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MICROEARTHQUAKE ACTIVITY IN THE ENVIRON OF PROPOSED TIPAIMUKH DAM SITE, MANIPUR

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ABSTRACT

Microearthquake activity in the environ of proposed 161.0 m high rock fill dam at Tipaimukh in Manipur state is mapped employing a temporary local network of portable smoked paper seismographs. More than 700 local earthquakes (S-P time ≤ 25.0 sec and $0.2 \leq M_L \leq 4.4$) were recorded and 103 could be located. Distribution of contemporary seismic activity follow NW-SE trend and is in general agreement with the regional tectonic setting. The microearthquakes are originating at shallow depths and possibly related to the bending and upward buckling of India plate thrusting beneath the Burmese plate. A cluster of microearthquake activity is delineated about 25 km to the east of the dam site. Seismic activity corroborating with the trends of lineaments seems to be related to the geological structure controlling the course of the Barak river. Geologically mapped local faults in the reservoir region did not exhibit microearthquake activity. A dense station seismological network should be operated in the close proximity of the dam site to map the seismic activity on more precise scale.

INTRODUCTION

A 161.0 m high rock fill dam namely, Tipaimukh dam is proposed to be constructed at the confluence of the rivers Barak and Tuivai at Tipaimukh in the Manipur state. The region around the dam site is having high seismicity and several local faults and lineaments are mapped in the reservoir region (Fig. 1). We investigated the contemporary seismic activity of this seismically active and tectonically complex region employing a short term reconnaissance microearthquake survey. The aims of the investigation were **i)** to ascertain the contemporary seismic status of the geologically mapped tectonic features falling in the reservoir region, **ii)** to delineate active tectonic features and seismic source zones required for the purpose of estimation of the design earthquake parameters, **iii)** to acquire short term sample of microearthquake activity prior to reservoir impounding, and **iv)** to plan future seismological network for continuous monitoring of seismic activity around the region of the dam site.

In total about three months of microearthquake survey resulted in the recording of 762 local earthquakes falling in the S-P time up to 25 sec. This paper describes the data acquisition and processing procedures and discusses the scientific findings keeping in view the aims of the investigation.

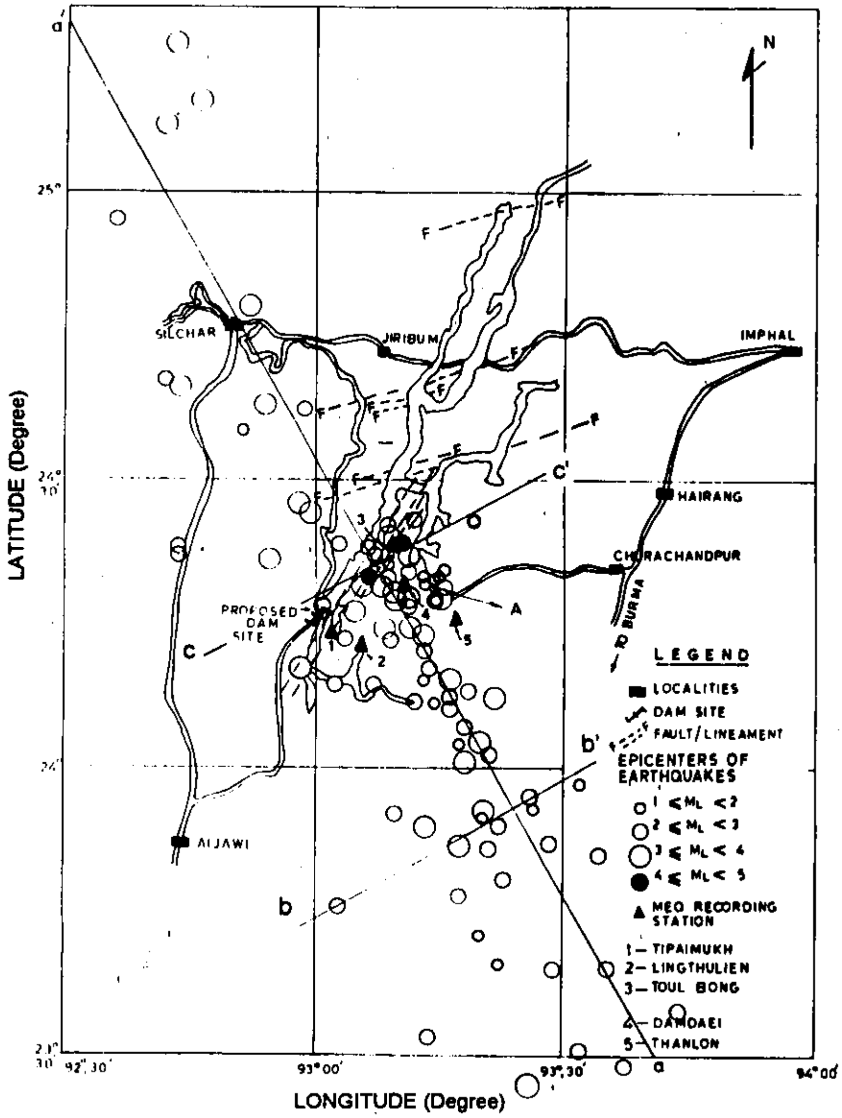

Fig. 1 Lineament and Fault map of the area showing dam site, microearthquake recording stations and epicenters of microearthquakes around Tipaimukh dam site.

INSTRUMENTATION AND FIELD RECORDING

The instrumentation employed for the purpose of microearthquake recording were Sprengnether MEQ 800 smoked paper seismographs coupled to either L-4C short period (1 Hz) vertical component seismometers or S-7000 short period (0.5 to 1.5 Hz) Sprengnether seismometers. The instruments were operated at 90 dB gain, 5/30 Hz filter setting and at a recording speed of 120 mm/sec to facilitate good quality recording. Each smoked paper seismograph has a built-in clock which impinges hour and minute marks on the smoked papers. The clocks were daily synchronised with the IST to achieve the inter station time control. During the period from January to April 1991 recording at five stations was carried out (Fig. 2). For most of the period a short aperture tripartite array with inter-station spacing of about 15 to 25 km was operated with one of the recording station located close to the proposed dam site. Operation of recording station close to proposed dam site allowed recording of microearthquakes occurring near the dam site. Most of these microearthquakes could not be registered at other stations. The details of various recording stations namely, station name, station code, geographical coordinate, elevation and period of recording are given in Table 1.

Table 1 : Details of Microearthquake Recording Stations

Sr. No.	Name of Station	Station Code	Latitude Deg Min	Longitude Deg Min	Elevation Meters	Period of Recording
1.	Tipaimukh	TPM	24.0 14.09	93.0 01.87	50.0	07.01.91 - 10.04.91
2.	Toulbong	TLB	24.0 23.25	93.0 09.26	800.0	09.01.91 - 02.03.91
3.	Thanlon	TNL	24.0 15.60	93.0 16.87	1160.0	11.01.91 - 21.04.91
4.	Damdaei	DMD	24.0 9.37	93.0 10.60	1740.0	19.03.91 - 21.04.91
5.	Lingthulien	LTN	24.0 12.70	93.0 05.50	1000.0	27.03.91 - 21.04.91

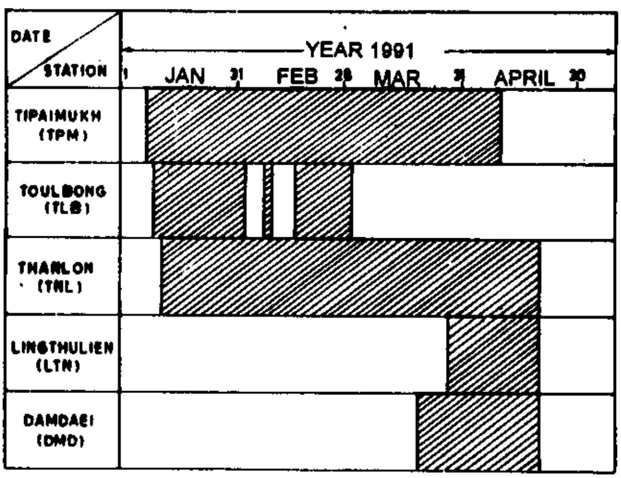

Fig. 2 Dates of microearthquake recording at various stations.

ANALYSIS OF DATA

Data

The records obtained from various recording stations were examined for the identification of microearthquakes falling within (S-P) time interval of 25.0 seconds which corresponds to a hypocentral distance of about 200 km from respective recording stations. This permitted the study of seismic activity within a radius of about 200 km from the short aperture array.

Seismological Network Bulletin (SNB) on the identified events was prepared listing various parameters namely, arrival time of P and S phases at each recording station, (S-P) time, total signal duration (coda length) and direction of onset of first motion, if readable. In total 762 microearthquakes were identified during 90 days of recording. However, events recorded simultaneously at two or more recording stations and within (S-P) time of 25 seconds were analysed for spatial distributions. Locations were attempted for 238 events recorded simultaneously at three or more stations. For the estimation of hypocenter parameters at least three P and two S arrival times were used. Majority of events were recorded on three stations either on 1,5,3 ; 1,5,4 or 2,5,4. No event recorded on 3,4,5 stations was located as station 3 and 4 were not operated simultanuously (Please see figure 2).

Spatial distribution of microearthquake activity

The spatial distributions for events recorded at TPM and TNL stations were prepared by grouping the events within 1.0 second (S-P) time interval (Fig. 3). This analysis did not include events for which (S-P) times could not be read. Assuming an isotropic homogeneous half space model with P-wave velocity of 5.11 km/sec, the (S-P) times were converted to approximate hypocentral distances by multiplying with a factor of 7.0. Observed peaks of activity, in these distributions, indicate possible sources of seismic activity falling at respective hypocentral distances.

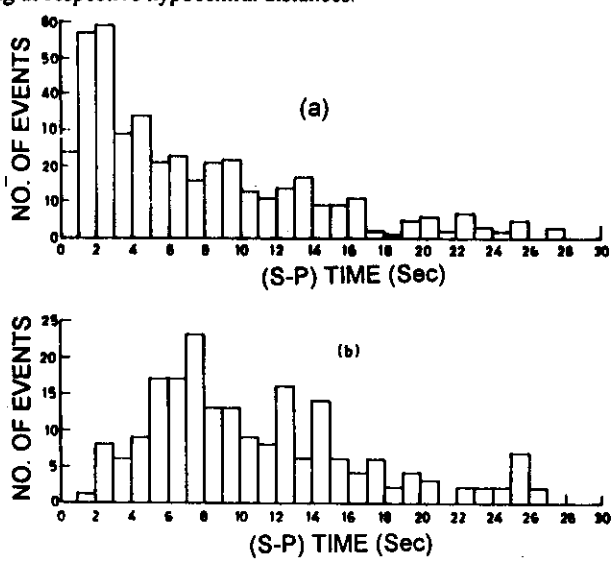

Fig. 3 Spatial distribution of microearthquakes recorded at a) Tipaimukh and b) Thanlon stations.

Spatial distribution of activity at TPM station (Fig. 3a) shows that, in general, the region surrounding the dam site is having a higher concentration of events. This is evidenced by the concentration of microearthquakes within (S-P) time of 1 to 3 sec corresponding to hypocentral distances of 7 to 25 km. There are 140 recorded events falling within a radius of about 25 km from the proposed dam site. Spatial distribution of activity at TNL station (Fig. 3b) indicates concentration of events within (S-P) time of 5 to 8 sec corresponding to hypocentral distances of about 35 to 56 km.

Location of epicenters

Hypocenter parameters for 238 events registered simultaneously at three or more stations were attempted employing Nonlinear Inverse Program (Kumar and Agrawal, 1989) which is a modified version of HYPOLAYR program (Eaton, 1969). This program incorporates second order travel time derivatives for estimation of hypocenter parameters.

Velocity model

The local velocity model for the region around Tipaimukh is not known and is an essential requirement for the precise estimation of hypocenter parameters. However, several velocity models for northeast India are given by various investigators (Table-2). Several test runs were made to evaluate the efficacy of these velocity models for locating recorded earthquakes employing test earthquake data. Study of the resolving power of model parameters and estimation of focal depths obtained employing these velocity models was carried out. The velocity model for the west of Arakan Yoma belt (Gupta et al., 1990) was selected for the estimation of hypocenter parameters for Tipaimukh region as this model provides the best results. This model comprises of a layer over a half space and was modified by incorporating a layer at a depth of 26 km with a velocity of 6.75 km/sec based on the available data on the depth of lithosphere in this region (Mukhopadhyay and Dasgupta, 1987; Mukhopadhyay, 1990). Incorporation of this layer allowed improvement in the estimation of hypocenter parameters of those events for which P-wave is not a direct arrival at the recording station. In view of these scientific considerations, the local velocity model given in Table 3 was finally adopted for locating microearthquake activity.

Table 3 : Local Velocity Model used in the study

Velocity (Km/sec)	Depth to the top of the layer (Km)
5.11	00.00
6.75	26.00
7.83	46.00

DISTRIBUTION OF MICROEARTHQUAKE ACTIVITY

The locations for 103 events are plotted in Fig. 1 and fall in the magnitude range of 1.01 to 4.40. Apart from the convergence, the selection of these events considered for

Table 2 : Available Crustal velocity models for North East India

Area	Velocity (km/sec)	Depth to top of the layer (km)	Type of Layer	Reference
NE India	3.98 5.58 7.91	00.0 02.0 20.0 46.0	Sedimentary Granitic Basaltic Moho	Tandon, 1954
NE India	5.58 + 0.19 6.53 + 0.31 7.87 + 0.07	10.0 22.0 41.0	Granitic Basaltic Moho	John et al., 1987
East of Arakan Yoma	5.64 7.99		Granitic Moho	Gupta et al., 1990
West of Arakan Yoma	5.11 7.83		Granitic Moho	
Mikir Shillong Massif	5.99		Granitic	
Shillong Massif	4.00 5.80 6.70 8.10	00.0 11.0 25.0 45.5	Sedimentary Granitic Basaltic Moho	Khattri et al., 1983
Shillong Massif	6.75 8.08		Basaltic Moho dip 3.7o towards N 296	Kharshiing, 1985
Tipaimukh Region	5.11 6.75 7.83	00.0 26.0 46.0	Granitic Basaltic Moho	Our Model Present Work
Shillong Massif	4.00 5.55 6.62 8.01 8.50	00.0 01.5 20.5 41.5 >41.5	Sedimentary Granitic Basaltic Moho	Kayal & De, 1987
West Bengal Basin	1.7 - 2.1 2.7 - 3.1 3.7 - 4.3 4.6 - 5.3 5.8 - 6.2		Sedimentary Sedimentary Sedimentary Sedimentary Granitic	Kaila and Tiwari, 1987
Shillong Massif	5.90 6.30 6.75 8.00	00.0 11.5 26.0 45.0	Granitic Inhomogeneous Basaltic Moho	Mukhopadhyay, 1990
Average of whole Earth	5.57 6.50 7.76	00.0 15.0 33.0	Granitic Basaltic Moho	Jeffery & Bullen, 1940

interpretation is guided by the study of the model resolution matrix and all these events are having well resolved epicenter parameters. Events numbering 22 for which focal depths could be resolved are plotted separately in Fig. 4. The general distribution of microearthquakes in the region around the dam site (Fig. 1) shows that the seismic activity is by and large trending in NW-SE direction. This is in agreement with the regional tectonic environment, as the region falls to the west of the subduction zone formed due to the underthrusting of India Plate beneath the Burmese Plate. About 60% of the events are falling in the grid bounded by 24 °N-24.5 °N of latitude and 93 °E-93.5 °E of longitude. The increase in scatter beyond 24 °N of latitude seems to be attributed to poor location capability for the events falling outside the network. The region in the close proximity of the dam site (within about 30 km radius) is exhibiting microearthquake activity but the distribution is not uniform and is primarily confined to the southeast, east, and northeast directions from the dam site. A cluster of microearthquake activity has been delineated about 25 km to the east of the dam site (Marked as A in Fig. 1). It seems that a seismogenic feature is active in this area although there is no geologically mapped tectonic feature. Few epicenters are aligned parallel to the trend of Barak river and to the NE-SW trending lineaments mapped in the region from the landsat MSS Imagery.

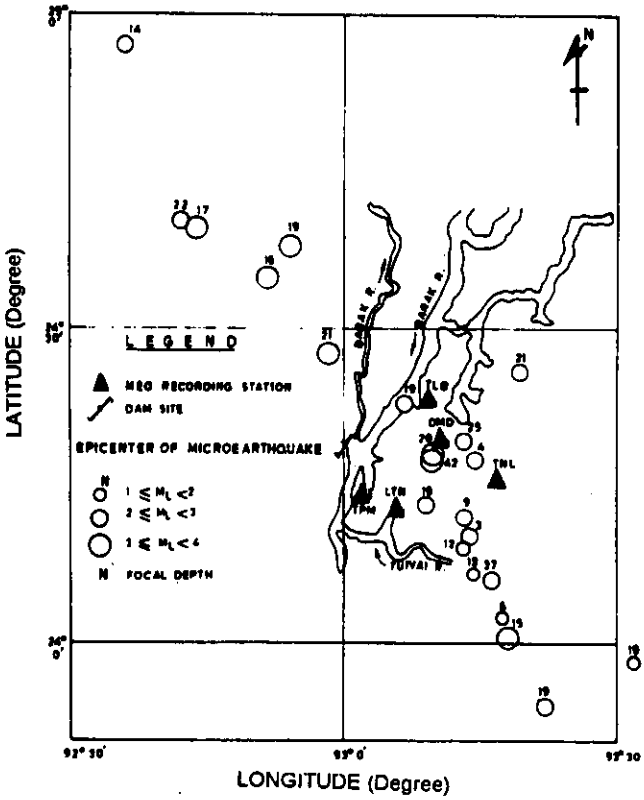

Fig. 4 Epicenters of microearthquakes with well resolved focal depths.

FOCAL DEPTHS AND DEPTH SECTIONS

The focal depth distribution of microearthquakes (Fig. 5) shows that the activity is of shallow origin and is, by and large, confined to the upper 30 km of earth's crust. Three depth sections of seismic activity (Fig. 6) have been drawn along and across the trend of the geological structures with a view to study the distribution of activity with depth. The depth section aa' is drawn in the NW-SE direction. All hypocenters falling to the narrow zone of approximately 20 km. wide and symmetrical to the line aa' are projected onto a plane passing through aa'.

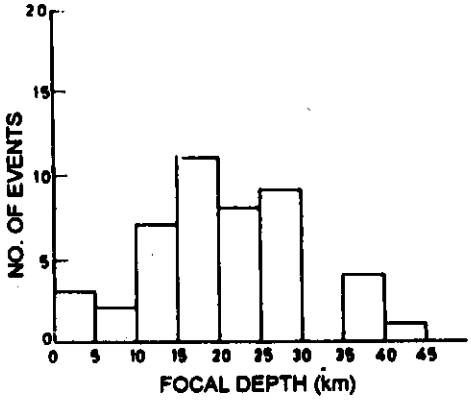

Fig. 5 Focal depth distribution of microearthquake activity for the region.

Majority of events in this section are confined to the depth range of 13 to 25 km. Few events are also having depths around 40 km. However, in the close proximity and to the southeast of the dam site, the events are also occurring at shallow depths of 3 to 15 km. This shallow microearthquake activity, seems to be related to the local tectonic features at shallow depths, and needs further study.

Cross sections bb' and cc' trending N30 ^{O}E are drawn orthogonal to the regional strike direction of the geological structure. The cross section bb' is lying southeast of the dam site whereas the cross section cc' is passing through the dam site. Hypocenters occurring along a narrow zone ± 20 km wide are projected onto the vertical planes passing through bb' and cc'. Both these cross sections show a scattered nature of activity and no trends with focal depth could be delineated. Barring two events occurring at shallow depths (<10 km.) in the cross section bb', the activity at shallow depths observed in the cross section aa' could not be observed in these sections as it lies in the region falling between the area covered by these cross sections.

MAGNITUDE AND RECURRENCE RELATION

Due to the various uncertainties involved in computing local magnitude of events employing trace amplitude, the local magnitudes have been estimated using signal duration (e.g., Tsumura, 1967; Crossen, 1972). The signal duration has been measured as the trace length from the onset of P-phase to the point where the trace amplitude of the events merges with the back ground noise level.

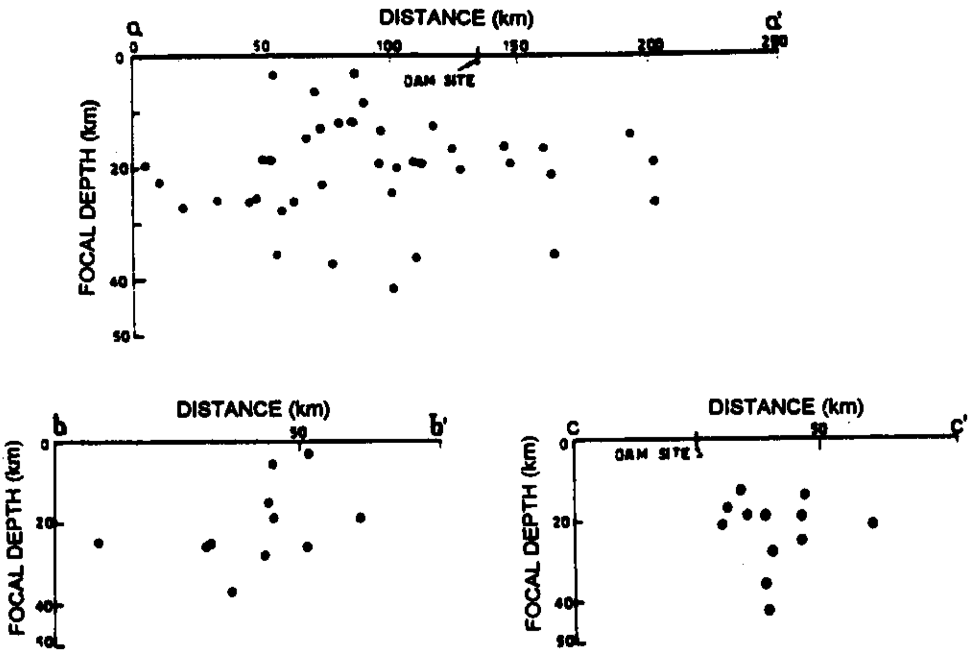

Fig. 6 Depth cross sections of microearthquake activity along aa', bb', and cc'.

In the absence of availability of appropriate calibration relationship for the region under study the following relation (Kayal & De, 1989) developed for the Shillong Massif has been adopted for estimation of local magnitudes using the signal duration :

$$M_L = -1.98 + 2.53 \, Log \; \tau + 0.00041 \, R$$

Where, M_L, τ & R are the duration magnitude of microearthquakes, signal duration and epicentral distance respectively.

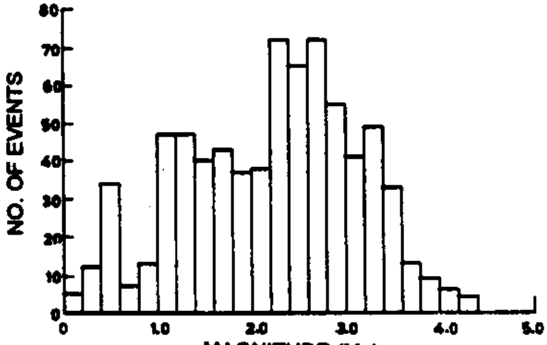

Fig. 7 Frequency distribution of microearthquakes with magnitude for the activity within $0 \leq$ S-P ≤ 25.0 sec.

The events were grouped in the magnitude interval of 0.2 and the frequency distribution of activity with magnitude (Fig. 7) shows that the entire microearthquake activity is confined in the range of $0.20 \leq M_L \leq 4.40$. However, the majority of events fall in the magnitude range $1.0 \leq M_L \leq 3.60$. Recurrence curve is drawn (Fig. 8) and a relationship of the form $Log\ N = a - b\ M_L$ (Gutenberg and Richter, 1954) fitted to the available data. The following recurrence relationship is obtained for the region :

$$Log\ N = 5.475 - 0.87\ M_L$$

Where N is the cumulative number of microearthquakes having magnitude M_L or greater. The above relation gives the b value for the region as 0.87.

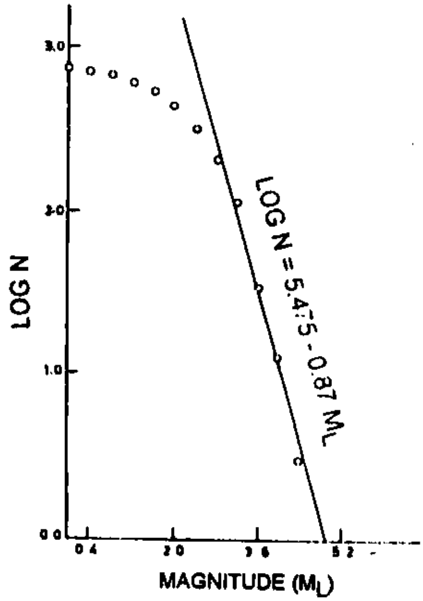

Fig. 8 Recurrence relation for the region around the dam site.

DISCUSSIONS

The prime aim of the reconnaissance microearthquake survey has been to investigate the contemporary seismic activity of the geologically mapped lineaments and local faults falling in the region around the proposed dam site covering the reservoir region. On the basis of the preliminary findings it seems that local faults mapped to the upstream of the dam site in the reservoir region are not exhibiting contemporary seismic activity. However, the parallel and sub-parallel lineaments running along the trend of the Barak river and distribution of microearthquake activity following the trends of lineaments seem to have a seismotectonic relationship with the geological structure controlling the trend of the Barak river. This needs further study employing a dense array of seismological stations.

The tectonic environment around the region of Tipaimukh dam site is having high compressive strains occurring on account of the collision of Burmese and India plates. The northwest to southeast distribution of located shallow depth microearthquake activity seems to demonstrate that this seismic activity is primarily associated with the strain release on the segment of India plate resulting due to its bending and upward buckling. The reported deep level of seismicity (Mukhopadhyay and Dasgupta, 1987) is related to the subducting front of the India plate which is located about 50 km to the east of the dam site. This activity could not be located by the present survey. The occurrence of large number of recorded microearthquakes seems to be related to the compressional strains due to collision of India and Burmese plates. These ambient tectonic strains are getting released through movements along local tectonic features. One such feature is identified at a distance of about 25 km to the east of the dam site during the present investigations.

Spatial distributions of microearthquakes indicate large concentration of activity in the close vicinity of the dam site. More than 100 events are recorded within a radius of about 25 km from the dam site which could not be located during the present survey. However, the survey has demonstrated that there is a need to identify the seismogenic features and study the style of faulting giving rise to this recorded microearthquake activity. The majority of recorded activity is confined to the magnitude range of 1.0 to 3.6 and the estimated b-value is 0.87 from the microearthquake data. This b-value is at large variance to the reported b-value of 0.44 for the Shillong region (Khattri et al., 1983) which is interpreted as having high strains.

The region around Tipaimukh holds a great promise for generating microearthquake data base to study the seismotectonic environment of this tectonically complex region. There is a need to deploy a dense station network in the region around dam site to locate the local activity which was recorded but could not be located. Further, to improve the locations of earthquakes occurring to the NW of the dam site few seismological stations need to be deployed in this direction.

CONCLUSIONS

The reconnaissance microearthquake investigations carried out in the environ of proposed Tipaimukh dam site has provided wealth of information regarding the pattern of seismic activity prevailing in the region. There is a considerable scope for extending these studies employing a dense station network. This will allow both the identification of seismogenic features in the close proximity of the dam site and to study the detailed seismotectonics of this tectonically complex region which lies to the west of the subduction zone formed due to the under thrusting of India Plate beneath the Burmese Plate.

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