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Precursory seismic observations in Himachal Pradesh and Shillong plateau

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ABSTRACT. Precursory changes in *P*-wave residuals were noticed before the earthquakes on 1 June 1969 (M=5.0) and on 15 May 1974 (M=4.8) near Shillong and another near Nurpur (Himachal Pradesh) which occurred on 23 January 1969 (M=4). . For these earthquakes, decrease in *P* wave velocity was observed one to two months prior to their occurrence.

Six monthly *b* values in Gutenberg Richter's frequency magnitude relationship showed a decrease in the value about 15 days and 3½ months before two other earthquakes of October 1969 and January 1970 in Himachal Pradesh. The decrease in *b* value for foreshocks as compared to the aftershocks was also noted for another earthquake on 5 November 1968. A well marked seismicity gap has been demarcated in Himachal Pradesh on the basis of epicentral distribution obtained with a close river valley project network of observatories. This could be indicative of a possible damaging earthquake in the region.

The foreshock occurrence in the Himalayan region was investigated on the basis of data upto 1975. Although no relationship between the time of first foreshock and the main shock could be established, the results show that there is a time lag of about 10 hours between the observed foreshock and the main shock on several occasions. However, foreshocks could be detected much earlier in Himachal Pradesh where a close network of seismological observatories is being maintained.

1. Introduction

Earthquake prediction research has gained momentum during the last decade. The seismic methods for this purpose include changes in the *P* and *S* wave velocities, the decrease in *b* value in Gutenberg Richter's frequency-magnitude relationship before the occurrence of large earthquakes, the decrease in *b* value in foreshocks compared to that in aftershocks, the concept of seismicity gap, micro-earthquake and foreshock observations (Rikitake 1976). A critical study of these methods shows that proper assessment about these can be made only at those places where a close network of seismological observatories is maintained. Further, because of geological and tectonic differences, none of these methods are of universal application and considerable research is needed in different parts of the world before these methods can be adopted for forecasting earthquakes.

In India, the detection capability of the seismological network in general is sufficient for earthquakes of magnitude 5 or more except in Himachal Pradesh where ten sensitive observatories are operating with Hagiwara Electromagnetic Seismographs (Fig. 1). A lot of seismic data has therefore been collected through these stations. In addition, the Shillong plateau in India enjoys seismic status similar to the foothills of Himalayas. In both these regions, two of the most destructive earthquakes occurred in 1905 (Kangra, Himachal Pradesh) and 1897 (Shillong) respectively. It was, therefore, considered worthwhile to utilize the seismological data for these regions and examine the applicability of the different methods for earthquake prediction. The findings are given in this paper.

2. Changes in seismic wave velocity

Apparent changes in seismic wave velocities with time were reported about twentyfive years ago (Hayakawa 1950). But the connection of such changes with earthquakes was systematically studied much later by several Russian seismologists (Nersesov *et al.* 1969, Semenov 1969). In these studies, the ratio of the velocity of compression waves V_p, to that of shear waves, V_s in parts of Garm region first abnormally decreased and then returned approximately to its normal level prior to several earthquakes. Similar changes in seismic wave velocities have been observed subsequently in many other regions (Aggarwal *et al.* 1973, Sutton 1974, Kanamori and Chung 1970, Wyss and Holcomb 1973, Feng *et al.* 1974). The data suggest that the major contribution to the variation of V_p/V_s ratio comes mostly through a decrease in V_p. The observation of this precursor phenomenon has been explained by the dilatancy diffusion model of changes in the earthquake zone by the U.S. scientists and by slightly modified model by the scientists of the Institute of Physics of the Earth, Moscow. Both these models show that along with the changes in the seismic velocities, changes in other geophysical parameters also should occur. Many of these changes have indeed been observed, thus triggering active research into earthquake prediction. In the light of these, a study of seismic wave travel times in the case of three earthquakes, two in Shillong plateau and one in Himachal Pradesh has been made.

3. Data and analysis

The source parameters of the events have been taken from the International Seismological Centre Bulletins (Table 1). All these earthquakes were located within 20 km of the nearest observatories, namely, Nurpur and Shillong with their foci in the crust. They were felt at the nearest observatories (Fig. 1).

The times of arrival of the waves at the seismic stations have been taken from the records where the timing is controlled by crystal clocks and the readings are accurate to a tenth of a second. For the event 3, the residuals with reference to Jeffreys-Bullen Tables were averaged over a month for Nurpur and Jawalamukhi observatories. For the events 1 and 2, the data from Shillong and Delhi observatories were taken. In order to reduce the source effect, the residual at the station located in the dilatant zone is compared with that at a far off station. This condition is ideally achieved in Himachal Pradesh where a close network of observatories is being maintained. In the case of the earthquakes near Shillong although Calcutta, Chatra and Bokaro are three seismic stations about 300 to 500 km from Shillong, none of them are high gain observatories and do not use crystal clocks for time keeping. Hence the only alternative was to take Delhi as the reference station for Shillong. Though far off from Shillong this was successful in reducing the source effects since all the teleseisms whose residuals were used, occurred in the Pacific, ranging from Kurile to Kamchatka. Thus although the effect of radiation pattern of the events may differ at Shillong and Delhi (which has, of course no effect on *P*-wave residuals), the events confined in this sector originated from the similar type of plate boundary of Eurasian and Pacific plates. In order to reduce the crustal and upper mantle anomalies, only the events in the epicentral distance range of 40° to 60° were considered for working out the mean monthly residuals and their differences from the reference station. The results are given in Fig. 2. For the event 1 mean *P* residuals were computed at Delhi and Shillong from August 1973 to June 1974. *P* wave residual difference between Delhi and Shillong started increasing from the month of February reaching maximum during April 1974. The difference residual again decreased in May when the earthquake occurred near Shillong with a felt intensity of IV on Modified Mercalli scale. If only the residuals at Shillong were examined from August 1973 onwards, it will be noted that

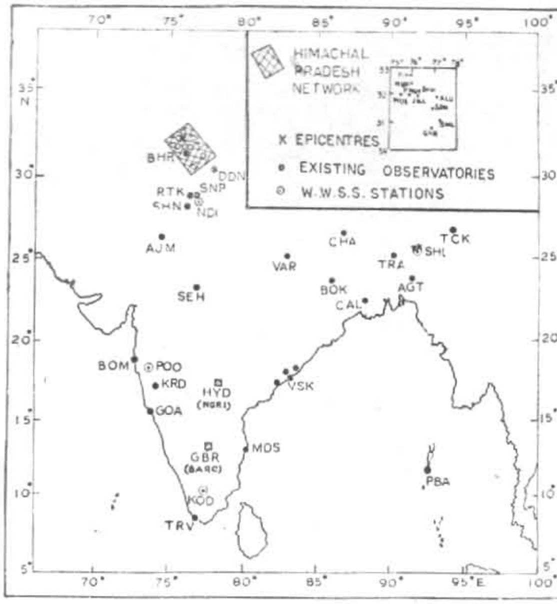

Fig. 1. Indian Seismological Network:
Inset shows closely located seismic stations in Himachal Pradesh for river valley projects.

P residuals decreased in September 1973 which could possibly be associated with earthquake occurrence although no such indication was available from residual difference between Delhi and Shillong. An earthquake occurred in October 1973 (epicentre 25.2° N, 92.5° E) which was located about 65 km from Shillong and because of the smallness of focal zone (Magnitude 4.3) the waves emerging at Shillong were not affected by the dilatant zone. Mean residuals also decreased at Shillong in June 1974 but was attributed to the source effect since no earthquake occurred close to Shillong during the next six months. The source effect became obvious by using difference residual between Shillong and Delhi. The number of micro-earthquakes also started increasing from February 1974, within 20 km of Shillong which gave further support to the validity of dilatancy model of earthquake occurrence in the region. For event 2 of June 1969 near Shillong, *P* wave residual difference increased from March to May by 0.5 sec which became normal in the month of May. Similarly, for the event 3 located near Nurpur in Himachal Pradesh the residuals increased about two months in advance during November 1968 which almost returned to its normal value by January 1969. No significant increase in micro-earthquakes was, however, noted for these two events.

4. Discussion

Both the regions used in the study namely Himachal Pradesh and Shillong were affected by the most destructive earthquakes of 1905 and 1897 respectively. A detailed study of earthquake occurrence in Himachal Pradesh was made in

TABLE 1

Earthquakes and the precursory phenomena in Himachal Pradesh and Shillong

Date	Epicentre		Origin time (GMT)			Magnitude	Focal depth (km)	Precursory phenomenon.
	Lat. (°N)	Long. (°E)	*h*	*m*	*s*			
15 May 1974	25·7	91·9	03	51	22	4·5	34	Decrease in *P* wave velocity
1 June 1969	25·8	91·8	08	35	22	5·0	20	Do.
23 Jan 1969	32·2	76·1	20	01	19	4.0	Normal	Do.
12 Oct 1968	32·8	76·6	19	06	21	5·0	Normal	Decrease in *b* value
19 Jan 1970	32·7	76·6	18	33	02	4·7	Normal	Do.
5 Nov 1968	32·3	76·5	02	02	45	4·8	Normal	Decrease in *b* in foreshocks as compared to aftershocks and general seismicity

connection with a river valley project with the help of a close network of seismic stations. Fig. 3 shows the activity during the period 1965 to 1974 and brings out the high level of activity in this area. The computation of magnitudes for some events beyond 1970 has still to be done and thus the return periods of earthquakes in the grid 32°-33°N, 76°-77°E were computed on the basis of the data upto 1970 only (Table 2). Earthquakes upto magnitudes of 5 are occurring at an interval of one to two years quite frequently and more damaging earthquakes are not unexpected in the light of regional tectonics, statistical probability and seismicity. Study of the mechanism of comparatively larger earthquakes in this area as well as near Shillong has shown that the nature of faulting is predominantly of thrust type (Chaudhury *et al.* 1974, Tandon and Srivastava 1975, Chaudhury and Srivastava 1976). Nur *et al.* (1970) have furnished laboratory evidence to suggest that thrust faults are capable of large dilatancy and the dilatant volume can be similar in size to the aftershock-zone. Since none of these events were followed by a large number of aftershocks, the linear dimension of the aftershock zone was estimated from the following relation (Tandon and Srivastava 1974) :

$$\log A = 0{\cdot}89\ M_L - 2.67 \tag{1}$$

Thus the linear dimensions for the three events in Himachal Pradesh and Shillong as estimated from their magnitudes are of the order of 20 to 25 km.

If V_1 and V_2 are the velocities before and after the dilatancy, t_2 and t_1, the corresponding times then :

$$\frac{\triangle V}{V} = \frac{\triangle t \times V}{\triangle} \tag{2}$$

If $V_P \approx 6$ to 8 km/sec, $\triangle t \approx 0{\cdot}3$ to $0{\cdot}6$ sec, and $\triangle \approx 20$ to 25 km, the percentage decrease in velocity comes out as 15 to 20 per cent.

The duration of the change in seismic wave velocity observed in this study is also in agreement with those observed by others (Rikitake 1976).

TABLE 2

Return period of earthquakes

(32°-33°N, 76°-77° E, 1965-1970)

	Magnitude						
Return period	3·5	4·0	4·5	5·0	5·5	6·0	6·5
Years	0·16	0·48	1·15	3·14	8·55	23·3	63·4

5. *b* value from short term seismicity data

The magnitude distribution can be studied by fitting the seismic data in Gutenberg Richter's relationship given by

$$\log_{10} N = a - bM \tag{3}$$

where N is the frequency of earthquakes of magnitude $M+dM$ and M-dM, and a and b are constants, The constant 'b' may also be estimated for a group of earthquakes from

$$b = \frac{0.4343}{\overline{M} - M_{\min}} \tag{4}$$

where $\overline{M}$ is the average magnitude of the sample and $M_{\min}$ is the lowest magnitude used. This equation gives the maximum likelihood estimate of b for a sample of earthquakes and holds good if the range of magnitudes in the sample is greater than two magnitude units. The approximate 95% confidence limits for the estimate of b are $\pm 1{\cdot}96\ b/\sqrt{n}$.

Large number of small earthquakes are occurring in the area bounded by the latitude 32°-33°N and longitude 76°-77° E (Fig. 3). The value of b worked out with the help of Eqn. (4) for six monthly periods is given in Fig. 4. Due to lesser number of observatories during the period January 1965 to June 1967 the data was meagre. From July to December 1967, the value of b was found as 1·09 which decreased to 0·73 during the next six months. An earthquake of magnitude 5·0 occurred in the region in October 1968. Another earthquake with several foreshocks and aftershocks again occurred close to the first shock

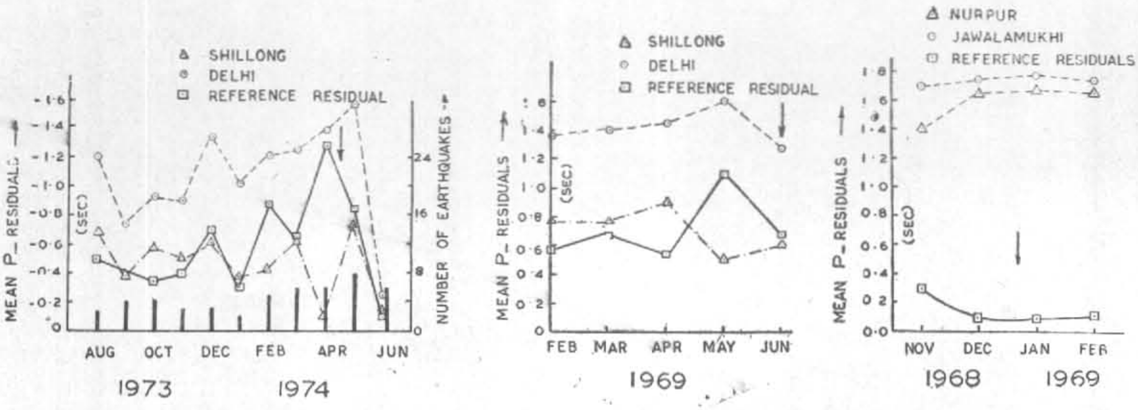

Fig. 2. Mean monthly P wave residuals at Shillong, Delhi (events 1 and 2) and Nurpur, Jawalamukhi (event 3) Reference residual is shown by a square (□).

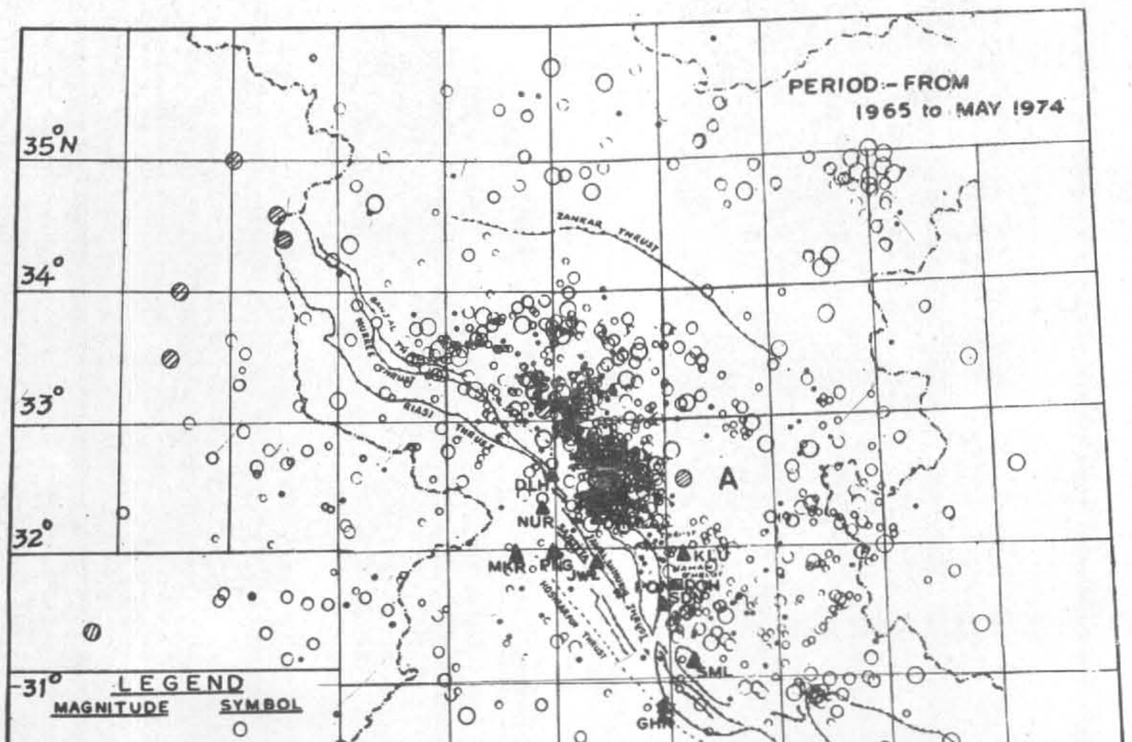

Fig. 3. Micro-earth quakes in Himachal Pradesh and neighbourhood during 1965 to 1974. Faults/thrusts and the observations (marked with a solid triangle) are also shown.

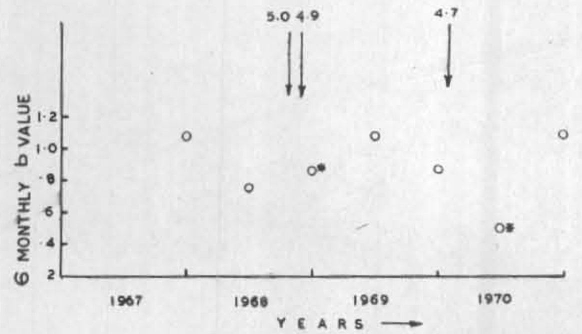

Fig. 4. Six monthly changes in b values in Himachal Pradesh (grid 32-33°N, 76-77°E) during the years 1967 to1970. Arrows indicate significant earthquakes associated with decrease in b value.

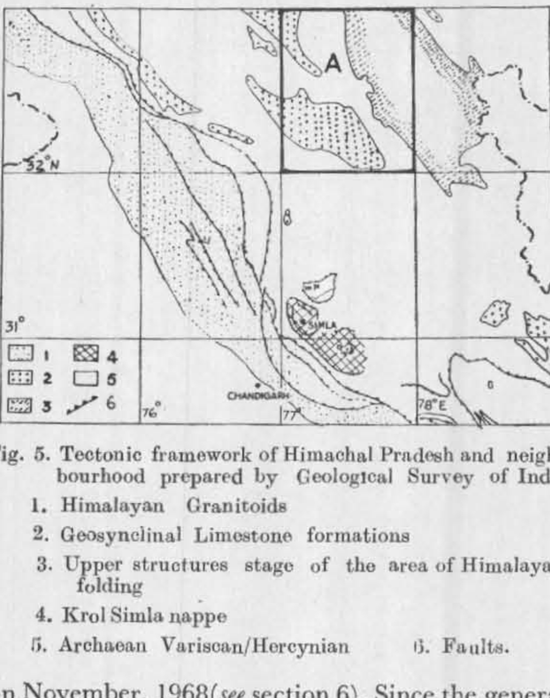

Fig. 5. Tectonic framework of Himachal Pradesh and neighbourhood prepared by Geological Survey of India

1. Himalayan Granitoids
2. Geosynclinal Limestone formations
3. Upper structures stage of the area of Himalayan folding
4. Krol Simla nappe
5. Archaean Variscan/Hercynian 6. Faults.

in November, 1968(*see* section 6). Since the general level of seismicity was contaminated by the foreshock-aftershocks, b value was less reliable for the period from July to December 1968. During the subsequent six months, the value of b rose to 1·08 which again fell to 0·87 from June to December 1969. An earthquake of magnitude 4·7 occurred in the region on 19 January 1970 followed by another in March 1970. During the first six months of 1970, a low value of b was obtained which was contaminated due to foreshock-aftershocks. During the remaining six months of 1970, the value of b was almost restored again. These results thus indicate that the value of b from the short term seismicity data may provide precursory observations. Similar results were observed from other parts of the world (Rikitake 1976). In order to apply this method, one may prefer to work out b value for a shorter period, say three months, but the population becomes too small to obtain a reliable estimate of b.

5. Comparison of b for foreshocks and aftershocks

During the ten-year period (Fig. 3) some earthquakes in Himachal Pradesh were preceded by foreshocks but their number was too small for any statistical study. The earthquake of 5 November 1968 which caused minor damage near Dharamsala was preceded by 24 foreshocks and more than 100 aftershocks. The values of b for foreshocks and aftershocks were found as $0{\cdot}69 \pm 0{\cdot}23$ and $1.09 \pm .13$ respectively which showed a lower value for foreshocks. Similar results were observed for the Ladakh earthquake of 11 February 1968 (Srivastava and Kamble 1971). The results are also in agreement with those of Suyehiro (1969). The value of b for this region was found to be 0·89 based on the seismicity data. Thus the value of b from foreshocks of 5 November 1968 earthquake is lower than that from seismicity data.

The generation of foreshocks is dependent upon the types of basement rocks, the degree and symmetry of applied stress and the focal depths of the main shocks. Hence this method of earthquake prediction suffers from the disadvantage that unless very large number of foreshocks can be monitored (which may be only achieved with shallow focus large earthquakes through sensitive observatories located close to the epicentral regions), the computation of b value is not always practical.

6. Seismicity gap

A region where seismicity is less as compared to neighbouring seismically active region is called seismicity gap. This type of observation was first utilized by Fedotove *et al.* (1970).

Fig. 3 shows the epicentral distrubution observed in western Himalayas during the years 1965-1974. The region where the largest number of events are clustered was the zone of Kangra earthquake of 1905. East of this zone, an earthquake in Kinnaur region (M_B=6.2 M_S=6.8) occurred on 19 January 1975. It is interesting to observe that a seismicity gap exists in the region marked by letter A. The question arises whether this could be a zone of a strong earthquake in future.

A reliable knowledge of the history of earthquakes is useful for the region of seismicity gap where destructive earthquakes are believed to recur. In the Indian region, however, the history of damaging earthquakes is available for the last 200 years only and this puts a limitation to the inferences drawn for the zone A.

Fig. 5 shows the tectonic features as given by Oil and Natural Gas Commission. 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 tertiaries (Siwaliks), older tertiaries, Punjal volcanics, krols, granite, gneiss and chails.

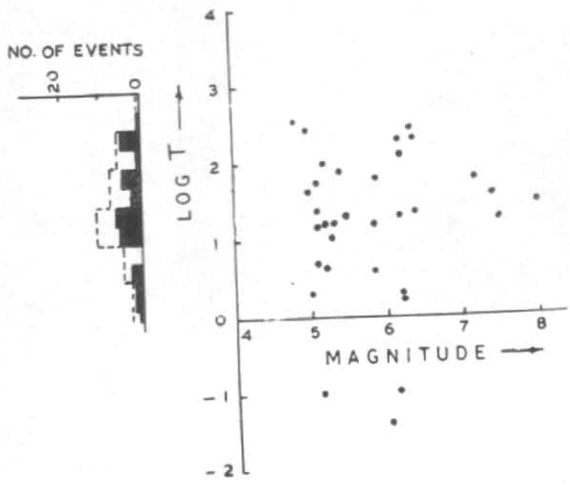

Fig. 6. Time interval (in log scale) between earliest reported foreshock and the main shock *versus* the magnitude of main shock.

Number of foreshocks occurring during different intervals of time from the main shock are also shown.

TABLE 3

Short term seismicity *b* value

(Grid : 32°-33°N, 76°-77°E)

Year		*b* value	Remarks
1967	I	—	Data insufficient
	II	1·09	
1968	I	*0·73*	
	II	0·86*	Large number of fore shocks aftershocks data contaminated
1969	I	1·08	
	II	*0·87*	
1970	I	0·51*	Data contaminated due to foreshock/aftershocks.
	II	1·10	

I and II denote the six monthly observations; Precursory *b* value are in italics.

The region A is located in middle Himalayas, not very far from the main boundary faults. Tremendous amount of strain is accumulating in the region due to the collision of the Indian and Eurasian plates. Focal mechanism solutions of earthquakes in the region have shown under thrusting along this plate boundary (Chaudhury *et al.* 1974, Tandon and Srivastava 1975) and the direction of presures are acting at right angles to the mountain front. Considering this and the history of earthquakes in neighbouring regions in Kangra (1905) and Kinnaur (1975), it is not unlikely that a strong earthquake may occur in the region marked A.

If the concept of seismicity gap can be used for earthquakes near continent-continent type of plate boundaries, the region A could call for detailed geological and seismological investigations. Crustal deformation measurements through geodetic surveys, precision tiltmeters and strain meters may throw light about the utility of integrated approach for earthquake prediction in such regions.

7. Foreshocks

Foreshocks provide potential clues to the occurrence of stronger earthquakes. The catalogue prepared by the India Meteorological Department, the bulletins of International Seismological Centre and the list of earthquakes upto 1975 prepared for the river valley projects in Himachal Pradesh were looked for this purpose. For earthquakes prior to 1900, foreshocks were chosen on the basis of descriptions given in the Memoirs of the Geological Survey of India. For the periods from 1900 to 1962, the epicentral locations were generally available for earthquakes upto magnitude 5 only. The detection capability increased considerably in Himalayan region after the World wide Standardised Seismograph network of stations was established in 1963. The foreshock occurrence could, however, be studied in greater detail in Himachal Pradesh due to the close network of highly sensitive Hagiwara Electromagnetic Seismographs which are in operation since 1965.

Although foreshocks may occur even years in advance or hundreds of kilometres away from the main shock, only closely located events in space and time were considered after studying the general level of seismicity in the regions. This had to be done because of the sparsely located observatives due to which not only the number of events considered as foreshocks was quite small but also, only relatively larger magnitude events were available. Greater confidence in picking up these foreshokcs was obvious for those events which were followed by aftershocks.

Fig. 6 shows the time interval in hours between the first reported foreshock and the main shock (in log scale) *versus* the magnitude of the main shock. The frequency distribution of the events *versus* time is also shown in the same figure. It would be seen that although there is a preponderence of events about ten hours before the main shocks, no relationship between the precursor time and the magnitude of the main shock could be seen. The results are broadly in agreement with Rikitake (1976).

As stated earlier, the network of sensitive observatories in Himachal Pradesh enabled us to determine the epicentral parameters of the events upto magnitude 1.5. Detecting smaller shocks without epicental determination was also possible. Thus a sudden spurt in the events at the same epicentral distance sufficiently well in advance was noticed in the case of many earthquakes like Anantnag earthquake (1967), Dharamsala earthquake (1968), Kishtwar earthquake (1973), Kinnaur earthquake (1975) and a few others. Although data is still meagre, there is some indication that the precursor time from foreshock observatories could possibly be related to the magnitude of the main shock. Even if this may not always hold good monitoring foreshocks by opening a close network of seismological observatories, can be considered a powerful tool in the Himalayan region.

Laboratory experiments on rock specimens have suggested that moderately fractured samples have a foreshock-aftershock sequence while homogenous rocks break almost suddenly (Mogi 1966). The large number of earthquakes preceded by the foreshocks, the tectonic features due to continent-continent type of collision of India and Eurasian plates with a wide zone of deformation suggests that the Himalayan region generally falls in Mogi's experiments of the type II. These considerations lend support to the inferences drawn above at closely located seismic monitoring stations in the Himalayas may provide a powerful tool for earthquake prediction.

8. Conclusions

The above study brings out the following results ;

1. A decrease in *P*-wave velocity is observed before the occurrence of earth quakes in Shillong plateau and Himachal Pradesh. All these earthquakes were located within 20 km from the nearest observatories where the dilatant effect was observed. Both these regions are characterised by thrust faulting.

2. A decrease in *b* value from short term seismicity was observed before the occurrence of two earthquakes in Himachal Pradesh.

3. Comparison of *b* value for the foreshock and aftershocks for the earthquake of 5 November 1968 in Himachal Pradesh showed a lesser *b* value for foreshocks.

4. A well marked seismicity gap is observed in Himachal Pradesh which could be indicative of a damaging earthquake. More intensive geological and other geophysical investigations may be called for in this region.

5. The time of occurrence of the earliest detectable foreshock does not appear to depend upon the magnitude of the main shock. However, monitoring the foreshocks appears to be useful for earthquake prediction in Himalayan region.

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DISCUSSION

(Paper presented by H. N. Srivastava)

P.L. NARULA (GSI) : The authors have tried to find a seismicity gap from the data from Beas network and data from Kinnaur earthquake and an area for probable event has been identified. The authors have further stipulated main boundary fault as some mechanism for Beas events but the source is not the same for Kinnaur earthquake. The seismic gap concept could be applied only if the source mechanism is the same for both the areas. Thus seismic gap identification with different sources may not be correct. I think we should look for seismic gaps along the continuitiy of same source.

AUTHOR : The seismiticy gap has been delineated on the basis of Beas network of stations only. Kinnaur earthquake has been mentioned because it occurred in a region of hitherto low seismicity. Since the gap is well defined, the impending even could possibly be associated with the main boundary fault which was responsible for the Kangra earthquake of 1905,