Fault plane solutions as related to known geological faults in and near India

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Summary. — Based on the focal mechanism solutions of newly determined solutions, and other recent workers the correlation between one of the nodal planes and the geological faults has been discussed for three regions namely Kashmir, Central Himalayas and northeast India including Assam. The variability between multiple solutions reported for some earthquakes and the limitations in the choice of the nodal plane from *P*-wave solutions have been brought out.

It is seen that no standard criteria either on the basis of isoseismals or of aftershocks can be used to distinguish the fault plane from the auxiliary plane. It has been found that in general there is good agreement between one of the nodal planes and the geological faults in Kashmir and the Central Himalayas. In northeast India, the strike directions obtained from the mechanism solutions generally agree with the trends of the main thrusts but the dip direction for shocks originating in the India-Burma border is generally in opposite direction than postulated by the geologists.

Riassunto. — Viene discussa, basandosi su soluzioni più o meno recenti del meccanismo focale, la correlazione fra uno dei piani nodali e le faglie geologiche relative a tre regioni, il Kashmir, l'Himalaya centrale e l'India nord-orientale, Assam compreso. Sono state messe in luce le diversità fra le molteplici soluzioni riportate per alcuni terremoti e le limitazioni nella scelta delle soluzioni del piano nodale ottenuto dalle onde *P*.

Si vede come non possano essere usati criteri standard né basandosi sulle isosisme né sulle repliche, per distinguere il piano di faglia da quello ausiliario.

In generale è stato trovato che c'è buon accordo fra uno dei piani nodali e le faglie geologiche nel Kashmir e nell'Himalaya Centrale. Nel-

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l'India nord-orientale la direzione nelle stratificazioni ottenuta dalle soluzioni del meccanismo, di solito concorda con l'orientamento delle spinte principali, mentre la direzione di inclinazione per le scosse che hanno origine al confine fra l'India e Burma è generalmente in senso opposto a quella stabilita dai geologi.

1. Introduction

The concept of Plate Tectonics offers a unified theory to explain satisfactorily such phenomenon as the sea floor spreading, bending of Ocean Trenches, continental drift volcanic eruptions, earthquakes and their occurrence along specified belts. According to this theory the surface of the earth can be divided into several distinct plates some of which are stationary while the others are moving. Earthquakes occur near the boundary of these plates. There are usually four types of boundaries namely at the crest of the mid oceanic ridges: (1) where the motion is due to tensile stresses; (2) the underthrusting of oceanic plate below the continent type plate into the mantle, such as in oceanic trenches; (3) boundaries along which the two plates move horizontally causing a *"strike slip"* motion, as along the San Andreas Fault in California; (4) boundaries along which two continental type plate collide as in the case of the Indian plate and the Asian plate. In a oceanic-continental type collision earthquakes are distributed along a narrow belt while in the case of a continent-continent collision they occur along a wide zone.

In order to study the type of motion which occurs along these plate boundaries focal mechanism solutions of earthquakes provide very valuable information. In addition to the faults located near the boundary of global plates, many other faults are located within the plates themselves. Correlation of these local geological faults with the observed fault plane solutions is of significance from the point of view of regional tectonics.

The object of this paper is to discuss the fault plane solutions of earthquakes in and near India in relation to the observed fault parameters. The discussion is based on 10 newly determined focal mechanism solutions from the P-wave first motion data whose details will be published elsewhere. In addition, we have included the solutions of Ichikawa et al. (1972)([12]) whose results were earlier interpreted only with reference to the main boundary faults along the foothills of Himalayas. Ichikawa et al. (1972) ([12]) surmised that *"focal mechanisms* *for such smaller earthquakes as used in the present study change often systematically from zone to zone in connection with local geology''.*

2. Limitations of Focal Mechanism Solutions

Before discussing the correlation between focal mechanism solutions and geological faults it may be worthwhile to examine the uncertainties inherent in such solutions. Very often a number of solutions are obtained for the same earthquake due to shortcomings in the data. Even after obtaining a good solution it is not possible to say with certainty as to which of the two nodal planes obtained in the solution represents the fault plane. Table 1 gives a list of such earthquakes occurring in India and the different solutions obtained by various workers. It will be seen that for earthquakes originating near the Nepal India border and those originating in the Koyna region (Maharashtra) the solutions differ rather widely. In some cases, for example the Koyna earthquake, there is a difference of opinion even in the nature of faulting which ranges from strike slip to dip slip. In the case of intermediate depth earthquakes such as those occurring in the Hindukush, the agreement between the solutions of various workers is much better. The discrepancies observed may be due to a number of causes, such as the use of data obtained only from published bulletins without consulting the original records or inclusion of doubtful first arrivals (weak) from long period records. The use of data obtained from distant observatories for shocks of magnitude less than 5.5, may also lead to unreliable solutions particularly because of lower magnification of long period seismographs. In this connection, Nowroozi (1972) ([16]) discussed the affect of crustal velocities on earthquake mechanism solutions since they influence the angle between the downward vertical and the seismic ray at the source. He found that the uncertainties of the crustal parameters have little affect on solutions which have a predominance of strike slip motion on a steeply dipping fault. The differences in the crustal velocities have however, significant effect for near stations and thus considerably influence the solutions which have a component of dip slip movement. These considerations have a special significance for earthquakes occurring in the foothills of the Himalayas where regional variations in velocities exist and dip slip mechanism may be predominant.

Table 1 – MULTIPLE SOLUTIONS OF SOME EARTHQUAKES IN AND NEAR INDIA.

No	Date	Epicentral parameters °N	°E	Region		Pressure Az. (Degrees)	Pl.	Tension Az. (Degrees)	Pl.	Type of faulting	Nodal planes 1 Strike	Dip	2 Strike	Dip	Reference
1.	1965 Mar 14	36.3	70.7	Hindukush	a)	215	15	35	75	DS, Thrust	—		—		Ritsema (1966) [18]
		15h 53m 07s			b)	184	23	10	67	DS, Thrust	—		—		Oike (1971) [17]
		219 km.			c)	220	14	40	76	DS, Thrust	—		—		Ichikawa et al. (1972) [12]
					d)	210	20	25	65	DS, Thrust	—		—		Nowroozi (1972) [16]
2.	1966 Jun 27	29.7	80.9	Nepal India border	a)	206	6	93	80	DS, Thrust	—		—		Fitch (1970) [6]
		10h 41m 9s			b)	212	18	9	71	DS, Thrust	—		—		Chandra (1971) [3]
					c)	—		—		SS, Thrust	—		—		Chauhan et al. (1973) [5]
		20h 69m 28s (aftershock)			d)	329	25	214	42	Thrust, ambiguous					Ichikawa et al. (1972) [12]
3.	1967, Dec 10	17.4 22h 51m 19.0s	73.8	Koyna	a)	—		—		SS, Thrust	26	66	110	74	Tandon and Chaudhury (1968) [27]
		8 km.			b)	—		—		DS, Normal	328	90	—	0	Gupta et al. (1969) [9]
					c)	—		—		SS, Thrust	37	72	126	84	Lee and Raleigh (1969) [15]
					d)	—		—		SS, Thrust	350	80	146	70	Khattri (1970) [13]
					e)	—		—		SS, Thrust	15	75	110	90	Sykes (1970) [22]
					f)	—		—		SS, Thrust	23	70	—	—	Tsai and Aki (1971) [29]
					g)	159	10	66	08	SS, Thrust	22	20	112	88	Banghar (1972) [2]

SS: Strike slip
DS: Dip slip

3. Choice of Nodal Planes

As pointed out earlier, each mechanism solution gives a choice of two nodal planes either of which may represent the fault plane. It is not possible to find out from observational data alone as to which of the solutions represents the fault plane. Different workers have used various criteria for choosing the correct solution, the most common being the consideration based on the local tectonic features. In addition to these, some workers have used the trends in isoseismals, epicentral parameters of the aftershocks and the orientation of observed ground fissures. Only in very rare cases surface faulting has been observed during an earthquake. In the case of San Fernandos earthquake of 1971, Whitcomb et al. (1973) ([32]) found that there was a close correspondence between the fault plane, the hypocentral locations of aftershocks and regional geology. The criteria used for some of the important Indian earthquakes is discussed below. The isoseismals for these earthquakes are shown in figure 1.

3.1. *Great Assam Earthquake 1950.*

The isoseismals of the great Assam Earthquake being elongated in a general east west direction and their tendency to come close together south of the epicentral tract in comparison to north enabled Tandon (1955) ([25]) to choose the first nodal plane as the fault plane in agreement with the trend of geological faults. Tandon (1954) ([24]) also determined the parameters of several of its aftershocks but due to the widespread aftershock activity involving many thrusts/faults, the fault plane could not be chosen on this criteria.

3.2. *Badgam earthquake 1963.*

The fault plane solution of Ichikawa et al. (1972) ([12]) shows that the nodal plane striking northwest-southeast dipping towards north-east chosen on the basis of Panjal thrust represents the appropriate fault plane. The isoseismals of this earthquake being oriented north-south (Srivastava et al. 1964) ([20]) do not fit with the fault plane solution.

3.3. *Anantnag earthquake 1967.*

On the basis of precise determination of the aftershock parameters, Tandon (1972) ([26]) found that the nodal plane dipping to SW indicates the fault plane which was not in conformity with the Panjal thrust dipping to north-east.

3.4. *Koyna earthquake 1967.*

In Koyna region where detailed geological information is not yet available, Gupta et al. (1969) (9) chose the fault plane on the basis of isoseismals. Most of the other solutions giving ENE-WSW striking left lateral strike slip fault plane are supported by the aftershock data.

3.5. *Bhadrachalam earthquake 1969.*

Based on the trend of the isoseismals Chaudhury et al. (1970) (4) considered the solution which gave a fault striking east-north-east as the correct one. This also agreed with the trend of the Eastern Ghats. On the contrary Gupta et al. (1969) (9) have chosen the nodal plane trending north-west on the basis of aftershocks.

3.6. *Broach earthquake 1970.*

For this earthquake Gupta et al. (1972)(10) have adopted a different criteria namely that of the trend of isoseismals and ground fissures for choosing the fault plane. The chosen solution agreed with the general east-east strike of the Narbada fault. Since no observatory existed close to the epicentre, aftershock data was not available. In this case Arora et al. (1971) (1) have however chosen a solution agreeing with the north-east trend of the Aravalli ranges.

The above discussion thus indicates that no standard criteria either on the basis of aftershocks or isoseismals can be adopted for choosing the fault plane from *P*-wave analysis for earthquakes occurring in India.

It may be interesting to mention that Green and Mc Garr (1972) (8) have also reported significant differences between the plane of faulting inferred from the aftershock zone and that inferred from the first motion analysis for the Ceres earthquake of September 1969 in south Africa. They inferred that the aftershock distributions do not necessarily define earthquake faults even though they may define a plane. From the study of the Salinas Watsonvilla California earthquake of 1963, Udias (1969) (30) also observed that the aftershocks were spread along the direction of the axis of pressure instead of along the direction of fracture.

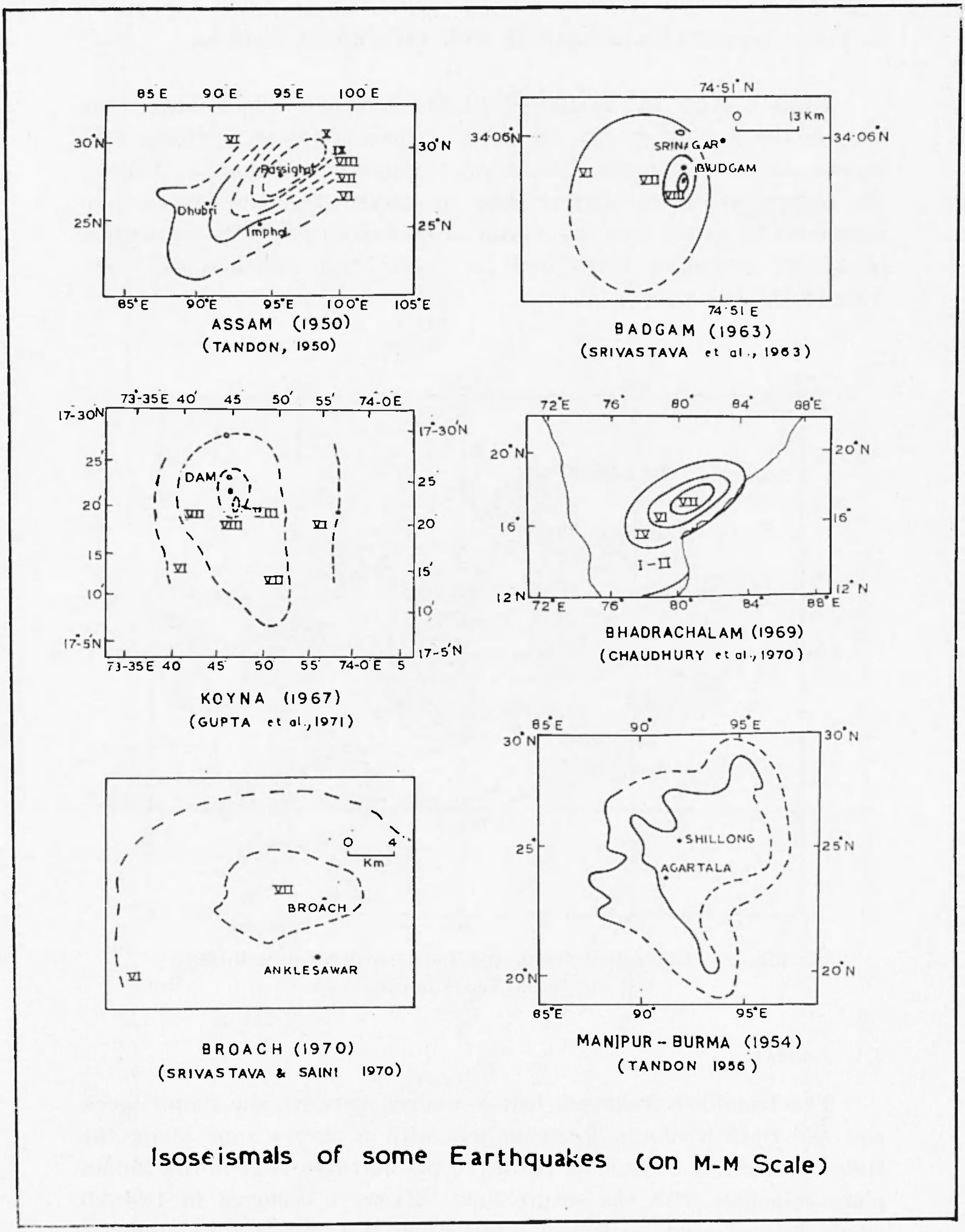

Fig. 1 – Isoseismals of Indian earthquakes.

4. Focal mechanism solutions and geological faults

Table 2 gives the results of all the solutions which have been used in the present study. In order to correlate these solutions with known faults along the Himalayan mountains (including Assam), the epicentres of the earthquakes considered and the known geological faults in the area are shown in figures 2 to 4. The correlation of known geological faults and the fault plane solutions for these regions are discussed below.

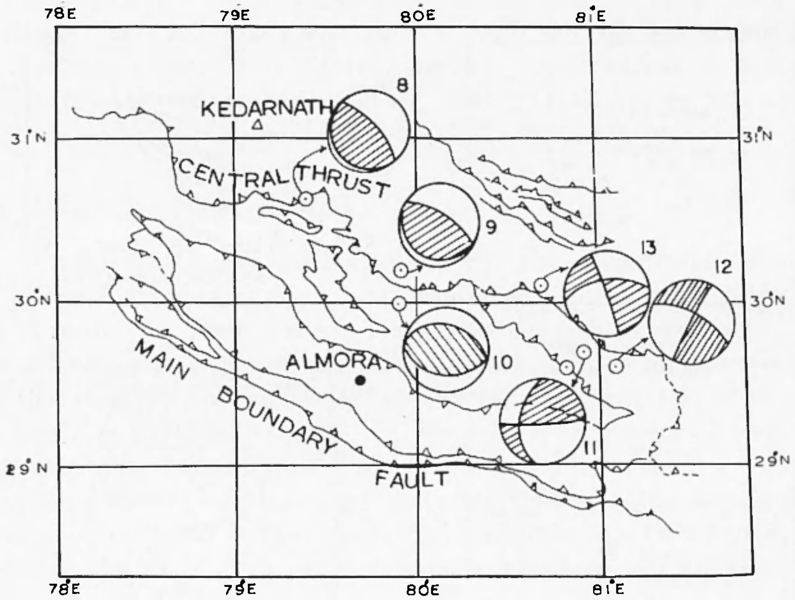

Fig. 2 – Geological faults and focal mechanism solutions in India-Nepal border.

4.1. *Ladakh.*

The Ladakh-Karakorum belt is wedged between the Pamir block and the Spiti-Kashmir Tethyan belt with a suture zone along the Indus. According to Gansser (1973), (7) the northern edge of the Indian plate coincides with the suture line. Event 1 occurred in Ladakh where due to poor geological information it is difficult to correlate this event with any known fault.

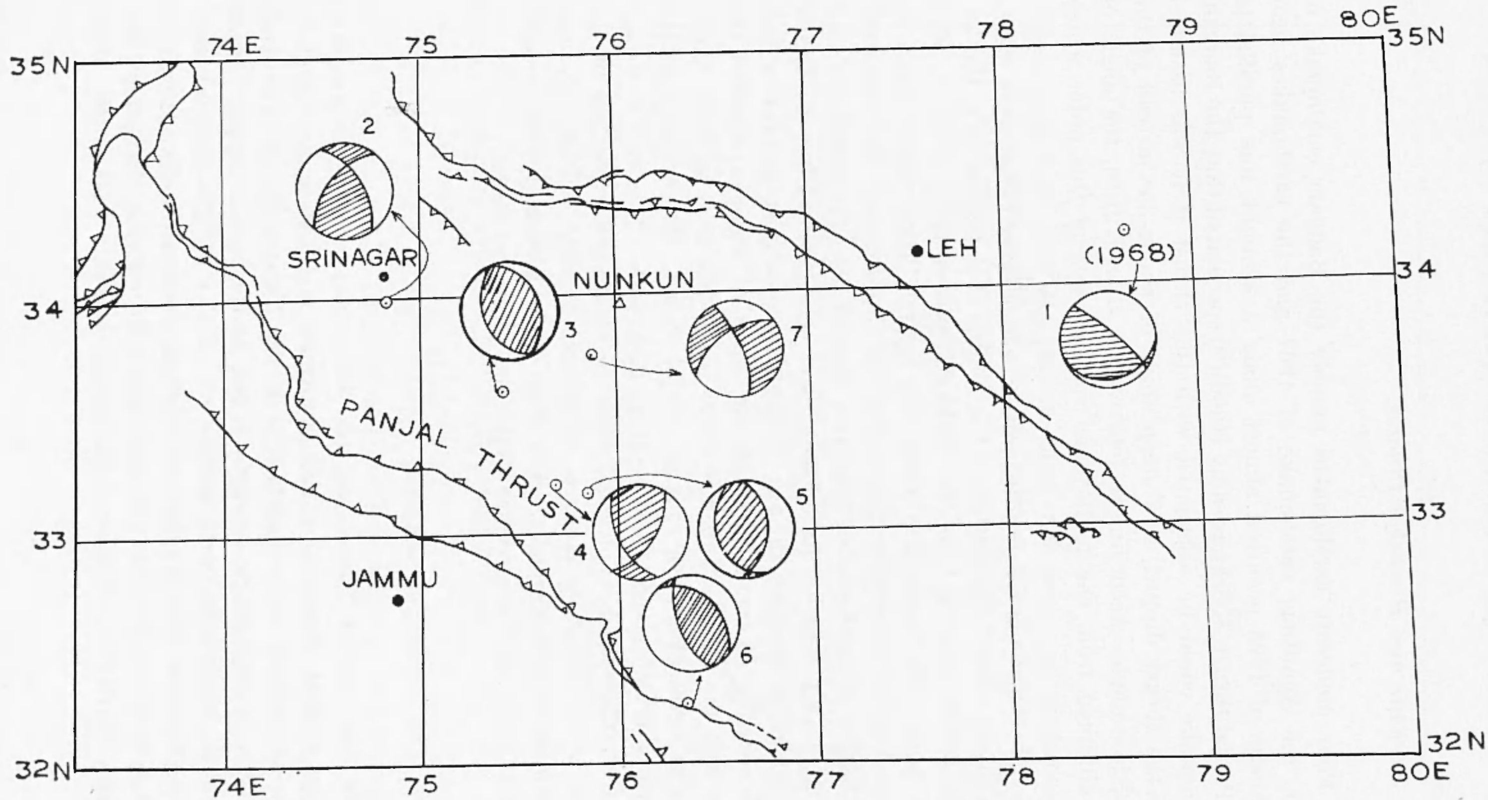

Fig. 3 – Geological faults and focal mechanism solutions in Kashmir.

4.2. *Kashmir and Himachal Pradesh.*

Four moderate earthquakes namely the Badgam earthquake of 1963, the Anantnag earthquake of 1967 and the earthquakes near Kishtwar of 1973 occurred almost along a straight line parallel to the Panjal thrust. Krishnaswamy (1966)([14]) speculated that the Badgam earthquake could be associated with this thrust if it was assumed that the thrust dipped at a steep angle of about 35° instead of the usual low angle. According to Ichikawa et al. (1972)([12]), the angle of dip obtained from the fault plane solution was of this order which may confirm the association of this earthquake with the Panjal thrust. Although the computed faulting was of the thrust type it gave a predominantly strike slip motion. It is known that in Kashmir, the Tethyan rocks supported by the Salkhales are actually involved in a large horizontal translation along the Panjal thrust which could be responsible for the predominance of strike slip motion. The Anantnag and Kishtwar earthquakes, however, showed dip slip thrust faulting. No agreement between focal mechanism solution and any geological fault could be found for the two earthquakes near Kishtwar. The fault plane solution of event about 50 km north of Kishtwar showed the strike and dip direction of one nodal plane (assumed as fault plane) to be in agreement with that of Panjal thrust, but in this case the nature of faulting conformed to a normal fault.

Event 6 with its epicentre close to Dharamsala occured in the region where the great Kangra earthquake of 1905 caused huge destruction of life and property. One of the nodal planes dipping towards the northeast was in agreement with the geological faults.

4.3. *Central Himalayas including Nepal.*

In the central Himalayas, the important geotectonic features are the central thrust, the Almora thrust, and the main boundary fault. According to geologists, the north Almora thrust dips at a moderate to high angle towards south and trends west-north-west in general, bending to north-north-west. The structural surface joins with the Srinagar fault further westward in Garhwal Valdiya (1973) ([31]) found a number of transverse tear faults throughout the Lesser Himalayan Territory. Figure 4 shows the epicentres of earthquakes

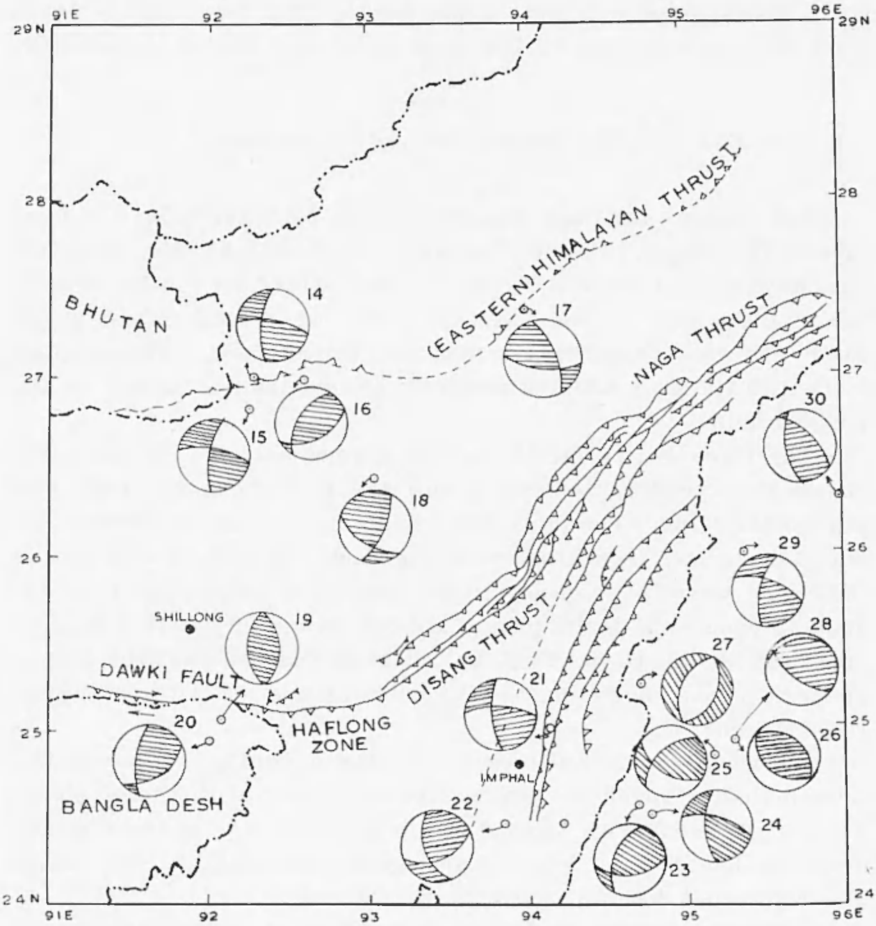

Fig. 4 – Geological faults and focal mechanism solutions in northeast India.

for which mechanism solutions are given in table 2, and the faults in the region.

The focal mechanism solutions of events 8 and 9 gave one nodal plane striking north-north-west in agreement with the strike of known faults. Event 10 which caused severe damage near Kapkote was located in between the two faults dipping in opposite directions. Considering the errors in the epicentral determination of this earthquake, the fault plane dipping towards north fits well with the geological faults. Event 11 indicated thrusting but none of the nodal planes could be associated with the regional faults. Such agreement is rather good for events 12 and 13 but large strike slip motion is indicated.

4.4. *Northeast India including Manipur-Burma region.*

Fig. 5 shows the main tectonic features of Assam along the foothills of Himalayas. Besides the main boundary fault, the other important tectonic feature is the Dawki fault where the motion is right lateral strike slip. In the Naga hills, there are several thrusts whose south westward extension is called the Disang fault. The junction of the Dawki fault and northeasterly Disang fault is known as the Haflong fault.

The three events 14, 15 and 16 showed that one of the nodal planes were possibly associated with the main boundary fault and showed thrusting. The fault plane solution of event 17 however did not indicate any correlation with this fault. Event 18 occurred in the region where little geological information is known and thus difficult to choose the faults plane. Events 19 and 20 occurred in close proximity to the Dawki fault but their mechanism solutions gave a northerly strike suggesting their possible association with the nearer Haflong zone.

Events 21 and 22 which occurred close to Manipur Burma thrusts showed that although the strike direction of one of the nodal planes was in agreement with them, the dip direction was in the opposite direction than deduced from the geological considerations. This result also holds good for the events 23, 24, 25 and 29.

Although detailed geological information is lacking in Burma, the strike direction inferred from the fault plane solutions for the events 26, 28 and 30 do not agree with the Manipur Burma thrusts. While most of the solutions in the region indicate thrusting with significant strike slip motion, the normal faulting for the event 27 and the reverse dip direction for the earthquakes near Manipur-Burma border needs further investigations.

It may therefore, be summarised that the correlation between the fault plane solutions and known geological faults is generally good for earthquakes occurring in Kashmir and along the foothills of Himalayas but fails for Manipur-Burma region where the faults are found to be dipping in the opposite direction than what has been deduced by the geologists.

Table 2 – Focal mechanism solutions of earthquakes near India.

No.	Region	Date	Epicentre °N	Epicentre °E	Origin time h.	Origin time m.	Origin time s.	Depth (km)	Magnitude	Nodal Plane 1 Strike (deg.)	Nodal Plane 1 Dip Dir (deg.)	Nodal Plane 1 Dip An (deg.)	Nodal Plane 2 Strike (deg.)	Nodal Plane 2 Dip Dir (deg.)	Nodal Plane 2 Dip An (deg.)	Fault type	Reference
1	2	3	4		5			6	7	8			9			10	11
	Ladakh																
1	—	11.2.68	34.2	78.7	20	38	27	24	5.1	314	44	80	270	180	15	Thrust	Present study
	Kashmir																
2	Badgam	2.9.63	34.0	74.8	01	34	32	44	5.1	331	61	59	041	311	60	Thrust	Ichikawa et al. (1972) [12]
3	Anantnag	20.2.67	33.6	75.4	15	18	40	25	5.7	336	66	33	330	240	57	Thrust, Dip slip	Tandon (1972) [-6]
4	Near Kishtwar	16.1.73	33.2	75.7	21	31	26	42	5.5	030	120	66	342	252	45	Thrust	Chaudhury et al. (1974) [4]
5	Near Kishtwar	24.10.73	33.1	75.9	05	23	51	33	5.4	001	091	56	346	256	34	Thrust	Present Study
6	Near Dharamsala	5.11.68	32.3	76.5	02	02	45	33	4.9	328	068	35	338	248	67	Thrust, Dip slip	Chaudhury et al. (1974) [4]
7	—	17.6.62	33.8	75.9	04	39	26	22	5.1	335	065	89	064	334	60	Normal	Ichikawa et al. (1972) [12]
	Nepal India border																
8	—	22.6.69	30.6	79.4	01	33	24	19	5.4	318	048	72	335	246	20	Thrust, Dip slip	Chaudhury et al. (1974) [4]
9	—	3.3.69	30.2	79.9	06	20	22	18	5.3	320	050	32	298	208	22	Thrust, Dip slip	Srivastava (1973) [19]
10	Kapkote	28.12.58	30.0	79.8	05	34	42	30	6.2	282	012	36	282	192	—	Thrust, Dip slip	Present study
11	—	27.6.66	29.7	80.9	10	59	18	33	6.0	270	180	80	010	280	40	Thrust	Ichikawa et al. (1972) [12]
12	—	2.12.64	29.6	81.1	08	21	43	23	5.1	300	030	70	030	300	90	Vertical, Strike slip	Ichikawa et al. (1972) [12]
	Northeast India																
13	—	26.9.64	30.1	80.7	00	46	30	50	6.2	341	071	89	070	340	60	Normal, Strike slip	Ichikawa et al. (1972) [12]
14	—	10.9.64	27.1	92.3	13	22	10	33	5.6	236	016	80	012	282	69	Thrust, SS.	Ichikawa et al. (1972) [12]
15	—	11.4.65	26.8	92.3	22	33	6	70	5.1	284	014	79	014	234	89	Thrust. SS.	Ichikawa et al. (1972) [12]
16	—	30.6.69	26.9	92.7	08	51	54	44	5.0	028	298	48	068	158	50	Thrust	Present study
17	—	19.2.70	27.4	94.0	07	10	02	52	5.3	344	070	050	283	193	060	Thrust	Chaudhury et al. (1974) [4]
18	—	17.7.71	26.4	93.2	15	00	56	52	5.4	020	110	84	307	217	46	Thrust	Chaudhury et al. (1974) [4]
19	—	21.6.63	25.1	92.1	15	26	31	56	5.6	001	271	50	001	091	40	Thrust, DS	Ichikawa et al. (1972) [12]
20	—	12.6.68	24.9	91.9	04	29	22	44	5.3	030	120	65	324	234	40	Thrust	Present study
21	—	18.2.65	25.0	94.2	04	26	35	36	5.4	360	270	70	082	172	70	Normal, SS	Ichikawa et al. (1972) [12]
22	—	1.7.57	24.4	93.8	19	30	23	41	6.0	342	252	69	88	352	65	Thrust, SS	Ichikawa et al. (1972) [12]
23	—	14.6.61	24.5	94.7	00	41	10	91	5.3	030	300	60	270	181	51	Thrust, Ambiguous	Ichikawa et al. (1972) [12]
24	—	2.10.66	24.4	94.8	04	31	49	75	4.9	007	277	54	294	021	69	Thrust, SS	Present study
25	—	22.3.54	24.4	95.2	23	42	12	180	7.5	050	NW	60	124	SW	61	Thrust	Tandon and Mukherjee (1956) [28]
26	—	4.2.61	24.9	95.3	08	51	49		5.5	306	216	39	306	036	51	Thrust, DS	Ichikawa et al. (1972) [12]
27	—	29.12.71	25.2	9.47	22	27	10	46	5.0	028	298	60	328	058	56	Normal	Present Study
28	—	12.7.64	24.9	95.3	30	15	59	152	5.5	318	288	76	076	346	45	Thrust, SS	Present study
29	—	29.7.70	26.1	95.4	10	16	25	59	6.0	017	287	060	293	023	77	Thrust. SS	Ichikawa et al. (1972) [12]
30	—	29.8.69	26.3	96.1	10	02	50	72	5.0	003	273	56	320	050	46	Thrust	Present study

Conclusions

The above study brings out the following results:

(1) – The relationship between strike and dip of the geological known faults with that derived from focal mechanism using *P*-wave data generally holds good along the foothills of Himalayas but fails near Manipur-Burma region where intermediate focus earthquakes occur frequently.

(2) – No standard criteria on the basis of isoseismals or aftershocks could be found out for distinguishing the fault plane from the auxiliary plane in the mechanism solutions for Indian earthquakes.

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REFERENCES

(1) Arora, S. K., C. J. Nair and T. G. Varghese, 1971. – *Broach earthquake of March 23, 1970.* "Earthquake Notes", **XLII**, 17.

(2) Banghar, A. R., 1972. – *Focal mechanism of Indian earthquakes.* "Bull. Seism. Soc. Am.", **62**, pp. 603-608.

(3) Chandra, U., 1971. – *Combination of P and S data for the determination of earthquake focal mechanism.* "Bull. Seism. Soc. Am.", **76**, 1655.

(4) Chaudhury, H. M., H. N. Srivastava and J. Subba Rao, 1974. – *Seismotectonic investigations of the Himalayas.* "Himalayan Geology", **IV**, Delhi-7, pp. 481-491.

(5) Chauhan, R. K. S., Singh, J. and V. K. Srivastava. *Seminar on Geodynamics of the Himalayan Region.* March 5-8. "National Geophysical Research Institute," Hyderabad, India, 201 (Abstract only).

(6) Fitch, T. J., 1970. – *Earthquake mechanism in the Himalayan, Burmese and Andaman regions and continental tectonics in Central Asia.* "J. Geophys. Res.", **75**, pp. 2699-2709.

(7) Gansser, A., 1964. – *Geology of the Himalayas.* Interscience Publishers.

(8) GREEN, R. W. E. and A. Mc GARR, 1972. – *A comparison of the focal mechanism and aftershock distribution of the Ceres, South Africa earthquake of September 29, 1969.* "Bull. Seism. Soc. Am.", **62**, pp. 869-871.

(9) GUPTA, H. K., H. NARAIN, B. K., RASTOGI and I. MOHAN, 1969. – *A Study of the Koyna earthquake of Dec. 10, 1967.* "Bull. Seism. Soc. Am.", **59**, pp. 1149-1162.

(10) GUPTA, H. K., B. K. RASTOGI, and H. NARAIN, 1972. – *Annual Report.* "National Geophysical Research Institute".

(11) GUPTA, H. K., I. MOHAN and H. NARAIN, 1972. – *The Broach earthquake of March 23, 1970.* "Bull. Seism. Soc. Am.", **62**, pp. 47-61.

(12) ICHIKAWA, M., H. N. SRIVASTAVA and J. DRAKOPOULOS, 1972. – *Focal mechanism of earthquakes occurring in and around the Himalayan and Burmese mountain belts.* Pap. in "Meteor. and Geophys.", **23**, pp. 149-162.

(13) KHATTRI, K. N., 1970. – *The Koyna earthquake seismic studies.* "Fourth Symposium on Earthquake Engineer," Roorkee, pp. 369-374.

(14) KRISHNASWAMY, V. S., 1966. – *Geo-seismological considerations relating to the planning and design of the Salal hydel project and other lower Chenab-valley hydel projects in Jammu and Kashmir state.* "Third symposium on Earthquake Engineering", Roorkee, India, pp. 44-60.

(15) LEE, W. H. K. and C. B. RALEIGH, 1969. – *Fault plane solution of the Koyna (India) earthquake.* "Nature", **223**, pp. 172-173.

(16) NOWROOZI, A. A., 1972. – *Focal mechanism of earthquakes in Persia, Turkey, West Pakistan, and Afghanistan and plate tectonics of the Middle East.* "Bull. Seism. Soc. Am.", **62**, pp. 823-850.

(17) OIKE, K., 1971. – *On the nature of occurrence of intermediate and deep earthquakes. The World distribution of the earthquake generating stress.* "Bull. Disast. Preven. Res. Inst.", **20**, 145.

(18) RITSEMA, A. R., 1966. – *The fault-plane solutions of earthquakes of the Hindukush Centre.* "Tectonophysics", **3**, pp. 147-163.

(19) SRIVASTAVA, H. N., 1973. – *The crustal seismicity and the nature of faulting near India Nepal-Tibet trijunction.* "Himalayan Geology", **3**, pp. 321-393.

(20) SRIVASTAVA, L. S., S. E. HASAN, R. H. MITHAL, A. R. CHANDRASEKARAN and KRISHNA, 1964. – *Badgam earthquake of Sep. 2, 1963.* "Bull. Ind. Soc. Earth. Tech.", (India), **1**, pp. 79-94.

(21) SRIVASTAVA, L. S. and S. S. SAINI, 1970. – *Earthquake damage during March 23, 1970 Broach Earthquake.* "Fourth symposium on Earthquake Engineering", 14-16, Nov. "School of Research and Training in Earthquake Engineering", University of Roorkee, Roorkee, India, pp. 25-43.

(22) SYKES, L. R., 1970. – *Seismicity of the Indian ocean and a possible nascent island arc between Ceylon and Australia.* "J. Geophys. Res.", **75**, pp. 5041-5055.

(23) TANDON, A. N., 1950. – *The very great earthquake of Aug. 15, 1950. Science and Culture,* "Indian Science News Association", **92**, pp. 147-155, Calcutta, India.

(24) TANDON, A. N., 1954. – *Study of the great Assam earthquake of Aug. 15, 1950 and its aftershocks.* "Ind. J. et. Geophys.", **5**, pp. 95-137.

(25) TANDON, A. N., 1955. – *The direction of faulting in the great Assam earthquake of 15 Aug. 1950.* "Ind. J. Met. Geophys.", **6**. pp. 61-64.

(26) TANDON, A. N., 1972. – *Anantnag earthquakes (February to April 1967).* "Ind. J. Met. Geophys.", **23**, pp. 491-502.

(27) TANDON, A. N. and H. M. CHAUDHURY, 1968. – *Koyna earthquake of Dec. 1967.* "India Meteorological Department" "Scientific Report", **59**.

(28) TANDON, A. N. and S. M. MUKHERJEE, 1956. – *The Manipur-Burma border earthquake of 22 March 1954.* "Ind. J. Met. Geophys.", **7**, pp. 1-10.

(29) TSAI, and K. AKI, 1971. – *The Koyna, India earthquake of Dec. 10, 1967* (Abstract only). "Trans. Am. Geophys.".

(30) UDIAS, A. S.J., 1965. – *A study of the aftershocks and focal mechanism of the Salinas-Watsonville earthquake of Aug. 31 and September 14, 1963.* "Bull. Seism. Soc. Am.", **55**, pp. 85-106.

(31) VALDIYA, K. S., 1973. – *Seminar on Geodynamics of the Himalayan region March 5-8, 1973.* Published by "National Geophysical Research Institute", Hyderabad (India, 9).

(32) WHITCOMB, C. R. ALLEN, J. D. GARMANY and J. A. HILEMAN, 1973. – *San Fernando Earthquake Series, 1971: Focal mechanism and tectonics.* "Reviews of Geophysics and Space Physics", **11**, pp. 693-730.