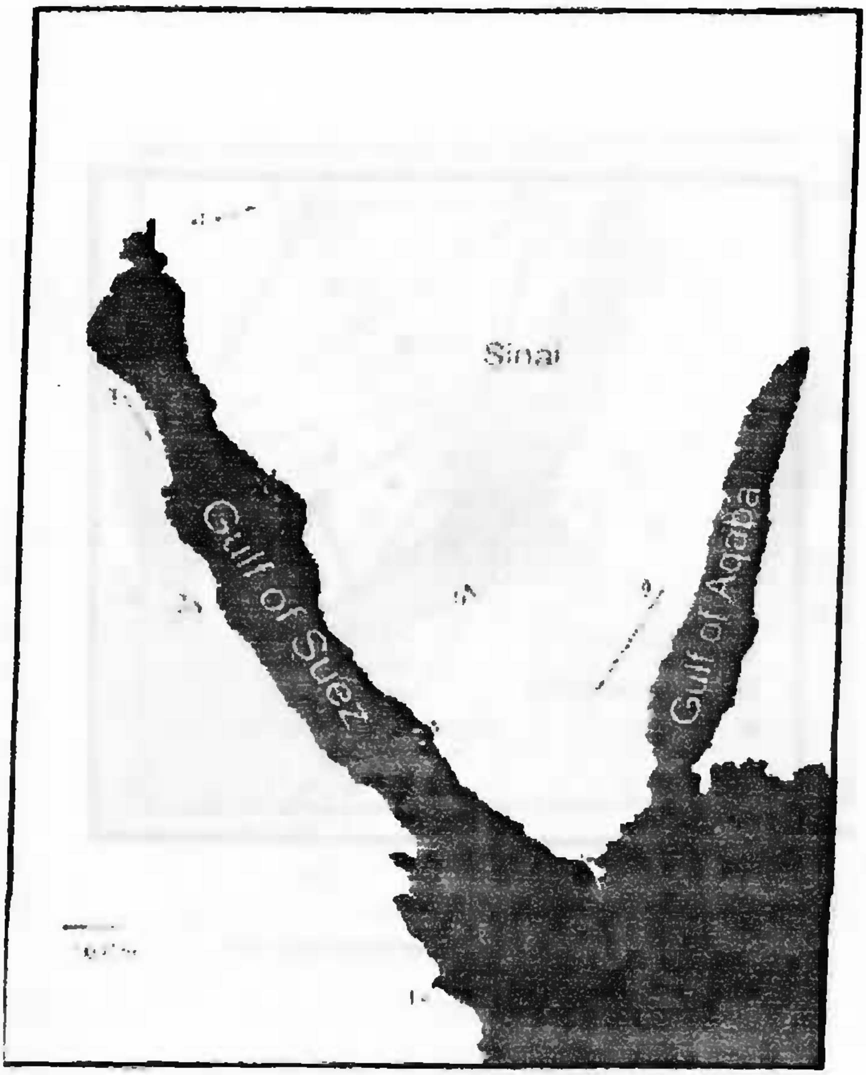

Fig. (3) point Displacement of the year 1999.

with respect to the year 1994 as a reference epoch

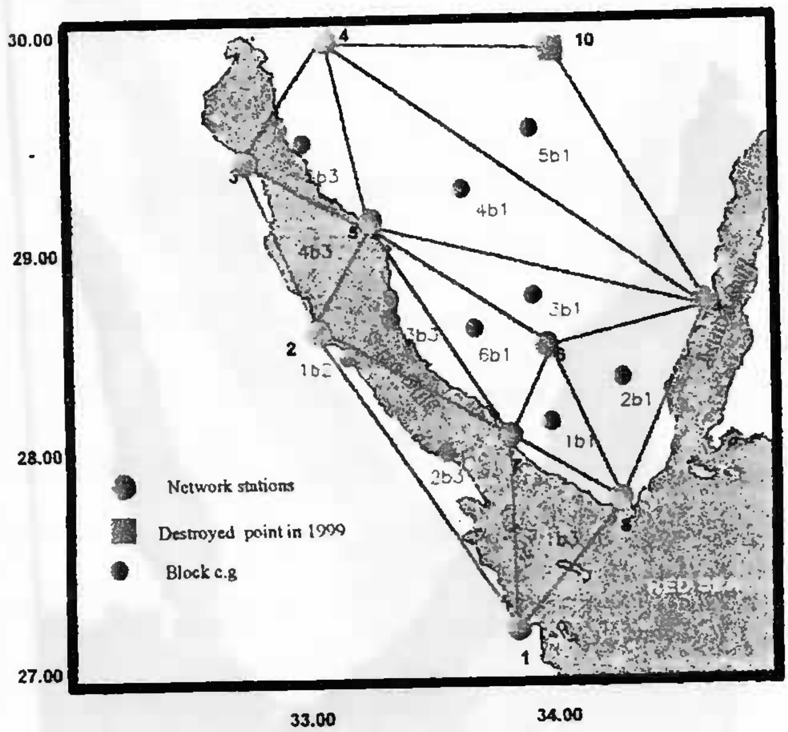

Fig. (4) The used blocks for strain estimation.

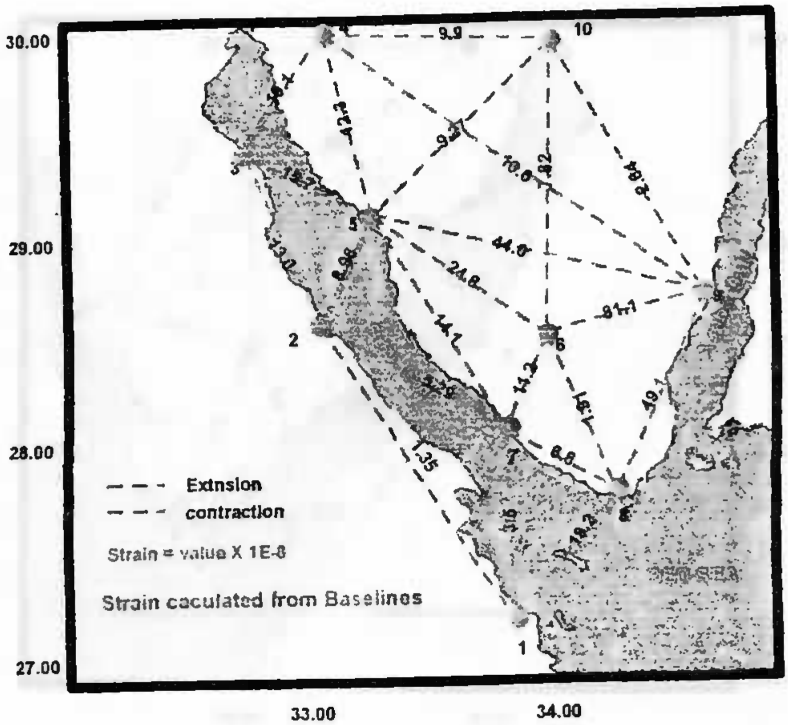

Fig. (5) Strain in the network baselines for the year 1996
with respect to the year 1994 as a referance epoch.

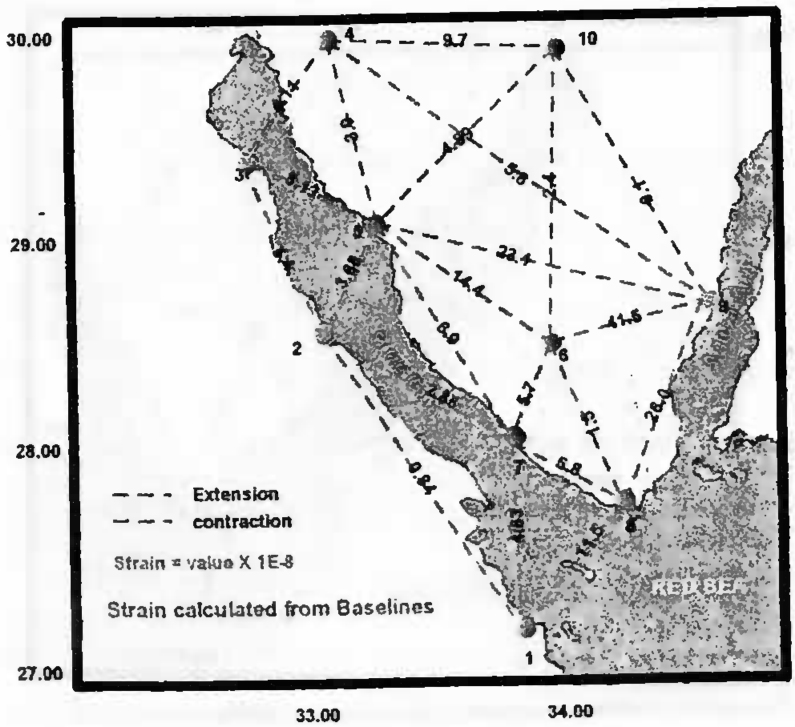

Fig. (6) Strain in the network baselines for the year 1998

(with respect to the year 1994 as a reference epoch)

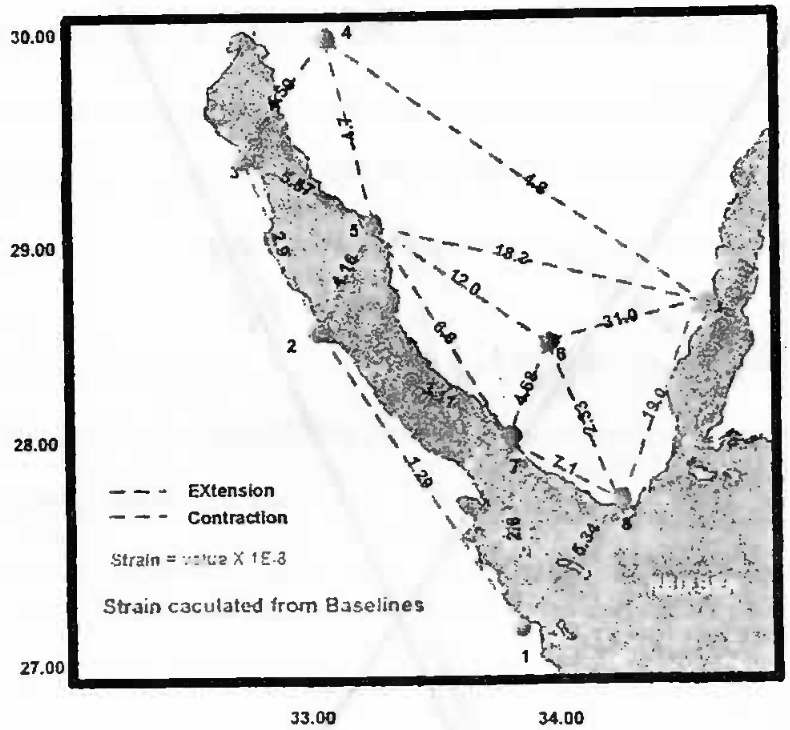

Fig. (7) Strain in the network baselines for the year 1999.

(with respect to the year 1994 as a reference epoch)

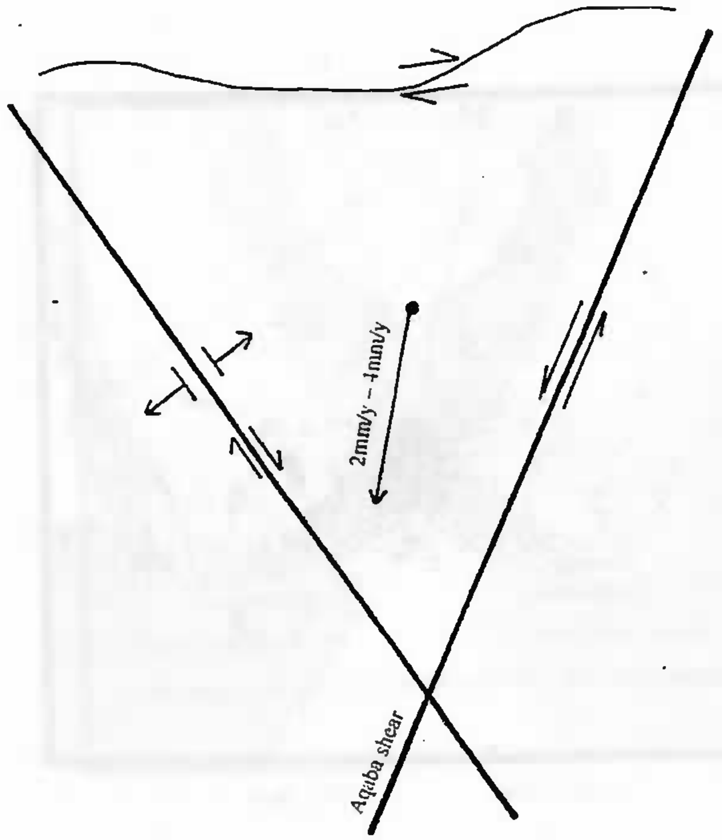

Fig. (8) A preliminary Geodynimcal model for Sinai Peninsula as depicted from 1996, 1998 and 1999 GPS Sat. observations with respect to 1994 as a reference epoch.