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550.341 (541.9)

Seismicity and focal mechanism of earthquakes in Andaman Islands

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ABSTRACT. Spatial distribution and temporal variation of earthquakes in Andaman-Nicobar Islands have been studied with the help of data from 1917 through 1974. Cross-sections showing the epicentral distribution *versus* focal depth along four zones in the region, were drawn to understand the nature of the dipping of the Indian plate. Earthquake recurrence curves were drawn for an area of 100 km radius around Port Blair Observatory for events upto the lowest magnitude 2 based on data during 1967-1974 and compared with these for the complete region for all the events recorded during 1964-1974 and also since 1917. Focal mechanism of earthquakes are also discussed in the light of regional plate tectonics. Normal as well as thrust faulting was observed for earthquakes in the region. The agreement between the focal mechanism solutions and the regional tectonics was relatively better in the Nicobar Islands region as compared to that in the Andaman Islands. Seismicity increase followed by decrease was also noticed prior to some earthquakes close to Andaman Islands.

1. Introduction

The Andaman-Nicobar region is one of the most seismically active regions in the Bay of Bengal which is the largest deep sea fan in the world extending from approximately 20° North to 7° South. Sediments in the Bay of Bengal have been derived predominantly from drainage of the *Ganga* and *Brahmaputra* rivers. The fan is divided by the Ninety East Ridge into two lobes: the main Bengal Fan and the eastern lobe called Nicobar fan (Curray and Moore 1971). A detailed cross-section in the Bay of Bengal in east-west direction is shown in Fig. 1 (Curray and Moore 1974). The significant features are Bengal fan, Andaman-Nicobar ridge, the active volcanic arc and the spreading axis of the Andaman Sea to the Malay Peninsula. Sediments of the Bengal fan ranging in age from early Cretaceous to Holocene are passing on the subducting plate into the Sunda Andaman Arc (Closs *et al.* 1974). Detailed seismic reflection profiles of the Andaman Nicobar ridge suggest that it is composed of folded sediments, arranged in eastward dipping thrust sheets or nappes.

A reconnaissance geophysical survey in the Andaman Sea island arc region (Peter *et al.* 1966) has shown parallel belts of positive and negative gravity anomalies extending over the inner igneous arc and the island platforms respectively. The axis of the negative anomaly belt passes through the Nicobar Islands and slightly to the eastern side of the Andaman Islands. Airy Heiskanen anomalies indicated that the islands are not in isostatic equilibrium. The highest heat flow is associated with the deepest portion of the basin. Also, the magnetic anomalies over the igneous belt are relatively large and negative. Difficulties, however, arise when the complicated tectonics of the region is examined in the light of major plate motions. Relative motion between the Indian and the Asian plates would suggest predominantly transcurrent motion along the northern part of the Sunda-Andaman arc. Folded structure of sediments, however, suggests compression. It is believed that this compression occurs because the Andaman Sea is presently and has been throughout much of tertiary time an extensional basin. The present extension is in a northwest-southeast direction although the spreading in the recent past was eastwards. Seismic evidence based on focal mechanism of earthquakes (Ichikawa *et al.* 1972) reported thrust as well as normal faulting in the region. The object of the present paper is to sudy the seismicity of the region based on reliable data and the focal mechanism of recent earthquakes (1971-1975) and to discuss the results in the light of the regional plate tectonics.

2. Seismicity of the region

Epicentral parameters of earthquakes for this study have been taken from the catalogues of the International Seismological Centre, Monthly Bulletins of U.S. Geological Survey, Tandon and Srivastava (1974) and bulletins/catalogues of India Meteorological Department. The paper also includes an analysis of the records of the Port Blair Observatory which is equipped with Benioff and Wood Anderson seismographs for assessment of local magnitudes and of the temporal variation of small earthquakes within 4° of the observatory

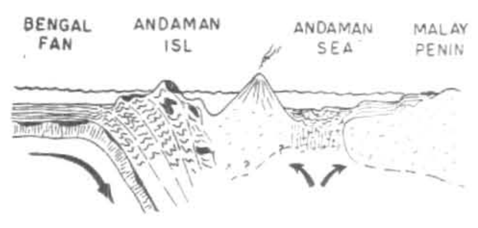

Fig. 1. East-west tectonic features in the Bay of Bengal

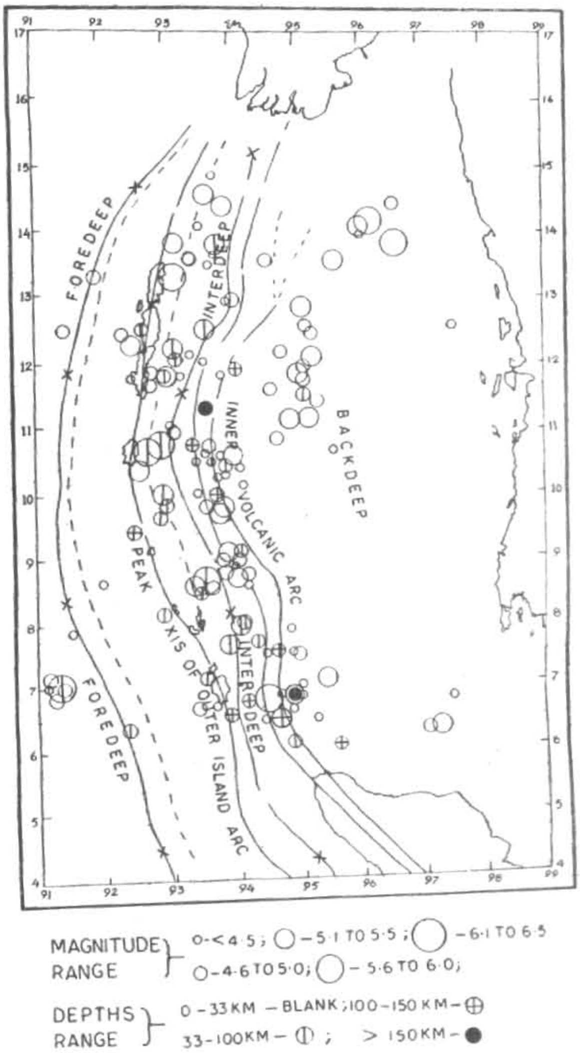

Fig. 2. Epicentres of earthquake in Andaman-Nicobar Islands (1964-1974). (Base map, Peter *et al.* 1966)

Catalogues of past earthquakes in the region have revealed several damaging earthquakes in the vicinity of Andaman-Nicobar Islands. In 1881 an earthquake of very severe intensity occurred in the Bay of Bengal which caused maximum damage at Port Blair. Significant damage to houses in Andaman Islands and flooding at Port Blair was caused by another great earthquake (Magnitude 8·1) of 26 June 1941 which was followed by several aftershocks. Some buildings cracked at Mayabandar, Diglipur and Port Blair due to another earthquake on 16 November 1962. Recently, cracks are reported to have developed at several places in concrete buildings at Mayabandar due to an earthquake of moderate intensity on 8 February 1978. Aftershock activity is a common feature in the region.

Earthquakes occur in the region at depths ranging from very shallow (within 5 km) to about 230 km. In the Andaman Islands the deepest earthquake occurred at 160 km while in the Nicobar region the focal depth increased to 229 km. The largest body wave magnitude of the earthquake as reported by ISC during 1964-1974 was 6·3.

Epicentres of recent earthquakes (1964-1974) have been plotted on the base map (Fig. 2) prepared by Peter *et al.* (1966) on the basis of reconniassance geophysical survey in Andaman and Nicobar Islands. It may be noticed that the 'interdeep' region is throughout dominated by earthquakes. Earthquakes also occur in the 'Inner volcanic arc'. Relatively, fewer earthquakes are located on the 'foredeep' region. With the exception of a small cluster of earthquakes near Lat. 7°N, Long. 91·3°E the seismic belt is narrow in the south Andaman Islands, and becomes wider northwards. The chain of epicentres east of Andaman Islands roughly along longitude 95°E is remarkable and needs more geophysical investigations.

Fig. 3 shows the depth distance cross-sections measured eastwards from longitude 92°E at the latitudes 7·5° N, 9·5° N, 11·5° N and 13·5° N (±1°). It may be noticed that the plane of dipping of the Indian plate towards east is clearly reflected from these cross-sections. The sloping focal zone appears more defined in the section at 7·5° N and it becomes rather diffuse as we proceed northwards.

Another feature that is seen in these sections as well as in Fig. 2 is the branching of the earthquake focal zones into two in the higher latitudes. While at 7·5° N latitude there is one cluster of epicentres and one sloping focal zone, at 11·5° N latitude the focal zone appears to branch into two at shallower depths giving a separate cluster near 95° E Long.

3. Space and time variations of seismicity

Fig. 4 shows the epicentres of the earthquakes of magnitude 6 and above in the Andaman-Nicobar Islands during the years 1917 to 1974. It may be noticed that no systematic migration of earthquakes either along the same tectonic features (northwards) or from one region to another occurs.

Fig. 5 (a) shows the plot of cumulative number of earthquake in the Andaman-Nicobar Islands

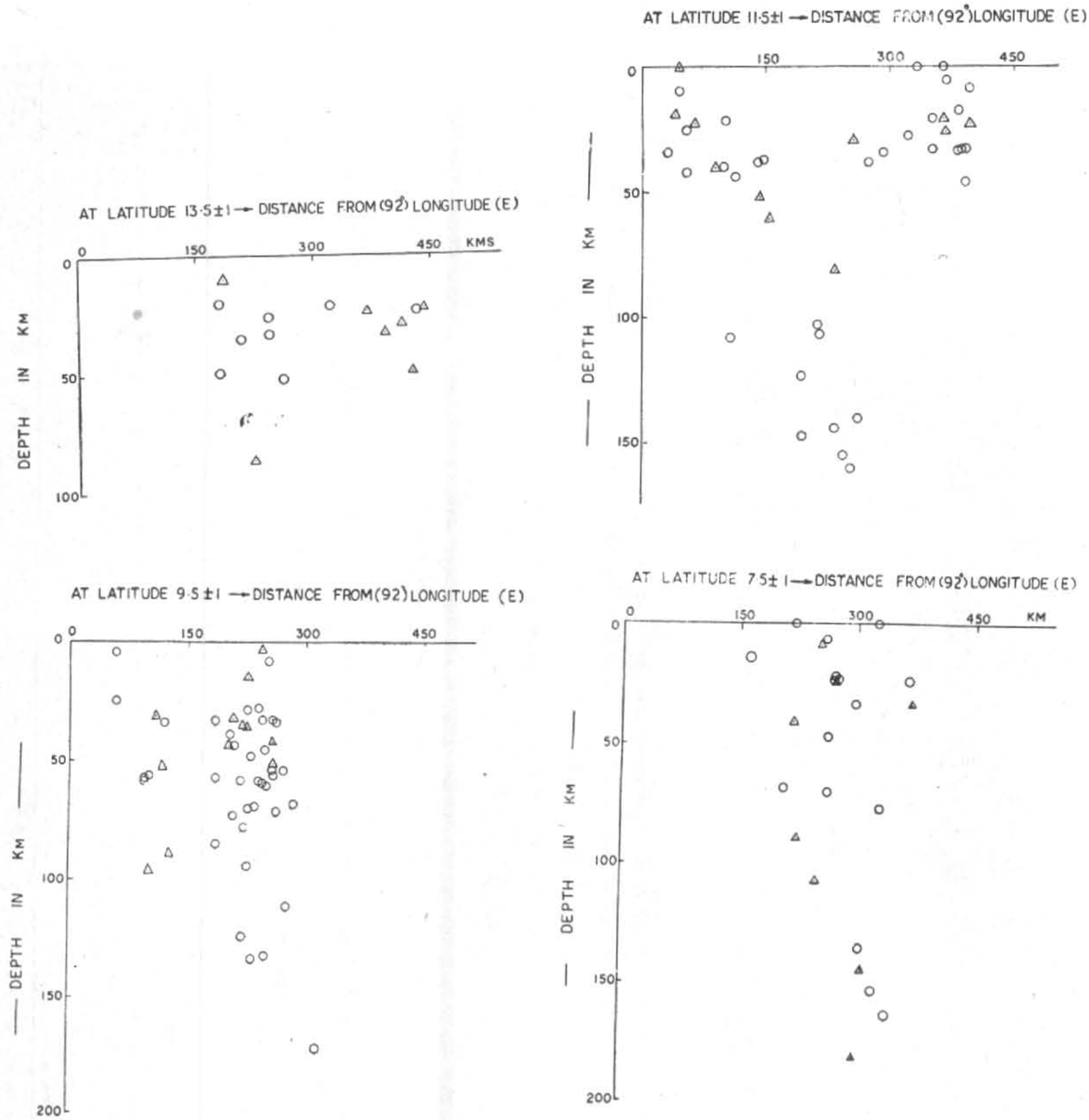

Fig. 3. Depth-distance cross-section in the Andaman-Nicobar region (1964-1974). Circles denote earthquakes upto magnitude 5 and triangles greater than 5.

region while Fig. 5 (b) gives the similar count of earthquakes restricted to north of latitude 9°N. For these studies all earthquakes included in the ISS, ISC and the other catalogues such as by Gutenberg and Richter, BCIS have been included. It may be noticed from the latter figure that there was seismic quiescence of more than ten years preceding the great earthquake of 1941. Similar results have been reported by several workers in different parts of the world (Rikitake 1976).

The cumulative numbers of events occurring within 1° and within 2° around Port Blair during the period 1967 to 1974 are shown in Fig. 6. No significant change in seismic activity observed prior to an earthquake of magnitude 5·6 in 1973. This could be due to the period of seismic quiescence if any being less than the one year interval between two consecutive points in the graph. In order to examine further the changes in seismicity associated with moderate earthquakes, the monthly number of earthquakes within 1° of Port Blair is plotted and shown in Fig. 7. In this figure the earthquakes with magnitude more than 4·5 are shown by arrows. The crustal thickness in the region is of the order of 25 km (Verma 1974) and the majority of earthquakes shown by arrow are seen to have occurred in the upper mantle.

Confining attention to the earthquakes with focal depths of less than 50 km, it would be noticed that, in general, there was an increase in the seismicity as revealed by larger number of earthquakes around Port Blair followed by a decrease prior to the occurrence of the earthquakes of Dec '70, Sep '72 and Jul '73. In the case of the event of February '74 the high seismicity in Dec'73 gave way to lower seismicity by Feb '74 and the event took place in the same month. Thus, in general the near crustal earthquakes appear to confirm Brady's hypothesis (1976, 1977).

4. Frequency-magnitude relationship

The earthquake frequency magnitude relationship is given by

$$\log_{10} N = a - bM \qquad (1)$$

where a and b are constants and N is the number of earthquakes in the magnitude range $M+dM$ and $M-dM$. This equation also enables us to compute the recurrence interval for earthquakes of various magnitudes in statistical terms. Fig. 8 shows the plot of log N *versus* M in the region.

The data has been divided into three groups. In the first case, all the data from 1917 to 1964 has been assigned surface wave mgnitudes and Eqn. (1) has been applied for the whole of Andaman-Nicobar region for all focal depths. In the second case, the body wave magnitude (ISC) data from 1964 to 1974 has been divided into two depths,0 to 33 km and greater than 33 km. b values havealso been computed separately for Andaman-Nicobar regions for both these depths by the maximum likelihood method (Aki 1965). Lastly, local magnitudes as determined from Wood Anderson seismograph have been taken within 1° radius around Port Blair for the period 1967-1974 (except for the year 1973 when the Wood Anderson seismograph remained out of commission). The results are given in Table 1. It may be seen that a lower value of b was obtained by using surface wave magnitudes. However, in general, the value of b was 1 to 1.4 when determined from body wave or local magnitudes, which is in agreement with that for Hindukush regions and northeast India (Drakopoulos and Srivastava 1972, Chaudhury and Srivastava 1976). The recurrence interval for earthquakes using different scales and data for different periods was found to be widely different (Table 1). This is attributed to the changes in the level of seismic activity during different intervals of time, and errors in the magnitude determination.

5. Focal mechanism and regional plate tectonics

The present tectonics in the Andaman-Nicobar region is shown in Fig. 9. Large arrow shows the direction of motion of the Indian plate. As indicated by Roman number I, extension in the Andaman Sea started in about oligocene to miocene time with direction of extension progressively

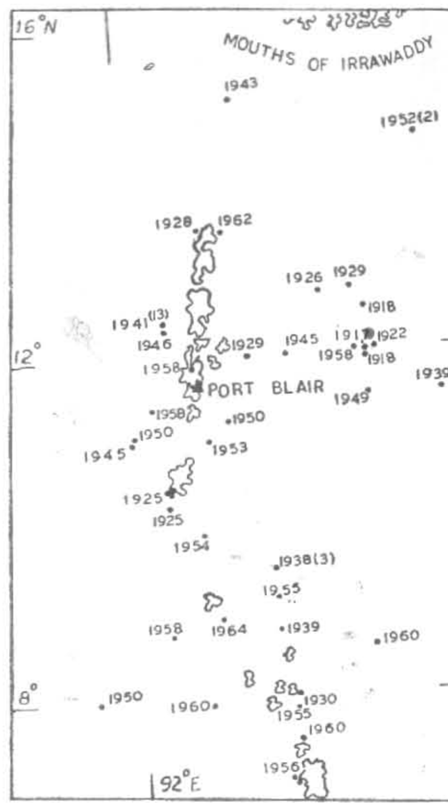

Fig. 4. Epicentres of earthquakes in Andaman-Nicobar region for earthquakes of magnitude 6 or more (1917-1974)

rotating clockwise (shown by II and III). Present rifting in the Andaman Sea, northwest southeast gives a component of subduction even along the northern Andaman Islands.

The first motion P wave data for all moderate earthquakes which occurred in the region during the years 1971 to 1975 was collected and mechanism solutions for seven earthquakes could be worked out. Seismograms of Indian observatories were personally scrutinised and while drawing the nodal planes, more emphasis was laid on the long period data. The results are given in Table 1 and also shown in Fig. 10.

Event 1 occurred in the upper mantle below the 'interdeep' in Nicobar Islands. The fault demarcated in this region was north-south and the nodal plane striking NNE taken as the fault plane agrees fairly well with the above. The dip of this nodal plane towards southeast supports the dipping postulated by the plate tectonics. Although the faulting is of thrust type it has some component of left lateral strike slip movement. Similar results were obtained for two recent Bay of Bengal earthquakes (Chaudhury and Srivastava 1974). The slip vector was southeasterly and showed thrust faulting. Tensions were oriented roughly along the strike of the fault while the pressures were obliquely inclined and more shallow. Ichikawa

TABLE 1

a and b values in Andaman-Nicobar region

S.N.	Region	Type of magnitude	Data source	a	b	Recurrence period for mag. 6 earthquake (years)	Remarks
1	1° around Port Blair	M_L	1° around Port Blair (1967-1974)	5·156	0·95	25	Using Gutenberg's Richter's relationship
2	Andaman Nicobar	M	Catalogues/ Bulletins of India Met. Dep.(1974) (1917-1964)	5·934	0·78	2·5	Do.
3	Andaman Nicobar	M_b	I. S. S. (1964-1974)	8.56	1·37	5	Do.
4	Andaman Islands (a) 0-33 km focal depth (b) 33 km	M_b	I. S. I. (1964-74)	—	1·08±0·16 0·96±0·15		Using maximum likelihood method
5	Nicobar Islands (a) 0-33 km focal depth (b) 33 km	M_b	I. S. S. (1964-1974)	—	1·08±0·16 1·45±·18		(Aki 1965)

TABLE 2

Focal mechanism of earthquakes in Andaman Nicobar Islands (1971-75)

S.N.	Date	Origin time (GMT) $h\ m\ s$	Epicentre Lat. (°N)	Epicentre Long. (°E)	Focal depth (km)	Magnitude M_b	Nodal planes I Dip dir.	I Dip angle	II Dip dir.	II Dip angle	P Az.	P Dip	T Az.	T Dip	Remarks
1	17-7-1971	05 32 43	6·98	94·65	144	5·6	339	56	116	53	138	02	204	27	Thrust
2	5-11-1971	22 11 15	10·11	92·93	53	5·9	308	71	073	40	293	17	174	53	Thrust
3	22-2-1972	18 43 38	10·42	92·48	4	5·4	098	56	353	71	292	29	218	40	Thrust
4	7-4-1973	03 00 59	7·00	91·32	39	5·8	340	40	116	60	242	26	134	85	Normal
5	9-7-1973	16 19 47	10·66	92·59	44	5·6	110	60	360	60	145	01	235	46	Thrust
6	16-2-1974	01 51 10	11·47	92·32	19	5·2	204	81	342	21	192	33	042	53	Thrust
7	15-5-1975	21 07 38	12·20	93·77	139	4·8	241	76	020	24	076	43	227	27	Normal

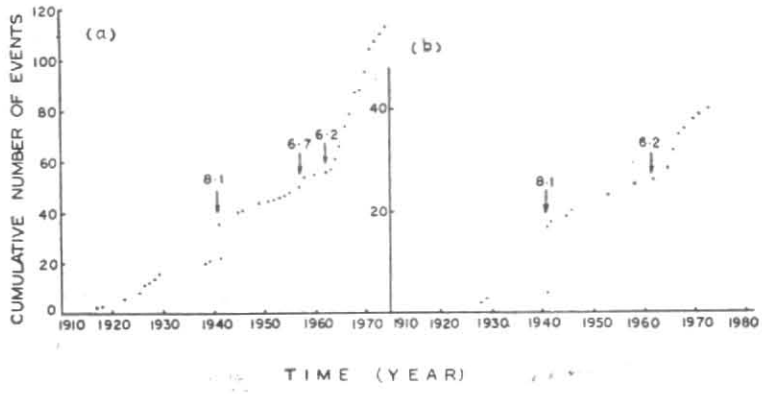

Fig. 5. Cumulative number of earthquakes in Andaman-Nicobar Islands (1917-1974)

Fig. 6. Cumulative number of earthquakes within 1° and 2° around Port Blair (1967-1974)

et al. (1972) have also observed almost similar results for an earthquake of 30 November 1964 in the vicinity.

West of foredeep, event 4 showed one of the nodal planes striking northnortheastwards dipping towards easterly direction with the tensions oriented along the dip. Pressures were obliquely inclined to the fault. The faulting was of normal type with left lateral strike slip movement. The slip vector was oriented in easterly direction. Another earthquake of 6 September 1964 located close to Andaman Islands also showed normal faulting (Ichikawa *et al.* 1972). Thus the Indian plate has started undergoing deformation near 7° N, 91° E (as is also evidenced by cluster of earthquakes) which extends till longitude 94° before undergoing thrusting (event 1).

Events 2, 3, 5 and 6 located in the Andaman Islands region showed thrusting. Event 2, which occurred in upper mantle, had one of the nodal planes oriented roughly along the movement of the Indian plate but dipping in the opposite direction to what is postulated on the basis of plate tectonics. Similar results were obtained for some earthquakes in Manipur-Burma region (Chaudhury and Srivastava 1976). If, however, slight discrepancies between the fault plane and the nodal planes are ignored, northnorthwesterly nodal plane dipping towards east may be taken as the fault plane. The strike slip movement is then, predominantly left lateral. Pressures are acting at right angles and are very shallow while tension is oriented almost along the general strike of the tectonic features. Event 3, located in the crust had one of its nodal planes roughly along the strike of the faults, dipping in easterly direction, the movement, however, being left lateral strike slip. The pressures were acting at right angles to the fault. Shallow dipping tension was inclined at a small angle. Similar results were found for the event 5 in the region. Slightly north of these earthquakes, event 6 showed that the pressures were oriented almost along the faults and tensions were inclined at an acute angle.

Event 7 occurred in the upper mantle with the pressure directions acting at right angles and the tensions inclined at acute angles to the faults in the region. Non-conformity of the nodal planes with the faults for events 6 and 7 may be attributed to the complex type of plate movements as we proceed northwards towards Burmese coast where the nature of faulting changes from island arc/type to that of continent-continent type. More focal mechanism solutions needed to be examined to understand the dominant mechanism in the region.

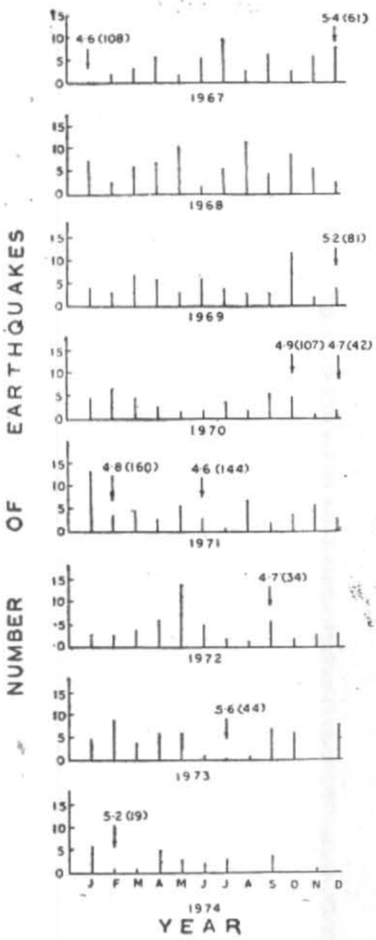

Fig. 7. Monthly number of earthquakes in Andaman-Nicobar region (1967-1974)

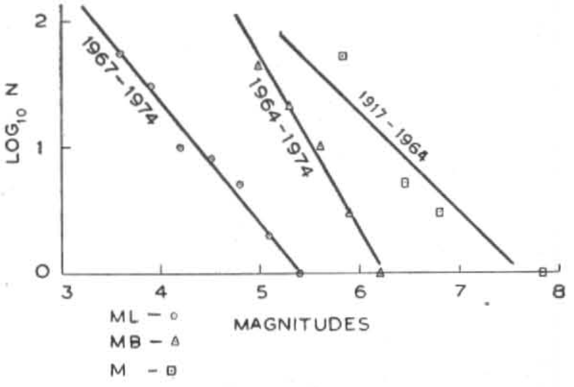

Fig. 8. Earthquake frequency magnitude relationship

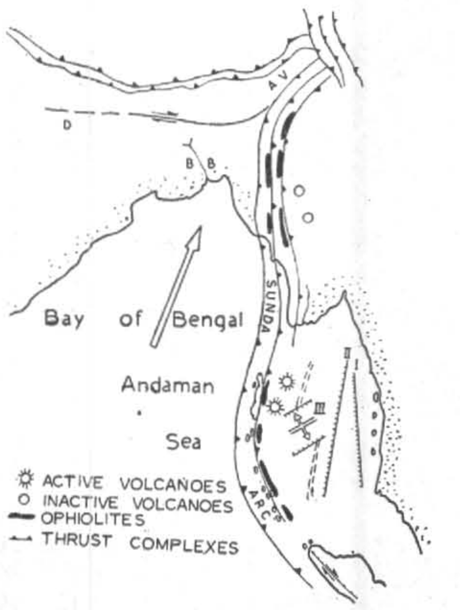

Fig. 9. Tectonics in Andaman-Nicobar Islands

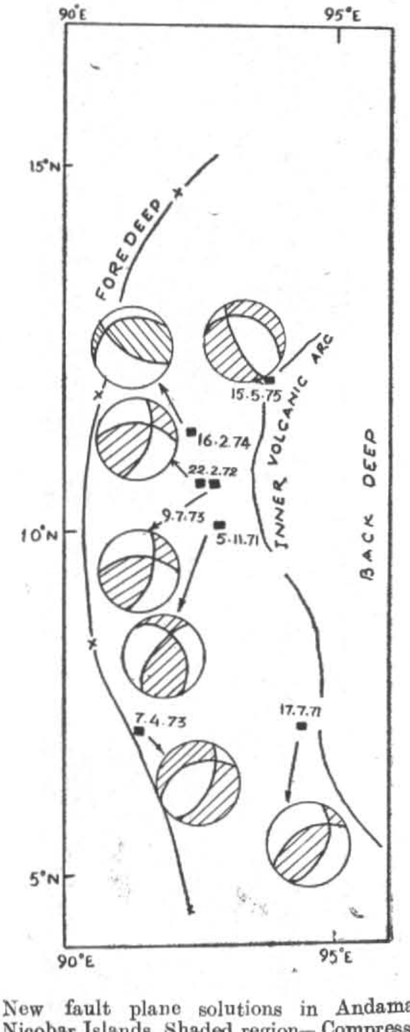

Fig. 10. New fault plane solutions in Andaman-Nicobar Islands. Shaded region– Compressions, Blank region– Dilatations.

6. Conclusions

The above study reveals the following :

1. Vertical cross-sections of epicentres in the Andaman-Nicobar regions show the dipping of the Indian plate towards east.

2. Seismicity increase followed by decrease is observed before several earthquakes in the region. No systematic migration of seismic activity in the region for earthquakes of magnitude 6 and above could be noticed.

3. The body wave and local magnitudes have given values of b as 1 to 1.4 in Gutenberg Richter's frequency magnitude relationship.

4. Earthquake mechanism solutions in Nicobar Islands region are broadly in agreement with the regional tectonics. However, the mechanism of earthquakes becomes more complicated as we move northwards.

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DISCUSSION

(Paper presented by H. N. Srivastava)

G.S. MURTY (BARC) : What is the lowest depth of the events in Andaman ?

2. Do you observe anomalies in S-wave arrival from Andáman ?

3. Can you resolve small depths of this order of 5 km?

AUTHOR : The lowest depth of the events is 5 km as given in I.S.S. catalogues.

2. This aspect has not been studied.

3. We have made use of the data as given in I.S.S. catalogues. For resolving smaller depths, a close network of stations is needed