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RECENT SWARM ACTIVITY IN THE GULF OF AQABAH REGION

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ABSTRACT

During the last two decades, the Gulf of Aqabah has been considered one of the most active seismogenic zones in the Eastern Mediterranean region. Recent seismicity and swarm activity in the gulf have been examined in relation to the tectonics and structures indicated by surface geology, remote sensing and new analysis of aeromagnetic data.

On November 22, 1995, a swarm of earthquakes began in the central part of the Gulf of Aqabah at the Aragonese fault step zone (Lat. 28.8° N & Long. 34.7° E) with a maximum magnitude of $M_D = 5.8$ and followed by nearly eight thousands aftershocks ($1.5 < M_D < 5.8$) in the next 40 days. The majority of seismic activity of this swarm is clustered in the area located between 28.3°- 29.3° N. and 34.3°- 34.9° E. More than 150 events were reported in the four countries surrounding the gulf and ranged in magnitude of M_D between 3.7 and 5.8. The remaining uncertainties in epicenter locations in the shield and the low level of seismicity in the southern portion of the gulf might be due to lack of seismographic station coverage and to the presence of diapiric structure respectively.

The most remarkable aspect of the earthquake swarm sequences in the Gulf is the spatial distribution overlapping of 1995 swarm with earthquake sequences in 1983, 1991, and 1993 and the migration of the epicenters northeastward about 60 km in 40 days with focal depths less than 10 km confirming the continual motion along the Arabian plate boundary.

The preliminary results obtained from this study indicate that the seismic activity occurs in the form of mainshock-aftershock sequences and may be attribute to stresses resulting from subsurface magmatic activity. The recent swarm may release energy that can be accumulated to cause larger events in the future. Aeromagnetic anomaly patterns and earthquake locations provide evidence for continuation of the strike-slip faulting regime from the gulf northeastward into the land, east of the gulf, suggesting that the northern portion of the gulf is subjected to more severe seismic hazard compared to the southern portion.

KEYWORDS

Gulf of Aqabah; earthquake swarm; tectonics; Arabian plate; mainshock-aftershock; seismicity; remote sensing.

INTRODUCTION

The Gulf of Aqabah, while not known to produce the most destructive earthquakes along the Dead Sea transform system has been considered one of the most seismic zones in 1980's and 1990's.

The earthquake swarm (M_L = 4.85) in February 1983 affecting the Gulf of Aqabah has been described by El-Isa *et al.*(1984) and lasted for four months. Two additional earthquake sequences in April 1990 and in May 1991, had maximum magnitudes of 4.1. In July 1993, an earthquake swarm began in the Gulf with foreshock sequences and followed by the mainshock of $M_D = 5.5$ in August 1, 1993. It followed by nearly 500 events with $M_D > 3.0$ in August, September, October and November of that year.

The most recent swarm activity began in November 22, 1995 in the central part of the Gulf of Aqabah with a maximum magnitude of $M_D = 5.8$. More than eight thousands aftershocks ($1.5 < M_D < 5.8$) were recorded in 40 days following the mainshock. The occurrence of the 1993 and 1995 Gulf of Aqabah earthquakes could imply that the Gulf of Aqabah is a region of moderate to high seismic hazard.

Most of the activity were recorded on permanent and portable short- period stations of King Saud University (KSU) and King Abdulaziz City for Science and Technology (KACST). The area of interest for this investigation (Fig.1) extends from the southern tip of the Sinai peninsula at 27.75° N to latitude 30° and from longitude 34° to the northwest portion of the Arabian Shield at 36° E. The purpose of this study is to investigate the propagation characteristics, spatial distribution and overlapping of swarm activities from 1980 - 1995. Correlating the seismicity of the region with the pre-existing tectonic and active faulting to evaluate the evidence relating to the potential seismic hazard in this segment of the Dead Sea transform system.

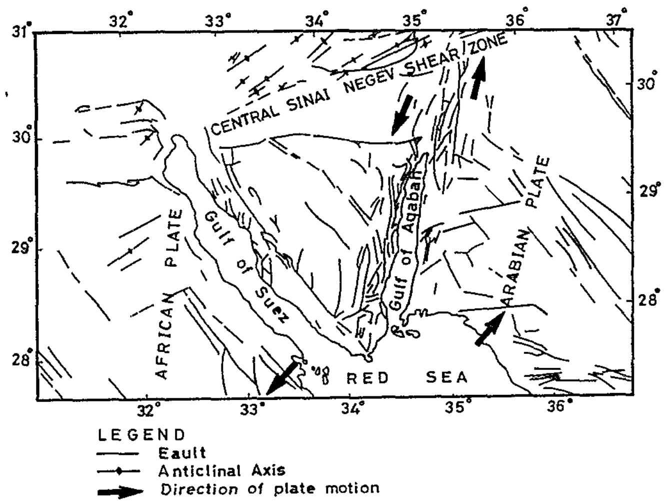

Fig.1. Regional tectonics and structural features of the Gulf of Aqabah region.
(Modified from Rotstein *et al.*, 1991)

STRUCTURE AND SEISMOTECTONIC SETTING

The Gulf of Aqabah is a morphotectonic feature located at the southern end of the Dead Sea transform, a system of faults that extend for a bout 1200 km from the Gulf of Aqabah along the Jordan and Bekka valleys, as far north as the Tourus-Zagros thrust fault in southern Turkey. The Dead Sea transform fault system links the spreading center of the Red Sea and the Tourus-Zagros thrust, and accommodates the transcurrent movement of the Arabian Plate.

The internal structure of the Gulf consists of three major left-stepping fault segments. This geometry combined with the left-lateral motion along the plate boundary, results in depressions at step zones, namely Elat Deep in the north, Aragonese Deep in the central part of the Gulf and Dakar and Hume deeps in the south (Fig. 2).

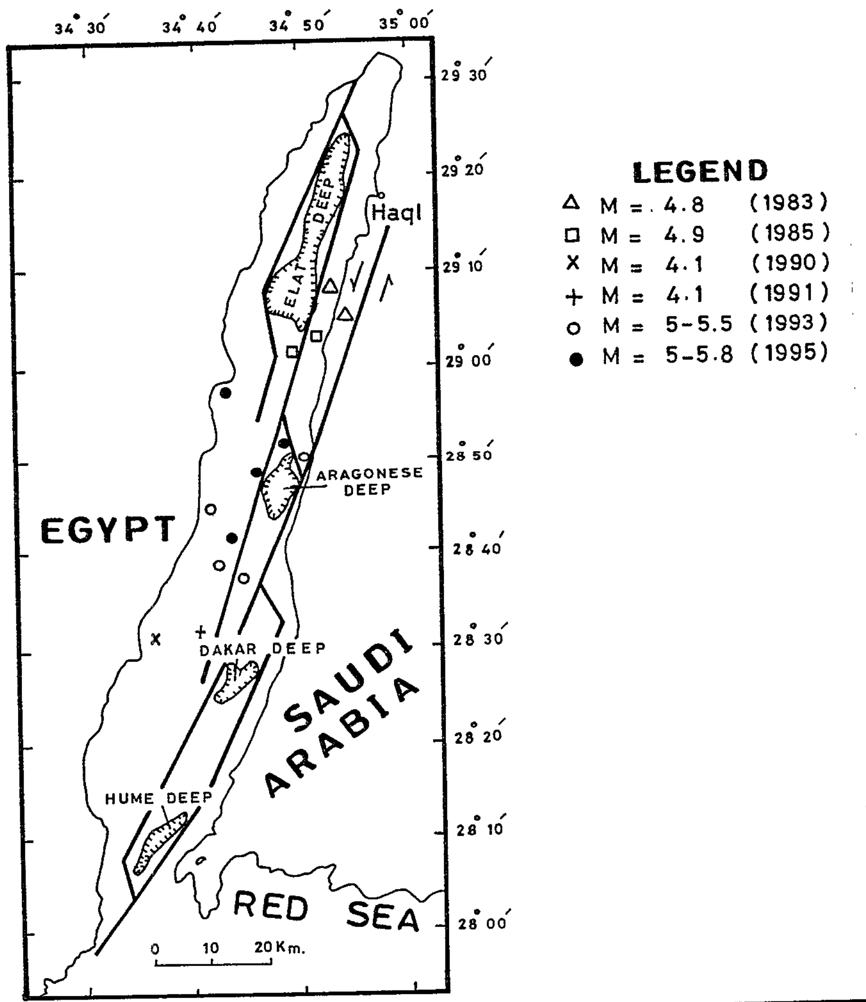

Fig.2. Generalized model for structure of the Gulf of Aqabah. The deeps result from en echelon rhomb-shaped grabens (Ben-Avraham, 1985). Earthquake locations provide evidence for continuation of the faulting regime from the Gulf northeastward into the land (this study).

The seismicity of the Dead Sea transform is characterized by both swarm and mainshock-aftershock types of earthquake activities. The instrumental and historical seismic records indicate a seismic slip rate of 0.15-0.35 cm/year during the last 1000-1500 years, while estimates of the average Pliocene-Pleistocene rate are 0.7-1.0 cm/year (Garfunkel, 1981).

The earthquake swarm of the Gulf of Aqabah in 1983 lasted for more than four months. This swarm indicates that the seismicity of the Dead Sea transform is characterized by both mainshock and aftershock as well as swarm types of activity (El-Isa *et al.*, 1984). Geological and tectonic information attribute this swarm to subsurface magmatic activities and consequent isostatic adjustments in the Gulf of Aqabah region. Extensional stresses responsible for Red Sea rifting have resulted in movements and magmatic activities along Tertiary-Quaternary and older tectonic lineaments. On spreading centers, earthquake swarms are generally associated with normal faulting (Sykes, 1967) and with major strike-slip faulting (Tatham and Savino, 1974).

Historical data strongly suggest that much of the activity is of the swarm-type and is related to volcanism of the 1256 earthquake of Al-Madinah and tectonism of the 1068 earthquake (Barazangi, 1981). Ben-Menahim (1979) indicated that about 26 major earthquakes ($6.1 < M_L < 7.3$) occurred in southern Dead Sea region between 2100 B.C. and 1900 A.D. Instrumental seismicity of the Gulf of Aqabah shows that 750 earthquakes ($3.5 < m_b < 6.1$) are reported to have occurred in the periods 1965 - 1994.

RESULTS AND DISCUSSION

The frequency of occurrence every day during the period Nov.22 to Dec.31, 1995 for more than 8000 shocks ($1.5 < M_D < 5.8$) is shown in Fig.3.

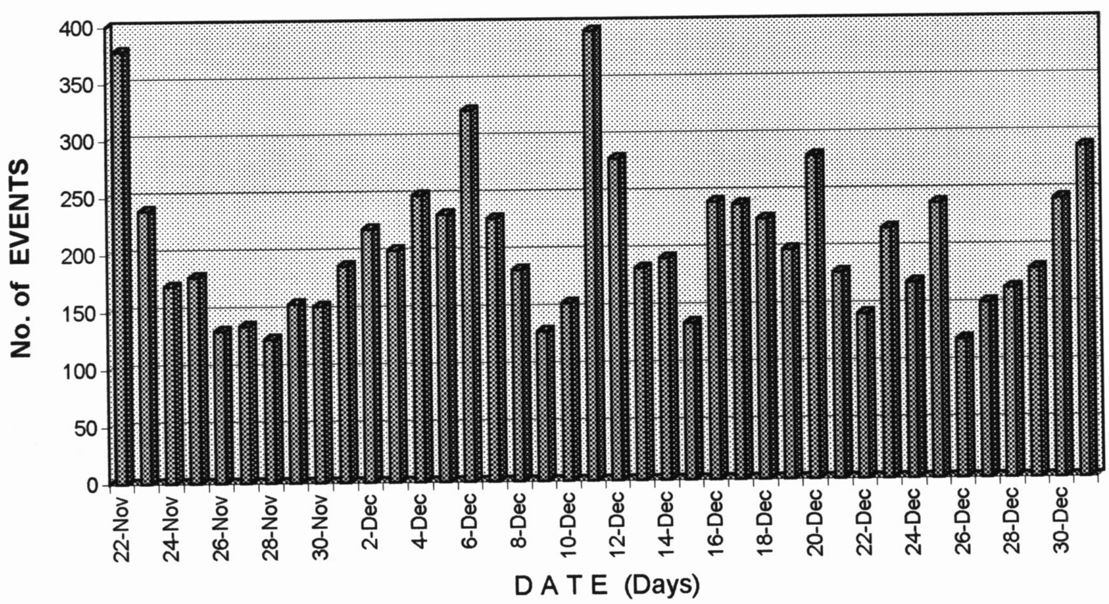

Fig.3. A histogram showing the frequency of occurrence for Nov.22, 1995 earthquake swarm comprising more than 8000 shocks during the period from Nov. 22 to Dec. 31 with magnitude range 1.5 - 5.8.

It shows the level of activity fluctuated with time and also indicates events of peak activity occurred on Nov. 22 and Dec.11. On Nov. 22, the first peak of activity occurred where 378 shocks were recorded within 20 hours. A second peak which is the highest with 393 shocks recorded in Dec. 11. On the following days of Nov. 23, 24, 25 and 26, the recorded shocks reached 723. It shows also a cyclic pattern of events consisting of seismic minima which may represent episodes of accumulation of energy, and seismic mexima which represent the release of energy.

The analog seismograms of 1995 swarm were read for P arrival times and polarities, S times and coda durations. The accuracy of readings for P ($P_{g,n}$) was ± 0.05 seconds and for S ($S_{g,n}$) was ± 0.07 seconds. The smaller accuracy for the S reading is due to the fact that the seismic traces are already in motion. Unfortunately, there are no seismic stations in the west-northwest direction to minimize these errors. Some of the observed first motions of the swarm were not easy to be identified because of limited dynamic range in analog recording and all stations are equipped with short-period vertical seismometers. Consequently, it was difficult to obtain a reliable fault plane solutions.

The duration magnitudes (M_D) for swarm shocks were estimated using the calibrated formula of King Saud University:

$M_D = 2.48 \log T - 2.1 + 0.0004 E$ for $E < 500$ km where :

T is signal duration in seconds , and E is epicentral distance in kilometers .

The epicentral distances of the events were estimated from S - P arrival time differences. The largest 14 shocks from 1983 onward are plotted on Fig.2. The largest 4 shocks in 1983 and 1985 have P- times in the range 3 - 5 seconds. Three epicentral radii equal to 20, 24, 30 and 40 km were determined for the values of S-P 3, 3.5, 4, and 5 seconds, respectively with their centers at Haql station. The farthest two shocks in 1990 and 1991 lie 10 km west of Dakar Deep and their epicentral radii about 80 km from Haql station.

The earthquake sequence of 1983 lasted from Jan-April and was associated with a maximum magnitude of 4.8. The spatial distribution of epicenters 10-50 km south of Elat Deep, overlaps with 1985 sequences which indicates that these events represent activity at the southern flank of the Elat Deep (Fig. 2).

The sequence of 1993 began in July near Aragonese Deep with a moderate increase in the frequency of background seismic activity followed by the mainshock in August 3. and lasted until November of that year. Most of activity concentrated 20 km SW of Aragonese Deep with focal depths between 15-20 km and migrated southward in October and reoccurred in the Aragonese Deep in November of that year. The latest swarm activity of Nov.22, 1995 still in motion and migrated 60 km northwards in forty days with focal depths less than 10 km. Preliminary location of epicenters indicate clear overlap with 1993 sequence west of Aragonese Deep suggesting also one tectonic event in the area located between Elat and Aragonese deeps. The remaining excess strain energy after 1993 released by 1995 sequence.

The a-values for the northern Red Sea including the Gulfs of Aqabah and Suez are 3.93 while the b-values are 0.59. The latter constant (b) increases northwards to attain a value of 0.71 in the Gulfs (El-Isa and Al- Shanti, 1989). Variations of a and b values are due to crustal heterogeneity which is believed to be caused by the presence of magmatic activity and diapiric structure. The epicenters of 1995 swarm were confined to a small focal area and probably shorter fault lengths which may indicate larger slip rates. The estimated seismic energy and moment for the largest shock of this swarm ($M_D = 5.8$) are 3.8 X 10^{22} ergs and 7.7 X 10^{19} dyne.m, respectively.

According to Richter (1959), earthquake swarms contain sequences of generally small-magnitude events with no large event predominating, and are usually small in aerial extent. Swarms have been classified by Mogi (1967) into three types, depending on whether or not they are associated with large earthquakes. Type 1 swarms contain mainshock - aftershock sequences; type 2 swarms contain foreshock - mainshock - aftershock sequences and type 3 swarms are not associated with any recognizable large events. The behavior of the three types of earthquake swarms has been explained by Aki (1984) in terms of the properties of the fault surface, upon which the earthquake occurs . The swarm activity of 1983 and 1993 fits type 2 of Mogi (1967) classification, whereas the activity of 1995 fits type 1.

The seismicity map of the largest 14 events is superimposed on a structural model of the Gulf of Aqabah (Ben-Avraham, 1985) in Fig. 2. It indicates a concentration of seismic activity in the area located between lat. 28.5° - 29.1° and long. 34.7° - 34.9°. This high activity may be due to the deeps in the step zones are sites of stress concentration, especially in the area between Elat and Aragonese Deeps where some active normal and strike slip faults interacted. Aeromagnetic anomaly patterns (Al-Amri *et al.*, 1991) and earthquake locations provide evidence for continuation of the faulting regime from the Gulf northeastward into the land as shown in Fig. 2. Three large historical earthquakes and many of recent activity occurred near this fault.

In addition, field geologic measurements indicate past faulting and confirm the activity on the land (Rowaihy, 1984). High pass filtering was applied in image processing techniques (Fig. 4) to prove fault extension and fractures. Strong dominance of lineaments are in NE-SW directions which are in good agreement with the regional trend of the Gulf of Aqabah. Comparison of observed lineaments with previously mapped features showed that many of them coincide with mapped faults.

It is believed that the low level of seismic activity south of latitude 28.5° compared with the northern segment of the Gulf of Aqabah could be due to one of the following reasons: (1) small-magnitude earthquakes occurring in the region do not give enough energy to be recorded on distant stations (2) the presence of magmatic activity and diapiric structure in Lisan basin to the east of Dakar Deep (3) lithospheric deformations in this region are occurring on the land. The most direct evidence to support the later assumption is the occurrence of some large historical earthquakes in 641, 1068, 1256, 1293, and 1588 which are reported to have been felt causing ground cracking and widespread destruction.

Thenhaus *et al.*, (1986) assumed that any significant future seismic activities in the shield has to be related to the seismic reactivation of the Precambrian faults. Additionally, the absence of dense seismic stations on the western side of the Gulf and lack of detection of small events is the main reason that no conclusive study has been carried out about the nature and level of the seismicity and the relationship between the uplift of continental crust and spreading rate of the Gulf of Aqabah.

Seismic hazard maps produced by Thenhaus *et al.*, 1986 and Al-Haddad *et al.*, 1994 give contours of accelerations (or velocities) having a 90 percent probability of not being exceeded in time periods of 50 and 100 years. The estimated peak ground acceleration for the Gulf of Aqabah region won't exceed 0.30 g (Thenhaus *et al.*,1986) and 0.2 g (Al-Haddad *et al.*, 1994).

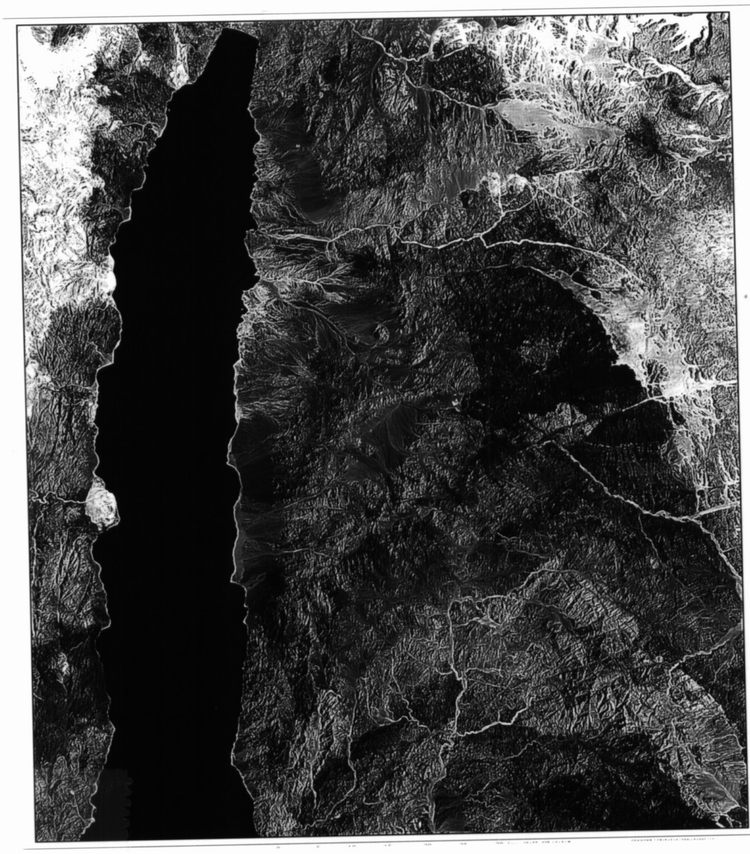

Fig. 4. The Landsat Thematic Mapper (TM) image of the Gulf of Aqabah showing the structural lineaments applying high pass filtering technique (Band-5, 1:10^6 scale).

CONCLUSIONS

It can be concluded from this study that the seismic activity along the Gulf of Aqabah occurs in the form of sequences, each lasting up to four months, reaching peak magnitude up to 6.1 and covering a specific tectonic segment of the Gulf. Geologic measurements and seismic data provide evidence for continuation of the faulting regime from the gulf northeastward into the land causing possible seismic hazard.

The low level of seismicity in the shield and poor correlation of the offshore epicentral distribution with the tectonics might be due to the presence of magmatic activity and diapiric structure, lack of detection of small events, and limited operational period of seismic stations. The swarm activity of the Gulf fits types 1 and 2 of Mogi (1967) classification. In terms of earthquake risk , the temporal distribution of events within each sequence with a few days to two weeks of gradually increasing magnitudes, suggest that the detection of the beginning of the sequence is feasible and can lead to relatively successful short-term prediction in the Gulf region. The recent swarm may release energy that can accumulate to cause larger events in the future. It should also be pointed out that installation of strong ground-motion instruments in this region will estimate the attenuation relationships and accelerations for better assessment of seismic hazard.

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