Egyptian Geophysical Society
EGS Journal, vol. 2, No. 1, 109-115 (2004)

MOMENT TENSOR COMPONENT OF THE GULF OF SUEZ EARTHQUAKES

Abu Bakr A. Shater and M. El- Amin

National Research institute of Astronomy and Geophysics

ممتد مركبات العزم لزلازل خليج السويس

الخلاصـة: تم استخدام طريقة التحليل المركب لميكانيكية البؤرة لخمس مجموعات من الزلازل التى حدثت فى منطقة خليج السويس والتى تم تسجيلها بواسطة شبكة الغردقة لتسجيل الزلازل فى الفترة من ١٩٩٤ م وحتى ١٩٩٥ م، وذلك لدراسة العلاقة بين نوع حركة ميكانيكية البؤرة والخصائص التركيبية لمنطقة خليج السويس وحساب مركبات ممتد العزم الزلزالى لكل مجموعة وقد خلصنا إلى النتائج التالية:

أظهر التحليل المركب لميكانيكية البؤرة للمجموعة الأولى أن حركة الصدع السائدة هى الحركة العكسية يصاحبه محور ضغط فى إتجاه جنوب شرق إلى شمال غرب، بينما المجموعة الثانية والتى تقع شرق المجموعة الأولى فإن حركة الصدع الملاحظ فيها من نوع الحركة العمودية مع محور شد فى إتجاه شمال شرق إلى جنوب غرب. كما أظهر التحليل أن الحركة بالنسبة لهاتين المجموعتين تتطابق مع محور الشد الناتج عن إنفراج البحر الأحمر.

وبالنسبة للتحليل المركب لميكانيكية البؤرة للمجموعتين الثالثة والرابعة فتتميزان بحركة صدع عكسية مع وجود مركبة لحركة إفقية (صدع مائل).

المجموعة الخامسة فتتميز بحركة عمودية مع شد فى إتجاه شمال غرب إلى جنوب شرق، وهى حركة متطابقة مع محور الشد الممتد إلى خليج السويس نتيجة لإنفراج البحر الأحمر.

هذا وقد تم حساب مركبات ممتد العزم الزلزالى لكل مجموعة من معاملات الصدوع وقد أكدت قيم المركبات النتائج المذكورة.

ABSTRACT: *Composite focal mechanism solutions are examined for five groups of earthquakes which took place in the Gulf of Suez and recorded by Hurghada seismic network during the period from 1994 to 1995 to investigate the trade off the type of the focal mechanism solution and the evidence of the tectonics for the area.*

The composite solution in the first group area is dominated by reverse fault with pressure axis S-E to N-W, while a normal fault solution in the second group area east of the first group with tension axis of NE- SW is observed.The solution is consistent with tension axis due to the opening Red sea

The third and the fourth groups are characterized by reverse fault with strike slip component (diagonal fault). The fifth group is characterized by a normal fault with tension axis of NW- SE, which is consistent with tension axis extended in the Gulf of Suez due to the opening of the Red Sea. The Moment Tensor components are calculated from the fault plane parameters (strike (ϕ), dip (δ) and rake (λ)) for each group.

INTRODUCTION:

The extent of oceanic crust underlying the Red Sea has been the subject of a long debate. Some believe that the northern Red Sea is almost entirely underlain by oceanic crust. The evidence for this view is based on plate kinemaetics (Mckenzie et al. 1970), gravity as well as magnetic data (Girdler and Styles 1974 and 1976, Rosser 1975, Styles and Hall 1980) and seismic data (Knott et al. 1966, Phillips and Ross 1970). Others believe that the oceanic crust is of limited extent or non-existent in the northern Red Sea (Hutchinson and Engels 1972, Lowell and Genik 1972, Ross and Shlee 1973 and Cochron 1983).

The Gulf of Suez is an extensional rift comprises a northwest- trending marine basin, flanked by gravel plains that are broken by several tilted blocks such as Esh El Mellaha and Gebel Zeit to the west and Gebel Araba to the east . The amount of extension is estimated at 25 to 50 % of its original width (Angelier 1985, Perry and Shamel 1985). Most of the tectonism and structural relief associated with the rift occurred after the early Miocene invasion, within the past 18 to 20 million years (Garfunkel and Bartov 1977). The rift is a tectonically active structure that is considered to be a subplate boundary that formed as a relict of the opening of the Red Sea. The seismic activity which follows the structure trend of the Gulf of Suez may continue more northerly towards the center of seismic activity of Abu Hammad (Maamoun at. al 1980).

Dagget et al. (1986) related the high rate of seismicity at the southern end of the Gulf of Suez to crustal movements among the Arabian and African plates and Sinai subplate as a result of the opening of the Red Sea extension in the Gulf of Suez and the left-lateral strike-slip motion in the Gulf of Aqaba

Source parameters of earthquakes permit us to get information about fault when it does not appear on the surface of the ground. The focal mechanism of an earthquake provides the state of stress in the source region and reveals important clue for physical understanding of the earthquake phenomenon. In addition, spatially well distributed accurate focal mechanisms are the key to discuss the regional and local tectonics of the seismic active area.

The history of focal mechanism study may be traced back to the late 1910, when Professor Shida of Kyoto University, Japan discovered a systematic distribution of the two senses of polarity (compressions or dilatations) in azimuth about the epicenter of an earthquake. Focal mechanism based on first-motion polarities of P-waves are still most widely used. In many cases they provide the only method available to obtain the focal mechanism.

Distribution of the initial P-wave pulses from an earthquake are simplified by the use of a focal sphere that surround the earthquake focus. Initial P-wave pulse from seismic stations are projected on points on the surface of the focal sphere by ray tracing back to the source. Their positions on the focal sphere are giving by the take off angle at the source measured from the vertical and azimuth measured from the north.

The composite focal mechanism can be made by superimposing data from a number of earthquakes projected onto a common focal sphere. This method is used when the number of stations is not enough to cover the focal sphere with data from a single earthquake and unique solution cannot be obtained for individual event. It tells us about two possible planes of faulting. The geological trends and the linear aspects of the earthquake aftershock distributions help to the more proper plane of faulting .It is useful also in helping to determine stress orientation and relating the earthquakes activity to geological structure which may be observed at the surface. Many authors (Scholz et al, 1969; Sbar et al, 1970; Langer et al., 1974; Armbruster et al , 1978; Herrmann and Canas, 1978) found that for a limited segment of an active seismic feature the focal mechanisms of microearthquakes are nearly identical. They also found that the plane of faulting inferred from the aftershocks distribution nearly coincides with the nodal plane obtained from focal mechanism studies.

DATA

Hurghada seismic network consistes of eight remote stations distributed around the both sides of the Gulf of Suez. Four stations are in the Southern Sinai Province and the other four are located in western side of the Gulf of Suez. Data acquisition and analysis center is located at Hurghada city (Hurghada Seismological Center, HSC, Ibrahim et. al (1995), Figure 1 and table 1). The data used in this study are the first arrival times of P-wave and their corresponding directions of motion from earthquakes occurring beneath the stations during the period of 1994 - 1995. The P-wave velocity structure model used in this study is the same as used in the routine work for earthquake location (table 2).

METHOD

The earthquake epicenters are divided into five groups whose P-wave first motion data are consistent to each other and whose epicenters are located close to each other so that the composite technique for each group could be applied. The set of observations of the P-wave first motion polarities are plotted on the lower hemisphere projection using computer program (PMAN, Suetsugu, D. 1995). This program was modified by A. Shater for this study. The two nodal planes that separate regions of different polarity are drawn manually using the Schmidt net. The plane of faulting has been chosen from the two orthogonal nodal planes by considering the orientation of the seismic pattern.

An alternative way to describe earthquake source is the moment tensor representation which is more suitable for objectively determining an earthquake source model by computer than the fault angle representation, because the moment tensor is linearly related to ground displacement recorded by seismometer.

The fault parameters (strike (ϕ) ,dip(δ) and rake (λ) obtained from the composite focal mechanism are used to calculate the Moment Tensor components in each group as described by Seth Stein (1987) and Suetsugu (1995):

$$M = \begin{bmatrix} M_{XX} & M_{XY} & M_{XZ} \\ M_{YX} & M_{YY} & M_{YZ} \\ M_{ZX} & M_{ZY} & M_{ZZ} \end{bmatrix}$$

where :-

M = moment tensor

M_0 = seismic moment

$M_{xx} = - M_0 (\sin\delta \cos\lambda \sin 2\phi_S + \sin 2\delta \sin\lambda \sin^2\phi_S)$

$M_{xy} = M_{yx} = M_0 (\sin\delta \cos\lambda \cos 2\phi_S + \sin 2\delta \sin\lambda \sin 2\phi_S)$

$M_{xz} = M_{zx} = - M_0 (\cos\delta \cos\lambda \cos\phi_S + \cos 2\delta \sin\lambda \sin 2\phi_S)$

$M_{yy} = M_0 (\sin\delta \cos\lambda \sin 2\phi_S - \sin 2\delta \sin\lambda \cos^2\phi_S)$

$M_{yz} = M_{zy} = - M_0 (\cos\delta \cos\lambda \sin\phi_S - \cos 2\delta \sin\lambda \cos^2\phi_S)$

$M_{zz} = M_0 \sin 2\delta \sin\lambda$

RESULT AND DISCUSSION

Composite Focal Mechanism of the first group:

The earthquakes of this group are located around latitude 27.4 ^{o} and longitude 34.0 ^{o}. The mechanism of this zone is characterized by almost dip slip fault (reverse fault). This solution agrees with the result obtained from the stress distribution of the second group.

From figure (2) the focal mechanism results can be summarized as follows:

(*) One of the nodal planes, strikes *64* ^{o}, and its dip is *68*^{o}. The rake angle of this plane is *99* ^{o}. The other nodal plane strikes *221* ^{o} with dip angle of *24* ^{o}, its rake angle is *69* ^{o}.

(*) The azimuth of the compression stress P is *147* ^{o} making an angle of *22* ^{o} with the horizontal line, while the azimuth of the dilatation stress T is *350* ^{o} making an angle of *66* ^{o} with the horizontal line. The strikes of these two nodal planes coincide with the seismicity distribution of this active zone.

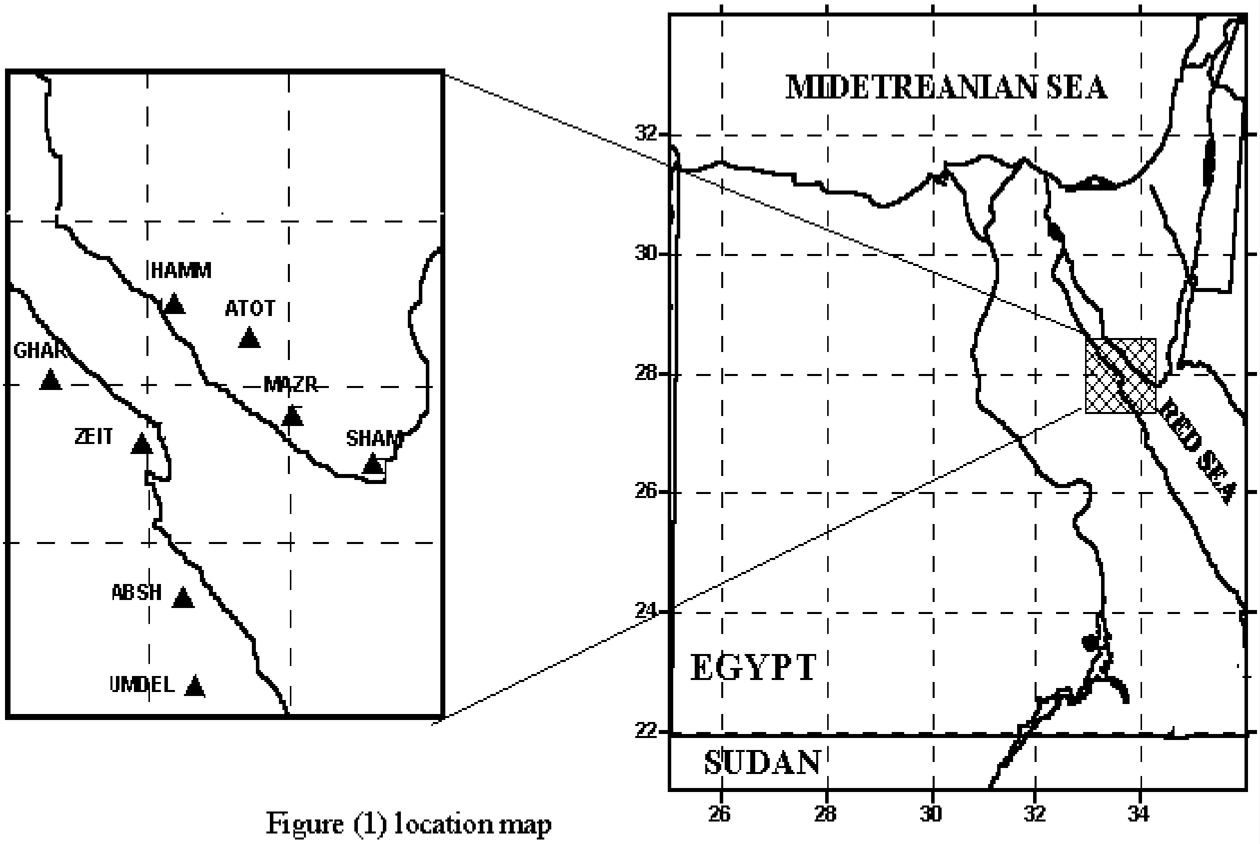

Figure (1) location map

Table (1) Coordinate of Hourghada seismic stations

station	latitude (degree)	longitude (degree)	elevation (km)
HAMM	28.27633	33.57783	0.241
ATOT	28.16833	33.86033	0.200
MAZR	27.92933	33.99483	0.200
ZEIT	27.87283	33.51616	0.100
ABSH	27.36800	33.62100	0.220
UMDL	27.08600	33.65166	0.100
GHAR	28.04000	33.12000	0.350
SHRM	27.85200	34.25783	0.300

Table (2) crustal structure modle

Vp(km/s)	Depth (km)
4.50	0.00
6.00	5.00
6.50	15.00
8.00	25.00

The moment tensor components are:

M_{xx}= - *0.4429575* M_{xy} = *0.3638029* M_{xz} = *0.6569126*

M_{yx}= *0.3638029* M_{yy}= - *0.2508280* M_{yz}= - *0.2566732*

M_{zx} = *0.6569126* M_{zy} = - *0.2566732* M_{zz} = *0.5937855*

Composite Focal Mechanism of the second group:

The earthquakes of this group are located around latitude 27.5 ^{o} and longitude 34.3 ^{o}. The mechanism of this zone is characterized by almost dip slip fault (normal fault). This solution is consistent with NE- SW tension axis due to the opening of the Red Sea.

From figure (3) the focal mechanism results can be summarized as follows:

(*) One of the nodal planes, strikes *308* ^{o}, and its dip is *43* ^{o}. The rake angle of this plane is *-87* ^{o}. The other nodal plane strikes *124*^{o} with dip angle of *47* ^{o}, its rake angle is *93* ^{o}.

(*) The azimuth of the compression stress P is 354^{o} making an angle of *216* ^{o} with the horizontal line, while the azimuth of the dilatation stress T is *350* ^{o} making an angle of *02* ^{o} with the horizontal line.

The moment tensor components are:

M_{xx}= *0.6532322* M_{xy} = *0.4746679* M_{xz} = - *0.0784587*

M_{yx}= *0.4746679* M_{yy}= *0.3429648* M_{yz}= - *0.0127256*

M_{zx} = - *0.784587* M_{zy} = - *0.0127256* M_{zz} = - *0.9951969*

Composite Focal Mechanism of the third group:

The earthquakes of this group are located around latitude 27.6 ^{o} and longitude 33.9 ^{o}. The mechanism of this zone is characterized by reverse fault with minor strike slip component (diagonal fault).

From figure (4) the focal mechanism results can be summarized as follows:

(*) One of the nodal planes, strikes *016*^{o}, and its dip is *81*^{o}. The rake angle of this plane is *066* ^{o}. The other nodal plane strikes *267* ^{o} with dip angle of *26* ^{o}, its rake angle is *160* ^{o}.

(*) The azimuth of the compression stress P is *125* ^{o} making an angle of *32* ^{o} with the horizontal line, while the azimuth of the dilatation stress T is *260* ^{o} making an angle of *48* ^{o} with the horizontal line.

The moment tensor components are:

M_{xx}= - *0.234320* M_{xy} = *0.4154839* M_{xz} = *0.1783201*

M_{yx}= *0.4154839* M_{yy}= - *0..479691* M_{yz}= - *0.8527144*

M_{zx} = *0.1783201* M_{zy} = - *0.8527144* M_{zz} = *0.2823011*

Composite Focal Mechanism of the fourth group:

The earthquakes of this group are located around latitude 27.7 ^{o} and longitude 33.8 ^{o}. The mechanism of this zone is characterized by reverse fault with strike slip component (diagonal fault).

From figure (5) the focal mechanism results can be summarized as follows:

(*) One of the nodal planes, strikes *154* ^{o}, and its dip is *75* ^{o}. The rake angle of this plane is *25* ^{o}. The other nodal plane strikes *58* ^{o} with dip angle of *66* ^{o}, its rake angle is *164* ^{o}.

(*) The azimuth of the compression stress P is *285* ^{o} making an angle of *06* ^{o} with the horizontal line, while the azimuth of the dilatation stress T is *18* ^{o} making an angle of *28* ^{o} with the horizontal line.

The moment tensor components are:

M_{xx}= *0.6419647* M_{xy} = *0.4770122* M_{xz} = *0.3635998*

M_{yx}= *0.4770122* M_{yy}= - *0.8468032* M_{yz}= *0.2338332*

M_{zx} = *0.3635998* M_{zy} = *0.2338332* M_{zz} = *0.2048385*

Composite Focal Mechanism of the fifth group:

The earthquakes of this group are located around latitude 28.2 ^{o} and longitude 33.7 ^{o}. The mechanism of this zone is characterized by dip slip fault (normal fault).

From figure (6) the focal mechanism results can be summarized as follows:

(*) One of the nodal planes, strikes *353* ^{o}, and its dip is *58* ^{o}. The rake angle of this plane is *-116* ^{o}. The other nodal plane strikes *216* ^{o} with dip angle of *40* ^{o}, its rake angle is *-55* ^{o}.

(*) The azimuth of the compression stress P is *214* ^{o} making an angle of *66* ^{o} with the horizontal line, while the azimuth of the dilatation stress T is *102* ^{o} making an angle of *10* ^{o} with the horizontal line.

The moment tensor components are:

M_{xx}= - *0.7793251* M_{xy} = - *0.2696812* M_{xz} = *0.2718609*

M_{yx}= - *0.2696812* M_{yy}= *0.8786398* M_{yz}= *0.3733421*

M_{zx}= *0.2718609* M_{zy} = *0.3733421* M_{zz} = *0.8067073*

Figure 7 shows the composite fault plane solution of the all groups with stress directions. The second group is the normal fault which are consistent with NE-SW tension axis due to the opening of the Red sea, The fifth group is characterized by a normal fault with tension axis of NW- SE, which is consistent with tension axis extended in the Gulf of Suez due to the opening of the Red Sea. The other groups are characterized by reverse faults which are consistent with the stress distribution of the second and fifth groups.

CONCLUSION

Composite focal mechanism solutions are examined for the earthquakes which took place in the Gulf of Suez during the period from 1994 to 1995 recorded by Hurghada seismic network to investigate the trade off the type of the focal mechanism solution and the evidence of plate tectonics for the area .

We have divided the earthquakes into five groups whose P-wave first motion data are consistent to each other and whose epicenters are located close to each other. The moment tensor components are calculated from the fault plane parameters.

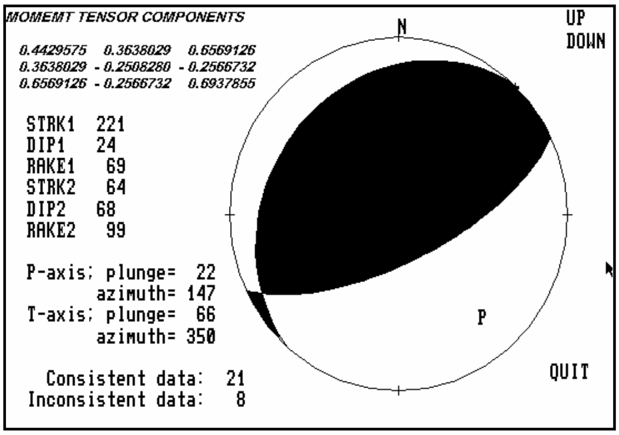

Figure (2) The first group earthquake mechanism (reverse fault)

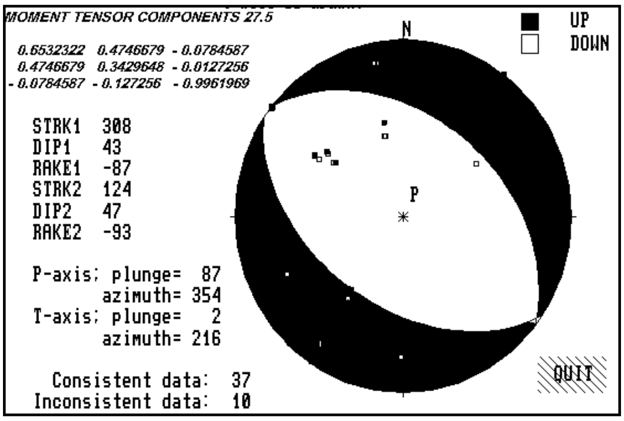

Figure (3) The second group earthquake mechanism (normal fault)

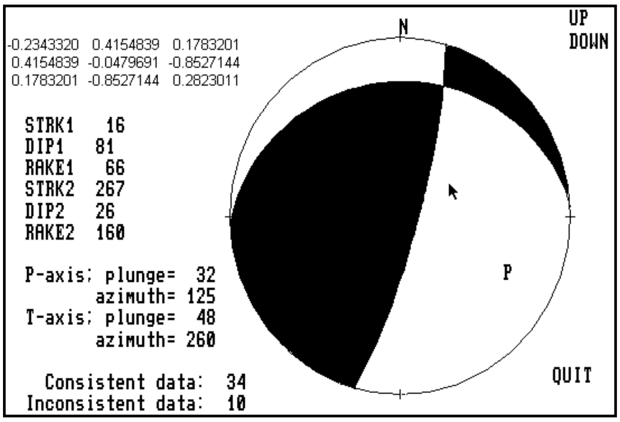

Figure (4) The third group earthquake mechanism (reverse fault with strik slip component)

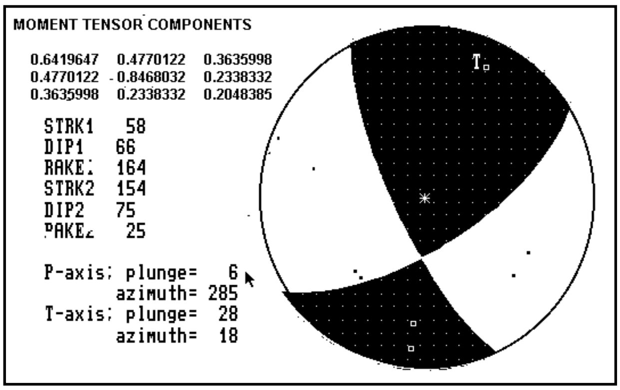

Figure (5) The fourth group earthquake mechanism (reverse fault with strik slip component)

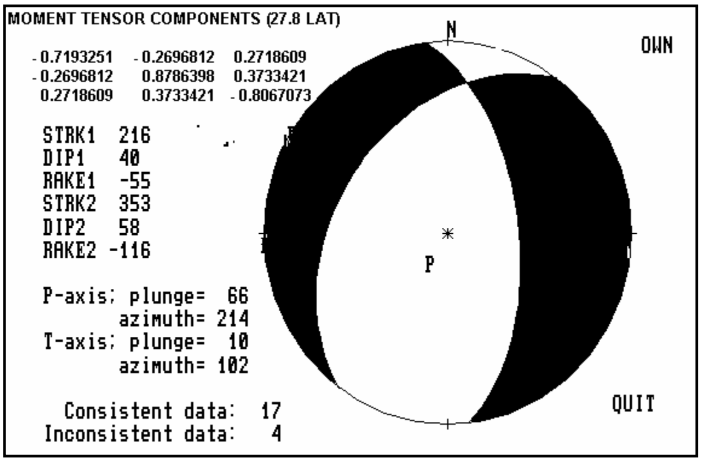

Figure (6): The fifth group earthquake mechanism (normal fault)

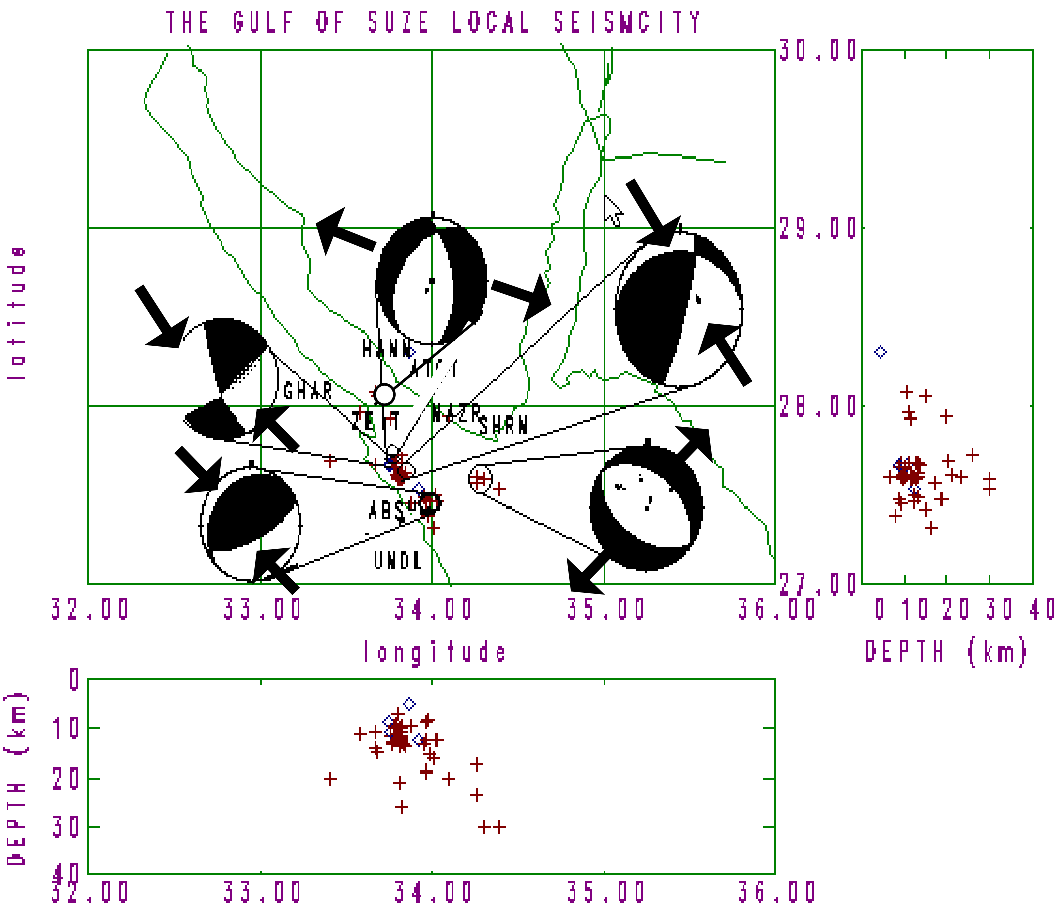

Figure (7) Earthquake focal mechanisms in Gulf of Suez with stresses directions

The analysis of fault plane solution of these five earthquake groups indicated that the second and fifth groups are characterized by dip slip faults (normal faults) with NE-SW tension axis which illustrates a considerable consistency with the tension axis of the opening of the Red Sea. Meanwhile, the analysis of composite focal mechanism of the other groups reveals that these groups are distinguished by reverse faults with strike slip component which are consistent with the stress distribution of the second and fifth groups.

ACKNOWLEDGMENT

We would like to express our sincere gratitude and appreciation to Dr. E. M. Ibrahim , Dr. R.M. Kebeasy and Dr. R. N. Albert for their help. We also wish to extend our thanks to all Hurghada seismic netwok staff.

REFERENCES

Angelier, J. , 1985, Extension and rifting; the Zeit region, Gulf of Suez. J. Struct.

Geol. 7: 605-612

Armbruster, J. , L. Seeber, and K. H. Jacop, 1978, The northwestern termination of the Himalayan mountain front . Active tectonics from microearthquakes, J. Geophys. Res. ,83,269-282

Cochron, J. R., 1983, A model for development of Red Sea . Bull. Am.Assoc. Petrol. Geol. 67: 41.49

Dagget, P. H. , P. Morgan, F. K. Boulos, S. F. Hennin, A. A. El Sherif and Y. S. Melek, 1986, Seismicity and active tectonics of the Egyptian Red Sea Margin and the northern Red Sea . Tectonophysics 125: 313 - 324

Garfunkel, Z. and Y. Bartov, 1977, The tectonics of the Suez rift. Bull. Geol. Surv.

Isr. 71: 1-48.

Girdler, R. W. and P. Styles, 1974, Two stages in he Red Sea floor spreading. Nature 274:7 -11

Girdler, R. W. and P. Styles, 1976, opening of the Red Sea with two poles of rotation - some comments. Earth and planet . Sci. Lett 33:169- 172

Herrmann, R. B. and J. A.Canas, 1978, Focal mechanism studies in the New Madrid Seismic Zone, Bull. Seism. Soc. Am. 68: 1095- 1102

Hutchinson, R. W. and G. G. Ehgles, 1972, Tectonics Significance of regional geology and evaporate lithofacies in northern Ethiopia. Phil.Trans. Roy. Soc London 267(A): 313-329

Ibrahim E., Mrazouk I., Hrukawa N. et al, 1995, Seismological bulletin of

Hourghada Seismographic Network (HSN) No 1 (Egypt, Cairo)

Knott, S. T , E. T Bunce and R. L Chace, 1966, Red Sea Seismic refraction studies: The World rift system . Geol. Surv. Canada, Paper 66/14:31- 61.

Langer, C. J. , M. G. Hopper, S. T. Algermissen, and J. W. Dewey, 1974, Aftershocks of the Managua, Nicaragua, earthquake of December 23, 1972, Bull. Seism. Soc. Am. 64:1005-1016

Lowell, J. D. and G. J. Genik , 1972, Sea floor spreading and structure evolution of the southern Red Sea. Bull. Am. Assoc. Petrol Geol. 56:247-250

Maamoun M. M., A. Allam, Abd El-Sammed Megahed and A. Abu El- Ata, 1980, New tectonics and seismic regionalization of Egypt, Bull. IISEE, Vol.18: 27-39.

Mckenzie, D. P. , D. Davies and P. Molnar, 1970, Plate tectonics of the Red Sea and east Africa. Nature 226: 243- 248.

Perry, S. K. and S. Schamel, 1985, Structure model of the southwestern Gulf of Suez and Gesma Plain , Egypt Technical Report, Earth Sci. Univ. South Carolina.

Phillips, J. and D. A. Ross , 1970, Continuous seismic refraction profiles in the Red Sea. Phil.Trans. Roy. Soc. London 267(A): 153-180

Sbar, M. L., J. M. W. Rynn, F. J. Gumper, and J. C. Lahr, 1970, An earthquake sequence and focal mechanism solution, Lake Hopatcong, northern New Jersy, Bull. Seism. Soc. Am., 60: 1231.

Seth Stein, 1987, Introduction to Seismology, earthquakes, and earth structure, department of geology Science, Northwestern University.

Scholz, C. H. , H. M. Wyss, and S. W. Smith, 1969, Seismic and Seismic slip on the San Andrea's Fault, J. Geophys. Res. , 74: 2049

Styles, P. and S. A Hall, 1980, A comparison of sea floor spreading histories of the western Gulf of Aden and the central Red Sea. In Geodynamic evolution of the afro- Arabian rift systems. Accad. Naz. Licei, Rome:587-606

Ross, D. and J. Schlee, 1973, Shallow structure and geologic development of the southern Red Sea . Bull. Geol. Soc. Am. 84: 3827-3848

Rosser, H. A., 1975, A detailed magnetic survey of the southern Red Sea. Feol. Jb. 13: 131 153

Suetsugu D., 1995, Source mechanism practice , International Institute of Seismology and Earthquake Engineering (IISEE), Japan.