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On relation between seismicity and tectonic features of Idukki region, Southwestern India

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A detailed investigations of the lineament and seismicity data of Idukki area have been carried out in connection with the location of June 7, 1988 earthquake and its associated significant aftershocks. The analysis of lineament data have indicated three major lineaments namely Idamalayar, Periyar and Kambam which have influenced the entire lineament fabric of the Idukki area. The study has indicated that the June 7, 1988 earthquake was associated with Periyar lineament in Nedumkandam area which has been found to be located at a distance of 22 km off Idukki. It has been observed that the isoseismals pertaining to maximum intensity VI MM and above show unidirectional elongation in WNW–ESE while lower intensity isoseismals have bi-directional elongation in WNW–ESE and NE–SW. The Periyar lineament trending WNW–ESE and NE–SW trending Kambam lineament have served as conduits for the propagation of seismic energy over long distances since its transmission is more efficient along rupture zones than in the transverse direction.

O odnosu seizmičnosti i tektonskih svojstava Idukki regije u jugoistočnoj Indiji

Provedena su detaljna istraživanja lineamenata i seizmičnosti područja Idukki kako bi se proučio potres koji se dogodio 7. lipnja 1988. i njegovi naknadni potresi. Pokazalo se da glavni lineamenti – Idamalayar, Periyar i Kambam – utječu na čitav ustroj lineamenata tog područja. Istraživanja ukazuju da je potres povezan s Periyar lineamentom u Nedumkandam području. Opaženo je da je pleistoseista (VI°MM i više) izdužena u smjeru ZSZ–IJI dok su izoseiste nižih intenziteta izdužene u dva smjera – ZSZ–IJI i SI–JZ. Zaključeno je da su zone uzduž Periyar (smjera pružanja ZSZ–IJI) i Kambam (u smjeru SI–JZ) lineamenata područja u kojima je transmisija energije efikasnija nego okomito na njih.

1. Introduction

The Indian Peninsula has been considered as one of the oldest land masses on the earth's crust which has undergone several phases of tectonic/orogenic activity in the geological past. However, recently available seismicity data have indicated that the region is moderately active resulting in a slow accumulation of seismic energy which may lead to earthquakes of significant magnitude from time to time. Oldham (1883) has catalogued historical earthquakes of the region. Gopal (1953) has reported the occurrence of a series of tremors in and around Kottayam region during 1952–1953. Indra Mohan et al. (1981) concluded based on analysis of seismicity data from 1967 to 1977 of Peninsular India that low magnitude earthquakes (magnitude < 4) occur often in the region. Studies carried out by Chandra (1977) and Rao and Rao (1984) indicate that the epicentres of earthquakes follow well defined patterns of tectonic features in Peninsular India. Further, epicentre plots of earthquakes from 1340 to 1983 show clustering of epicentres along a line from Madras to Kottayam. Hari Narain and Subramaniyam (1986) have identified the Bellary-Malabar zone to be seismically active.

During recent years, the authors reported seismic activity along the west coast of India (Singh et al., 1988, 1989; Singh and Raghavan, 1989, 1990). The main shock of earthquake sequence of June 7–8, 1988 (Singh at al., 1989) with Richter magnitude of 4.5 has occurred in the vicinity of the giant Idukki reservoir causing considerable panic among the local inhabitants and resulting in damage to several buildings located in the meizoseismal area. The main shock was followed by several aftershocks prominent among which occurred on June 7 & 8, 1988. The Idukki event was one of the largest reported in the recent times and was felt over a large area. In comparison, the Trivandrum event of September 2, 1988 and the Trichur event of March 15, 1989 were of a localized nature and mild intensity (Singh and Raghavan, 1989, 1990).

It is well known that tectonic earthquakes occur invariably in association with faults/weak zones. However, attempts to correlate seismic events with these features in the Peninsular India are few and far in between. Hence, the relation between the seismic activity associated with major tectonic features remains to be poorly understood in the region, probably due to its low seismic activity.

The present study is based on interpretation of LANDSAT MSS images and analysis of seismicity data of Idukki region. An attempt has been made to establish relationship between lineaments and the recent earthquake sequence of June 7–8, 1988 at Idukki.

2. Tectonic setup of the region

The southern Peninsular India is traversed by numerous faults/megalineaments (Grady, 1971; Drury et al. 1984; Katz, 1982). Several dyke swarms and acid igneous bodies of varying ages occur either along or sub-parallel to these lineaments or faults. Major lineament trends observed in the region include the NW–SE, NE–SW, NNW–SSE and WNW–ESE trending sets. Geological data suggest that these lineaments or fracture systems/faults are of Precambrian origin and have been periodically reactivated during the geological past. However, a few lineament sets are possibly of neotectonic origin and do not relate to Precambrian tectonic events.

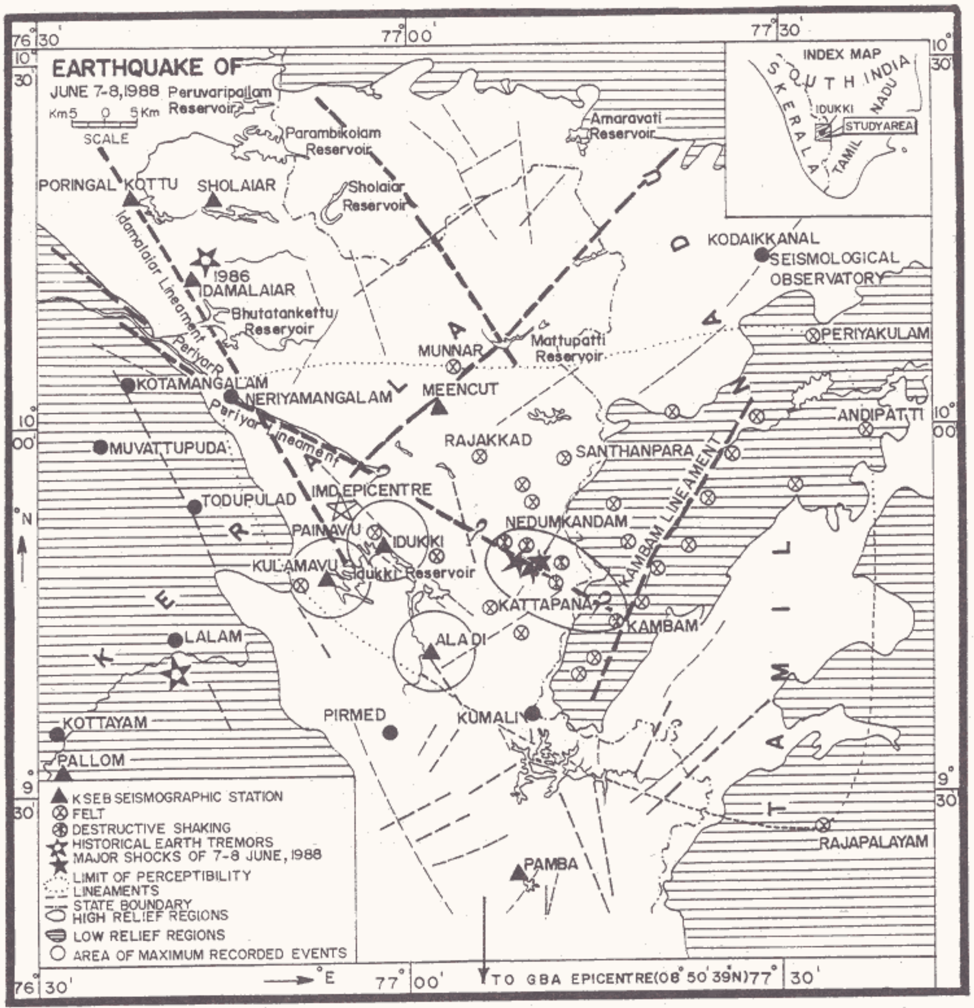

Figure 1. Lineament map of Idukki and its vicinity based on present lineament data analysis. The seismographic stations operational in the area are shown by solid triangles. The places which were visited during the earthquake for macroseismic data collection are shown by crossed circles. The epicentre (instrumental) of main shock and two aftershocks of Idukki earthquake of June 7, 1988 are shown near Nedumkandam by solid stars along with limit of perceptibility. The epicentres computed by IMD and GBA array for the same earthquake are also shown in the north of Painavu and in the south of Pamba, respectively. The circular areas around Idukki, Kulamavu and Aladi indicate the areas in which most of the recorded events are located.

3. Lineament analysis

The study area (Idukki and its vicinity) is shown in Figure 1. In order to study lineament patterns of the study area, the LANDSAT MSS data (band 5, 7 and false colour composite) of 1:250000 scale have been interpreted using conventional visual interpretation techniques. It was observed that the area is

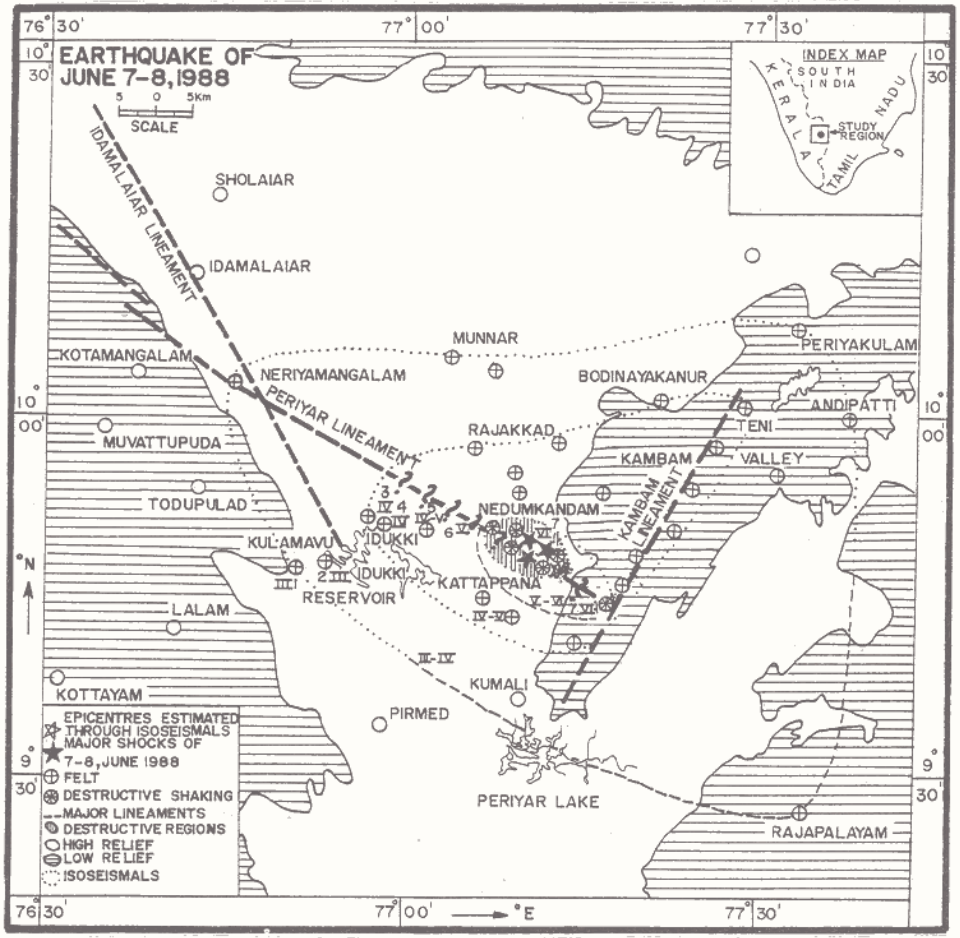

Figure 2. Map showing isoseismals of main shock of June 7, 1988 earthquake of Idukki along with meizoseismal area. Two significant aftershocks are also shown. The epicentres of main shock and its aftershocks estimated based on macroseismic data are shown by open stars located close to but in the southeast of the instrumental epicentres. The three major lineaments namely Periyar, Idamalayar and Kambam are plotted. It is evident that the main shock and its two aftershocks are located at the extended part of the Periyar lineament indicating positive relation between the epicentres of earthquakes and the lineaments. The meizoseismal area encloses Nedumkandam and its vicinity.

traversed by numerous major and minor lineaments of which the WNW–ESE and NW–SE trending sets are predominant. The Idamalayar (NW–SE), Periyar (WNW–ESE) and Kambam (NE–SW) lineaments constitute three major lineaments in the region which have been interpreted as deep seated fractures (Figures 1 and 2). Rao (1978) observed that the Idamalayar and Periyar lineaments are marked by intense shearing of rocks and veining of granitic materials and suggested that these represent shear zones. The Periyar lineament is not clearly defined on the Landsat from the north of Idukki to Kambam which has been shown by dashed thick lines passing through Nedumkandam (Figures 1 and 2). However, it is confirmed to be a major fault based on gravity data of the region (Mishra et al., 1989). The NE–SW trending Kambam lineament has also been reported as a major shear zone (Rao, 1978; Katz, 1982). These three major lineaments are shown in Figure 2.

The analysis of lineament data of Idukki area has been carried out in order to examine relationship between these lineaments and the epicentres of the June 7, 1988 earthquake and associated aftershocks. Digitized lineament co-ordinates have been summarized using a series of computer programmes developed for lineament analysis (Venkatesh Raghavan and Panchanathan, 1989 a, b). The results obtained are summarized in Table 1. The rose diagram (Figure 3) depicts the lineament patterns observed in the region. The NE–SW trending sets show a broad peak ranging from N 30 to N 60 E deg. and constitute 33.3%

Table 1. The lineament frequency (FREQ), total lineament length (AZLEN) and average lineament length (AVLEN) per azimuth class computed for 18 azimuth classes (N) with 10 degree azimuth interval in and around Idukki area

N	CMIN	CMAX	FREQ	AZLEN	AVLEN	L%	N%
1	270.0	280.0	0	0.0	0.0	0.0	0.0
2	280.0	290.0	0	0.0	0.0	0.0	0.0
3	290.0	300.0	0	0.0	0.0	0.0	0.0
4	300.0	310.0	6	169.0	28.2	12.5	19.2
5	310.0	320.0	3	45.7	15.2	6.3	5.2
6	320.0	330.0	5	145.5	29.1	10.4	16.5
7	330.0	340.0	4	74.1	18.5	8.3	8.4
8	340.0	350.0	5	54.2	10.8	10.4	6.2
9	350.0	360.0	2	34.6	17.3	4.2	3.9
10	0.0	10.0	1	5.0	5.0	2.1	0.6
11	10.0	20.0	1	7.1	7.1	2.1	0.8
12	20.0	30.0	2	57.5	28.7	4.2	6.5
13	30.0	40.0	5	46.8	9.4	10.4	5.3
14	40.0	50.0	5	137.4	27.5	10.4	15.6
15	50.0	60.0	6	78.7	13.1	12.5	8.9
16	60.0	70.0	2	19.9	10.0	4.2	2.3
17	70.0	80.0	1	5.6	5.6	2.1	0.6
18	80.0	90.0	0	0.0	0.0	0.0	0.0
Total			48	881.11			

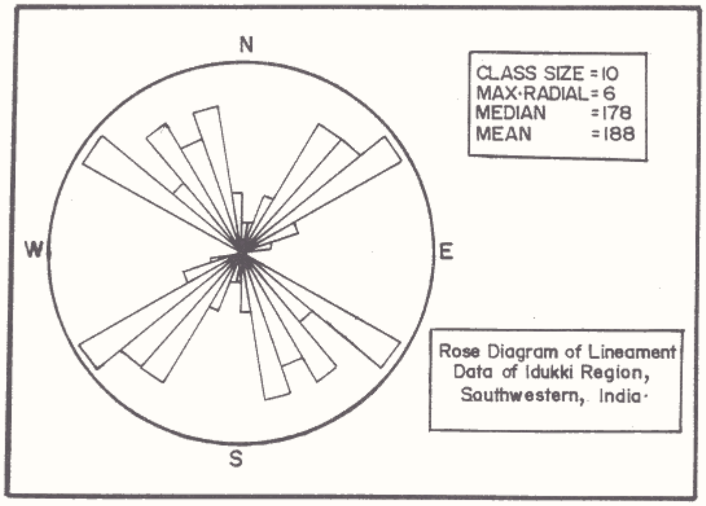

Figure 3. Rose diagram showing lineament patterns in the Idukki region, southwestern India.

of the total lineaments. The Kambam lineament constitute a major lineament of the NE–SW trending set. The WNW–ESE trending sets constitute a 2.5% of the total lineaments which include the major Periyar lineament. In addition, the NNW–SSE trending sets constitute around 29% of the total population and include two major lineaments namely Idamalayar and Munnar lineaments. The total and average length of lineaments show similar pattern (Figure 4). Shorter lineaments (<20 km) are most predominant which are sub-parallel to the major lineaments (Figure 4). These constitute 75% of the total lineaments and account for 80% of the total line kilometers of mapped lineament. It is evident from the lineament analysis that the general lineament patterns in the region are sub-parallel to the large scale lineaments namely, the Periyar, Kambam and Idamalayar. It is, therefore, reasonable to assume that small scale fractures were formed contemporaneous to the large scale fracture suggesting an influence of major lineaments on the overall lineament fabric of the region (Figure 1).

4. Seismicity associated with Idukki earthquake sequence

The mainshock of the Idukki earthquake sequence occurred on June 7, 1988 at 03h 07m 00s (GMT) and was followed by numerous aftershocks among which two were significant. They occurred on June 7 and 8, 1988 at 15h 26m 00s and 03h 05m 00s (GMT), respectively. Low magnitude aftershocks were reported to continue till October, 1988. Some of them were recorded on four portacorders temporarily installed in the epicentral region. Subsequent to the occurrence of the earthquake, a field work was undertaken in the affected area of Idukki in

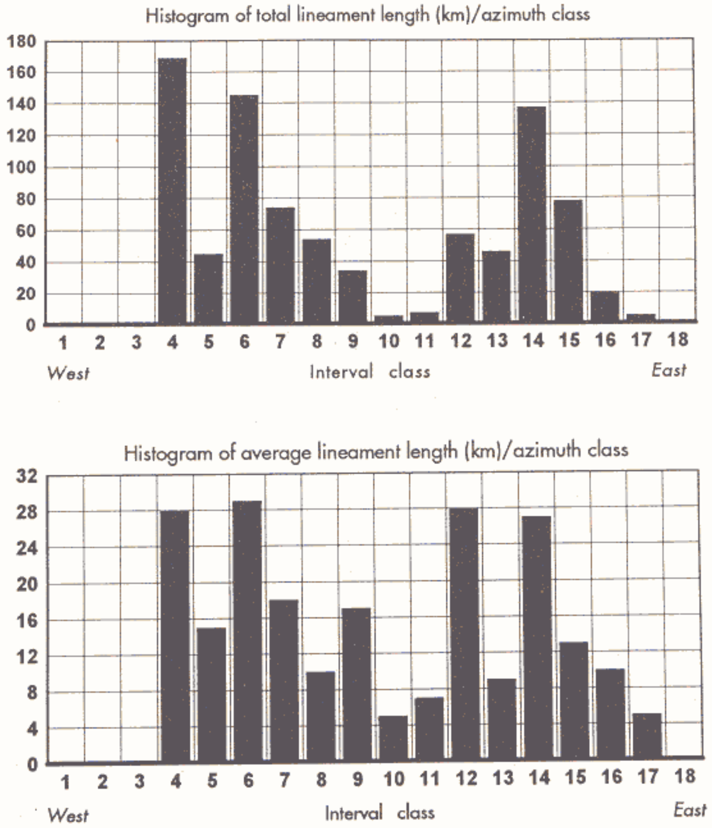

Figure 4. Histograms showing total and average lineaments at 10 degrees azimuth class interval of Idukki region.

order to collect macroseismic data for the determination of epicentres and magnitudes of mainshock and associated aftershocks. The earthquake received wide media coverage soon after its occurrence since it created considerable panic among the local inhabitants and resulted in noticeable damage to several buildings in the epicentral region in the form of development of cracks. In addition, seismicity and reservoir water level data were collected to study the possibility of a reservoir induced earthquake (RIS).

The lineaments of the study area shown in Figure 1 were obtained based on interpretation of lineament data of the area. A seismic network consisting of nine stations is operative in and around Idukki region (Figure 1). The seismic network has been functional since 1974 with the help of which numerous microearthquakes have been recorded. The Sg–Pg time difference for majority of events do not exceed 0.8 seconds which indicates that the events are of very localized nature. The circular areas drawn around the Idukki, Aladi and Kulamavu observatories (Figure 1) include majority of the events recorded at these stations and is an indication that these events are located in the immediate vicinity of the reservoir. The radius of these circular areas have been approximated to 6 km based on the epicentral distances of events recorded at these seismological stations. These stations constitute inner net of the Idukki seismic network. The outer net includes stations located at Pamba, Pallom, and Meencut. The number of events recorded at these stations are found to be meager as compared to events recorded at stations in the inner net. Three more stations were added at later stage at Poringalkuthu, Sholayar and Idamalayar. Certain isolated events have also been recorded which have occurred at larger distances (>15 km).

The determination of epicentres and magnitudes of mainshock and its associated aftershocks were constrained due to inadequate data since most of the stations of the Idukki seismic network were not operational during the earthquakes. The coordinates of the epicentres of the mainshock and two of its aftershocks shown in Table 2 are estimated based on epicentral distances measured at 4 stations in the Idukki seismic network. (Singh et al., 1989). The magnitudes are calculated using the signal duration obtained from the seismograms of Idukki observatory only. A relation between surface wave magnitude and signal duration for the Koyna region has been established by Gupta et al. (1980) and is considered applicable for the Idukki region too due to stabilized tectonic setup of the Peninsular India. Thus the surface wave magnitude of the mainshock and two of its aftershocks are estimated to be 4.5, 4.1 & 3.4 respectively (Singh et al., 1989). Due to non-availability of accurate P-wave polarity data, focal mechanisms for these earthquakes could not be estimated. However, it is important to mention here that these parameters were found to be most reliable as compared to the values determined by GBA and IMD (Singh et al., 1989). The reason may be due to attenuation of seismic energy before arriving at IMD and GBA stations which are located at comparatively larger distances than the stations in Idukki region.

On interpretation of felt reports it was found that the earthquake was felt over a large area ($\sim$5000 km^2). Maximum damage in the form of cracks in several houses were observed in and around Nedumkandam and in Kambam in an area of 180 km^2 (Figures 1 and 2). Based on the felt reports, the maximum intensity VI on the Modified Mercalli (MM) scale has been estimated in the epicentral region of the main shock which occurred at a distance of 22 km to the east of Idukki observatory.

Macroseismic data collected during field work have been used to draw isoseismals for the Idukki earthquake which is shown in Figure 2. The meizoseismal area (vertically hatched area in Figure 2) corresponding to the isoseismal of intensity VI and above show unidirectional elongation along the WNW–ESE direction. The isoseismals of intensity III and IV show bi-directional elongation

Table 2. Focal parameters for Idukki earthquake sequence of June 7-8, 1988.

No.	Date	Origin time (GMT)			Epicentres	Focal depth (km)	Magnitude
		h	m	s			
1	07.06.1988.	03	07	00	9°48'40"N 77°11'10"E	–	4.5
					(9°47'27"N 77°12'41"E)	(19)	(5)
2	07.06.1988.	15	26	00	9°48'55"N 77°12'12"E	–	4.1
					(9°47'42"N 77°13'31"E)	(19)	–
3	08.06.1988.	03	05	00	9°49'45"N 77°11'50"E	–	3.4
					(9°48'32"N 77°13'11"E)	(19)	–

Note: Values shown in bracket are estimated by using macroseismic data.

in WNW–ESE and NE–SW directions. Felt reports corresponding to intensity III could not be obtained due to inaccessibility in the south and south east of Kambam. The epicentres and magnitudes estimated based on macroseismic data are given in Table 2. The epicentres determined based on instrumental and macroseismic data of the main shock and its two significant aftershocks are shown by solid and open stars respectively which are located close to each other near Nedumkandam (Figure 2). The remaining aftershocks are also located in the same area. It is evident from the shape of the isoseismals that the seismic energy propagated over long distances in WNW–ESE and NE–SW directions. This suggests that the regions along these directions are more conductive for the propagation of seismic energy.

5. Discussion and conclusions

The Idukki region is traversed by several major lineaments (Figure 1). The Idamalayar (NW–SE), Periyar (WNW–ESE) and Kambam (NE–SW) constitute three major lineaments and are located within the limits of perceptibility of the main shock and have been interpreted as deep seated crustal fractures. These three lineaments represent major shear zones (Rao, 1978; Katz, 1982). The lineament fabric of the region shows a predominance of WNW–ESE and NE–SW trending sets parallel to the major tectonic lineaments indicating an influence of large scale lineaments over the tectonic fabric.

The epicentres of the main shock and its aftershocks are located along the projected extension of the Periyar lineament near Nedumkandam about 22 km east of Idukki. The elongation of meizoseismal area of the main shock is unidirectional in WNW–ESE direction. This indicates that the initial bursting of rocks during the earthquake has taken place along projected extension of the Periyar lineament in Nedumkandam area. The lower intensity isoseismals of the Idukki earthquake show bi-directional elongation WNW–ESE and NE–SW parallel to the predominant lineament trends. The earthquake was felt over a long distance along Periyar and Kambam lineament which is evident from the isoseismals drawn based on macroseismic data. Further, it is well known that the propagation of seismic energy is more efficient along weak zones than in transverse directions. It is, therefore, reasonable to consider that seismic energy which was released from the focal region has been polarised along the Periyar lineament and was felt up to Neriyamangalam located about 60 km from the epicentre (Figure 2). The energy propagating in the ENE direction has encountered a major weak zone (Kambam lineament) near Kambam. The close proximity of the Kambam to the epicentre resulted in transmission of seismic energy in the NE–SW direction along the Kambam lineament. The junction point between the Kambam lineament and the extended part of the Periyar lineament has, perhaps, acted as a secondary source of energy which could explain the damage observed at Kambam and also the propagation of seismic energy along the Kambam lineament over a long distance. It is probable that the seismic energy was not transmitted along the Idamalayar and Munnar lineaments since their long distance from the epicentre (~40 km) had resulted in dissipation of a major part of the seismic energy and hence further deflection along these weak zones was not possible.

It has been very well established that tectonic earthquakes occur invariably in association with fault/rupture zones of a region. Generally, the orientation of meizoseismal area of an earthquake is found to be elongated in the direction of fracture system of a region. In the present case, the isoseismals of Idukki earthquake show bi-directional elongation parallel to the predominant lineaments trends. Further, the meizoseismal area (vertical hatched area shown in Figure 2) of Idukki earthquake is elongated only in the WNW–ESE direction which indicate the presence of a weak zone/fault along this direction. This indicate that the initial bursting of rock has occurred in Nedumkandam area along projected extension of WNW–ESE running Periyar lineament. With the above discussions, it can be said that the Idukki earthquake has occurred in association with the Periyar lineament since this major lineament is elongated in the direction of the meizoseismal area of the earthquake.

The occurrence of the events in the proximity of the Idukki reservoir have resulted in speculations regarding a possible RIS triggering mechanism. The probable cause of Idukki earthquake could be attributed to two mechanisms, namely tectonic and reservoir induced. There are certain characteristics which are useful to differentiate between natural and induced earthquakes. Gupta (1986) has described the common characteristics of RIS which are as follows: 1) Earthquake of shallow depth (~ 10 km) within the immediate vicinity of the reservoir; 2) Correlation of seismic activity with high water levels; 3) Foreshocks activity preceding the main RIS event and subsequent aftershocks continuing over a long period of time; 4) High b-values in the frequency-magnitude relationship; 5) Magnitude of the largest aftershock could be comparable to the main-shock magnitude; 6) Induced earthquakes are of strike-slip or normal type prevalent in regions of low seismicity and events are generally small.

Singh et al. (1989) have studied these characteristics of RIS in relation with the Idukki earthquakes. Due to inadequate instrumental data, precise focal depth, b-values, and epicentres of earlier occurring events could not be calculated, which is important to study temporal migration of events. The water level data and number of events recorded since the construction of the dam at Idukki

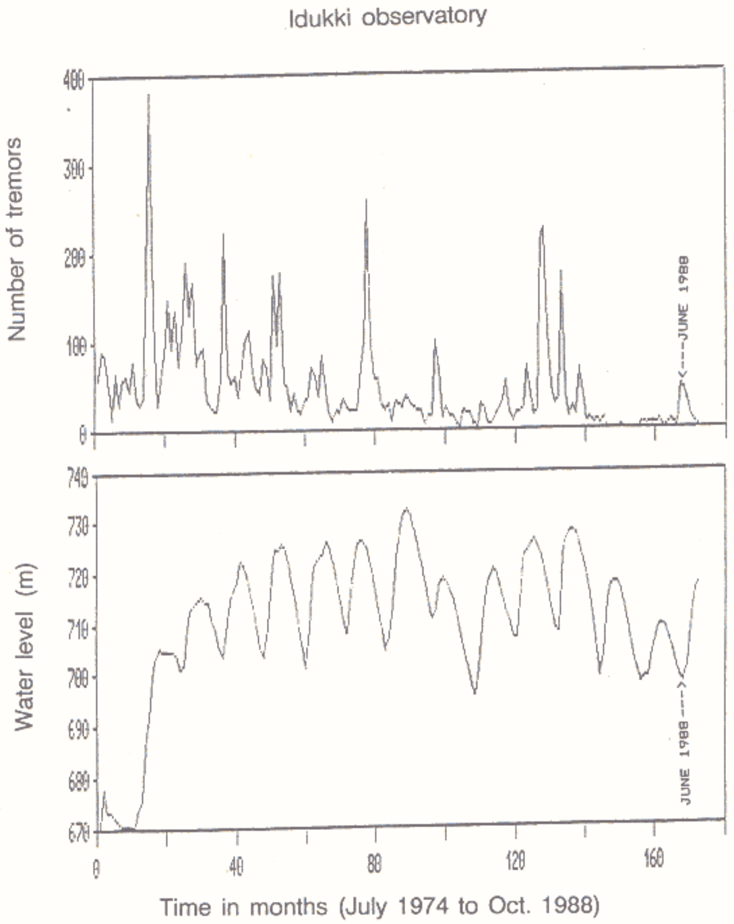

Figure 5 a. Relation between reservoir water level and number of events observed at Idukki observatory.

and Kulamavu observatories are shown in Figure 5 a and b respectively. It has been pointed out that majority of events recorded during the initial stage can be attributed to blasting during the construction of the dam. However, during the subsequent period, after the impoundment no direct correlation between the number of events and water level in the reservoir was observed. It is to be mentioned here that the increased seismic activity during June, 1988, subsequent to the Idukki earthquake sequence, has occurred when water level was in its minimum during the year. Similarly, no correlation between water level and number of events were observed at any other observatories. Further, when average water level and number of events over a period of twenty months interval are studied, a noticeable fluctuations in the number of events are observed although average water level has nearly remained constant (Singh et al.,

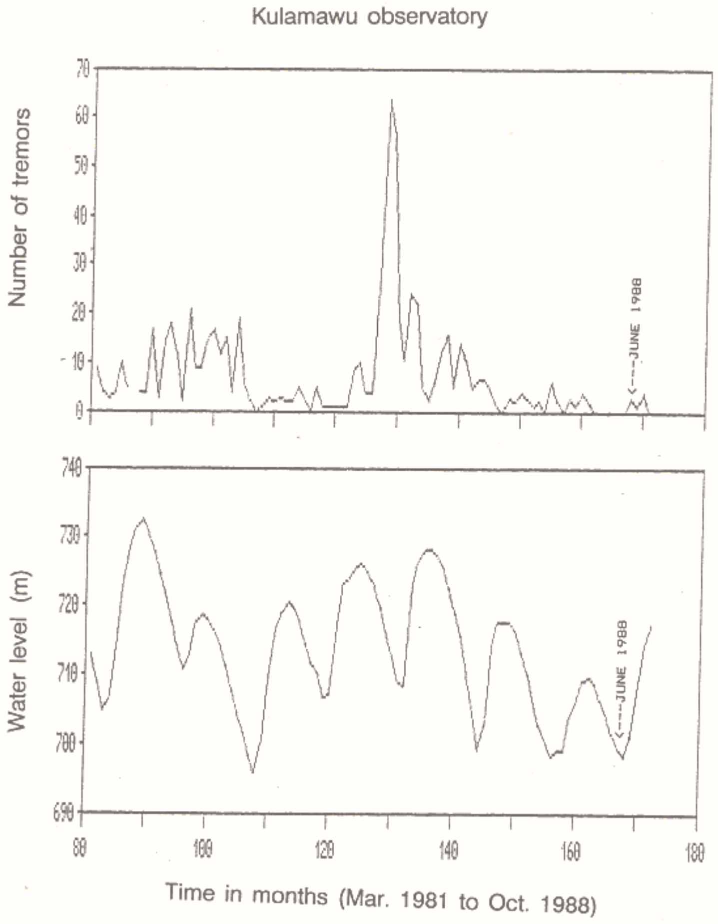

Figure 5 b. Relation between reservoir water level and number of events observed at Kulamavu observatory.

1989). No foreshock activity was observed prior to the main event other than one localized event on 2nd June, 1988 recorded at Idukki observatory. A total of 28 aftershocks have been recorded at Idukki observatory from the onset of the main event from 7th to 8th June, 1988 and all are located at a distance of about 25 km. Seismicity data of the region reveal that significant aftershock activity has almost ceased after 48 hours of the mainshock. Of the 46 events recorded during June, 1988, 65% of events occurred between 7th and 9th June, 1988 and only 18 highly localized events were recorded during the remaining period of the month. A total of 21 events located at a distance of more than 12 km from the Idukki observatory have been recorded from July to September, 1988. After September, 1988 the activity was found to become normal as it was prior to the main shock. It is evident with the above facts that the ratio between the magnitudes of the mainshock and its largest aftershock (0.9) is the only characteristic which favours RIS triggering mechanism. This parameter is of secondary importance and highly dependent on the geological setup and therefore is inadequate to support a RIS case.

It is therefore concluded based on available information that the Idukki earthquake of June 7, 1988 was a tectonic event associated with Periyar lineament of the region. The Periyar and the Kambam lineaments have acted as conduits for the transmission of seismic energy over long distances. It is, therefore, suggested that the lineament tectonics of the region have played a significant role in triggering the Idukki earthquake of June 7, 1988.

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