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Seismicity study in relation to recent earthquakes in Jammu and adjoining Himachal Pradesh

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सार — पूर्वी कश्मीर एवं निकटवर्ती हिमाचल प्रदेश में हाल के चार भूकम्पों से संबद्ध भूकंपनीयता का अध्ययन इस क्षेत्र के पास-पास लगे भूकम्पविज्ञान सम्बन्धी उपकरणों की सहायता से किया गया । मालूम हुआ कि जम्मू प्रदेश के भद्दू और मलार क्षेत्रों में अगस्त 1980 में और निकटवर्ती पश्चिमी हिमाचल प्रदेश में 1973 एवं 1976 के दो भूकम्प निम्न भूकम्पी सक्रियता वाले क्षेत्र में आए ।

4 से 5 परिमाण वाले इन भूकम्पों से पहले वहां भूकम्पी सक्रियता प्रायः अनियमित थी और पिछला भूकम्प 3 से 7 वर्ष पहले आया था । 23 अगस्त 1980 (21 घं० 36 मि० 52.3 से०) और 7 जनवरी 1976 के दो भूकम्पों के भ्रंशतल हल क्षेप भ्रंश दर्शाते हैं और इस क्षेत्र के मुख्य परिसीमा भ्रंश से संबंधित है । तथापि ऐसा लगता है कि 23 अगस्त 1980 (21 घं० 50 मि० 02.90 से०) का दूसरा भूकम्प सुरिन-मस्तगढ़ अपनति से संबंधित है ।

ABSTRACT. Seismicity variations associated with four recent earthquakes in eastern Kashmir and adjoining Himachal Pradesh have been studied with the help of closely spaced seismological network in the region. It was noticed that earthquakes of August 1980 in Bhaddu and Malar regions of Jammu province and two other earthquakes (1973, 1976) in adjoining western Himachal Pradesh occurred in a region of low seismic activity. These earthquakes of magnitude 4 to 5 were preceded by anomalous seismic activity with the precursory duration ranging from 3 to 7 years. Fault plane solutions of two earthquakes of 23 August 1980 (21 *h* 36 *m* 52.3 *s*) and 7 January 1976 show thrust fault and are associated with the main-boundary fault in the region. However, the second earthquake of 23 August 1980 (21 *h* 50 *m* 02.90 *s*) appears to be associated with Surin-Mustgarh anticline.

1. Introduction

Study of seismicity around Pong and Pandoh dams on the *Beas* river in the Himachal Himalayas (Western Himalayas) required a close network of ten seismological observatories (shown by solid triangles, Fig. 1) to record near earthquakes upto micro-earthquake level. One more observatory at Jyotipuram under another river valley project near Jammu has been added since 1979. Large amount of earthquake data has been collected through these observatories from 1965 and a seismicity map of the area of the period 1965 to 1974 was prepared as shown in Fig. 1. A close look at this map brings out interesting features; one of them being some areas with high degree of seismicity like Kangra region near Dharamsala (DHM) while others with diffused seismicity marked 'B'.

In the region of diffused seismicity, four earthquakes have occurred recently (Fig. 2). Of these, the earthquakes of 23 August 1980 in Jammu province were responsible for the loss of lives of 15 people besides major damage to the houses. Macroseismic observations suggest an intensity of VIII on M. M. Scale in the vicinity of the instrumental epicentres which is much higher than could be associated with earthquakes of similar magnitudes. Foreshocks were generally absent while aftershocks were too few in number to be recorded even at Nurpur observatory within the epicentral distance of about 50 km. This aroused considerable interest to undertake a study of the seismicity associated with these earthquakes as presented in this paper. However, other seismo-tectonic aspects have also been investigated to get an idea about the association of these earthquakes with geologically known tectonics of the region.

2. Geotectonics and seismic history of the region

The Himachal Himalayas, popularly known as Punjab Himalayas in geological literature and the Kashmir Himalayas are important tectonic block in the Western Himalayas. Seismo-tectonics of the region provides many interesting results to infer about the continent-continent collision of Eurasian and Indian Plates (Srivastava and Chaudhury 1979). Many active faults in the region have been delineated as shown in Fig. 1 along with the epicentres of earthquakes for the period 1965 to 1974. The tectonic sequence in the region consists of Precambrian basement overlain by upper tertiary rocks and covered by the alluvium of the plains followed by younger granite, gneiss and Chail. The region is characterised by the presence of many important faults known as the Main boundary fault, the Murre thrust, the Jwalamukhi thrust, the Hoshiarpur thrust, the Nahan and Krol thrusts. The Chamba and Ruper tears in the *Ravi* and *Sutlej* rivers also contribute to the seismicity of the region.

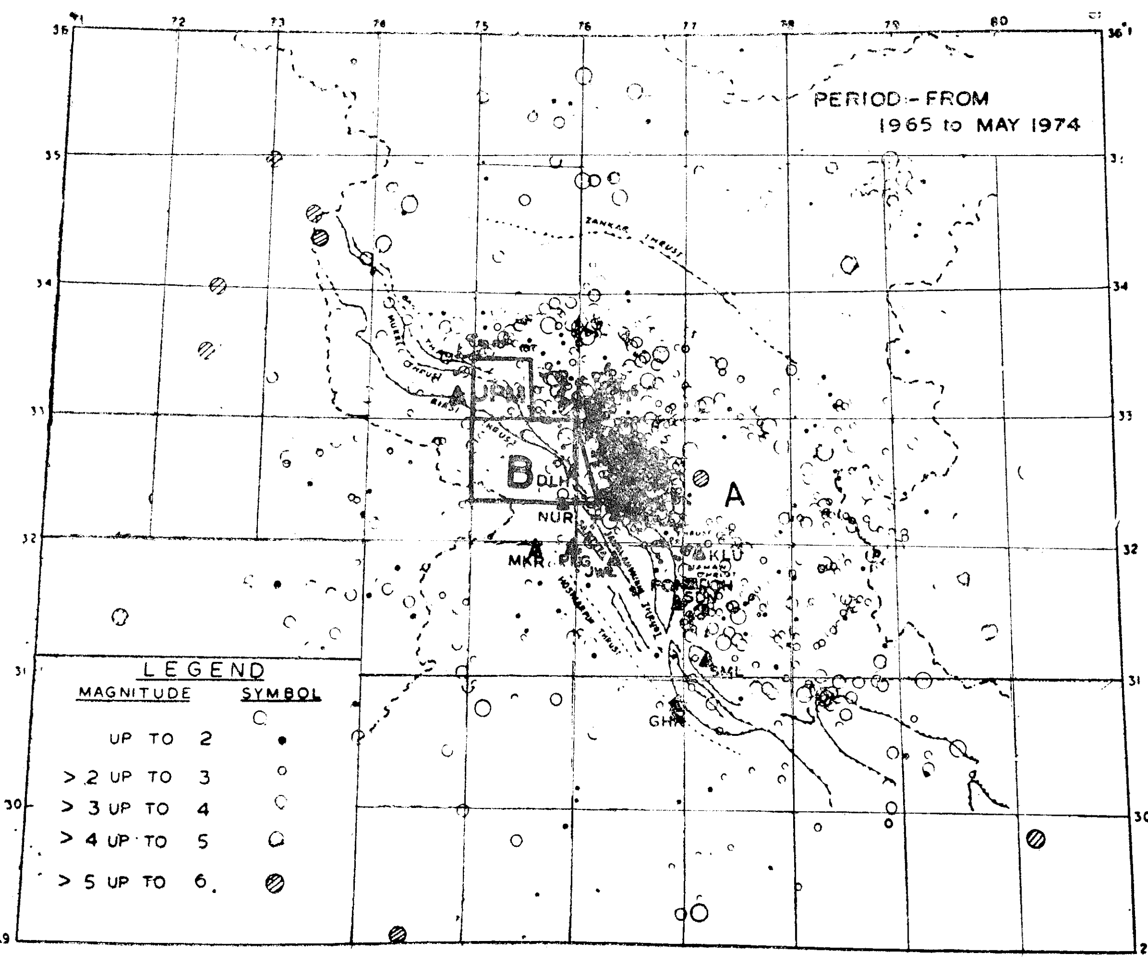

Fig. 1. Epicentres of earthquakes in the Himachal and Kashmir Himalayas

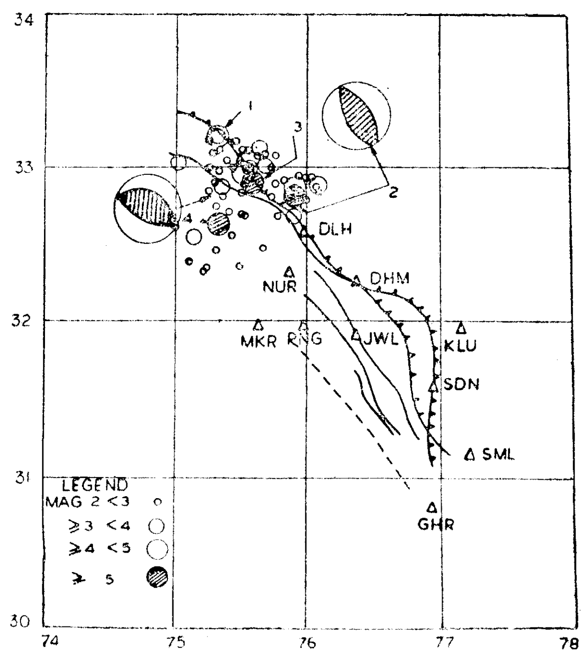

Fig. 2. Epicentres of four recent earthquakes and other earthquakes in vicinity for the period 1965-1980

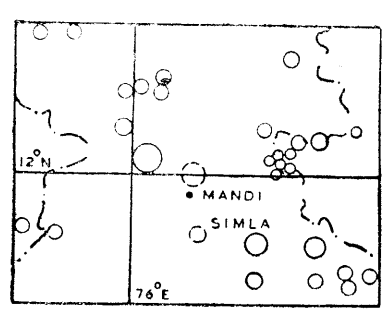

Fig. 3. Epicentres of earthquakes of magnitudes 5 during last 100 years

The tectonics described above has been the source of many damaging earthquakes in the region. The data for the earthquakes during the last two hundred years were collected from the following sources :

(1) Bulletins of I.S.S. or I.S.C., (2) B.C.I.S. Bulletins, (3) U.S.G.S. Preliminary data report, (4) Seismological Bulletins of the India Met. Dep. ; (5) Seismicity of the earth by Gutenberg and Richter and (6)

TABLE 1

Parameters of recent earthquakes

S. No.	Date	Agency	Origin time (GMT) h	m	s	Location of epicentre Lat. (°N)	Long. (°E)	Focal depth (km)	Magnitude (mb)	RMS	ERH	ERZ
1	13 Jul '73	IMD	22	03	31.00	33°12.07′	75°18.28′	2.65	—	0.67	—	—
	13 Jul '73	ISC	22	03	38.1	33.17	75.67	48	4.8	—	—	—
	13 Jul '73	USGS	22	03	38.7	33.10	75.50	52	4.8	—	—	—
2	7 Jan '76	IMD	00	24	51.66	32°52.70′	75°49.02′	15.00	5.4	0.51	15.00	4.4
	Do.	ISC	00	24	52.90	32.97±0.021	76.12±.024	40.00	5.3	—	—	—
	Do.	CGS	00	24	54.1	32.9	76.2	50.00	5.4	—	—	—
3	23 Aug '80	IMD	21	36	52.35	32°53.65′	75°33.49′	15.00	5.2	0.71	8.4	3.7
	Do.	CGS	21	36	51.6	32.91	75.63	25.00	5.2	—	—	—
4	23 Aug '80	IMD	21	50	02.90	32°37.16′	75°19.68′	5.43	5.2	0.48	7.1	3.2
	Do.	CGS	21	50	03.00	32.83	75.63	33.00	5.2	—	—	—

Oldham's Catalogue of earthquakes. An epicentral map of earthquakes of magnitude 5 and above for the above period has been also shown in Fig. 3. A closer look at this map also supports the diffused pattern of seismicity in the region 'B'. However, the epicentres can be broadly associated with northeasterly dipping main faults.

3. Epicentral parameters of earthquakes

Epicentral parameters of the four recent earthquakes studied in this paper were determined making use of Hypo-71 computer programme of U. S. Geological Survey. The P and S wave data from all ten observatories of Beas Project and Jyotipuram observatory of Salal Project (locations given in Fig. 1) were considered for determination. Crustal model of the region after Kamble *et al.* (1973) was used for the purpose. Details of the parameters thus obtained are given in Table 1. It may be mentioned that these observatories use Hagiwara electromagnetic short period ($T_0 = T_G = 1.0$ sec) seismographs recording on 35 mm film together with power amplifier and crystal clocks. However, Jyotipuram observatory has PS : IA recorder (Kinemetrics, USA) with Ranger seismometer. Accuracy in time reading of the order of one tenth of a second or better could be achieved. Time corrections were applied using standard time signals. The local network in the region is such that earthquakes of magnitude 2 or more are detected invariably. The occurrence of the main earthquakes near Dalhousie and Nurpur observatories has also enabled us to check the foreshock occurrence of smaller magnitudes from the records of these stations.

Even though non-availability of a good azimuthal coverage of observatories due to difficult terrain appears to have come in the way of achieving a higher degree of accuracy in the determination of epicentres, a look at the error factor in Table 1 suggests reasonably good accuracy. Comparison of India Meteorological Department epicentral determination using Hypo-71 with those from the bulletins of United States Geological Survey (USGS) or the International Seismological Centre (ISC) shows fairly good agreement except in focal depth and origin time which have been considerably improved with the help of local station data from the Indian network. In order to ensure about the shallow focal depth of these earthquakes, a copy of the Wood Anderson seismogram of Delhi observatory given in Fig. 4 shows crustal phases very clearly, revealing the errors in the depth reported by ISS or USGS. Improved locations of epicentres when superimposed at the appropriate place on the epicentral map (1965-74) reveals that the earthquakes have taken place in the region of diffused seismicity.

Field observations suggest that the damaging earthquakes of 23 August 1980 were associated with different tectonic features. (G.S.I. personal discussion). Their instrumental epicentral locations were about 20 km west of the meizoseismal area where the maximum intensities were around VIII on M.M. Scale. The two earthquake occurred close to two major structural units namely Murree thrust and Surin Mustgarh anticline (Fig. 5). According to Talukdar and Sudhakar (1974) the anticline is based on a fault in the basement. A recent geological map prepared by the Geological Survey of India suggests a number of northnortheast oriented lineaments in the region (unpublished). It is possible that the event 4 which occurred about 14 minutes later was possibly triggered through a lineament extending between the two fault systems. Lay and Kamamori (1980) have reported that large shallow thrust earthquakes tend to occur in closely related pairs in the Soloman islands region. This is attributed to the existence or relatively large, isolated high stress zones on the fault. Failure of these discrete zones induces high, rapidly accumulated stress concentrations on adjacent areas leading to a second major failure and the doublet behaviour. Similar mechanism could possibly operate of the doublets of 23 August 1980.

An interesting feature of the earthquakes of 23 August 1980 is that very few aftershocks occurred ; the magnitude of the largest aftershock being 2.8 on Richter scale. However the earthquake of 7 January

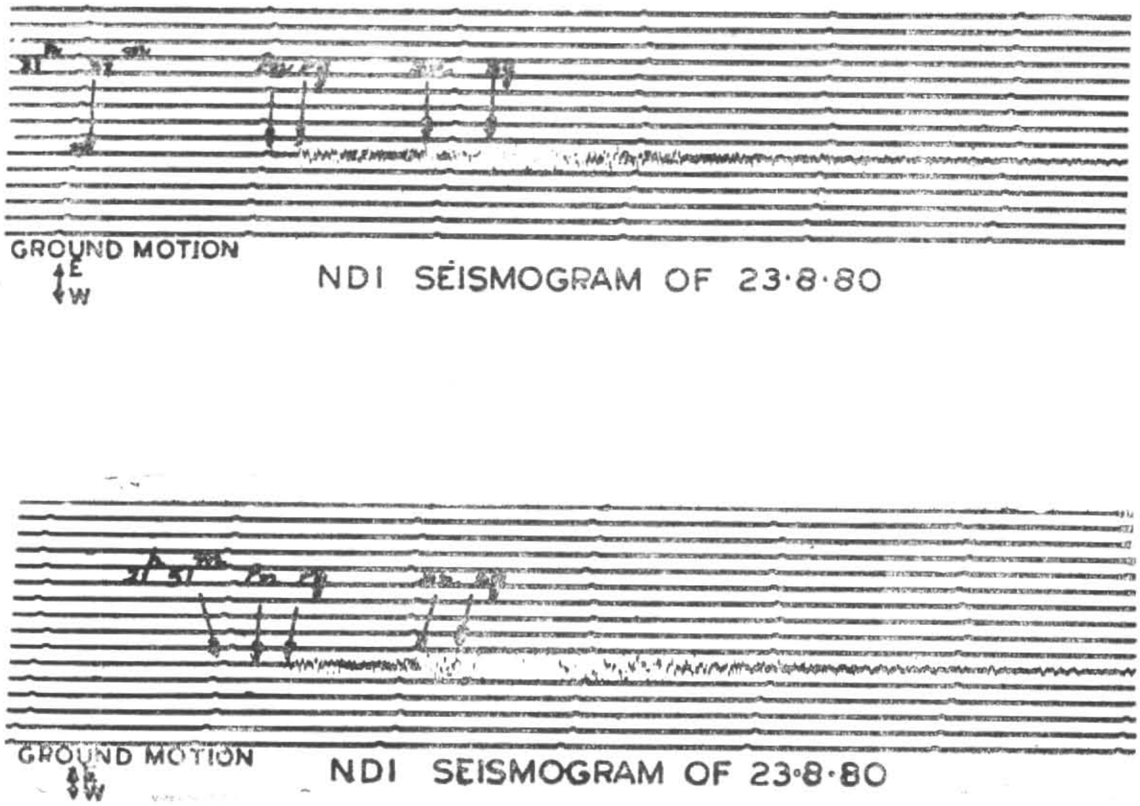

Fig. 4. Wood Anderson seismograms of Delhi observatory

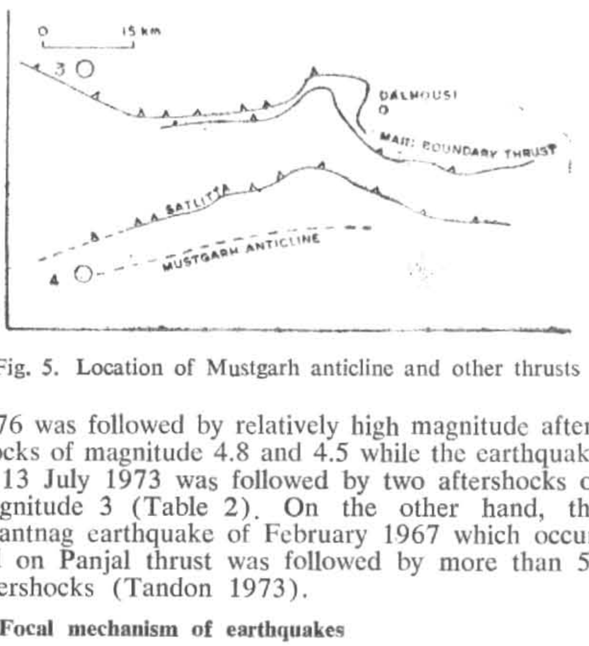

Fig. 5. Location of Mustgarh anticline and other thrusts

1976 was followed by relatively high magnitude aftershocks of magnitude 4.8 and 4.5 while the earthquake of 13 July 1973 was followed by two aftershocks of magnitude 3 (Table 2). On the other hand, the Anantnag earthquake of February 1967 which occurred on Panjal thrust was followed by more than 50 aftershocks (Tandon 1973).

4. Focal mechanism of earthquakes

In order to determine the nature of faulting associated with these earthquakes, P wave first motion data from near as well as distant stations of the world were plotted on equal area projection of the lower half of the focal sphere using the Jeffrey's Bullen earth velocity model. Since some of the stations in Himachal Pradesh were well within the distance of which the first arrival would be P_g waves, the observations were plotted by adding 180 deg. to the azimuth corresponding to the location of such stations. The data gave an excellent control for fixing the nodal planes (Fig. 6).

TABLE 2

List of main earthquakes and their aftershocks

Date	0 time h m s	Epicentres Lat (°N)	Long. (°E)	Depth of focus	Magnitude
13 Jul'73 (Main)	22 03 31.00	33.20	75.30	15	4.8
16 Jul'73	05 45 48.5	33.12	75.72	10	2.7
18 Jul'73	22 55 13.2	33.10	75.54	63	—
18 Jul'73	23 25 07	33.10	75.60	65	—
20 Jul'73	20 41 37.0	33.21	75.83	10	3.0
25 Jul'73	23 16 37.0	33.42	75.71	10	2.2
2 Aug '73	17 57 31.0	33.17	75.82	10	2.3
7 Jan'76 (Main)	00 24 51.66	32.88	75.82	40	5.3
8 Jan'76	22 34 25.50	32.95	76.15	43	4.5
8 Jan' 76	23 45 21.00	33.00	76.2	46	—
9 Jan'76	23 50 16.50	32.78	76.00	96	4.5
10 Jan'76	00 45 33.00	33.20	76.10	96	—
13 Jan'76	10 36 26.00	33.3	76.5	96	—
16 Jan'76	14 01 11.00	32.9	75.5	96	—
18 Jan'76	05 04 19.00	32.7	76.0	00	—
23 Aug'80 (Main)	21 36 52.40	32°53.55′	75°33.49′	15.0	5.4
Do.	21 50 02.90	32°37.17′	75°19.68′	5.43	5.4
23 Aug'80	22 52 56.20	33.01	75.76	3.09	1.8
23 Aug'80	22 55 38.00	32°32.60′	75°14.34′	15.0	—
24 Aug'80	14 10 20.95	32°18.10′	75°28.29′	15.0	2.1
5 Sep '80	05 35 14.20	32°46.88′	75°14.34′	2.6	2.8
5 Sep '80	20 33 07.00	33°3.47′	75°36.88	8.36	1.6

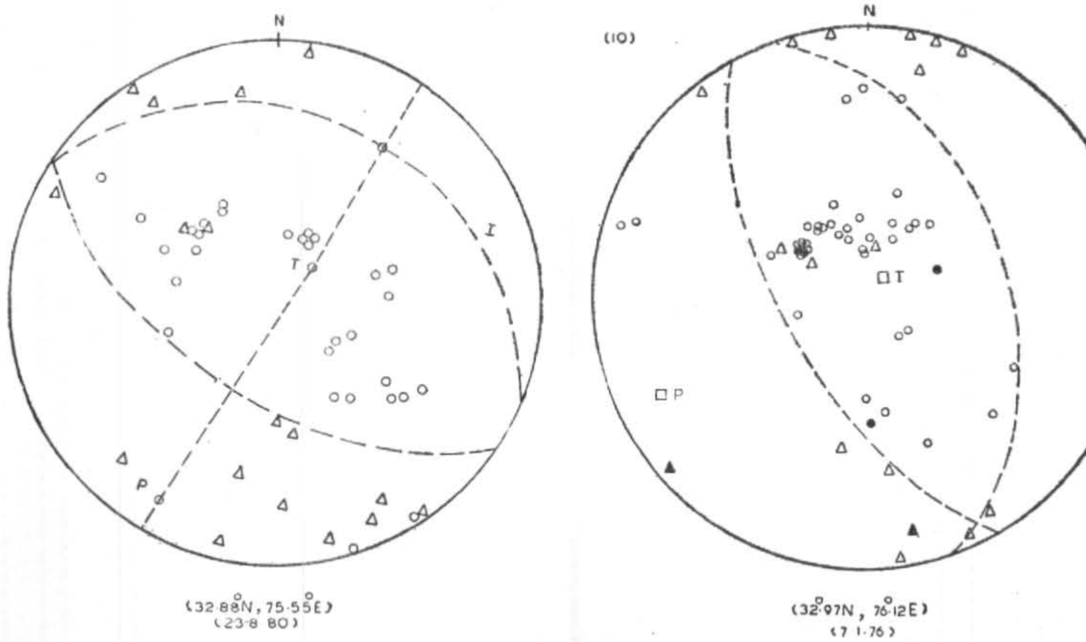

Fig. 6. Fault plane solutions of earthquakes 2 and 3

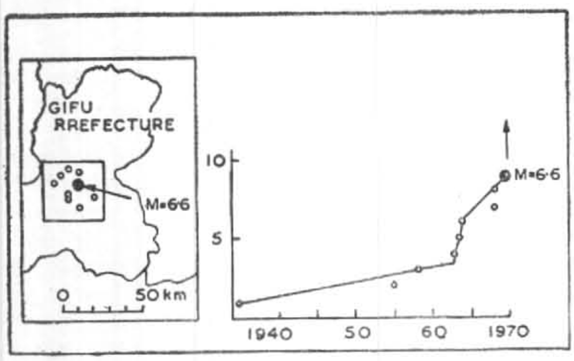

Fig. 7. Seismic activity near focal region observed prior to the central Gifu earthquake of 9 September 1969 of magnitude (*M*), 6.6

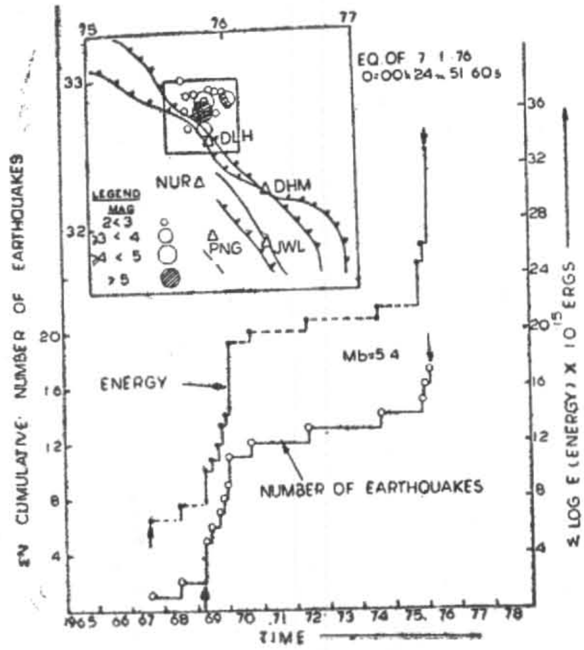

Fig. 8. Seismic activity in the focal region observed prior to the earthquake of 7 January 1976 (Period: 1965-Jan 1976)

Of the four earthquakes, reliable nodal planes could be obtained for the events 2 and 3 (Table 1). Event 1 was rather of small magnitude to be recorded at world-wide stations while the beginning of event 4 merged with the continuing disturbances on the seismograms due to the event 3 which occurred about 14 minutes earlier.

It may be seen that the events 2 and 3 show thrust faulting with northwesterly oriented fault dipping towards northeast. The northeasterly dipping nodal plane may be taken as the fault plane in conformity with the local tectonic features. Shallow pressures were acting at right angles to the faults implying build up of tectonic strain in the region in the vicinity of the plate boundary.

5. Seismicity variations

Spatio-temporal variation of seismicity in different regions of the world have been studied to understand the physical processes preceding earthquakes. In general, there are five important patterns of seismicity as follows :

(a) Preseismic quiescence in the epicentral area (Kelleher and Savino 1975, Ohtake *et al.* 1977),

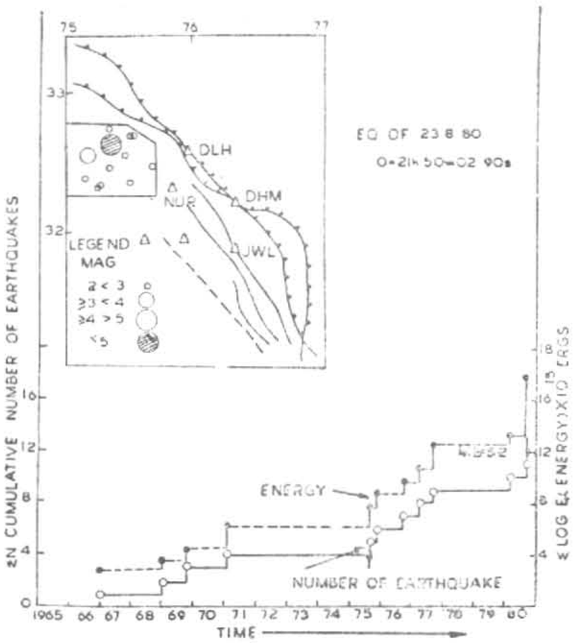

Fig. 9. Seismic activity in the focal region observed prior to the earthquake of 23 August 1980 (Period: 1965-August 1980)

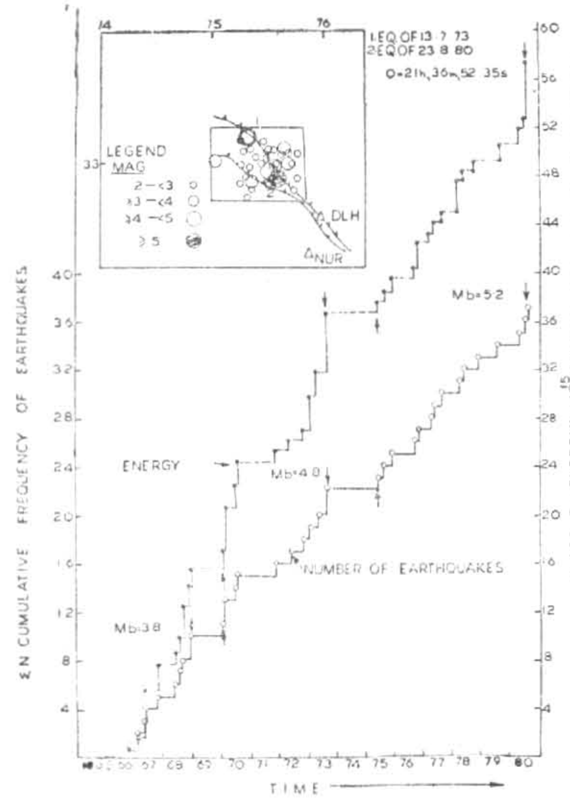

Fig. 10. Seismic activity in the focal region observed prior to the earthquakes of 13 July 1973 and 23 August 1980 (Period : 1965-August 1980)

(b) a precursory swarm (not immediate foreshocks) (Evison 1977),

(c) change in seismicity in the surrounding area, *i.e.*, decrease (Mogi 1969) or increase (Inoue 1965),

(d) clustering of activity immediately before the main shock (Ishida and Kanamori 1977),

(e) Seismicity calm surrounded by a seismically active region called doughnut pattern (Mogi 1968).

Mogi (1968) showed that before Tanankai (1944) and Nankaido (1946) earthquakes, the focal region became very calm while the surrounding region was active at the same time. Some other Japanese workers (Mitsunami and Kubotera 1977 and Yamashina and Inoue 1979) have reported similar doughnut pattern prior to earthquakes of magnitude around 6 in Kyushu and Shimane prefecture, Japan. In view of the wide variations in the patterns of seismicity in different tectonic zones, none of them can be used for prediction purposes with a degree of confidence.

Sekiya (1978) has surmised that there is a typical pattern of precursory seismic activity which is different from ordinary foreshocks. He defined such a pattern of "activity as pre-seismic anomalous activity" which is recognised as relative increase in the number of events during certain period preceding the main earthquake. It has also been observed that precursory time has a definite relation to the magnitude of the main shock and seems to occur also even before large earthquakes which are not preceded by ordinary foreshocks. Fig. 7 shows the seismic activity near focal region observed prior to the central Gifu earthquake of September 1969 which had magnitude of 6.6 on Richter scale with a precursory duration of 7 years and 5 months. In view of low seismicity in the region 'B', similar technique as adopted by Sekiya (1978) has been used in the present paper to study the changes in the seismic patterns before four earthquakes. In selecting the area surrounding these earthquakes, due consideration was given to the plausible focal dimensions using the relations by Dube and Chatterjee (1979), Tandon and Srivastava (1974) and tectonic features of the region. The area in the close vicinity of the epicentre in the figure is shown as closed blocks. All earthquakes of magnitude 2 or more have been included. Seismic activity associated with these earthquakes is shown in the epicentral maps in Figs. 8-10.

In order to study the temporal variations of seismicity near the epicentre of each earthquake, cumulative number of monthly frequency of earthquakes of magnitude 2 or more against the month of the year has been plotted in Figs. 8 - 10. Locations of epicentres of earthquakes in the focal region of these four earthquakes, for the period mentioned in the figures, have also been plotted as inset. A look at these figures brings out a reasonably similar temporal seismicity variation near the epicentres of all the earthquakes.

In these figures upward arrows indicate the onset of commencement of anomalous seismicity characterised

TABLE 3

List of earthquakes and period of anomalous seismicity

Date of earthquake	Magnitude	Precursory duration
13 Jul '73	4.8	3 years 6 months
7 Jan '76	5.4	7 years
23 Aug '80	5.2	5 years
23 Aug '80	5.2	5 years 2 months

by an increase in the number of earthquakes as compared to trend of adjacent previous period. For example in Fig. 8 it may be noticed that the number of seismic events during the period 1965 to 1968 were 2 which suddenly increased to 11 (as indicated by the arrow) during the year 1969. After 1970 the activity again slowed down till October 1975 from where a rise was shown till the occurrence of the earthquake of 7 January 1976.

Fig. 9 shows a slow increasing trend of seismic activity from 1966 to 1970 when near seismic quiescence was observed till September 1975 from where the number of events showed markable increasing trend (five in two years from September 1975 to August 1977) as marked by an upward arrow. This commencement of anomalous seismic activity occurred about five years before the second damaging earthquake of 23 August 1980. It may be pointed out that one could expect some earthquake to take place in 1970. However, since reliable data prior to 1966 is not available, this aspect cannot be emphasized.

In the grid bounded by Lats. 32.8 - 33.4 N and Longs. 75.0 - 75.7 E, three earthquakes of comparatively higher magnitude, *viz.*, 3.8, 4.8 and 5.2 occurred during the period 1965 to 1980. In Fig. 10, monthly frequency of earthquakes numbering 37 of magnitude two or more on the Richter scale are plotted against the month during this period. It can be seen that the commencement of increase in seismic activity appears well marked and continues from May 1975 to April 1978 in case of the earthquake of magnitude 5.2. During the period from April 1978 to April 1980, the seismic activity started decreasing. However, this period of lesser seismic activity is not so well marked as in case of previous two earthquakes in Figs. 8 and 9.

The time difference (T) as given in Table 3, between the time of occurrence of the main event and commencement of anomalous seismicity appears to bear some relationship with the magnitude of the impending earthquake. It may be added here that occurrence of fourth event of magnitude 4.8 in 1973 in the vicinity of the epicentral zone of the earthquake of 23 August 1980 (0 Time, 21 h 36 m 52.40 s) is also broadly in agreement with these observations. It is also interesting to note that the period of lesser seismic activity sandwitched between relatively higher activity prior to the occurrence of impending earthquake also seems to be dependent upon its magnitude (6, 15, 25 - 28, 60 months respectively for magnitudes 3.8, 4.8, 5.2 and 5.4 earthquakes). In view of the lesser number of observations, no attempt is made to arrive at an empirical relationship between T and M_b. However, the results are in agreement to those observed by seismologist in other regions as discussed later.

In order to have corroborative evidence regarding the anomalous seismicity preceding the earthquake, energy release, during the period 1965 to 1980 was calculated from the magnitudes, M using the following relationship :

$$\log E = 11.8 + 1.5 M$$

The results are shown in Figs. 8 - 10. A look at these figures appears to support reasonably well the conclusions drawn based on the number of anomalous seismic events in the focal region.

6. Discussion

The region of diffused seismicity observed through the close network of observatories during the years 1965 - 1974 lies in the vicinity of the boundary of Indian and Eurasian plates where considerable strain is developing through relative motion of these plates.

The occurrence of the four recent earthquakes in the region of diffused seismicity is therefore not unexpected. It may be noticed that anomalous seismicity occurs fairly in advance, *i.e.,* 3 - 7 years before the occurrence of main earthquakes of magnitude 4 - 5 (Figs. 8, 9 and 10). The pattern of seismicity in such zones from prediction point of view is therefore of medium range value. Such patterns of seismicity were observed by many workers, as given below with which the present observations seem to be in agreement.

$\log T = 0.79 M - 1.88$	(Tsubokwa 1969, 1973)	(2)
$\log T = 0.685 M - 1.57$	(Scholz *et al.* 1973)	(3)
$\log T = 0.80 M - 1.92$	(Whitcomb *et al.* 1973)	(4)
$\log T = 0.75 M - 1.83$	(Rikitake 1975)	(5)
$\log T = 0.77 M - 1.65$	(Sekiya 1978)	(6)

As mentioned earlier, another interesting result found from this study is that immediate foreshocks or significant increase in seismicity expected in according with the dilatancy diffusion model of earthquakes is not conspicuous in Jammu and adjoining Himachal Pradesh.

7. Conclusions

The above study brings out the following interesting results :

(1) Data obtained through a close river valley network of seismic stations has enabled us to delineate a zone of diffused seismicity marked 'B'. Inside this region four earthquakes have occurred out of which three were of damaging intensity. The field intensity assessed was higher than that expected from the magnitudes of the two earthquakes in Jammu region.

(2) The recent damaging earthquakes in Jammu were not preceded by foreshocks or followed by significant aftershocks.

(3) The focal mechanism of two of these earthquakes provide evidence for their association with the local tectonic features, namely, thrust faults.

(4) The anomalous pattern of seismicity preceding these earthquakes was broadly similar. The time since the anomalous seismicity preceding these earthquakes commenced appears to be broadly in agreement with the other regions of the world.

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