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SEISMICITY PATTERN NEAR ASWAN RESERVOIR, EGYPT

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ABSTRACT

Based on the Aswan reservoir (Egypt) microearthquake data during the period January 1982 to February 1990, the aftershock decay has been examined in comparison to the characteristics observed around the Koyna reservoir (India). It was noted that near the Aswan reservoir the value of decay constant 'h' in Omori's law of aftershocks remained unchanged and close to 1 for immediate aftershocks (Kebeasy et al, 1987) and the microearthquakes up to the period 1990, limiting its use as a quantitative tool to distinguish reservoir associated from normal earthquakes. It was noted that a zone of seismic quiescence developed at a distance between 8 to 18 km from the main shock prior to four significant earthquakes of magnitude 3.9 or above. Keeping in view the low strange attractor dimension and 'b' values of the same order both these regions in the intraplate setting, extension of the model for Koyna region (Srivastava et al, 1991) suggests estimation of the future largest magnitude earthquake in Aswan region.

KEY WORDS: Seismicity pattern, Aswan reservoir, Strange attractor

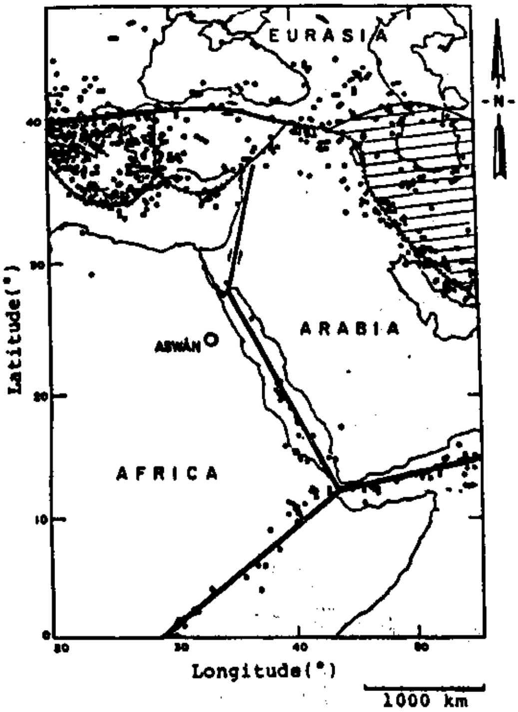
INTRODUCTION

The earthquake of November, 14, 1981, occurred 60 km upstream south-west of the Aswan High Dam at Wadi Kalabsha about 17 years after the filling of the lake in 1964. Monitoring of seismic activity through telemetered arrays shows continuing seismic activity in the vicinity of the lake Nasser though on a decreasing scale. Kebeasy and Ibrahim (1982) suggest that the expanding area of the reservoir and the rising water level allow water to seep into the Nubian sandstone. Lateral and vertical variations in permeability caused by faults and aquacludes play an important role in determining the distribution of water within the sandstone and the access of pore pressure to faults. Attempts have been made to understand common and discriminatory characteristics between the normal and induced seismicity (Gupta et al, 1972, a, b, Srivastava et al, 1991). The objective of this paper is to study the spatio temporal variations in seismicity patterns prior to 4 earthquakes ($m \geq 3.9$) which occurred in Aswan region during the period 1982 to 1990 and examine the decay of the after shock activity in relation to Koyna and Bhatsa regions in India.

TECTONIC SETTING

The Aswan high dam is located on the northeast of the African plate which has tectonically active plate boundaries with the Eurasian and Arabian plates (Fig.1) (Mckenzie et al, 1970 Mckenzie, 1972). Although plate interactions may extend far away from plate boundaries, they do not appear to have significant influence on the Aswan region. Kamel (1991) studied the regional fracture pattern of Egypt, south of latitude 29°N based on land-sat images and aerial photomosaics. Based on the geographic distribution of seismicity and centres of high fracture density on the structural contour maps, the area south of latitude 29°N of Egypt was divided into three regions namely the Red Sea, Western desert and Aswan region. It was seen that the fractures are trending NNE and WNW in the Red Sea, N-S in the western desert and E-W and NNW in Aswan region. It was also observed that fractures with higher density are more susceptible to earthquakes in the locations characterised by two dominant sets of fractures especially at their intersections.

Important geological features in the region have been shown in Fig.2. Five faults namely Kalabsha, Seiyal, Gebel el Barger, Kurkur and Khor-Ramla have been identified as seismically active. Kalabsha fault strikes eastwest through the centre of Wadi Kalabsha, passing south of the limestone plateau. Geomorphic and quaternary geologic evidences (ESGMA,



From McKenzie and others(1970),
McKenzie(1972)

EXPLANATION

Rift margin

Convergent margin and area

Horizontal slip margin

NOTE

Tectonic boundaries with the Eurasian plate are greatly simplified.

Fig. 1. Location of Aswan Reservoir and Tectonic boundaries.

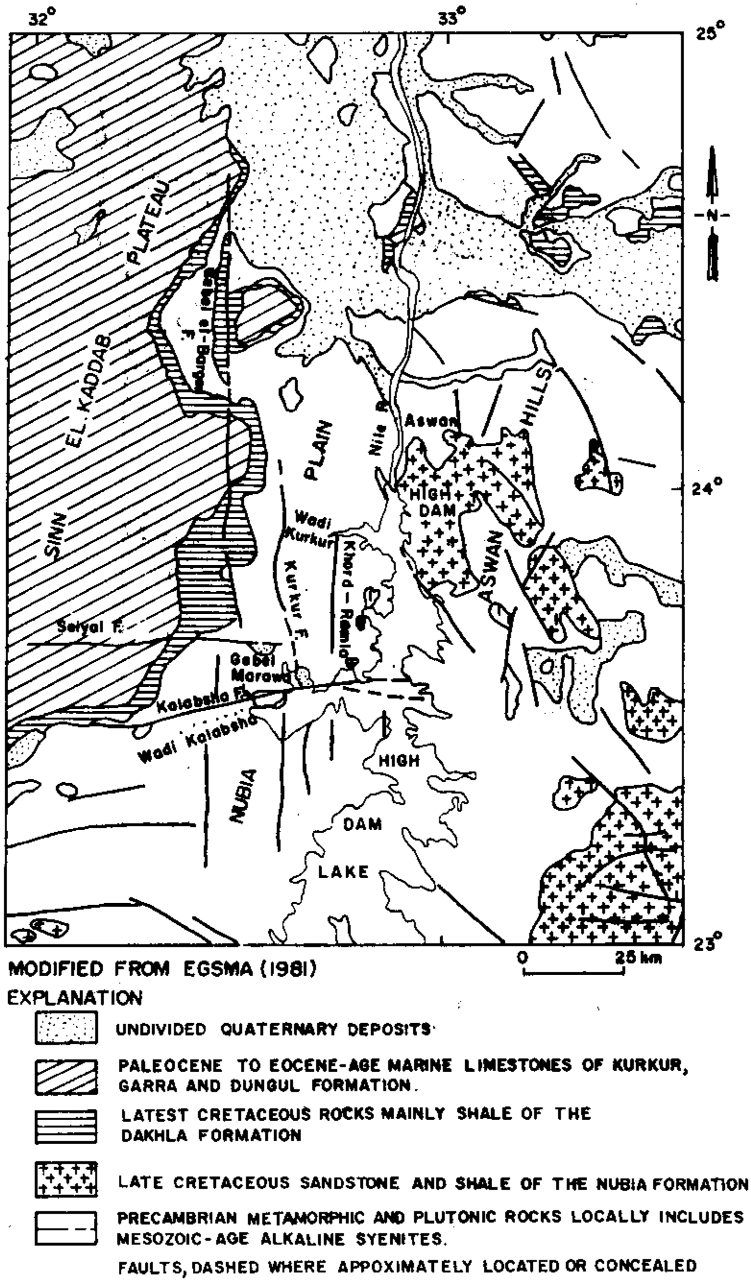


Fig. 2. Geological map of Aswan Region.

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1981) suggest it to be seismically active. Between the Aswan Dam and Wadi Kalabsha lies a broad plain of Nubian sandstones overlying granitic precambrian basement. More on the geology of Kalabsha area has been given by Issawi (1969). The reservoir (Lake Nesser) lies within 10 km of the old Nile River Channel.

Focal mechanism solutions of earthquakes of Kalabsha during 1981 and Gulf of Suez during 1969 events indicate strike slip and oblique normal fault types respectively. Further evidence on the nature of the tectonic stress system based on the pattern of late Cenozoic faulting suggests predominantly normal faulting at the Red Sea fault system, east of the crest of the Red sea mountains, and strike slip motion at the faults of the western Desert fault system of the Nubia Plain.

SEISMICITY AROUND THE ASWAN RESERVOIR

Kebeasy et al. (1987) discussed the seismicity around the Aswan reservoir based on historical data and results from the WWSSN station at Halwan near Cairo, short period portable microearthquake records (early December 1981 to June 1982), and those obtained by a telemetered network installed by Halwan observatory in collaboration with Lamont Doherty Geological observatory, New York. The seismicity was found to be clustered in three main zones. The most active area was found beneath Gabel Marawa, an outlying remnant of the limestone plateau on the Kalabsha fault with foci concentrated near a focal depth of 10 to 15 km. Fig.3 shows the epicentral map together with the location of seismic stations. The predominant focal mechanism was found to be right lateral strike slip on an east west plane. Further east along the Kalabsha fault between Gabel Marawa and the main body of the reservoir, we find lower seismic activity. Another cluster was observed about 10 km south of the reservoir near Wadi Kurkur. Gupta (1992) provides an excellent review of the seismicity of Aswan. The magnitude of earthquakes was determined based on the total signal duration using the following relationship (Lee et al, 1972).

$$Md=2.0 \log (T) + 0.0035\Delta - 0.87 \qquad (1)$$

where Md is magnitude, T is signal duration of the earthquake recorded (in seconds),Δ is epicentral distance (in km.).

Kebeasy et al, (1987) observed that the main earthquake of November 14, 1981 occurred soon after the seasonal peak in the water level. The largest aftershock of magnitude 4.5 also occurred when the water level started rising from its minimum level. Table 1 gives the epicentral parameters of the main earthquake and of the significant aftershocks. Three of the earthquakes mentioned in Table 1 are discussed in detail by Simpson et al. (1990) in connection with their relation to rate of filling the reservoir. Among

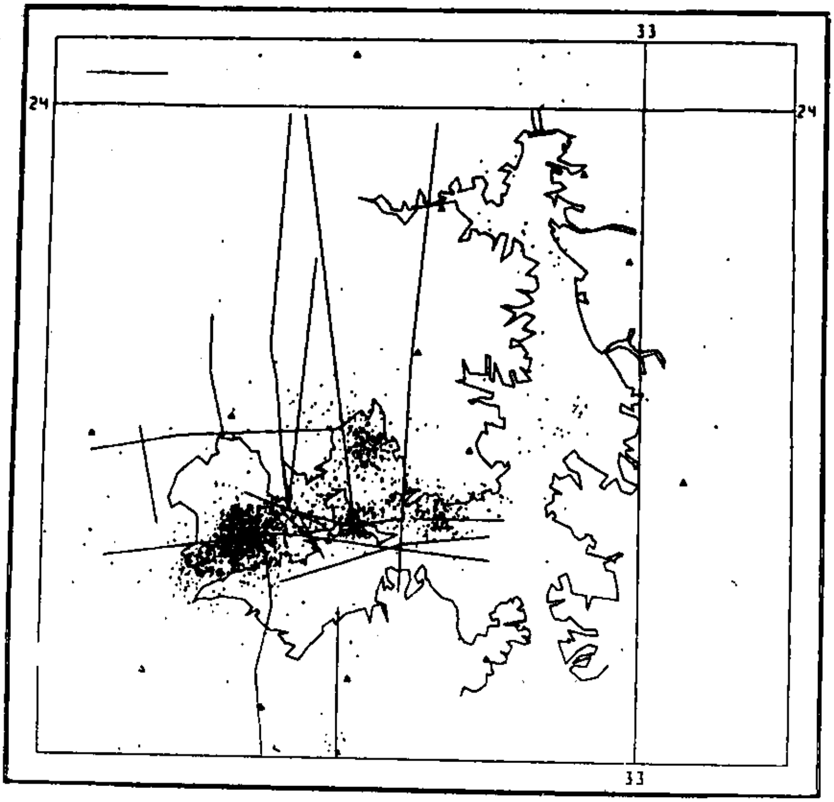

Fig. 3. Microearthquakes recorded near Aswan reservoir upto 1990.

the discriminatory characteristics for reservoir associated and normal earthquakes, slow decay of aftershocks is almost a universally observed phenomenon associated with reservoir seismicity. A question arises whether this aspect could be quantitatively expressed by the decay constant h in the well known Omori's relationship.

$$N(t) = At^{-h} \qquad (2)$$

where N(t) is the number of earthquakes during $t-\delta t/2$ to $t+\delta t/2$ and A and h are constants. Fig.4 a and b show the decay of aftershocks of the November 14, 1981 main shock taking interval (δt) as 30 days and 90 days respectively from January 1,1982 till February, 1990. The results for these two intervals are:

$$N(t) = 10491\ t^{-0.996} \qquad (3)$$
$$N(t) = 29952\ t^{-0.969} \qquad (4)$$

The decay constant h was reported as 1 for immediate aftershocks by Kebeasy at al (1987) for the Abu Simbel and Aswan stations for the period November, 1981 to February 1982. Thus (3) and (4) show that the microearthquakes recorded till February 1990 (Fig. 4a, b) does not show a significant change in the values h which remained close to 1. The value of h for earthquakes near Bhatsa reservoir in the peninsular India was larger, namely 1.2 to 1.6 for the period 1983 to 1986. However for the Koyna reservoir extremely low decay constant of 0.15 from 1967 to 1987 was reported by Srivastava et al (1991), as compared to 1.0 for immediate aftershocks (upto 1968). These differences may be attributed to the local geology keeping in view that Koyna region is characterised by Deccan traps overlain by grantic layer as compared to sedimentery province in the Aswan dam region. Thus the criteria based on 'h' value cannot be quantified for reservoir associated seismicity.

DISCUSSION

Felt earthquakes around a reservoir attract public concern when seismologists are required to clarify whether the increased seismicity is a precursor to a major earthquake, and if so the maximum magnitude of such an event. Based on historical earthquakes (Sieberg, 1932 and Ben-Menahem, 1979), and limited instrumental data upto 1984, an area recurrence model was developed obtaining the 'b' value in Gutenberg Richter's frequency magnitude relationship as 0.7 (Woodward Clyde Consultants, 1985). For earthquakes of magnitude 5 and greater on the Kalabsha fault, the recurrence time predicted by the model is 350 years. For the period July 1981 to December 1990, the value of 'b' was found as 1.07 (Ghaleb, 1995). For Koyna region, we found similar value of 1.08 for the period 1968 to 1980. Srivastava et al (1991) suggested a model for the Koyna region which has been shown to fit with an asperity model (Kanamori, 1981) after modifying late aftershock characteristics and called it a 'Modified Asperity model'

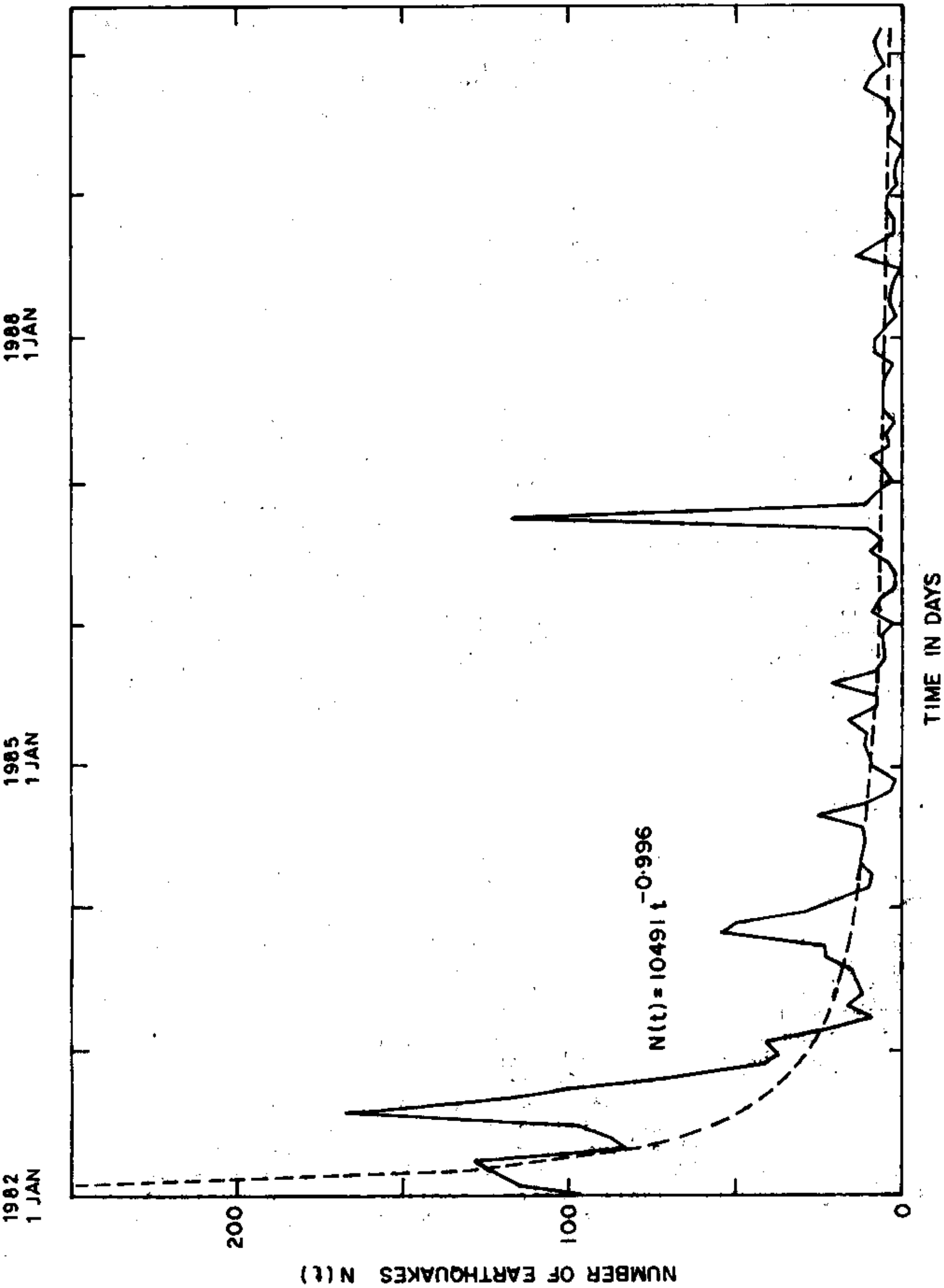

Fig. 4. Aftershock decay in Aswan Region from Jan. 1, 1982.

a) 30 days interval

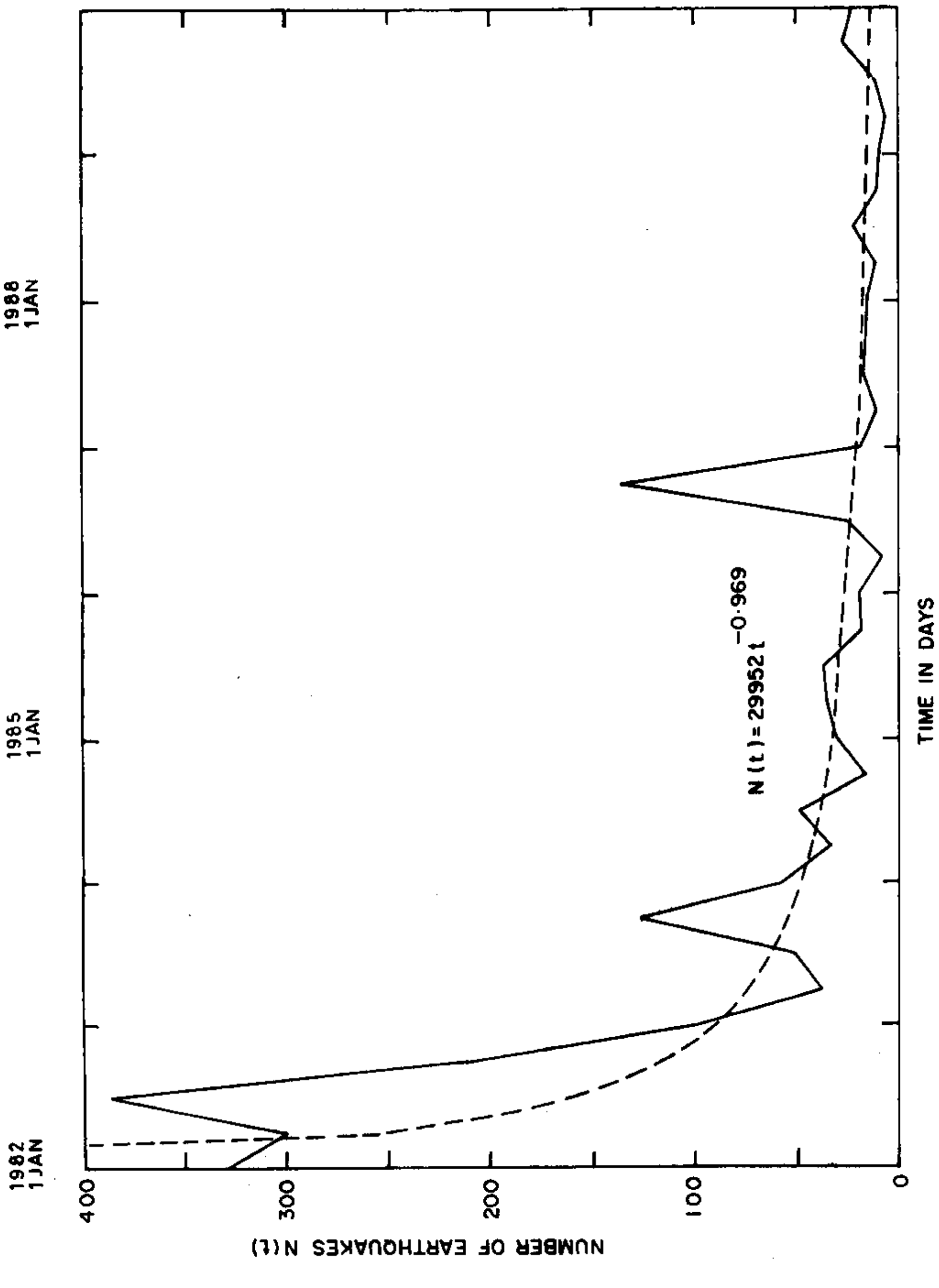

Fig 4. b) 90 days interval

(Srivastava, 1990). According to this model, the maximum magnitude of a future earthquake around the reservoir would not exceed that of the largest aftershock namely 5.0 and 4.0 in Koyna and Bhatsa regions respectively. The largest recent earthquake of 28 August 93 after October, 1980 which recurred in Koyna region had a magnitude of 5.1 thus validating this model again after successful prediction of Bhatsa earthquake of 1991. On applying this model for the Aswan region, therefore, a suggestion of estimation of the largest magnitude in the region in the near future is significant if we consider similarity in strange attractor dimensions reported by Srivastava et al (1994, 1995) as 4.2 and 3.4 for Koyna and Aswan regions respectively implying that the largest earthquake in Aswan region may not exceed magnitude 4.5 in near future.

It may be noted from Fig.4 that during the period of observations from January 1982 to February 1990, there is a declining trend of microearthquakes detected by the telemetered seismic array. However, decay of aftershocks based on Omori's decay constant as discussed earlier (eqns. 3 and 4) cannot be used to distinguish reservoir associated earthquakes from normal earthquakes if the values are compared with those observed in tectonic earthquakes (Srivastava et al, 1991).

Seismicity Pattern

Identification of quiescence of the observed seismicity as a precursor has been receiving attention during the last two decades. In order to understand this precursor near the Aswan reservoir, four significant earthquakes of magnitude 3.9 were selected during July 1982 to December 1990 (Table 1, S.No. 2 to 5). The hypocentre to hypocentre distance of the pre-events within 40 km radius from each of these significant earthquakes are plotted in figs 5 to 8 as a function of time upto the occurrence of a significant earthquake. For this purpose, we have kept in view the empirical studies relating to magnitude and period during which the anomaly is observed (Srivastava, 1981).

a) A significant earthquake of magnitude 5.0 ocurred on 20 August 1982. Distances of earthquakes of magnitude$\geq$1 from this major earthquake prior to its occurrence are shown in fig. 5a. In a zone between the distance of 10 to 18 km, seismic activity was absent before this major earthquake. There were several events of magnitude above 3 prior to this earthquake. The figure 5b is same as fig. 5a but shows seismicity pattern for pre-events of magnitude$\geq$2. We find almost similar feature of seismicity if we compare figs 5a and 5b implying that the pattern of seismicity is not significantly affected by the cut off magnitude. Thus the observations of Cao and Aki (1984) about precursory quiescence dependence on cut off magnitude of 3.0 in southern California need not necessarily hold good in all regions. Habermann

TABLE 1

Epicentral Parameters of Earthquakes in Aswan Reservoir Region

S.No.	Date		Origin Time (GMT) h	m	s	Epicentre δ_N	δ_E	Magnitude+
1.	14 Nov. 1981	i.	09	05	27.8	23.67	32.54	5.1(ISC)
		ii.	09	05	30.4	23.70	32.71	5.1 (NEIS)
		iii.		-		23.55	32.55	5.6(Helwan)
2.	20 Aug. 1982		12	57	37.8	23.565	32.563	5.0++
3.	24 Feb. 1983		00	23	8.24	23.526	32.576	4.5
4.	11 Apr. 1984		10	20	16.98	23.531	32.548	4.0
5.	8 July		05	41	49.43	23.546	32.551	3.9

\+ Data based on Telemetered array in Aswan Region.

++ Magnitude 4.5 (Simpson et al, 1982).

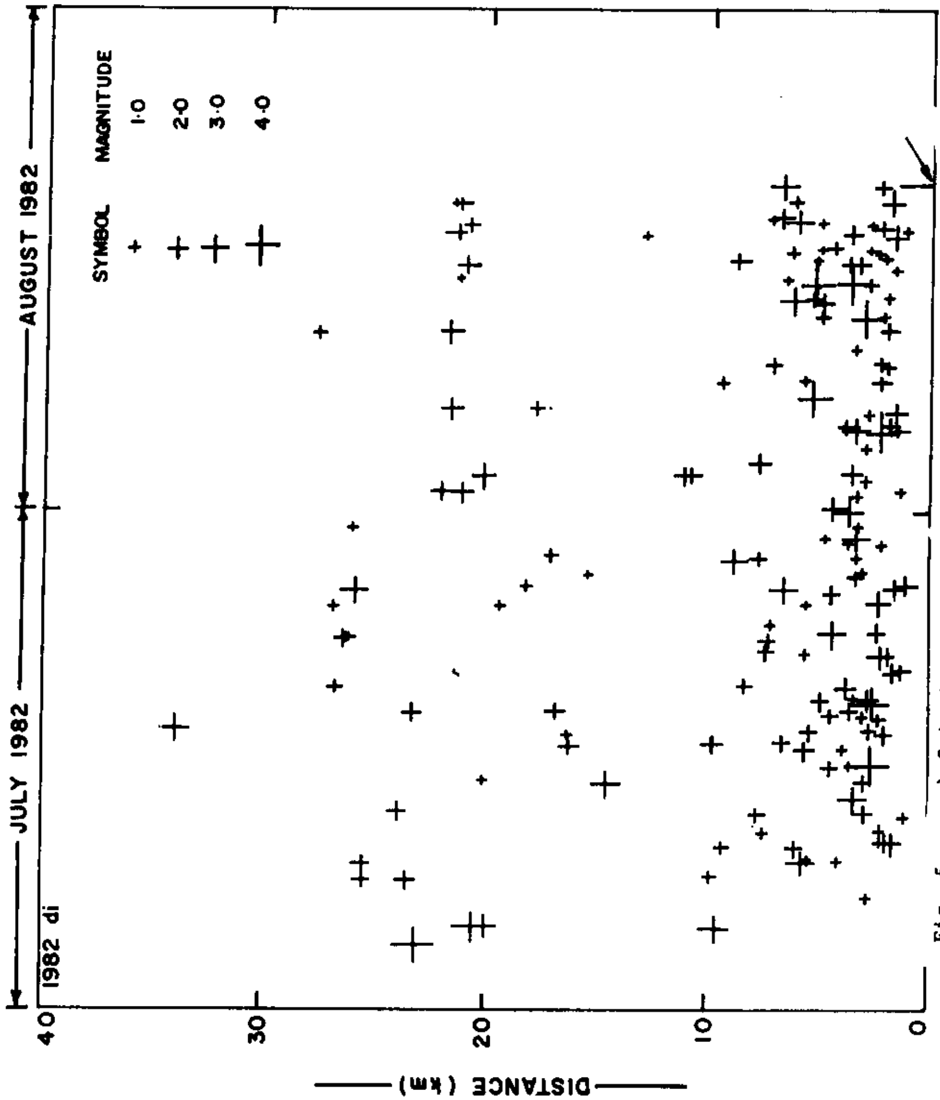

Fig. 5. a) Seismicity pattern magnitude M 1.0 preceding the significant earthquake of August 20, 1982, whose location has been shown by an arrow at the right bottom.

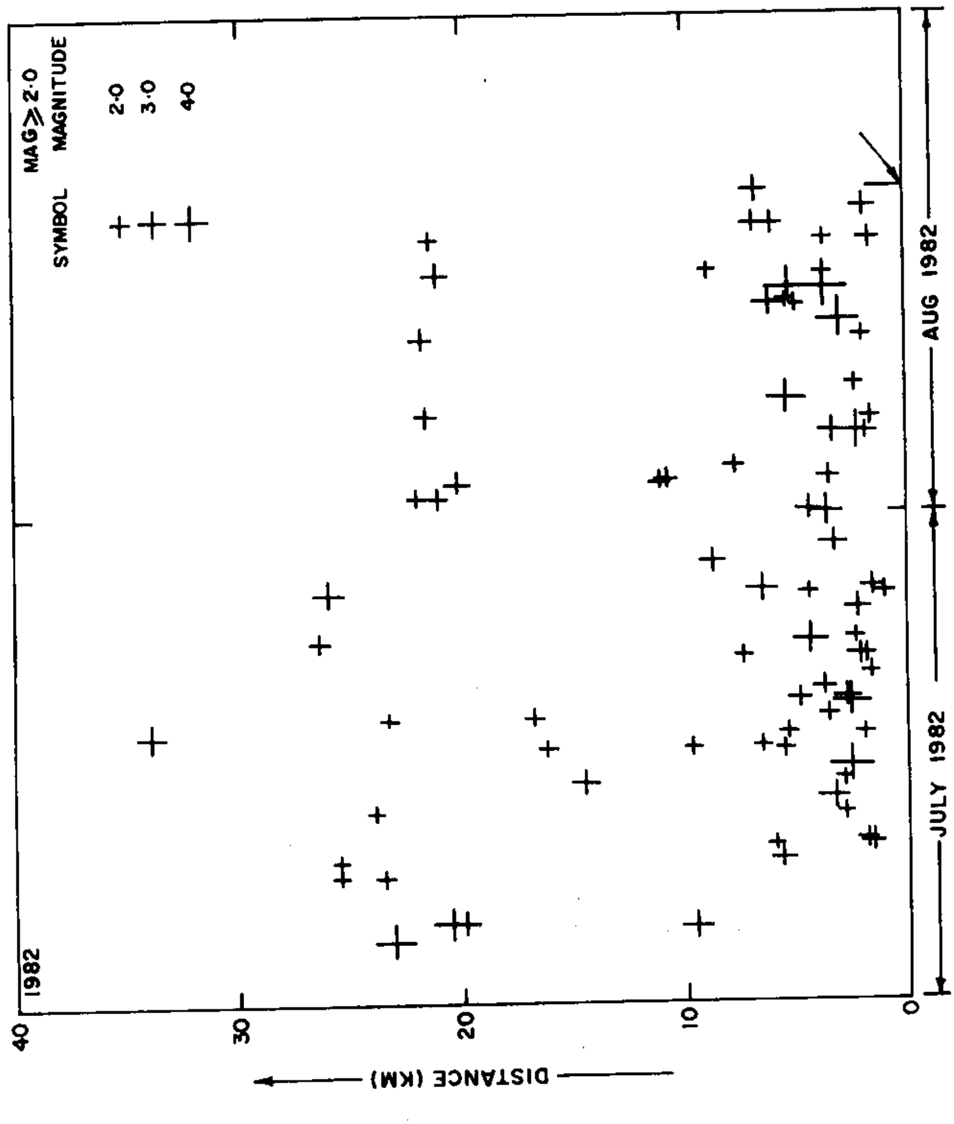

Fig. 5 b) Seismicity pattern magnitude M 2.0 preceding the significant earthquake of August 20, 1982 whose Location has been shown by an arrow at the right bottom.

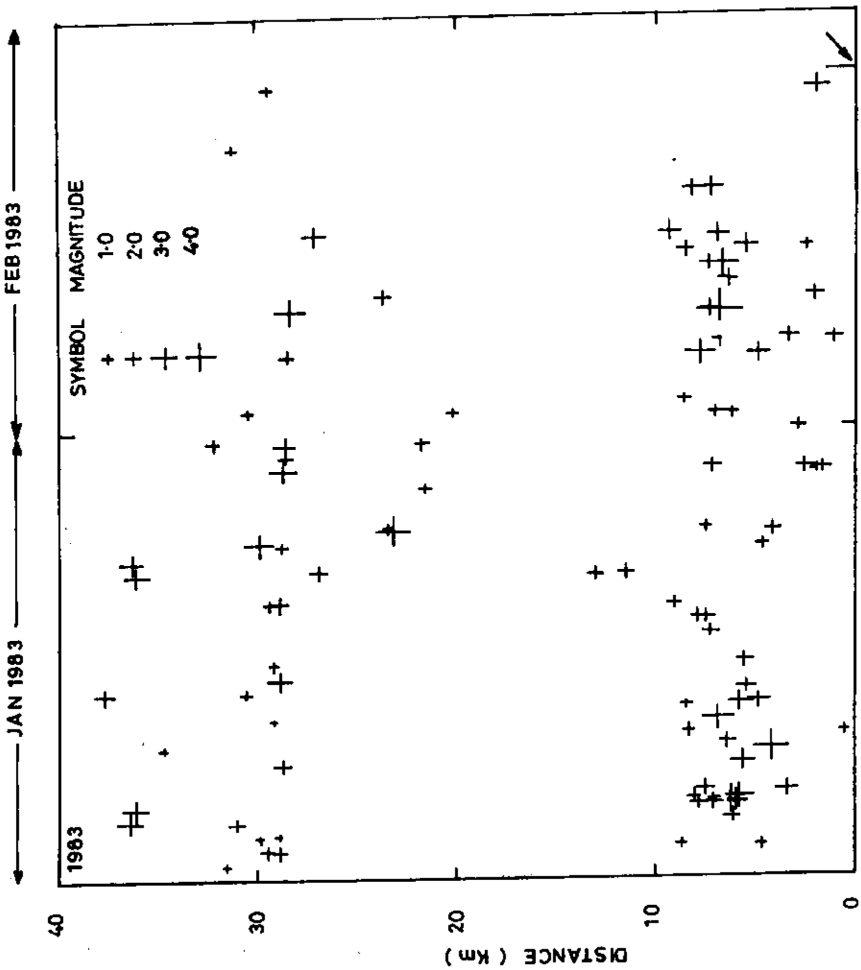

Fig. 6. Seismicity pattern preceding the significant earthquake of February 24, 1983 whose Location has been shown by an arrow at the right bottom.

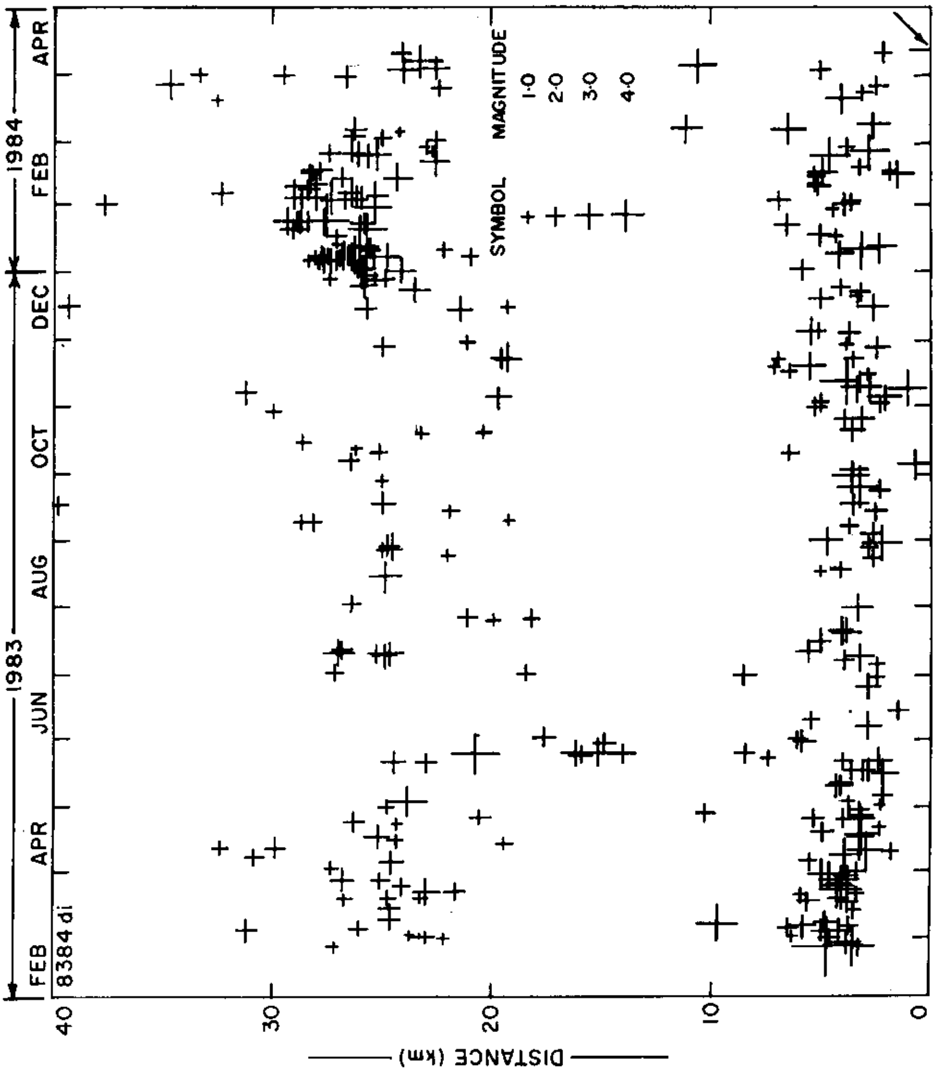

Fig. 7. Seismicity pattern preceding the significant earthquake of April 11, 1984 whose Location has been shown by an arrow at the right bottom.

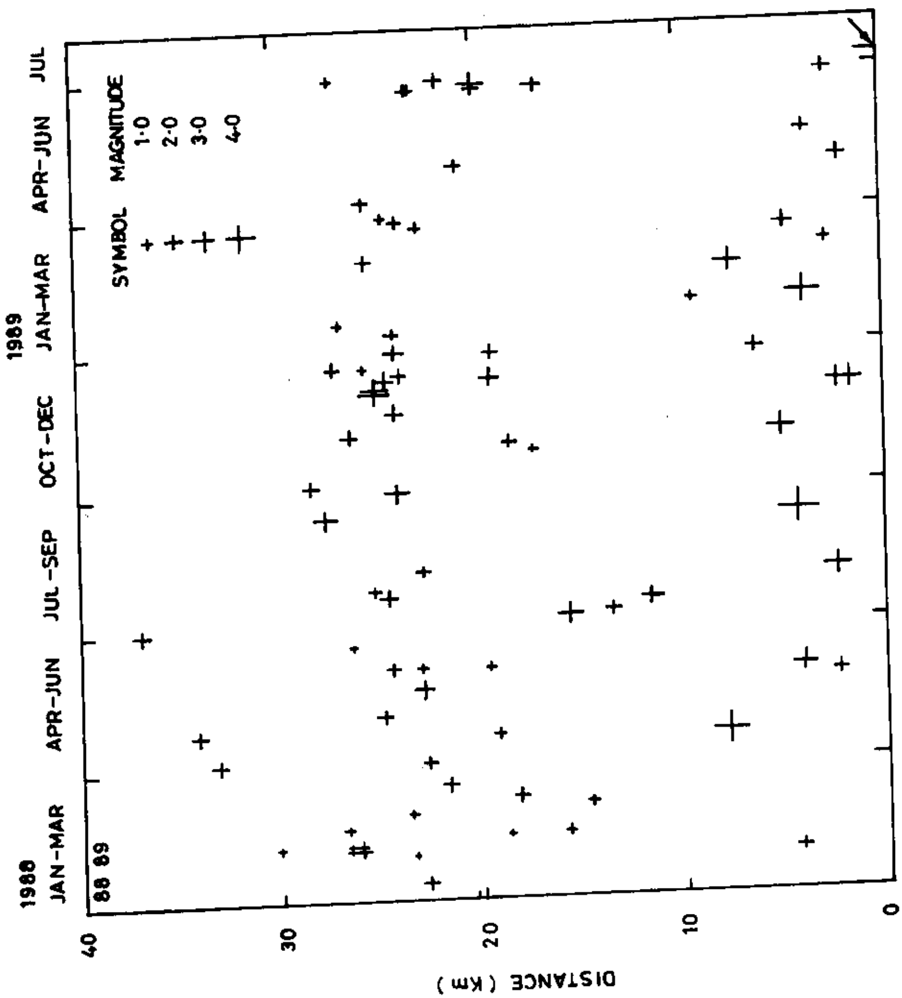

Fig. 8. Seismicity pattern preceding the significant earthquake of July 8, 1989 whose Location has been shown by an arrow at the right bottom.

(1983) also discussed the effect of detection level changes in the seismicity pattern. For all the next three major earthquakes, we plotted spatio temporal variation at pre-events of magnitude 1.0.

ii) Spatio-temporal variation of pre-events of significant earthquake of 24 February 1983 is depicted in Fig. 6 and shows an increased seismicity followed by a quiescence. Seismic activity was absent in a zone between 10 and 28 km. However immediately prior to this earthquake, the zone of quiescence decreased slightly.

iii) Preceding the earthquake of 11 April, 1984 (fig.7). there was a spurt in seismic activity with a well marked concentration of seismic activity about 25 to 30 km away from the main shock. A zone between 8 and 18 km remained seismically inactive for a long period prior to this earthquake.

iv) Prior to the earthquake of 8 July 1989, seismic activity was low in general. However, a quiescence zone between 8 and 18 km is discernible.

It may be seen from figs. 5 to 8 that prior to a significant earthquake, earthquakes are generally concentrated within 10 km in addition to a small cluster at about 15 to 25 km. Further we find that a zone of quiescence developed in all these cases between 8 and 18 km from the epicentres of significant earthquakes. It is possible that this zone is acting as asperity where energy could be released during larger events.

It may also be mentioned that the physical mechanism for quiescence is attributed to dilatancy hardening in a fault zone, decrease of shear stress level due to slip softening and increase in frictional resistance due to a drop in pore pressure.

Srivastava (1992) presented an evaluation of seismicity patterns preceding earthquakes in the Himalayan region and found that well defined increased seismicity followed by quiescence developed for four earthquakes out of six. However, seismicity pattern prior to significant earthquakes of 1973 and 1980 in Koyna region fail to produce a well defined mode of occurrence even though both the events occurred under similar conditions of reservoir loading. The largest aftershock of magnitude 4.0 in January 1984 at Bhatsa reservoir was, however, preceded by temporal increase in seismicity followed by quiescence before the occurrence of the main earthquake (Srivastava et al 1991). It may, therefore, be concluded that there is no uniformity in the seismicity pattern associated with reservoirs.

CONCLUSION

1. The decay constant 'h' in Omori's law of aftershocks remains close to 1 for the period ending February 1990 as compared to Koyna region which was exceptional with 'h' value of 0.15. Limitations have been found to use this decay criteria as a quantitative tool to distinguish between normal and reservoir induced earthquakes.

2. Seismic quiescence before the occurrence of four earthquakes could be noticed in the Aswan reservoir region.

3. Dimensions of strange attractor at Aswan and Koyna regions were noted as 3.4 and 4.2 respectively showing low dimension of attractor in both the regions. Further both regions fall in intraplate setting. Thus we can extend the modified Asperity model around Koyna region (Srivastava et al, 1991) to Aswan region. This model estimates that the future largest earthquake magnitude in Aswan region may not exceed 4.5 in the near future.

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