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SOURCE MECHANISM OF EARTHQUAKES IN KANGRA–CHAMBA REGIONS OF HIMACHAL PRADESH, INDIA

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INTRODUCTION

Among the great Indian earthquakes during the present century, the earthquake of 1905 in Himachal Pradesh took the maximum toll of 20,000 human lives besides major property damage in Kangra valley and adjoining areas. The other significant earthquakes in Himachal Pradesh occurred in Chamba district (1945) and Kinnaur region (1975) which also caused lots of damage. Also two earthquakes of magnitude 5.0 which were widely felt in Himachal Pradesh and caused some damage in Dharamsala town, occurred in the years 1968 and 1978. Of these, the mechanism of Kangra earthquake was associated with the main boundary thrust (Middlemiss, 1910). However the only reliable solutions based on instrumental data from a close network of stations as well as teleseisms was reported for the earthquakes of 1968 near Dharamsala and 1975 near Kinnaur (Chaudhury et al 1974: Chaudhury and Srivastava, 1977). The faulting associated with these earthquakes were thurst and normal type respectively. A look at the seismicity map (Fig. 1) for the period 1965-1974 prepared for Himachal Pradesh and neighbourhood (Srivastava and Chaudhury, 1979) suggests that there is a well marked concentration of seismic activity bounded by the grid 32-33°N, 76-77°E. Thus stress concentration in Kangra region is continuing even 75 years after the occurrence of the great earthquake of 1905. The recent earthquakes in the region even though of slight to moderate intensity suggest that the mechanism of earthquakes needs be understood in detail keeping in view the possibility of reccurrence of more damaging earthquakes in the region due to higher concentration of stresses.

The object of this paper is therefore to present the fault plane solutions of recent earthquakes in the region and discuss their association with the known geological faults and regional plate tectonics.

GEOTECTONICS OF HIMACHAL HIMALAYAS

Himachal Himalayas are a part of Punjab Himalayas whose

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geology has been described in detail by Gansser (1964). The following structural units from south to north are recognized in Himachal Himalayas (Roy Chaudhury, 1973).

1. Autochthon of the Siwalik molasse belt which occupies the lowest tectonic level: During an active phase of the Himalayan orogeny, a foredeep between the northern peninsular shield and the Himalayan chain was formed in which a great thickness of the Siwalik molasse accumulated.

2. The parautochthon of the Palaeogene belt and the Shali subsidiary belt of Bandle range: It is an uplifted wedge of Shali belt which is attributed to severe horizontal compression in a linear sedimentary basin.

3. The main shali structural belt, the Simla structural belt and the Outer Krol belt: Of these, the main shali structural belt occurs in two anti-formally folded digitisations with a southeasterly plunge. The Simla group is thrust over the Tertiaries at some places. Similarly the rocks of Outer Krol belt appears to be sliding over the Simla group basement along the Krol Giri thrust.

4. The Deoban structural belt, the Jaunsar structural belt and the Inner Krol belt: The Jaunsar structural belt with its cover of Inner Krol belt is thrust over its own basement of the Deoban in the outhern part of the belt along the Tons-Chail thrusts.

5. The Larji structural belt and the Rampur parautochthon in the window zone: The Central Himalayan zone which lies to the northeast of the Larji window zone represents the homeland of the Jutogh nappe.

6. The lower and upper Jutogh nappes: Of these, the upper Jutogh nappe represents the highest tectonic unit. Jutogh thrust has retained its normal sedimentary sequence. Further north, the Tethys Himalaya of the Himachal represent a unique sequence of well framed sediments ranging from Pre-cambrian to Crataceous in the classic area of Lahaul Spiti.

In the present investigation, more attention has been given to the Chamba and Kangra regions. In the Chamba area, new outcrops of fossiliferous Carboniferous-Permian out liers having affinity with the Tethys of the Kashmir basin have been reported. The main tectonic feature in the region is the Chamba tear which was responsible for the Chamba earthquake of 1905. In the Kangra region, the Satlitta thrust is estimated to lie at a depth of 25 to 30 km below the valley which appears to intersect the Palaeozoic Precambrian basement and the tertiary formations. Krishnaswamy (1962) has attributed the great earthquake of 1905 to the downdip extension of this thrust.

Fig. 1 shows some of the main thrusts in Himachal Himalayas which more commonly known by their local names.

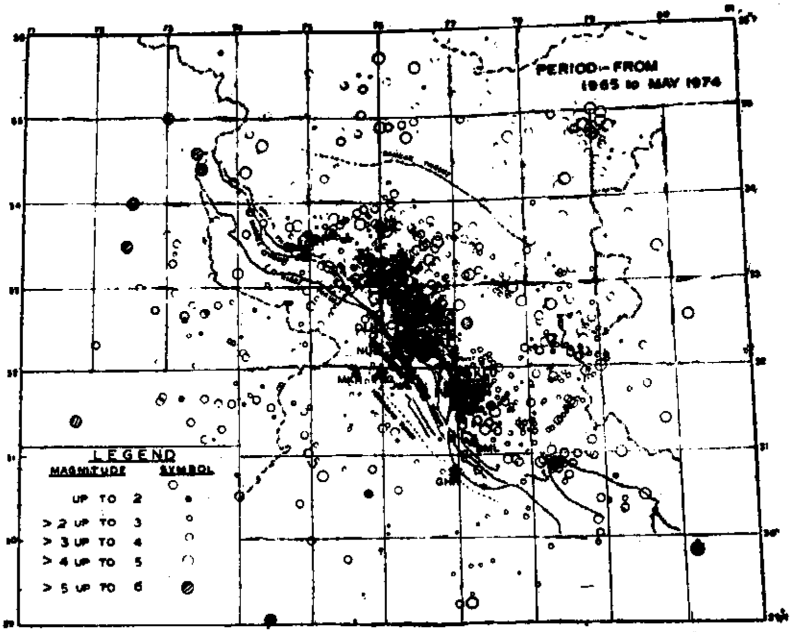

Fig. 1 The Seismic activity in Himachal Pradesh and neighbourhood for the period 1965–1974 (After Chaudhury and Srivastava, 1979).

SEISMICITY OF THE REGION

Fig. 1 shows the earthquake activity monitored with the help of ten seismological observatories which were opened to study the seismicity of Pong and Pandoh dams. The coordinates of these observatories are given in Table 1. It may be noticed that even though there is no azimuthal control from the northeastern quadrant, the errors in the epicentre and focal depth rarely exceeded ±5 and ±10 kms respectively. Table 2 gives the hypocentral locations determined by the U. S. Geological Survey programme Hypo 71 (revised) based on near earthquake data and the details given by the bulletins of the International Seismological Centre (ISC). The seismograms of these earthquakes have shown the P_g and S_g phases distinctly which points out the errors in ISC determinations using world wide data. The following velocity model was adopted for this purpose.

TABLE—1

Coordinates of Observatories in Himachal Pradesh

Stations	Code	Coordinates	
		Lat. (°N)	Long. (°E)
Pong	PNG	31°55.00'	75°55.00'
Mukerian	MKR	31°57.00'	75°37.00'
Nurpur	NUR	32°18.00'	75°52.00'
Jawalamukhi	JWL	31°52.00'	76°20.00'
Dharamsala	DHM	32°13.00'	76°20.00'
Sundernagar	SDN	31°33.00'	76°54.00'
Kulu	KUL	31°57.63'	77°06.25'
Simla	SML	31°07.00'	77°10.00'
Ghaggar	GHR	31°47.50'	76°55.00'
Dalhousie	DLH	32°32.50'	75°58.00'

$P_g = 5.72$ km/sec

$p^* = 6.66$

$P_n = 8.22$

Granitic layer 24 km

Basaltic layer 21 km

Table 3 gives a list of 22 earthquakes in the region whose epicentres have been reported by the Bulletin of International Seismological Centre. The magnitudes of these events ranged from 3.9 to 5.3. Active seismicity in the region of Chamba and Kangra earthquakes can be easily inferred from this list.

MECHANISM SOLUTIONS USING P-WAVE FIRST MOTION DATA

Focal mechanism of the earthquakes have been determined for five master events which occured in this region. In addition, composite fault plane solutions have been worked out for three regions (A, B and

C) as shown in Fig. 2 for earthquakes listed in Table 4. The P-wave first motion data was read from the seismograms of Indian stations. Of these the stations in Himachal Pradesh record earthquakes on 35 mm film which is read through a projector. The P-wave data from teleseismic stations were taken from the Bulletins of International Seismologi-

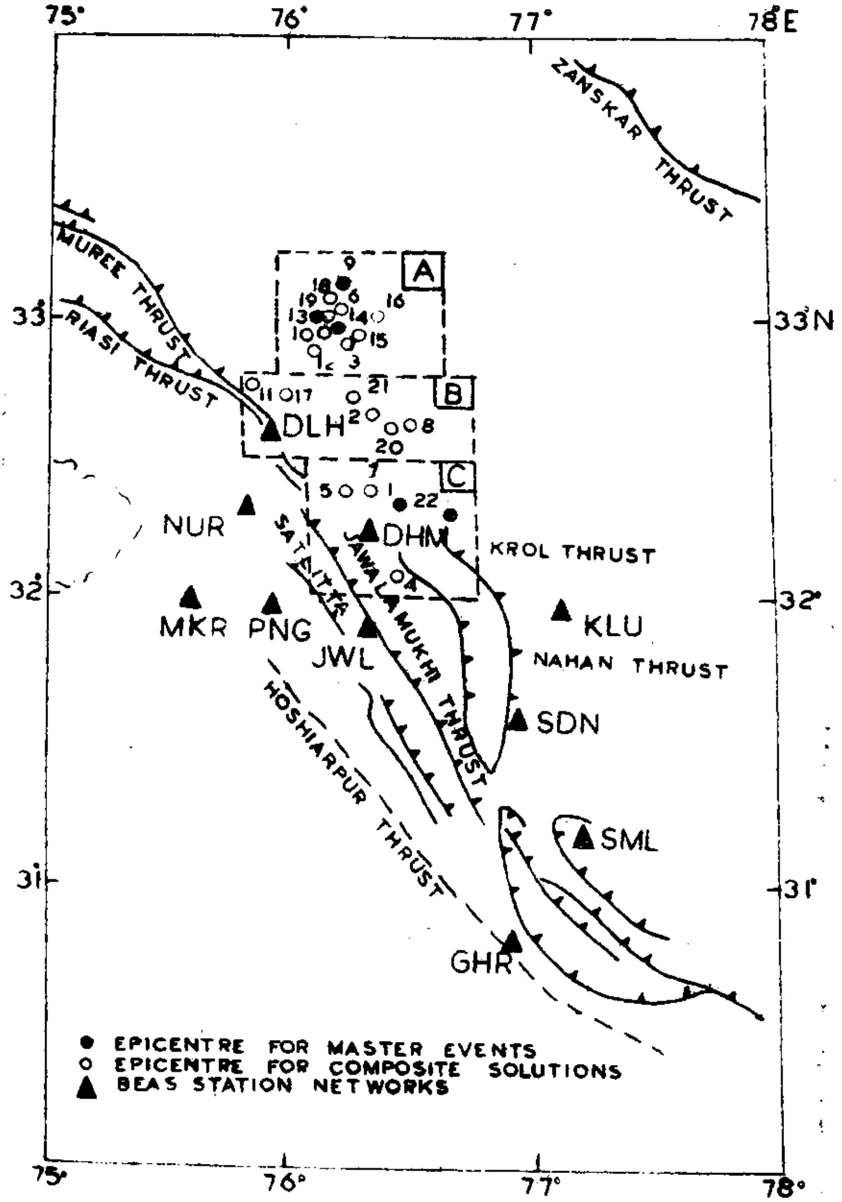

Fig. 2 Epicentres of the earthquakes used for focal mechanism studies. The regions marked A, B and C represents the area of composite mecha-

TABLE 2

Comparison of epicentres of Beas Grid between I.M.D. and I.S.C. determinations

Date	Agency	Origin Time GMT h m s	Location epicentre		Depth of focus km.	Mag.	RMS	ERH	FRZ
			Lat.	Long.					
16.9.75	I.S.C.	04 20 26.0	32.34	76.25	59.0	4.6	—	—	—
	I.M.D.	04 20 22.34	32° 25.35’	76° 24.0’	15.0	4.6	0.08	1.4	9.0
7.1.76	I.S.C.	00 24 52.9	32.97±0.021	76.12±0.024	40	5.3	—	—	—
	I.M.D.	00 24 51.66	32°52.70’	75° 45.02’	15	—	0.51	15.1	4.4
28.5.78	I.S.C.	05 32 16.5±0.60	33.49±0.033	76.05±0.058	40	4.6	—	—	—
	I.M.D.	05 32 11.32	33°37.26’,	76°7.95’	1.37	—	0.61	5.6	4.0
2.6.79	I.S.C.	13 05 21.3±0.39	33.75±0.051	76.01±0.077	33	4.7	—	—	—
	I.M.D.	13 05 20.84	33°21.39’	76°17.04’	0.32	4.7	0.32	6.4	7·5

cal Centre. The coordinates used for plotting were the angles of incidence at the focus, In, and the azimuth on Wulff's net (lower hemisphere projection). Some stations were such that the direct phase Pg was clearly recorded. These were plotted 180° opposite in azimuth, The angle of incidence at the focus was based on the travel-time velocities of Jeffreys and Bullen (Hodgson and Storey, 1955). Double couple hypothesis was assumed to act at the focus. While drawing the nodal planes separating the areas of compressions from dilatations, weightage was given to long period data if available. It would be seen that very few inconsistent observations have been found. Past experience has shown that among the stations in the region, observations at Mukerian and Ghaggar located on alluvium and Nilore and Warsak Dam in Pakistan often report inconsistent signs of P-wave observations for earthquakes occurring in Western Himalayas. Of the 22 earthquakes (Table 3), sufficient data was available to work out the focal mechanism solutions of four earthquakes as shown in Fig. 3(a). However the remaining earthquakes in regions A, B and C were used for composite solutions as shown in Fig. 3 (b). The results obtained from these solutions, therefore, form the basis with reference to which precursory changes in the orientation of the stress azix can be examined in future earthquakes. The detailed source parameters for five master events and composite solutions are listed in Table-4 (a) and Table-4 (b) respectively.

RESULTS AND DISCUSSION

Fig. 4 shows the geological thrusts and the newly determined fault plane solutions as well as for the earthquake of November, 1968 as reported by Chaudhury et al (1974). It is interesting to note that the nature of faulting was thrust type. The shallow dipping pressures were acting at right angles to the main Himalayan boundary fault while the tensions were steeply dipping. In view of the orientations of either of

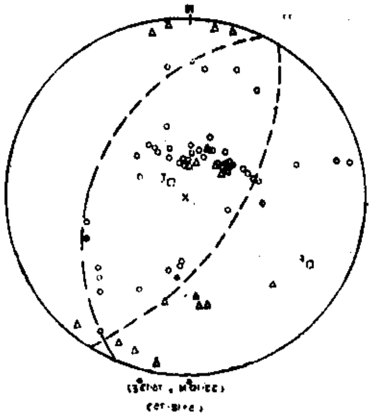

Fig. 3(a) i

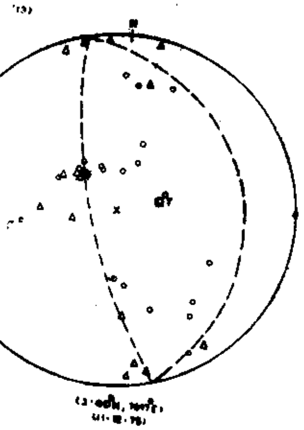

Fig. 3(a) ii

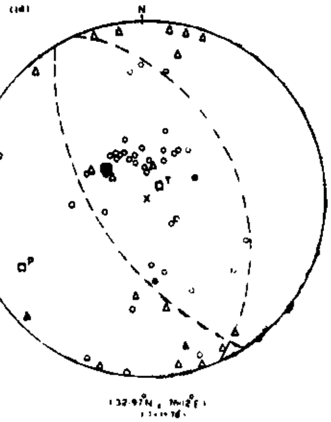

Fig. 3(a) iii

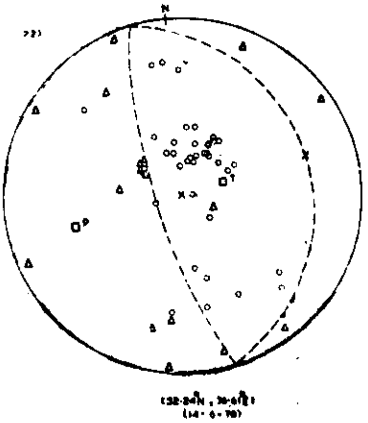

Fig. 3(a) iv

Fig. 3(a) Focal mechanism solutions for five master events using P-wave first motion data (lower hemisphere projection). Open circles and triangles denotes compressions and dilatations on short period respectively. Filled ones denotes long period observations.

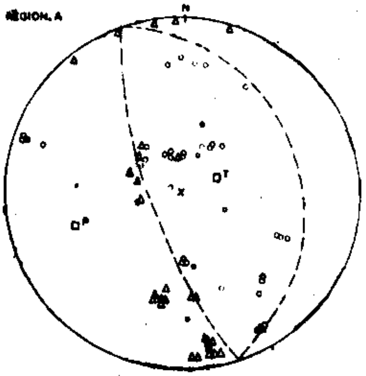

Fig. 3(b) i

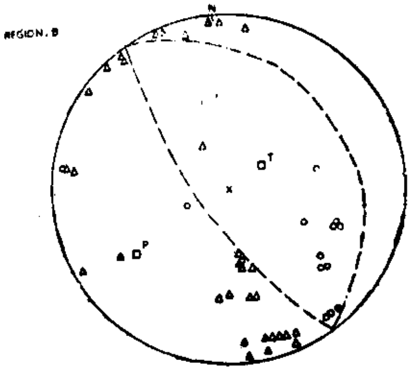

Fig. 3(b)ii

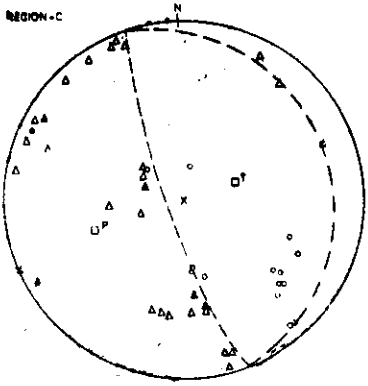

Fig. 3(b) iii

Fig. 3(b) Composite focal mechanism solutions for regions A, B and C using P-wave first motion data. Symbols same as fig. 3(a).

TABLE 3

Parameters of earthquakes in Himachal Pradesh

Event No.	Date	Epicentre (°N)	Epicentre (°E)	Origin time (GMT) h	m	s	Magnitude (mb)	Depth (km)
1.	05.11.1968	32.30	76.38	02	02	45	5.0	33
2.	25.2.1971	32.60	76.30	04	30	24	—	150
3.	29.1.1972	32.91	76.23	06	45	09	—	47
4.	26.10.1972	32.05	76.35	14	05	55	4.4	82
5.	16.12.1973	32.36	76.79	09	16	12	4.6	12
6.	16.11.1974	33.01	75.23	16	18	34	4.8	36
7.	16.9.1975	32.34	76.25	04	20	26	4.6	59
8.	16.11.1975	32.60	76.50	19	34	32	—	96
9.	5.12.1975	33.10	74.23	07	37	10	5.3	24
10.	10.12.1975	32.95	76.10	03	26	05	5.3	5
11.	10.12.1975	32.72	75.92	05	03	47	4.7	76
12.	10.12.1975	32.91	76.08	08	08	44	4.6	70
13.	11.12.1975	33.00	76.17	10	09	50	5.0	42
14.	7.1.1976	32.97	70.12	00	24	52	5.3	40
15.	8.1.1976	32.95	76.15	08	22	34	4.8	43
16.	8.1.1976	33.00	76.20	23	48	21	—	46
17.	18.1.1976	32.70	76.00	05	04	19	—	N
18.	27.1.1976	33.03	76.11	19	23	20	4.8	45
19.	1.3.1976	33.00	76.07	15	26	35	—	53
20.	10.4.1976	32.05	76.39	07	09	19	4.3	52
21.	16.4.1976	32.70	76.20	20	15	13	3.9	92
22.	14.6.1978	32.24	76.61	16	12	05	5.0	7

TABLE 4 (a)

Orientation of nodal plane for master events (Direction and Angle in degrees)

Event No.	Nodel Plane I			Nodel Plane II			P-axis		T-axis		Fault type
	Strike Dir.	Dip Dir.	Dip An.	Strike Dir.	Dip Dir.	Dip An.	Ax.	Pl.	Az.	Pl.	
1.	340	70	35	348	258	67	248	22	78	80	Thrust*
2.	158	68	34	330	340	56	243	12	48	80	Thrust
13.	166	76	16	346	256	74	256	27	75	63	Thrust
14.	158	68	34	330	240	56	243	12	48	80	Thrust
22.	168	78	18	348	258	72	258	26	78	64	Thrust

*Chaudhury et al (1974)

TABLE 4 (b)

Orientation of nodal planes for composite solutions (Direction and Angle in degrees)

Region	Event Nos.	Nodal Planes I			Nodal Planes II			P-axis		T-axis		Fault type
		Strike Dir.	Dip Dir.	Dip An.	Strike Dir.	Dip Dir.	Dip An.	Ax.	Pl.	Ax.	Pl.	
A	3, 6, 10, 12, 15 16, 18, 19	158	68	20	338	248	70	248	25	68	75	Thrust
B	2, 8, 11, 17, 20, 21	150	60	20	330	248	78	248	25	68	75	Thrust
C	4, 5, 7	162	72	12	342	252	78	252	34	72	56	Thrust

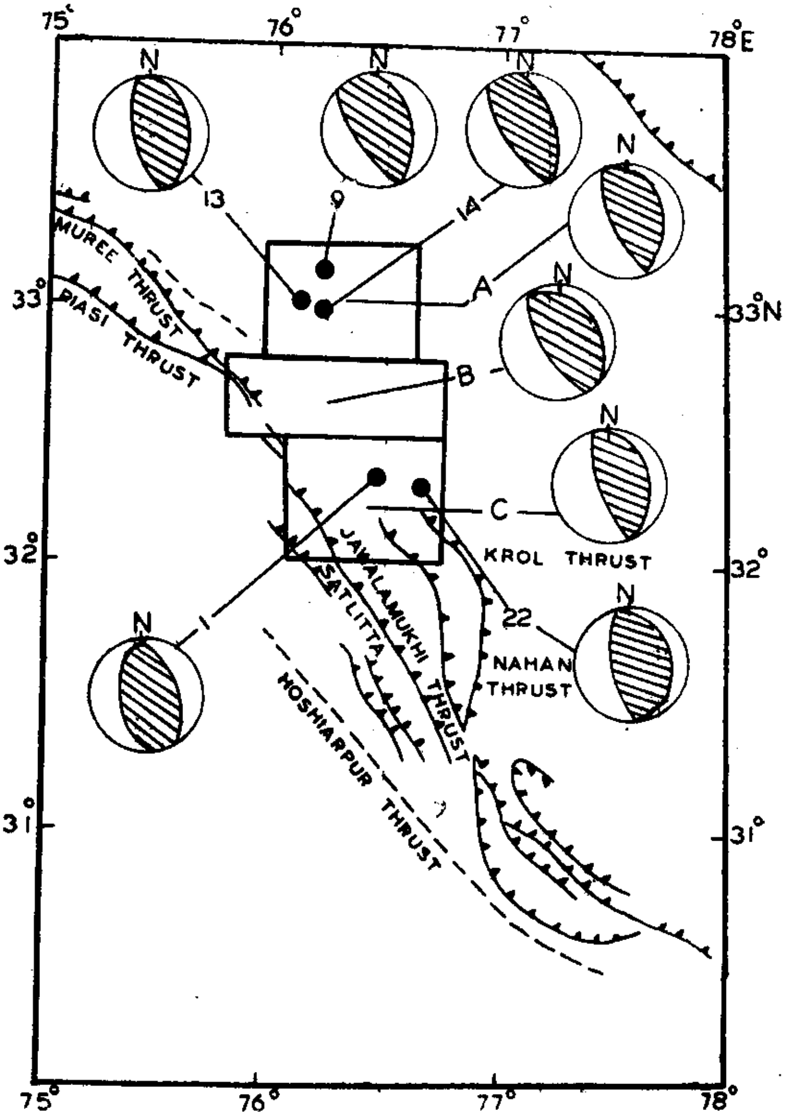

Fig. 4 Geological thrusts and newly determined fault plane solutions in Himachal Pradesh (lower hemisphere projection). Event 1 after Chaudhury et al 1974. Shaded and blank region denotes compressions and dilatations respectively.

the nodal planes across the boundary fault, the plane dipping towards the northeast was chosen as the fault plane based on the geological considerations. The fault plane also gives a northeasterly slip vector in conformity to the concepts of regional plate tectonics, according to which the Indian plate is moving in north-northeasterly direction relative to the Eurasian plate.

It may be mentioned that in the neighbouring region the mechanism solutions of the 1967 earthquake in Anantnag (Tandon, 1972) and 1980 Jammu earthquake (Dube and Srivastava, 1981) located near the main boundary fault also showed thrust faulting. The Kishtwar earthquake of 1973 also gave similar evidence of thrust faulting but its nodal planes were oriented in north-northeasterly direction (Chaudhury and Srivastava, 1974). Of the two nodal planes for the focal mechanism solution of Anantnag earthquake, Tandon (1972) found evidence on the basis of aftershocks that the nodal plane dipping towards the southwest represents the probable fault plane. No similar evidence could however be presented for the two earthquakes in the region due to meagre number of aftershocks. Lineament map (prepared by Geological Survey of India, unpublished) suggests that a number of north-northeasterly lineaments in the region intersect roughly at right angles to the main boundary fault. The isoseismals of the recent Dharamsala earthquake (1978) were oriented roughly along this (i.e. NNEly) direction (event 22, (Geological Survey of India, unpublished report, 1981). It was surmised that the earthquake of 1978 near Dharamsala is related to a tear fault which has displaced the main boundary fault.

The area is crossed by east-west trending Shali and Dharamasala thrusts which are seismically active as revealed by more than 1000 earthquakes recorded during the period of 1975 to 1978 within 100 km around Dharamsala. Its focal mechanism (Fig. 4) as worked out in the present studies showed thrust faulting with north-northwest orientation of the nodal planes. It is interesting to note that none of the solutions presented in this paper for earthquakes of magnitude 4 and above brought the mechanism of the lineaments in the region along which the motion would be predominantly strike slip.

CONCLUSIONS

The above study brings out the following:

The focal mechanism solutions of earthquakes show dip slip thrust faulting with the pressures acting at right angles to the main faults in the region. The mechanism solutions derived on the basis of composite data also reveal the same trend. The results lend unequivocal support to the regional plate tectonics model.

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