

## Seismicity and focal mechanism of some recent earthquakes in North-east India and neighbourhood

H. M. CHAUDHURY (\*) - H. N. SRIVASTAVA (\*)

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**SUMMARY.** — The seismicity of northeast India has been studied in the light of the known geotectonic features based on the data from 1881 to 1972. New focal mechanism solutions of earthquakes using double couple hypothesis have been discussed with reference to the plate theory of global tectonics and the geological faults.

It was found that the constant  $b$  in Gutenberg-Richter's frequency magnitude relationship was nearly 1 for both the periods of observations namely 1920-1972 and 1963-1972 which was in agreement with the other highly seismic regions of the world. Most of the new fault plane solutions show significant strike slip movements with thrust faulting in this region. Near the main boundary fault in northeast Himalaya, the pressures are oriented almost along the strike of the fault while along the Manipur-Burma border region, the pressures are acting at right angles or at acute angles to the mountains and are shallow dipping.

**RIASSUNTO.** — La sismicità dell'India nord-orientale è stata studiata alla luce delle conoscenze delle caratteristiche geotettoniche basate sui dati relativi al periodo 1881-1972.

Nuove soluzioni del meccanismo focale dei terremoti, ottenute usando l'ipotesi della doppia coppia, sono state discusse secondo la teoria a placche della tettonica globale e delle faglie geologiche.

Si è trovato che la costante  $b$  nella relazione frequenza-magnitudo di Gutenberg-Richter ha valore pressoché identico ad 1 per i periodi di osservazione 1920-1972 e 1963-1972, cosa, questa, in accordo con le altre regioni del mondo ad elevata sismicità.

Moltissime delle nuove soluzioni del piano di faglia mostrano significativi movimenti nella direzione di scorrimento con fagliature di spinta in questa regione.

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(\*) Seismological Division, India Meteorological Department, Lodi Road, New Delhi 3, India.

Presso il limite della faglia principale, nell'Himalaya nord-orientale, le pressioni sono orientate per lo più lungo la direzione di faglia, mentre lungo la regione di confine Manipur-Burma, le pressioni agiscono ad angolo retto o acuto nelle montagne e con pendenza superficiale.

## 1. - INTRODUCTION

The northeast Indian region is one of the well known seismically active regions of the world, where two of the largest Indian earthquakes of 12 June 1897 and 15 August 1950 have occurred causing widespread damage. Being close to the junction of the Himalayan and Burmese arcs the region bears resemblance to that of Pamir knot at the other extremity of the Himalayas. In view of its exceptional seismotectonic interest, we discuss in this paper the seismicity of the region based on earthquake data from historical times upto 1972. New focal mechanism solutions in the region have been discussed in the light of plate tectonics and geological faults.

## 2. - GEOTECTONIC FEATURES

Besides the main boundary fault near the Lesser Himalayan foot hills, the region is bounded in the east by Patkai-Naga-Lushai ranges, striking NNE-comprising Tertiary and Cretaceous sediments intruded by ophiolites. The extension of the Naga thrusts to the southwest is called Disang thrust which extends as Haflong fracture zone and joins the east-west striking Daeki fault. Parallel to it, a number of faults having southerly dip have been found. Of greater seismological interest is the Shillong plateau of archaic shield of altitude about 2 kms, which has been affected by several large earthquakes shown in figure 1. The western and the northern boundaries of the plateau follow the Brahmaputra river. On its southern side, the old rocks of the plateau are thrust over the Haflong-Disang fault zone. The western edge of the plateau is limited by the Dhubri tear fault on which the great earthquake of 1930 occurred. Thus, the seismic activity of the plateau is controlled by the East-west, Northwest-southeast and north-south trending basement faults which are causing the earthquakes. The Shillong shield extends northeastward as a foreland under the Brahmaputra alluvium.

The geology of the eastern syntaxis of the Himalayas is quite complex. In the area between the Siang valley and the Nao-Dihing

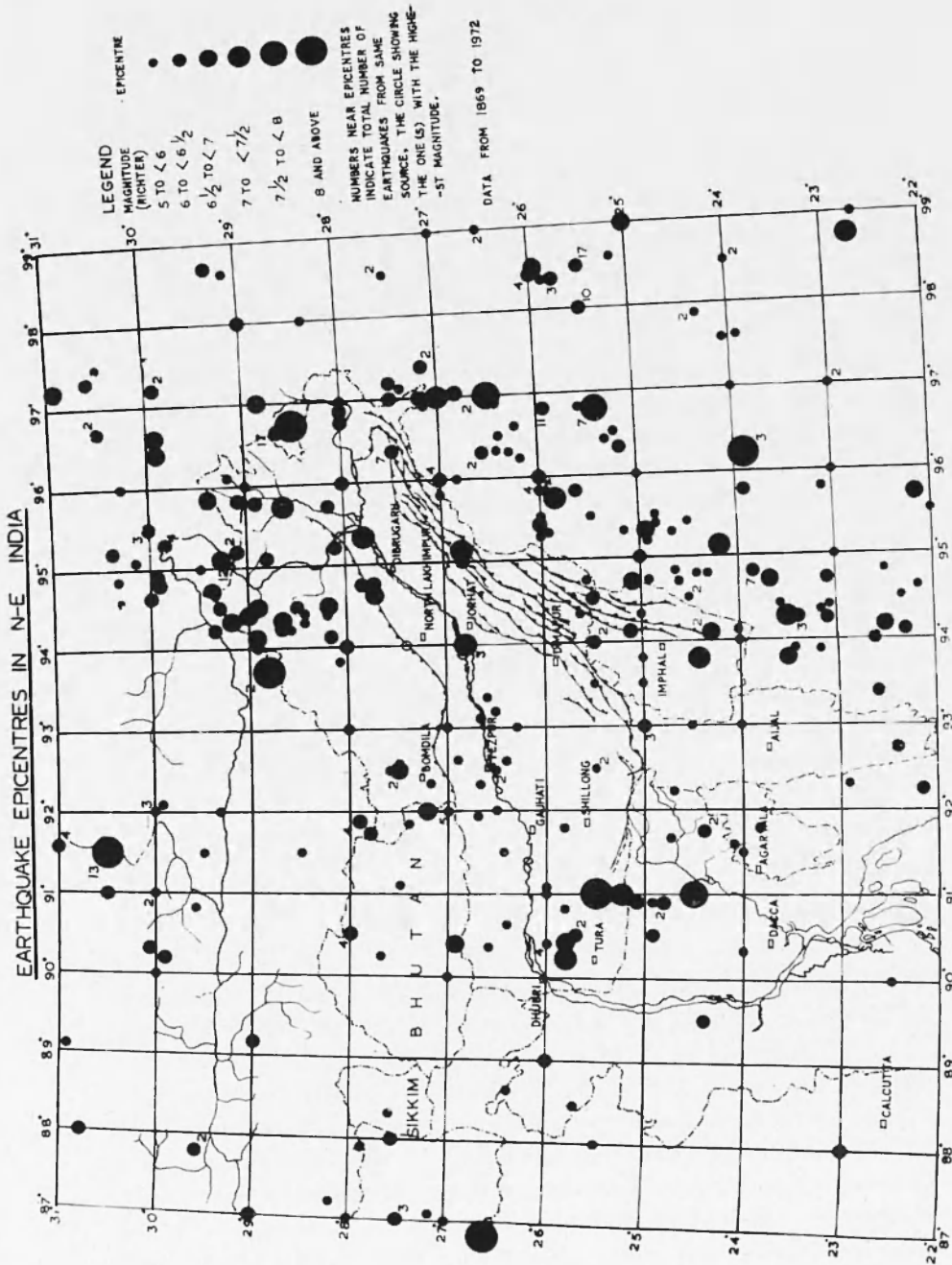


Fig. 1 - Spatial distribution of earthquakes in Northeast India.

valley, two major thrusts called the Mishmi thrust and the Lohit thrust have been mapped. The Mishmi thrust trends WNW-ESE in the Nao-Dihing valley from Kumki ( $27^{\circ}15' N - 96^{\circ}00' E$ ) and continues upto Dibang river where it turns westward joining the main boundary fault of the Himalaya foothills. This thrust is concealed under the alluvium in the Lohit river section. It has also obliterated the Naga thrust in Tirap district. The Lohit thrust has been mapped from the Chulum pass ( $27^{\circ}47'45'' N, 96^{\circ}41'55'' E$ ) to near Endoline ( $28^{\circ}30'40'' N, 95^{\circ}31'25'' E$ ) in the Dibang valley for about 200 kms. In general, both these thrusts dip in northeasterly direction with dip angle varying from  $30^{\circ}$  to  $75^{\circ}$ .

Thus the syntaxis of northeast India has resulted from the meeting of the three independent tectonic units namely, western Arunachal Pradesh Himalaya with the Lohit Himalaya along the Siang river section and the Lohit Himalayan block with the northward extension of the Naga-Manipur-Arakan Yoma block along the Mishmi thrust.

A very long tear fault near Bangla Desh - Assam border is called Madhupur fault with the eastern segment moving southwards and is seismically active.

Inside Burma, two arcuate mountains are separated by the valley of the Irrawaddy river. Along the outer Arakan-Yoma arc, several important shocks were reported. A boundary fault (separating the younger sediments from the Archean and unclassified crystalline rocks exposed at the margin of the plateau) has been mapped from east of Rangoon to Mandalay.

### 3. - SEISMICITY OF THE REGION

In the northeastern region there were so far only two seismological observatories at Shillong and Tocklai. While the observatory at Tocklai is equipped with Wood-Anderson seismographs at 1000 magnification, the one at Shillong being located on quartzite sandstone, is equipped with a set of short period Benioff Seismograph under WWSSN scheme working at a peak magnification of 200k. From the analysis of seismograms for events within the epicentral distance of  $4^{\circ}$  around Shillong, it may be mentioned that about 2500 earthquakes were recorded during the years 1970-1973. The magnitudes of most of the events were too small to be determined by the Wood An-

person seismographs. Their distribution at every half a degree distance interval around Shillong is given in figure 2. It may be seen that the maximum number of events occurred within the epicentral range of 0.6 to 1.0 degree, while about 50% of the total number of events oc-

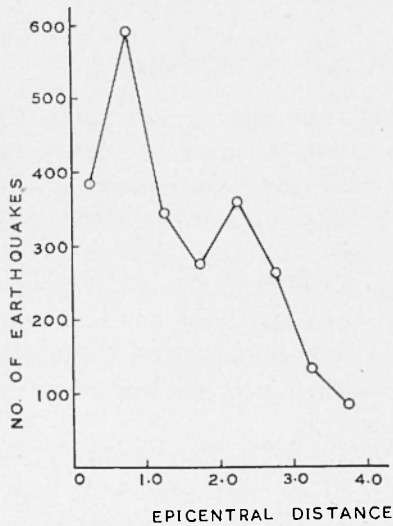


Fig. 2 - Earthquakes with  $4^{\circ}$  around Shillong.

urred within 1.5 degree. This would emphasize the active seismicity of the Shillong plateau. In view of the lack of data for determining the epicentres of microearthquakes the relative seismic status of the faults around the Shillong plateau could not be assessed.

The seismicity of the region had thus to be studied based on the epicentral determination of moderate to great earthquakes. A catalogue of earthquakes was prepared for all earthquakes of magnitude 5 and above on the basis of historical and instrumental data upto 1972 from the following sources:

- a) Report of the British Association for the advancement of Science, 1911.
- b) Catalogue of earthquakes by T. Oldham from historical times to 1869.
- c) Monthly weather review (1891-1937).

- d) Seismicity of the Earth by Gutenberg and Richter (1904-1954).
- e) I.S.S. (1916-1958).
- f) B.C.I.S. Strasbourg (1959-1962).
- g) U.S.C.G.S. Epicentre data sheets (1963-1972).
- h) India Meteorological Department Seismological Bulletins (1938-1972).
- i) Bulletins of the I.S.C. (1964-1970)

The epicentres of these earthquakes during the period have been plotted for northeast India in figure 1. The magnitudes of the shocks not reported in International Seismological Bulletins were indirectly assessed on the basis of the epicentral distance upto which the shocks were recorded. For this purpose, all the shocks which were recorded at distances more than 100 degrees were assigned magnitudes greater than 6, while the shocks clearly recorded between 40 and 100 degrees had their magnitudes assigned between 5 and 6. An independent check of the method adopted here with the magnitudes reported in B.C.I.S. showed good agreement.

In figure 1, the size of the earthquake circles indicates as per legend the magnitude of the earthquakes. It may be seen that while Assam as a whole is highly seismic, there are regions of very high seismicity with other small areas of comparatively less activity. The north-east corner of Assam where the river Brahmaputra cuts through the Himalayas and enters the valley, the western end of the Assam plateau and the region bordering Assam, Manipur and Tripura may be seen to be the sources of a majority of the earthquakes. These bear close relationship with the broad tectonic features discussed earlier.

The earthquake frequency magnitude relationship is given by:

$$\log_{10} N = a - bM \quad [1]$$

where  $a$  and  $b$  are constants and  $N$  is the number of earthquakes in the magnitude range  $M + dM$  and  $M - dM$ .

Figure 3 shows the plots of the data marked I and II for the periods 1920-1972 and 1963-1972 respectively. Although the list of earthquakes included events occurring much earlier, data from 1920 onwards only were used due to their reliability. It may be seen that the value of  $b$  comes out as nearly 1.0 in both the cases.

Another method for estimating the value of  $b$  has been proposed by Aki (1965)<sup>(4)</sup>. The *maximum likelihood estimate* of  $b$  for a certani

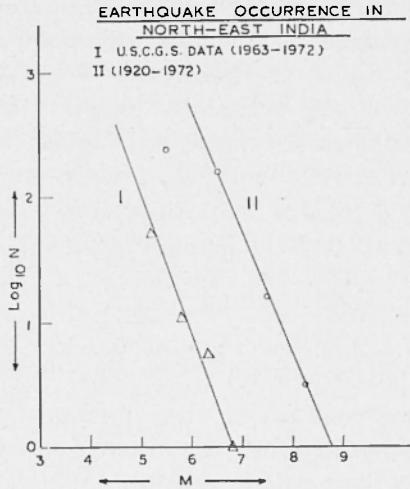


Fig. 3 - Magnitudes-frequency relationship of earthquakes.

earthquake group which follows the Gutenberg-Richter's relations is given by:

$$b = \frac{0.4343}{M - M_0} \quad [2]$$

where  $M$  and  $M_0$  denote the mean and the lower limit of magnitude from each earthquake group. The upper and lower limits of confidence of  $b$  for 95% probability are  $\pm \frac{1.96}{\sqrt{n}}$ , where  $n$  is the number of earthquakes.

Taking the lower limit of  $M_0$  as 5.0, the value of  $b$  comes out as  $1.08 \pm 0.24$ . This is in agreement with that reported by Evernden (1970) (2) for an area within 1000 km of Shillong (Fig. 2). This value of  $b$  in the present study is consistent with the results of Karnik (1964) for Alpine folding system, Miyamura (1962) (6) for circum-Pacific and Alpidic belts and Tandon and Chatterjee (1967) (10) for Himalayan region.

The value of  $b$  is dependent upon the degree of heterogeneity and symmetry of the applied stress. In this connection it may be mentioned that Molnar et al (1973) (7) have inferred a lower  $b$  value in this region, and took this as one of the indications of higher shear stress in Asia than in most regions. Their inference of the lower  $b$  value in the region was drawn indirectly from the fact that there are relatively fewer

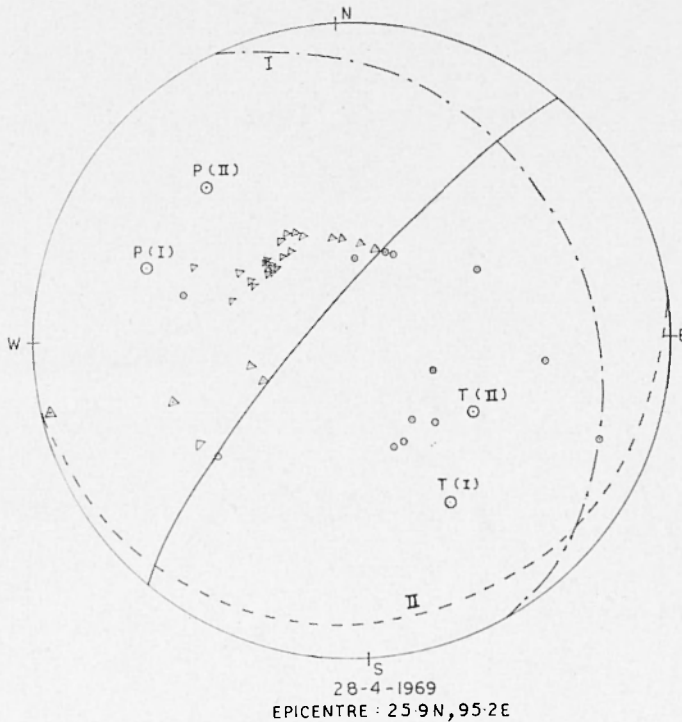
events from this region for which fault plane solutions could be determined indicating a deficit in the number of earthquakes of magnitude between 5 and 6 in comparison to the number of great earthquakes. Instead of bringing in the availability of the fault plane solutions, the occurrence of earthquakes of various magnitudes has been studied directly by us from the list of events recorded so far (by Evernden 1970) <sup>(2)</sup> and from the reliable data available in the recent past. Both these studies suggest that the value of  $b$  is not low in this region.

#### 4. - FOCAL MECHANISM AND PLATE TECTONICS.

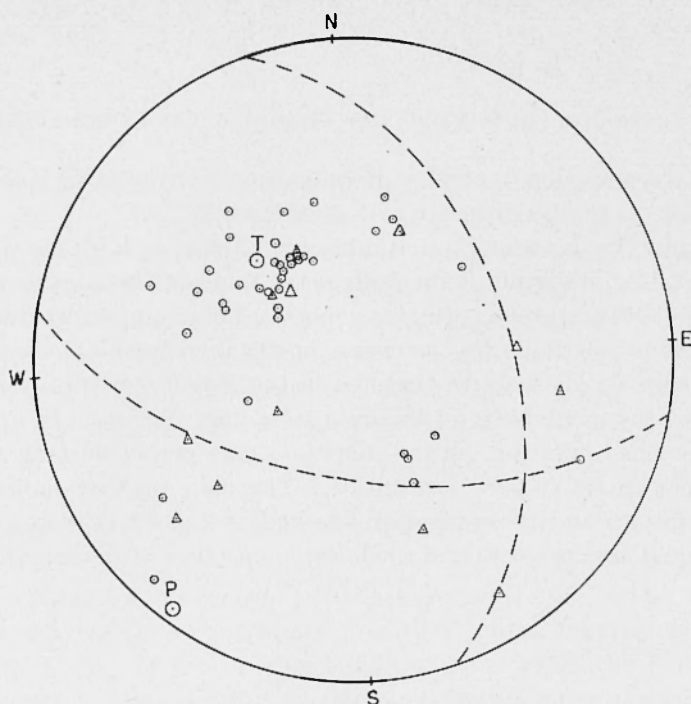
According to the concepts of Plate Tectonics the Indian Plate is moving in a north-north-easterly direction and is underthrusting the Eurasian Plate. In the northern collision zone along the Himalayas, this underthrusting should be revealed in the mechanism of earthquakes by a northerly slip vector and along the eastern Indian Boundary zone where the Indian Plate encounters the Burmese mountains by slip vectors directed towards the east. Study of the focal mechanism from the first motions from earthquakes occurring in the above zones have been reported by Fitch (1970) <sup>(3)</sup>, Oike (1971) <sup>(8)</sup>, Ichikawa et al. (1970, 1972) <sup>(4,5)</sup>, Molnar et al. (1973) <sup>(7)</sup>. Fitch (1970) <sup>(3)</sup> in his studies which were, however, based on limited data concluded that the mechanisms were consistent with underthrusting on a plate dipping towards north, namely beneath the Himalayan mountain fronts. Along the mountain range of Burma, he found that for intermediate depth earthquakes in the downward descending lithospheric plate the tension axes were oriented down the dip of the descending plate. These were consistent with the plate tectonics. However, Ichikawa et al. (1972) <sup>(5)</sup> and Tandon and Srivastava (1975) who studied a large number of earthquakes did not find such a consistent relationship between the focal mechanism solutions and the above concepts. In eastern India they found that the pressure and tension axes whose plunges were shallow nearly parallel and perpendicular to the mountain ranges. In the Burma region also the pressure axes were found to be nearly parallel to the trend of the mountains. Molnar et al. (1973) <sup>(7)</sup> while finding support for the underthrusting by the Indian plate remark that in eastern India the slip vectors do not give the direction of relative motion between the Indian Plateau and the Tibetan Plateau, from the computed pressure directions, however, they conclude that in

the Himalayan region in north-east India the underthrusting is towards north whereas in the Burma region it is towards east.

It may be mentioned that although Fitch and his co-workers (1970-1973) (3,7) determined the fault plane solutions from seismograms of the WWNSS stations, the first motion data from observatories in USSR, China and India for the events in this region were not included. The dip slip thrust faulting expected in the region is critically dependent upon the availability of the data from near stations. In order to overcome this limitation, all the short and long period seismograms of 30 stations in India were scrutinised. The data thus available from Indian stations and those given in the bulletins of I.S.C. were plotted on the equal area projection of the lower hemisphere of the focal sphere.



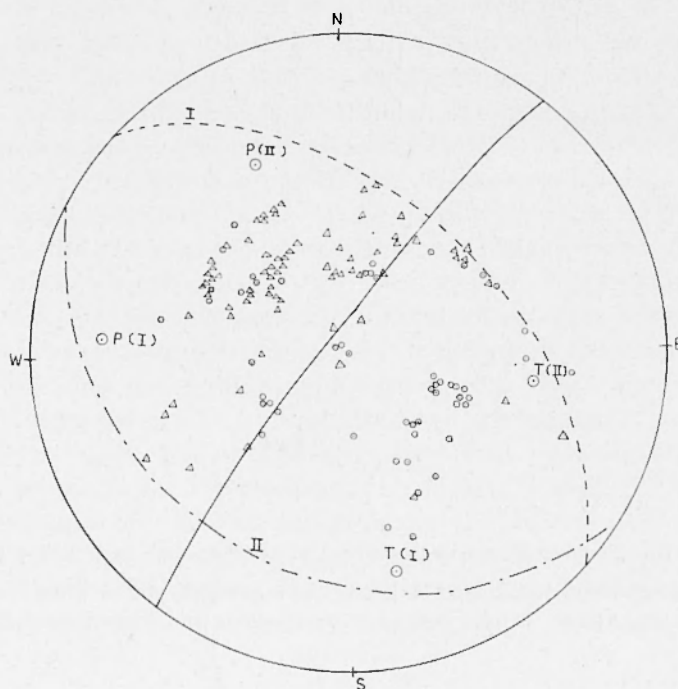
Figs. 4-11 - Focal mechanism solutions of earthquakes in northeast India. The Roman subscripts I and II denote two possible nodal planes and the corresponding stress. Circles indicate compressions and triangles rarefactions.



DATE 19.2.70

EPICENTRE 27.4N ; 94.0E

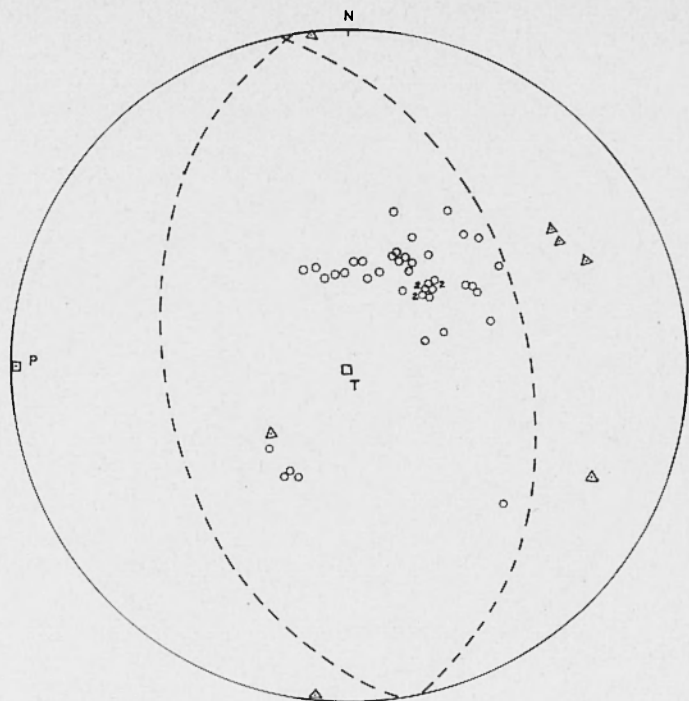
Fig. 5



29-7-1970

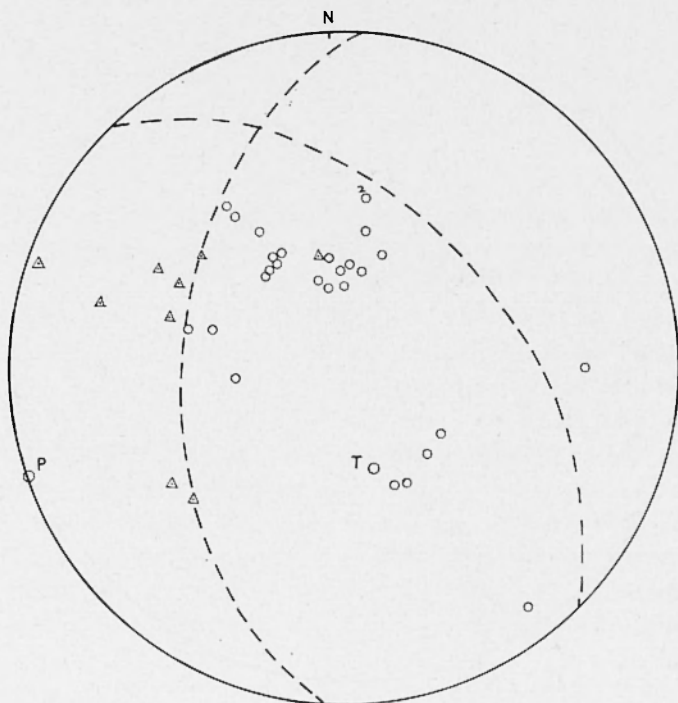
EPICENTRE 26.0N, 95.3E

Fig. 6



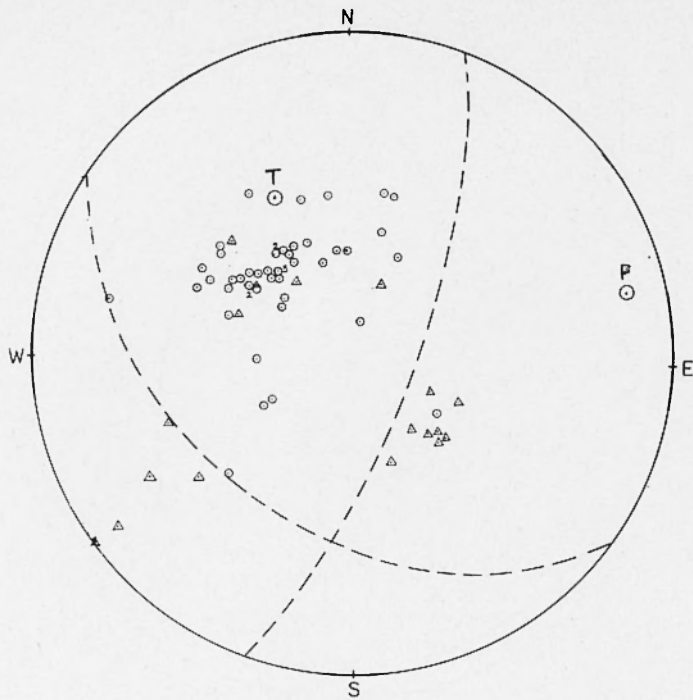
2. 2. 71  
23.71 N, 91.66 E

Fig. 7



26. 6. 71  
24.60N, 94.78E

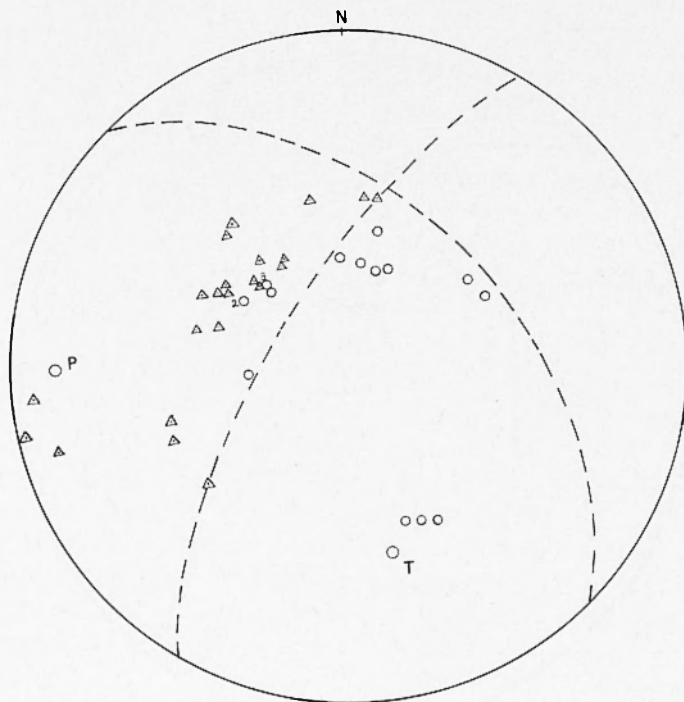
Fig. 8



DATE 17.7.71

EPICENTRE 26.4 N; 93.2 E

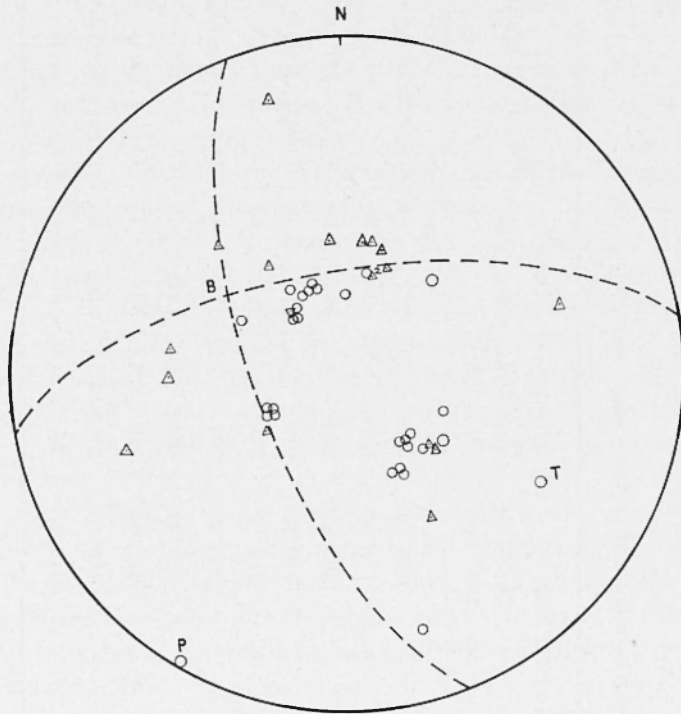
Fig. 9



1.11.72

26.44 N, 96.37 E

Fig. 10



28.4.72  
16.99N, 94.85E

Fig. 11

While drawing the nodal planes, more emphasis was laid on the good quality long period data of WWNSS stations. The fault plane solutions for the new events are shown in figures 4-11 and the results are given in Table 1. It may be mentioned that the two nodal planes could be fairly well drawn for all the events except in the case of events 1 and 3 of the Table 1 where it was possible to draw only one nodal plane unambiguously. Due to lack of data from the near stations in some azimuths, we have drawn the limits within which the other nodal planes could be fitted on the basis of the orthogonality criteria. In these two cases, the nodal planes have been shown by dotted lines. It may be seen that in these cases, while there could be a remarkable difference in the dip and the strikes of the second nodal plane, the orientations of the stresses showed lesser variation.

TABLE 1.

Focal mechanism of some recent earthquakes in northeast India and Burma.

No	Date	Origin time h m s	Epicentre		Depth (km)	Nodal Planes				Pressures		Tension		Type of faulting
			°N	°E		Dip Dir. Angle	Dip Dir. Angle	Dip Dir. Angle	Dip Dir. Angle	Azim.	Plun- ge	Azim.	Plun- ge	
1.	28. 4.69	12 50 15	25.9	95.2	68	312 22	a.	063 27	292	35	123	45	Thrust, strike slip	
							b.	173 13	320	37	150	55		
2.	19. 2.70	07 10 02	27.4	94.0	52	074 50		193 60	220	06	321	55	Thrust, strike slip	
3.	29. 7.70	10 16 25	26.0	95.3	59	312 84	a.	046 50	275	20	172	33	Thrust, strike slip	
							b.	210 30	335	35	102	43		
4.	2. 2.71	07 59 56	23.8	91.7	37	282 46		099 45	091	01	179	89	Thrust, dip slip	
5.	26. 6.71	02 16 37	24.6	94.8	94	276 51		050 41	254	01	166	66	Thrust, strike slip	
6.	17. 7.71	15 00 56	26.4	93.2	52	110 84		217 47	080	18	333	45	Thrust, strike slip	
7.	28. 4.72	11 30 17	17.0	94.8	28	248 68		349 66	210	01	120	35	Thrust, strike slip	
8.	01.11.72	21 53 46	26.4	96.4	93	302 73		047 50	270	04	167	45	Thrust, strike slip	

Events 1,3, and 8 occurred close to Naga thrust near Indo-Burma border where the motion though predominantly strike-slip indicated some thrusting as well. Also, the pressures were at right angles or inclined at an acute angle to the seismic zone and were rather shallow. It was however interesting to note that the uniquely determined nodal planes are oriented along the Naga thrusts but their dips are opposite to what is shown by the tectonic map prepared by the Oil and Natural Gas Commission or the Geological Survey. According to the focal depths reported by the Bulletin of the I.S.C. all these events occurred in the Upper Mantle. Tandon and Srivastava (1974) have also reported similar results for some earthquakes. An additional solution reported by Tandon and Mukherjee (1954)<sup>(9)</sup> for the Manipur-Burma border earthquake of 22 March 1954 indicated thrust faulting striking N 50°E dipping towards northwest at an angle of 60°.

Event 2 which occurred in close proximity to the main boundary fault showed that while the orientation of the fault was north-north-east, one of the fault planes was inclined towards north-north-west. The pressure directions were rather parallel to the strike of the fault with the predominance of strike slip faulting. Similar results were reported by Ichikawa et al. (1972)<sup>(5)</sup>. Tandon and Srivastava (1975)<sup>(11)</sup> have, however, found that the pressures for the earthquake of 30 June, 1969 were oriented almost at right angles to this fault. Event 6 occurred slightly south of River Brahmaputra but detailed geological information near the epicentre was not available. If the nodal plane striking north-west is assumed to be the fault (on the considerations that the thrusts south of Brahmaputra river are dipping towards the south), the pressures are acting within 45 degree of the strike of the fault. However, if the strike directions are assumed to be less reliable than the pressure directions determined, the pressures are almost directed along the strike of the faults similar to event 3 near the main boundary fault.

Event 5 which was located close to Manipur-Burma border showed that the pressures were acting almost at right angles to the faults and the steeply dipping tensions lie rather parallel to the Naga thrusts. If northerly plane is chosen to represent the fault plane, the dip is in opposite directions to geological fault as found for the events 1,3 and 8.

Event 7 occurred in Burma where the pressures were inclined at acute angle to the thrusts and were almost horizontal.

Event 4 which occurred near Bangla Desh-India border showed dip slip thrust faulting with the pressure directions almost horizontal

and at right angles to the strike directions of either of the nodal planes. Although detailed geological information is lacking, the mechanism solution postulates the existence of northerly faults in the region almost parallel to the Arakan Yoma Burmese mountains. This well determined solution is in conformity with the concept of the plate tectonics.

Table 1 shows that except for event 1, the nodal planes of all the events are steeply dipping whichever is chosen as the fault plane. Further except for the event 4 and in Burma, and Bangla Desh-India border all the earthquakes occurred in upper mantle. If therefore, the nodal plane oriented along the strike of the geological faults is chosen as the fault plane, it would call for further investigations to explain the oppositely dipping fault plane postulated along Manipur-Burma border.

Towards resolution of this problem further studies of earthquake mechanism with the help of well distributed and reliable data are needed.

## 5. - CONCLUSIONS

The above study brings out the following results:

1. - The frequency magnitude relationship has given  $b$  values as nearly 1.0 which is consistent with the results for Alpine folding system and circum-Pacific belts.

2. - All the fault plane solutions in this paper show thrusting with significant strike-slip movements in northeast India except for the event of February 1971 near Bangla-Desh India border.

3. - The new fault plane solutions which could be associated with the main boundary fault indicated that the pressures were shallow and almost oriented along the strike of the fault.

Along Manipur-Burma region, the pressure directions were acting at right angles or at acute angles to the mountains and were shallow.

4. - While the strike determined from one of the nodal planes is oriented along the thrusts, the corresponding dip has been found to be opposite to what has been postulated by the geologists except for the earthquake located near Bangla Desh-India border.

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