Proceeding of the 7th Conf. Geology of Sinai for Development
Ismailia, 2004, pp. 289-296

EVALUATION OF THE CRUSTAL DEFORMATION IN THE GULF OF SUEZ REGION USING GPS TECHNIQUES

S. Mahmoud[1]., H. Ghazala [2], M. Rabah [1], H. Khalil[1], and N. Abo-Aly [1]
[1]*National Research Institute of Astronomy and Geophysics, Helwan.*
[2] *Geology Department, Faculty of Science, Mansoura University.*

ABSTRACT: Recently, one of the important methods for studying crustal deformation, by means of space techniques, is the Global Positioning System (GPS). The earth's crust deformation attains values of only few mm/yr and can be determined according to the spatial and time density of the measurements as well as their degree of accuracy. A geodetic network consists of 11points was established early in 1997 in southern Sinai . This network was observed six times in different campaigns during the period 1997 – 2003. The observed data were analyzed using Bernes 4.2 software to determine velocity vectors along the Gulf of Suez and Sinai Peninsula. The estimated horizontal velocity vectors in the International Terrestrial Reference Frame (ITRF2000) show that the velocity of Sinai Peninsula ranges from 1.8 to 2.3± 0.5 mm/yr in the NE direction. This velocity is consistent with those predicted by the model NUVEL-1A in the same direction but smaller in magnitude.

The strain Tensor program was used to estimate the principal axes of strains. The principal axes of the strain indicate that the studied region is mainly divided into two areas: western part, around Gulf of Suez, where extensional strain is predominant and the eastern part, around the Gulf of Aqaba, where compressional strains prevail. Principal axes of the strain indicate that an extensional force is acting along the Gulf of Suez in NE-SW direction. Moreover, the principal axes of strains show a good correlation with the directions obtained from earthquake focal mechanisms.

1. INTRODUCTION

Crustal movement studies are very important in the geodynamical research tools which help in understanding the properties of the earth in global, regional and local scales. The worldwide tools for such studies are mainly the repeated geodetic measurements. Space techniques have become increasingly prominent in studying deformations of plate boundaries and have approached the level of precision of global plate models. Early space geodetic studies have shown a high correlation between observed relative site velocities and the predictions of the model of NUVEL1A (Smith et al., 1990). Global Positioning System uses the radio wave signals that are transmitted from the satellite called NAVSTAR satellite. There are three distinct parts of the GPS: space segment, control segment and user segment. The satellite system consists of 24 satellites, in six orbital planes with 55° inclination to the equator. The satellites are placed at a height of about 20,200 km with 11 hours 58 minutes orbital period. They are operated by the United States Department of Defense (DOD) for accurate determination of position, velocity and time. All the GPS satellites are controlled by system tracking stations, ground antennas and the master control station.

Although Egypt is not a major seismic zone, earthquakes may represent a significant seismic hazard. Seismic zones of moderate seismic activity may affect the economic, strategic and civilized areas of the country. According to the distribution of the earthquakes occurrences in Egypt, National Research Institute of Astronomy and Geophysics (NRIAG) has started a program of monitoring recent crustal movements by means of geodetic space techniques since 1994 as shown in Figure (1). This program includes establishing, measuring and analyzing of the data from the different geodetic networks.

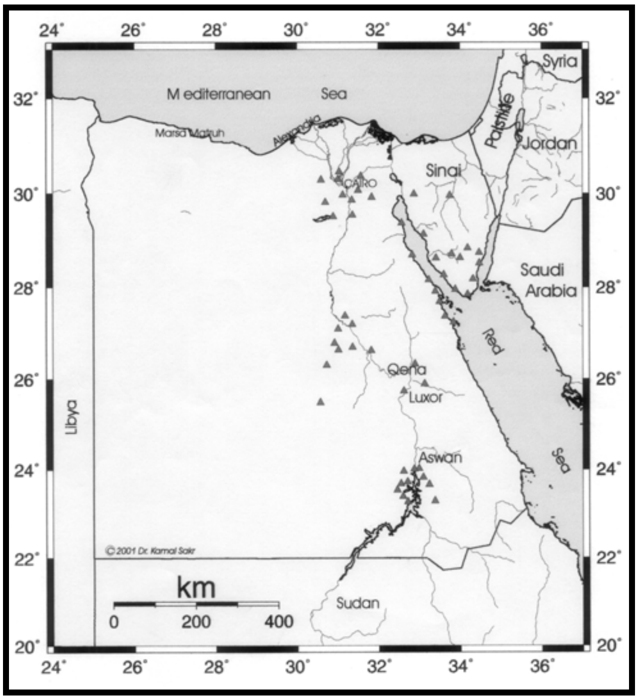

Figure 1. Distribution of the GPS networks in Egypt.

2. STRUCTURAL, TECTONIC SETTING AND SEISMICITY OF GULF OF SUEZ

The Gulf of Suez is the northern termination of the Red Sea rift and it is bounded on the east by Sinai massif and on the west by hills of the Eastern Desert. The Gulf of Suez is also one of the best examples of the integration of outcrop and subsurface data to enhance hydrocarbon exploration and exploitation (Gawthorpe et al., 1990; Patton et al., 1994; Sharp et al., 2000 a, b).

The NW-trending Gulf of Suez is about 300km long, and it is considered as a complete rift basin, varying in width from about 50km at its northern end to about 90 km at its southern end where it merges with the Red Sea (Fig. 2).There are three distinct basins within the Gulf of Suez: the Darag basin at the northern end, the central basin or Belayuim Province in the middle, and the southern Amal-Zeit Province (Fig. 2). Each sub-basin is asymmetric, bounded by major NW-trending border fault system with large throws (4-6 km in general) together with a dominant stratal dip direction toward the border fault system. Complex accommodation zones are oblique to the rift trend and separate the three Provinces (Moustafa, 1976; Bosworth, 1985; Coffield and Schamel, 1989). These accommodation zones appear to be wide (up to 20 km) areas of complex faulted blocks of variable dips and interlocking “flip-flop” conjugate fault systems. Colletta et al., (1988) interpreted that the change in rift geometry across the Morgan accommodation zone (Fig. 2) is accomplished principally by a major through-going oblique transfer fault. However, this is not supported by the outcrops (Moustafa and Fouda, 1988;Coffield and Schamel , 1989) Within each of the three main half-grabens there are second-order sub-basins formed by individual fault blocks, each of which has its own characteristic syn-rift stratigraphy (McClay et al., 2001).

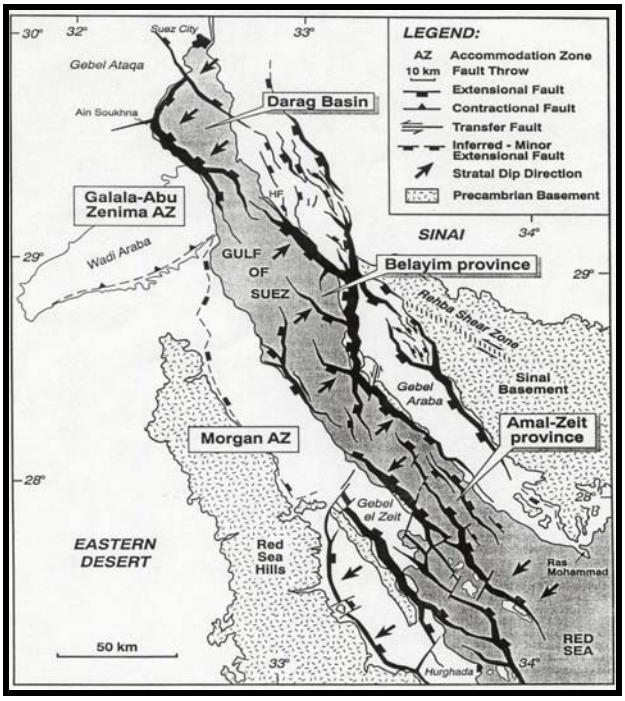

Figure 2. Tectonic and accommodation zones in the Gulf of Suez (After Khalil, 1998).

The Gulf of Suez is an area of significant intermediate magnitude (4.0- 6.0) earthquake activity (Gergawi and El-Khashab, 1968; Fairhead and Girdler, 1970; Daggett et al., 1986). Jackson et al., (1988) has suggested that these earthquakes represent continued movement on the Gulf of Suez rift trend. They result in footwall uplift of the numerous Pleistocene coral terraces.

The most two significant events recorded for the southern Gulf of Suez were located on Shedwan island (March 31, 1969) with magnitude 6.0 and east of Ashraif Island (June 28, 1972) with magnitude 5.5. Another earthquake of magnitude 5.0 was occurred near Shukheir area on (June 12, 1983). This active seismicity of Shedwan area is considered to be due to the location of this area at Sinai triple junction (Salamon et al., 1996). Hurukawa et al., (2001) determined the fault-plane solutions using P-wave first-motion data for the events more than or equal to nine polarity data points identified by the Hurghada network. These solutions are shown in Figure (3) and Table (1). The Gulf of Suez region have a normal faulting mechanism striking NW, which is parallel to the Red Sea.

3. DATA ACQUISITION AND ANALYSIS

GPS network consisting of 11 observation stations was established early in 1997 to detect the postseismic crustal deformation of the 1995 earthquake and to monitor the relative plate motions that surround the Sinai region (Mahmoud et al., 1998).

There are seven stations in Sinai and four stations along the western side of the Gulf of Suez. These stations were located in Hurghada “HURG”, Ras Gemsa “GEMS”, Gabal El Zeit “ZEIT”, Ras Gharb “GARB” , Abu Derba “DERB”, EL Tour “ TOUR”, Ras Kensa “KENS”, Saint Kathreina “CATH”, Sharm El Shikh “SHAM”, Nabq “NABQ”, and Dahab “DAHA”. Six GPS campaigns were carried out with dual frequency Trimble 4000 SSE/SSI. The first campaign was from 20 to 30, November 1997; the second campaign was performed, from 25 to 31 May 1998; the third one was on 4 August, 1999; the fourth campaign was from 18 to 19 September 2000 ; the fifth one was from 14 to16 May 2002 and finally the last one was in from 22 to 25 September 2003.

The observing session time span was eight hours with 30 seconds sampling rate and 15-degree mask angle. The Sinai data of six GPS campaigns were processed using the Bernese software version 4.2 (Hugentobler et al., 2001), using free network solution. The Sinai data was processed together with the selected data of some IGS permanent stations ‘Mattera “Mate” in Italy, Nicosia “NICO” in Cyprus, Sofia “SOFI” in Bulgaria and Zelenchukskaya “ZECK” in Russia.

4. RESULTS AND DISCUSSION

4.1. Velocity Results

Bernese V4.2 and ADDNEQ2 Software's were used to compute the common sets of the coordinates and velocities in the ITRF2000 for epochs from 1997 to 2002. The output of horizontal site velocities of the Sinai (free network solution) of each epoch were represented in Figures 4, 5 and 6.

As shown in figure (4), the maximum movement in the period from 1997 to 1998 was 6.4 mm/yr at DERB station in the NE direction while the minimum movement was 1.2 mm/yr at KENS station in the NEN direction. The mean velocity of the eastern side of the Gulf of Suez (Sinai subplate) was 2.7 mm/yr in NE direction. In the western side of the Gulf of Suez (African plate), the mean velocity was about 2.2 mm/yr in the NE-direction.

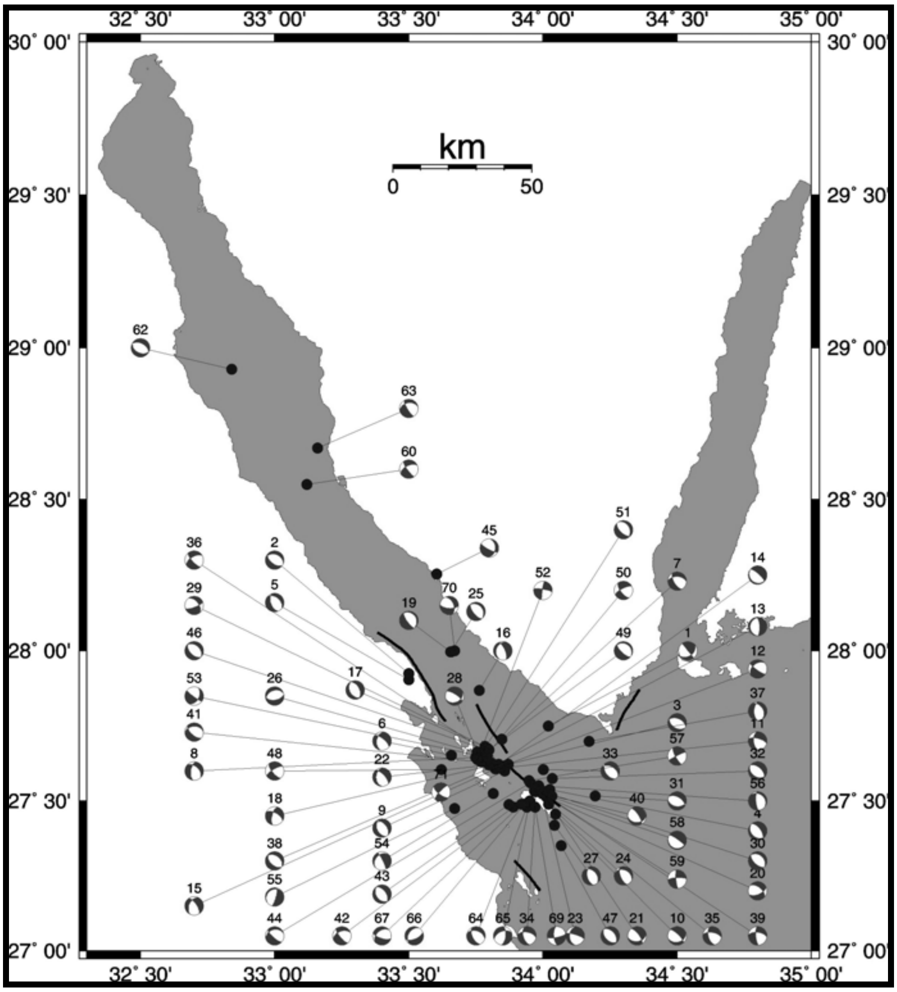

Figure 3. Mechanisms of earthquakes (M<4.6) from the period 1994 to 2002 (After Megahed et al., 2004).

Table 1. The parameters of the earthquakes during the period from 1994 to 2002.

No.	Date	O.T	Lon.	Lat	D	M_d	St	Di	RA	Ref.
1	940926	172706	34.02	27.75	19	3.6	321	89	-50	K
2	950105	150255	33.5	27.924	20	3.8	127	55	-80	R
3	950116	151544	33.871	27.623	20	2.9	123	42	-81	R
4	950119	123518	34.025	27.539	14	2.9	131	31	-101	R
5	950209	155246	33.5	27.904	19	3.4	161	54	-70	R
6	950221	102909	33.659	27.652	6	2.3	190	41	-36	R
7	950315	92035	33.847	27.706	20	4.1	150	62	-51	R
8	950403	182627	33.749	27.645	11	3	188	59	-53	R
9	950406	52504	33.858	27.6	16	3.9	155	44	-80	R
10	950406	74343	34.046	27.456	7	3.2	74	31	-146	R
11	950416	151632	33.841	27.61	11	2.8	175	54	-30	R
12	950420	104154	33.823	27.608	15	3.8	126	78	-49	K
13	950420	104906	33.818	27.618	11	2.9	185	20	-83	R
14	950421	53506	33.826	27.616	12	3	125	16	-96	R
15	950421	132023	33.832	27.611	11	2.8	205	42	-39	R
16	950429	113035	33.762	27.869	16	2.9	199	29	-51	R
17	950512	181139	33.795	27.675	20	3.1	151	39	-92	R
18	950517	50750	33.819	27.622	17	2.7	193	66	-33	R
19	950522	63738	33.656	27.996	15	2.7	145	73	-89	R
20	950524	63710	34.012	27.515	18	3.2	67	58	-135	R
21	950528	70648	34	27.526	20	2.9	83	38	-144	R

Table 1. Cont.

22	950601	40244	33.799	27.62	12	2.6	182	35	-50	R
23	950607	120946	33.994	27.528	14	2.9	182	39	-19	A
No.	Date	O.T	Lon.	Lat	D	M_d	St	Di	RA	Ref.
24	950720	103920	34.021	27.49	14	2.8	157	65	-68	R
25	950804	215034	33.657	27.996	13	2.9	143	66	-86	R
26	950809	203033	33.755	27.66	14	3.6	251	39	-98	A
27	950810	192002	34.043	27.42	15	2.7	166	54	-72	R
28	951002	3107	33.755	27.663	6	3.1	67	29	-141	R
29	951011	100419	33.784	27.682	13	3.1	69	73	-136	R
30	951015	114329	34.001	27.532	15	2.9	133	59	-89	R
31	951022	71007	34.195	27.517	6	3.2	98	40	-108	R
32	951022	100559	34.034	27.575	11	2.9	124	36	-96	R
33	951211	190825	34.001	27.605	5	3.1	147	48	-69	R
34	951214	230840	33.974	27.531	7	3.2	164	58	-41	R
35	951231	64815	33.968	27.534	15	3.3	165	58	-38	R
36	960529	214250	33.781	27.668	20	3.1	138	72	-34	K
37	960620	35955	34.172	27.699	13	3	182	58	-68	R
38	960625	50403	33.835	27.623	16	3	132	51	-86	R
39	960720	43732	33.998	27.524	13	3	175	74	-34	R
40	960807	44046	34.033	27.517	10	2.7	91	30	-142	R
41	960812	215233	33.809	27.626	11	2.7	132	62	-64	R
42	960818	92901	33.889	27.48	8	3.1	141	73	-45	K
43	960819	3340	33.873	27.489	5	2.9	144	36	-89	R
44	960827	101354	33.953	27.561	13	2.9	132	73	-64	R
45	960915	51811	33.604	28.254	20	3.1	118	76	-120	A
46	961005	55559	33.784	27.673	11	3	136	52	-87	R
47	961029	192215	34.068	27.352	4	3	136	46	-92	R
48	961202	33147	33.621	27.605	19	2.8	141	69	-20	A
49	961203	2416	33.799	27.67	12	3.3	299	21	-104	A
50	961217	72120	33.769	27.631	15	3.8	144	65	-20	K
51	961217	113133	33.758	27.642	12	4.2	134	60	-99	A
52	961217	122539	33.756	27.638	11	3.1	188	85	-10	A
53	961217	143159	33.794	27.645	9	3.1	126	82	-134	A
54	961223	85314	33.814	27.526	9	3.9	225	28	-21	A
55	970513	184909	33.67	27.475	15	2.9	236	16	-51	A
56	971004	60900	33.984	27.552	12	3.3	175	75	-74	H
57	971119	232222	33.948	27.568	12	3.4	243	86	-166	H
58	970807	214411	33.998	27.524	16	3	305	81	-88	H
59	970809	142842	33.999	27.524	16	2.8	175	80	-12	H
60	000509	184332	33.12	28.55	7	3.2	144	77	-34	E
61	000625	191848	33.48	28.21	18	4.6	196	77	-166	E
62	001103	211903	32.84	28.93	23	4.4	117	41	-90	E
63	010105	190037	33.16	28.67	12	3.7	149	77	-55	E
64	10818	54859	33.94	27.48	13	3.9	155	59	-59	E
65	10819	160025	33.95	27.5	14	3	6	62	-131	E
66	10820	25711	33.93	27.49	16	3.5	211	35	-121	E
67	10820	155510	33.92	27.49	16	3.1	229	40	-142	E
69	10820	172435	33.97	27.48	16	3.9	175	68	-164	E
70	20213	185210	33.67	28	15	3.7	336	47	-38	P
71	21025	180441	33.62	27.53	10	3.8	128	67	-12	P

Key to the references:

A Megahed (personal communication)	E Egyptian national seismic network bull. No 1,2 and 3.
H Hurukawa et al., (2001)	R Abdel Fattah, R. (1999).

P Abou Elenean, K. (personal communication).

As given in Figure 5, the maximum observed velocity of the epoch 1999-2000 was 2.3 mm/yr at NABQ station nearly in the NE direction while the minimum movement was 0.5 mm/yr at SHAM station in the same direction. The computed mean velocity for this epoch was about 2.0 mm/yr NE for the stations located on the western part of the Gulf of Suez and 1.5 mm/yr in the ENE direction for the stations located on the western part of the Gulf of Suez in Sinai Peninsula

The maximum movement of epoch 2000-2002 represented in Figure 6 was 2.8 mm/yr in the NE direction at DERB station while the minimum movement was 2.1 mm/yr at SHAM station in the ENE direction. The mean velocity was 2.5 mm/yr in NE direction of the both sides of the Gulf of Suez. In this epoch we have noticed that the estimated velocities of all stations were semi-equal ranging from 2.4 to 2.7 mm/yr in the NE to ENE directions, respectively. The stations of CATH and KENS were destroyed in this epoch.

By comparing all campaigns, we can postulated that the motion of Sinai block and the Gulf of Suez takes the NE to ENE directions with velocity of about 2-3 mm/yr which agree with the result of McClusky et al., (2003). The combined solutions of all epochs from 1997 to 2003 are outlined in Table 2 and Figure 7.

The maximum velocity was 21.5 mm in six years at SHAM and NABQ stations in NE direction while the minimum velocity was 19.5 mm in six years at KENS station in the NE direction. The mean velocity was about 19 mm in six years also in the same direction. We notice from Table 2, that the movements of all stations in the east direction are slightly larger than those in the north direction. The velocities of Sinai network station were also estimated using Nuvel1-A model program (Table 2). These velocities are nearly equal to the ones derived from the ITRF2000 velocities. In terms of global kinematics, these results of velocity show that the motion of Sinai and the Gulf of Suez area matches the African plate motion defined by NUVEL-1A model (De Mets et al., 1994).

4.2. Strain Results

The principal axis of strains in Sinai and around the Gulf of Suez was calculated using strain tensor program (Mahmoud, 2001). The output of this program was shown in Figures 8, 9, and 10.

Figure 8, shows that the maximum extension, 0.051 µs/yr at NABQ station in the NE direction, for the period from 1997 to 1998, however, the minimum extension, was 0.012 µs/yr in the NEN direction at GARB station. On the other hand, the maximum compression which is perpendicular to the extensional direction was 0.081 µs/yr in NW direction at SHAM station and the minimum compression was 0.002 µs/yr in the NNW direction at CATH station.

Figure 9, shows that the maximum extension at ZEIT station was 0.09 µs/yr in the ENE direction in the period from 1999 to 2000, while the minimum extension was 0.02 µs/yr in the NE direction at CATH station. On the other hand, the maximum compression was 0.07 µs/yr in NW direction at SHAM station and the minimum compression was 0.005 µs/yr in the NW direction at CATH station.

For the period 2000 to 2002, the maximum extension was 0.07 µs/yr in the ENE direction at ZEIT station while the minimum extension was 0.02 µs/yr in the NE direction at GEMS station (Fig.10). However, the maximum compression was 0.05 µs/yr in NE direction at DAHA, GEMS and SHAM stations while the minimum compression was 0.001 µs/yr in the NNW direction at ZEIT station. During that period the CATH and KENS stations were destroyed.

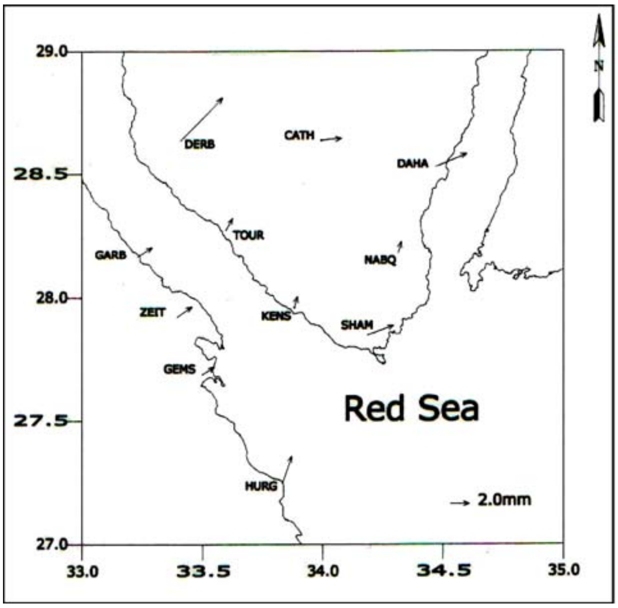

Figure 4. The horizontal (Hz.) velocities of Sinai network relative to IGS permanent stations from 1997-1998.

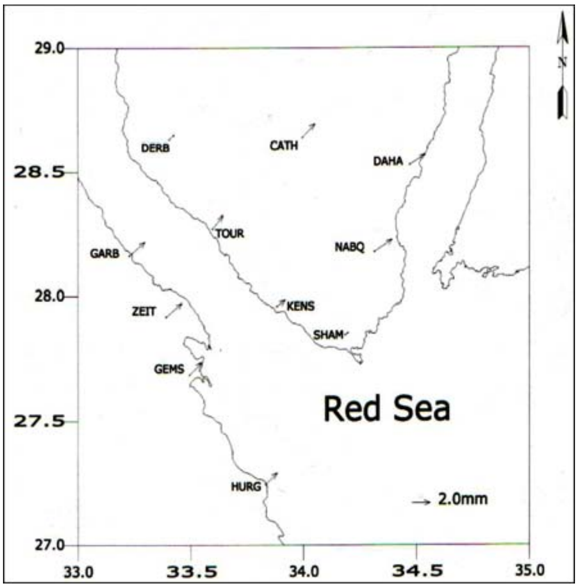

Figure 5. The Hz. Velocities of Sinai network relative to IGS permanent stations from 1999-2000.

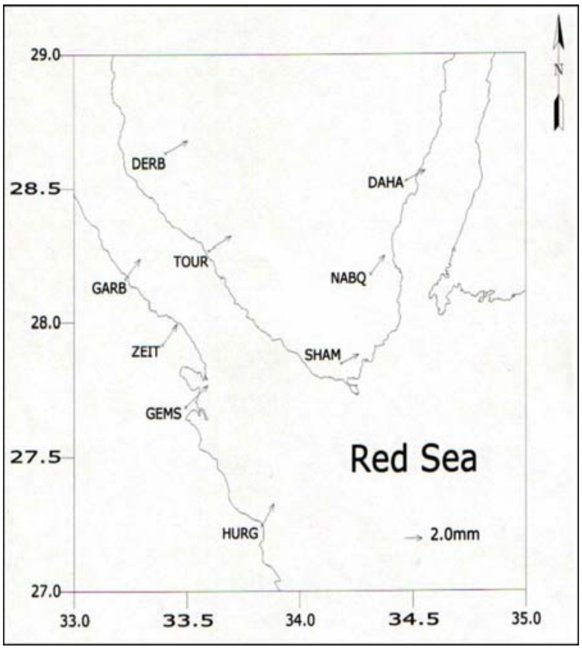

Figure 6. The Hz. Velocities of Sinai network relative to IGS permanent stations from 2000-2002.

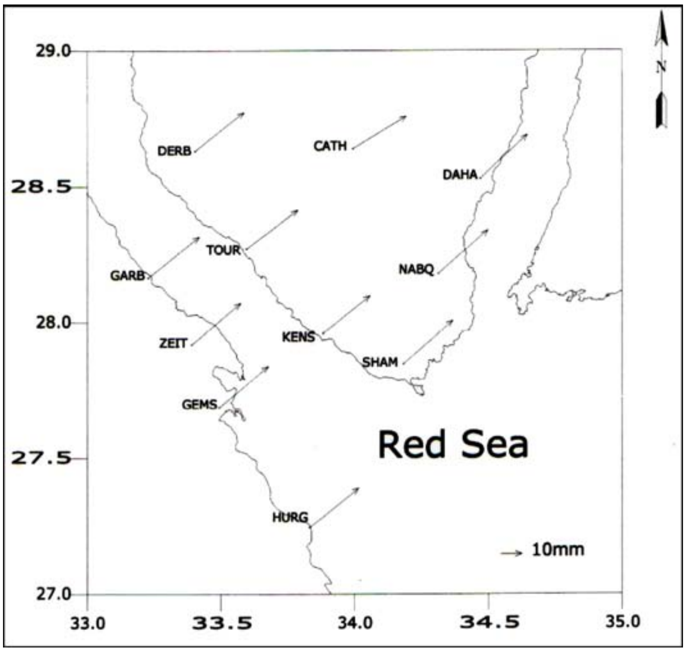

Figure 7. The Hz. Velocities of Sinai network relative to IGS permanent stations from 1997-2003.

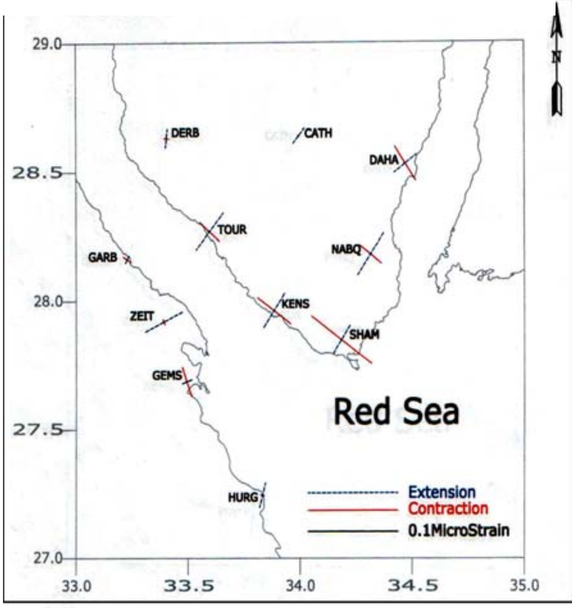

Figure 8. The principle strain of Sinai from 1997-1998.

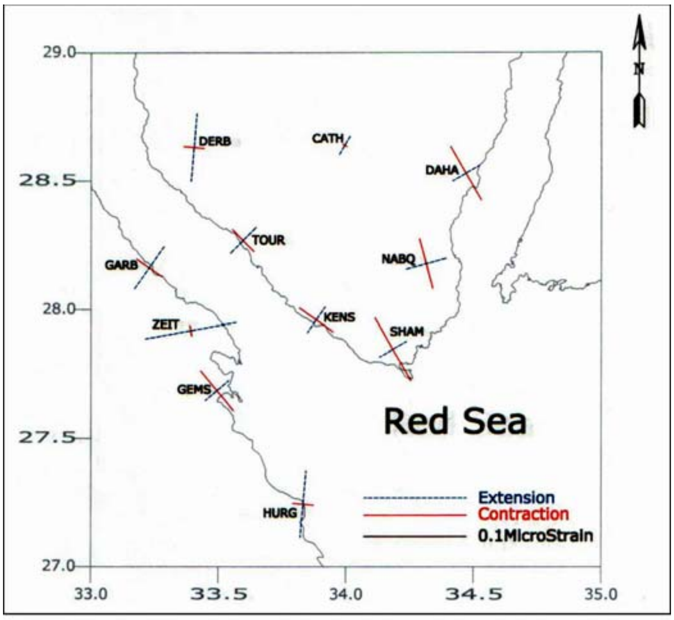

Figure 9. The principle strain of Sinai from 1999-2000.

Summarizing all results mentioned above, we can conclude after studying of the principal axis of strains in Sinai and around the Gulf of Suez that the maximum extension seems to be in the NE-SW direction in general. The principal axes of strains also indicate that the studied region is mainly divided into two areas: western part, around Gulf of Suez, where extensional strain is predominant and the eastern part, around the Gulf of Aqaba, where compressional strains prevail. There is another high contraction in Sham and Nabq stations which may be due to the seismic activity in the Gulf of Aqaba. This results of principal strains are completely agreed with the seismological analysis given by Abu-Elenean (1997) and Megahed et al.(2004), which distinguishes the Gulf of Suez by extensional strain.

	Campaign year						Geographic coordinate		ITRF00 velocity		Nuvel1-A velocity	
Station ID	97	98	99	00	02	03	Lat°	Long°	V_N mm/6yr	V_E mm/6yr	V_N mm/6yr	V_E mm/6yr
Cath	▨	▨	▨	▨			28.639	34.00	15±01	25±01	19.5	25.0
Daha	▨	▨	▨	▨	▨	▨	28.529	34.470	20±01	22±02	19.5	25.1
Derb	▨	▨	▨	▨	▨	▨	28.630	33.404	18±03	23±01	19.6	24.9
Garb	▨	▨	▨	▨	▨	▨	28.163	33.228	19±02	24±01	19.6	24.9
Gems	▨	▨	▨	▨	▨	▨	27.686	33.494	19±01	23±01	19.6	25.0
Hurg	▨	▨	▨	▨	▨	▨	27.267	33.869	18±02	23±00	19.6	25.1
Kens	▨	▨	▨	▨			27.960	33.883	17±01	22±03	19.6	25.0
Mate	■	■	■	■	■	■	40.649	16.704	ITRF2000			
Nabq	▨	▨	▨	▨	▨	▨	28.178	34.314	20±02	23±02	19.5	25.1
Nico	■	■	■	■	■	■	35.141	33.396	ITRF2000			
Sham	▨	▨	▨	▨	▨	▨	27.846	34.184	20±01	23±01	19.5	25.1
Sofi	■	■	■	■	■	■	42.556	23.395	ITRF2000			
Tour	▨	▨	▨	▨	▨	▨	28.269	33.596	18±03	24±02	19.6	24.9
Zeck	■	■	■	■	■	■	43.788	41.565	ITRF2000			
Zeit	▨	▨	▨	▨	▨	▨	27.919	33.392	19±02	23±01	19.6	24.9

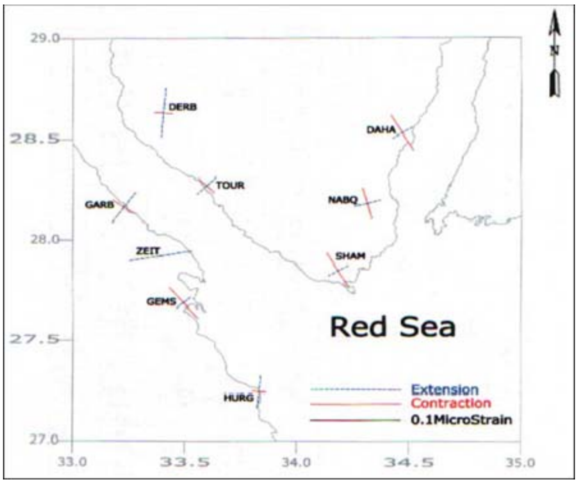

Figure 10. The principle strain of Sinai from 2000-2002

SUMMARY &CONCLUSIONS

Egypt occupies the northeastern corner of the African plate and it is not a major seismic zone, but earthquakes represent a significant hazard. The African plate is moving northward direction, at a rate of about 10 mm/yr, and colliding the Eurasian plate. Differential motion between Africa and Arabia (~10-15 mm/yr) is to be taken up predominantly by left-lateral motion along the Dead Sea transform fault (McClusky et al., 2000). The difference in magnitude and direction of the horizontal movements in the studied area is deduced from the different of tectonic patterns. The analysis of the GPS data shows, in general, that the velocity of Sinai Peninsula is 3-5 mm/yr NE. This velocity is coincides with that predicted by the model NUVEL-1A in the same direction but smaller in value. Also, the analyses presented show that there is a little motion between Sinai area and African plat by about 2.0 mm/yr the in the NNW direction. There is an extension (2-4 mm/yr) at the opening of the Gulf of Suez. The calculated crustal strain for the study area shows that an extension in the NE trend which may coincide with the focal mechanisms of some majorearthquakes in this region.

REFERENCES

Abdel-Fattah, R. (1999): Seismotectonic studies on the Gulf of Suez region, Egypt. M. Sc. Thesis, Fac. of Sci., Geology Dept. Mansoura Univ.

Abou Elenean, K., (1997): A study on the Seismotectonics of Egypt in relation to the Mediterranean and Red Sea Tectonics. Ph.D. Thesis, Ain Shams University, Cairo, Egypt.

Bosworth, W., (1985): Geometry of propagation continental rifts. Nature, Vol. 316, pp. 625-627.

Coffield, D. Q. and Schamel, S., (1989): Surface expression of an accommodation zone within the Gulf of Suez rift, Egypt. Geology, Vol. 17, pp. 76-79.

Colletta, B., Le Quellec, P. Letouzer, J. and Moretti, I., (1988): Longitudinal evolution of the Suez rift structure (Egypt). Tectonophysics, Vol. 153, pp. 221-23

Daggett et, P., Morgan, P., Boulos, F., Hennin, S., El-Sherif, A., El-Sayeda, Basta, N. and Melek, T., (1986): Seismicity and Active Tectonics of the Egyptian Red Sea margin and the northern Red Sea. Tectonophysics, Vol. 125, pp. 313-324.

DeMets , C., Gordon, R.G., Argus, D.F., and Stein, S., (1994): Effects of Recent Revisions to the Geomagnetic Reversal Time Scale on Estimates of Current Plate Motions, Geophys. Res. Lett., Vol. 21, pp. 2191-2194.

Fairhead, J.D.,Girdler,R.W. (1970): The Seismicity of the Red Sea, Gulf of Aden, and Afar Triangle.

Philos. Trans. R. Soc. London, Ser.A. 267: pp. 49-74.

Gawthorpe, R.L., Hurst, J.M., and Sladen, C.P., (1990): Evolution of Miocene footwall-derived coarse-grained deltas, Gulf of Suez, Egypt: Implications for exploration. Amer. Ass. Petrol. Geol. Bull. 74: pp. 1077-1086.

Gergawi, A., and El-Khashab, H.W. (1968): Seismicity of the United Arab Republic. Helwan Observ. Bull. pp. 76-27.

Hugentobler, U., Schaer, S., and Fridez, P., Beutler, G., Brockmann, E., Fankhauser, S., Gurtner, W., Johnson, J., Mervert, L., Rothacher, M., Springer, T. and Weber, R. (2001): Bernese GPS software version 4.0. Documentation, edited by Rothacher, M. and L. Mervert, pp. 418.

Hurukawa . N., Seto, N., Inoue, H., Nishigami, K., Marzouk, I., Megahed, A., Ibrahim, E.M., Murakami, H., Nakamura, N., Haneda, T., Sugiyama, S., Ohkura, T., Fujii, Y., Hussein, H.M., Megahed, A.S., Mahmmed, H.F., Abdel-Fattah, R., Mizoue, M., Hashimoto, S., Kobayasi, M. and Suetsugu, D., (2001): Seismological Observations in and around the Southern Part of the Gulf of Suez, Egypt. Bull. of the Seismological Society of America, Vol. 91, No. 4, pp. 2001-2010.

Jackson,J.A., White,N.J., Garfunkel,Z., and Anderson, H., (1988) : Relations between Normal- Fault Geometry, Tilting and Vertical Motions in Extensional Terrains: an example from the Southern Gulf of Suez. J. Struct. Geol. Vol. 10, pp. 155-170.

Khalil S., (1998) : Tectonic Evolution of the Eastern Margin of the Gulf of Suez, Egypt. Ph.D. Thesis, Royal Holloway, University of London, pp.349.

Mahmoud, S.M., (2001): Strain Analysis deduced from the results of GPS measurements in Sinai Peninsula and around the Gulf of Suez, Egypt. Bull. of NRIAG, Cairo, Egypt. pp. 265-282.

Mahmoud, S.M., Koivula, H., Mohmed, A.S., Khalil, H., and Kebeasy, T.R., (1998) : Monitoring recent movement in Sinai and around Gulf of Suez, Egypt, in the Ninth International Symposim on Recent Crustal Movements (CRCM 98), Cairo, Egypt.

McClay, K.R., Royal Holloway, and Bosworth, W., (2001) : Gulf of Suez Field Excursion Us Margins Workshop, Egypt, pp. 2-8.

McClusky, S., Balassanian, S., Barka, A., Demir, C., Erigintav, S., Georgiev, I., Gurkan, O., Hamburger, M., Hurst, K., Kahle, H., Kastens, K., Kekelidze, G., King, R., Kotze, V., Lenk, O.,Mahmoud, S.M., Mishin, A., Nadariya, M., Ouzounis, A., Paradissis, D., Peter, Y., Prilepin, M., Reilinger, R., Sanli, I., Seeger, H., Tealeb, A., Toksoz, M., and Veis, G., (2000): Global positioning system constraints on plate kinematics and dynamics in the eastern mediterrnean and Caucasus. JGR Vol. 105 No. 3, pp. 5695-5719.

McClusky, S., Reilinger,S., Mahmoud, S.M., Ben Sari, D., and Tealeb,A., (2003): GPS constraints on Africa (Nubia) and Arabia plate motions, Geophys. J. Int., 155, pp.126-138.

Megahed, Ali S. , Marzouk, I. A., Korrat, I., Hussein, H. M., Sherif, M. R., Dessokey, M. M. and Hurukawa, N., (2004): Seismic deformation studies on the souther part of the Gulf of Suez region, Egypt. Presented in the 22th Annual meeting of the Egyptian Geophysical Soceity (EGS).

Moustafa, A.M., (1976): Block Faulting in the Gulf of Suez. Proceedings of the 5th Exploration Seminar, Egyptian General Petroleum Organization, Cairo, pp.35-36.

Moustafa, A.R., and Fouda, H.G., (1988): Gebel Surf el Dara accommodation zone, southwestern part of the Suez rift part. Ain Shams Univ, Earth Sci. Ser., Vol. 2, pp. 227-39.

Patton, T.L., Moustafa, A.R., Nelson, R.A., and Abdine, S.A., (1994): Tectonic evolution and structural setting of the Suez rift.In: S.M. London Edition, Interior Rift Basins, Am. Ass. Petrol. Geol, Mem, Vol. 59, pp. 7-55.

Sharp, L.R., Gawthorpe, L.R., Underhill, J.R., and Gupta, S., (2000a): Fault- propagation folding in extensional setting: Examples of structural style and syn-rift sedimentary response from the Suez Rift, Sinai, Egypt. Geological Society of America Bull., 112: pp. 1877-1899.

Sharp, L.R., Gawthorpe, L.R., Armstrong, B., and Underhill, J.R., (2000b): Propagation history and passive rotation of mesoscale normal faults: implication of syn-rift stratigraphic development. Basin Research, Vol. 12, pp. 285-306.

Smith, D. E., R. Kolenkiewicz, P. J. Dunn, J. W. Robbins, M. H. Torrence, S. M. Klosko, R. G. Williamson, E. C. Pavlis, N. B. Douglas, and S. K. Fricke, (1990): Tectonic motion and deformation from Satellite Laser Renging to LAGEOS. J. Gephys. Res., Vol. 95, No. 22, pp. 13-41.

Salamon, A., Hofsteiter, A., Garfunkel, Z., nd Ron, H., (1996): Seismicity of the Eastern Mediterranean region perspective from the Sinai subplate. Tectonophysics, Vol. 263: pp. 293-305.