Mausam, (1990), **41**, 1, 59-64

550.348.098.64 : 550 347.62

Crustal investigations and micro-earthquake survey along Hirapur, Jabalpur, Mandla profile using deep seismic sounding explosion data

V. K. MITTAL, S. N. BHATTACHARYA and H. N. SRIVASTAVA

Meteorological Office, New Delhi

(*Received 27 December 1988*)

सार – गहरे भूकम्पी ध्वनि विस्फोट आंकड़ों का प्रयोग करके मध्यप्रदेश क्षेत्र में हीरापुर, जबलपुर, मांडला के आसपास भूपर्पटी संरचनाओं का अध्ययन किया गया। अपवर्तन अध्ययनों से यह पता चला है कि वहां दो सतही पर्पटी है। इस क्षेत्र में, ग्रेनाइट की ऊपरी सतह 23 कि. मी. और बैसाल्टिक सतह 16 कि. मी. की है।

इस कार्य में नियमित वेग निदर्श का प्रयोग करते हुए, सूक्ष्म भूकम्पों के अवकेन्द्र प्राचलों का परिकलन किया गया है। यह देखा गया है कि यद्यपि प्रेक्षणों की अवधि के दौरान क्षेत्र में भूकम्पी प्रतिक्रिया काफी धीमी रही और और वह उथली गहराई तक सीमित है पर कटंगी भ्रंश के पास जबलपुर के पश्चिम में सूक्ष्म भूकम्पों का संकेन्द्रण है जिन्हें कि गहरे भूकम्पी ध्वनि आंकड़ों से गहन रूप से स्थित पाया गया है।

ABSTRACT. The crustal structure around Hirapur, Jabalpur, Mandla profile in the Madhya Pradesh region has been studied using the Deep Seismic Sounding (D.S.S.) explosion data. Refraction studies have revealed that there is a two-layer crust. The top layer consists of 23 km of granite and 16 km of basaltic layer in the region.

Using the velocity model deduced in this work, the hypocentral parameters of micro-earthquakes have been computed. It has been observed that although the seismic activity in the region has been very low during the period of observations and is limited to shallow depth, there is indication of a concentration of micro-earthquakes west of Jabalpur, close to Katangi fault which has been found to be deep seated from D.S.S. data.

1. Introduction

During the year 1983-84, Deep Seismic Sounding (D.S.S.) experiments were carried out by the National Geophysical Research Institute along Hirapur, Jabalpur and Mandla profile in Madhya Pradesh region. India Meteorological Department (IMD) also participated in the project and set up four temporary seismological observatories around the profile to record the explosions for crustal studies and micro-earthquakes in the region.

The main objectives of participation of IMD in the project were as follows :

(*i*) To study the crustal structure and the seismic wave velocity in the region which can be obtained more reliably from chemical explosions of known origin time and location.

(*ii*) To monitor the seismic activity with high gain portable instruments for mapping the seismic activity and orientation of the faults/lineaments and to understand the processes taking place in the crust/mantle.

(*iii*) To study the attenuation of seismic waves which may throw light on the existence of anomalous zones in the region, if any (Chaudhury *et al.* 1984, Srivastava *et al.* 1980). However, the data from this region was insufficient to study this aspect.

2. Regional geology and tectonics

Five major tectonic provinces are recognisible in craton of north-central India. The oldest metamorphics green stone have been extensively penetrated and metasomatically transformed by about 200 m.y. old granodiorite-tonalite suite of granitic rocks. Together they constitute the Bundelkhand complex representing a shield. The Bundelkhand-Berach shield fringed to the south by the Bijawar (Satpura) province represented by basic lavas (partly submarine chemical precipitated and flysch). Repeatedly deformed, the south and the west part of this unit have been fashioned by later tensional tectonics with horsts - the Satpura and the Aravalli. The Bijawar rocks of the Majholi - Sihora area in Jabalpur district, exhibit NE-SW trending elongate, tight, overturned isoclinal folding of the earlier phase, superposed with steeply SE-plunging cross folds (Chowbey 1971). This complicated folded belt is separated from the upper Vindhyan, immediately to the northwest, by a great transcurrent fault—the Narmada - Son fault.

3. Seismic history

Although the area has not been the source of any major earthquake in the past, a number of minor

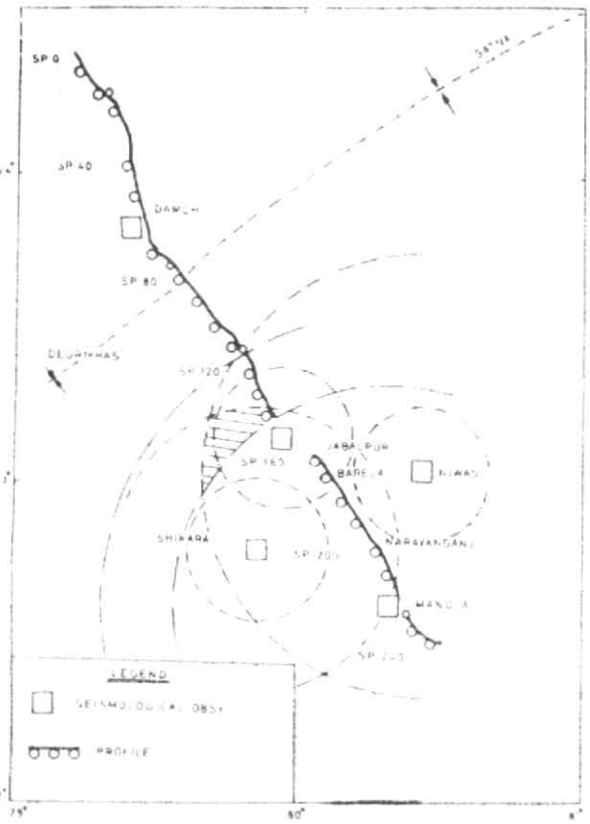

Fig. 1(a). D.S.S. profile along Damoh-Jabalpur-Mandla

TABLE 1

List of earthquakes in Madhya Pradesh and neighbourhood

Date	Lat. (°N)	Long. (°E)	Location	Mag./Inten.	Ref.
27 May 1846	23.0	80.0	Near Damoh	6.5	OLD
16 Nov 1868	23.2	80.0	Jabalpur	III	IMD
17 May 1903	23.0	80.0	Jabalpur	VI	TRI
02 Jun 1927	24.0	82.0	Son valley	6.5	GR
14 Mar 1938	21.5	75.7	Satpura	6.3	GR
25 Aug 1957	22.0	80.0	Balaghat	5.5	SHL
17 Oct 1957	21.5	79.0	Near Nagpur	—	SHL
26 Mar 1969	22.6	78.1	Near Itarsi (MP)	4.2	IMD
12 Jul 1973	23.2	80.0	Jabalpur	IV	IMD

GR—Gutenberg & Richter (1954), IMD—India Meteorological Department, New Delhi, OLD—Oldham (1883), SHL—Shillong (India), TRI—Turner *et al.* (1911)

TABLE 2

Coordinates of observatories and type of instruments with magnification

Station	Code	Lat. (°N)	Long. (°E)	Instrument	Magnification/gain
Hirapur, Jabalpur, Mandla profile					
Jabalpur	JBP	23° 08′ 20″	79°55′20″	E.M. (Z) MEQ	50 K 78 db
Niwas	NWS	23° 02′ 40″	80° 26′ 45″	MEQ	84/78/72 db
Mandla	MDL	22° 37′ 50″	80° 20′ 15″	MEQ	84 db
Shikara	SKR	22° 47′ 50″	79° 51′ 23″	MEQ	84/90 db

Filter setting for the MEQ 800 was kept at 5-30 Hz at all the stations

TABLE 3

Coordinates of shot points

Shot point No.	Latitude Deg.	Latitude Min.	Latitude Sec.	Longitude Deg.	Longitude Min.	Longitude Sec.
0	24	22	49.4	79	13	48.3
0A	24	20	23.6	79	10	53.6
0B	24	23	39.8	79	14	17.0
10	24	16	56.4	79	14	44.8
30	24	05	36.6	79	21	42.6
40	24	01	16.0	79	23	16.7
60	23	54	20.6	79	24	51.9
70	23	47	49.6	79	27	40.0
80	23	41	19.0	79	33	44.4
80A	23	41	31.1	79	33	15.9
95	23	34	31.7	79	39	43.7
105	23	31	21.5	79	40	20.2
120	23	26	32.4	79	48	45.2
120A	23	25	02.9	79	47	45.7
135	23	19	45.8	79	50	54.4
150	23	13	17.3	79	53	55.4
160	23	05	19.2	80	00	50.0
170	23	01	20.1	80	06	46.3
190	22	55	29.2	80	12	00.0
200	22	46	55.7	80	17	27.9
215	22	42	25.3	80	20	32.0
235	22	33	14.3	80	22	58.6
A 1	23	23	17.3	79	33	11.4
B 2	23	19	11.0	79	39	35.0
C 3	23	15	46.0	79	44	22.1

TABLE 4

Results obtained from refraction data

	Velocity (km/sec) P-wave	Velocity (km/sec) S-wave	Thickness (km)
Granitic layer	5.94	3.54	23.0 ± 0.5
Basaltic layer	6.65	—	16.0 ± 1
Upper mantle	8.19	4.73	—
Depth of Moho	—	—	39.0

TABLE 5

Standard deviations/errors in wave velocities and intercepts

Phase	V	σ_V	B.E. (V)	a	σ_a	BE(a) ±
P_g	5.94	00.001	00.000	−0.19	0.798	0.126
P^*	6.65	00.003	00.001	3.49	0.833	0.340
P_n	8.19	00.004	00.001	8.14	1.11	0.555
S_g	3.54	00.002	00.002	0.16	1.32	0.245
S_n	4.73	00.003	00.001	13.4	0.713	0.356

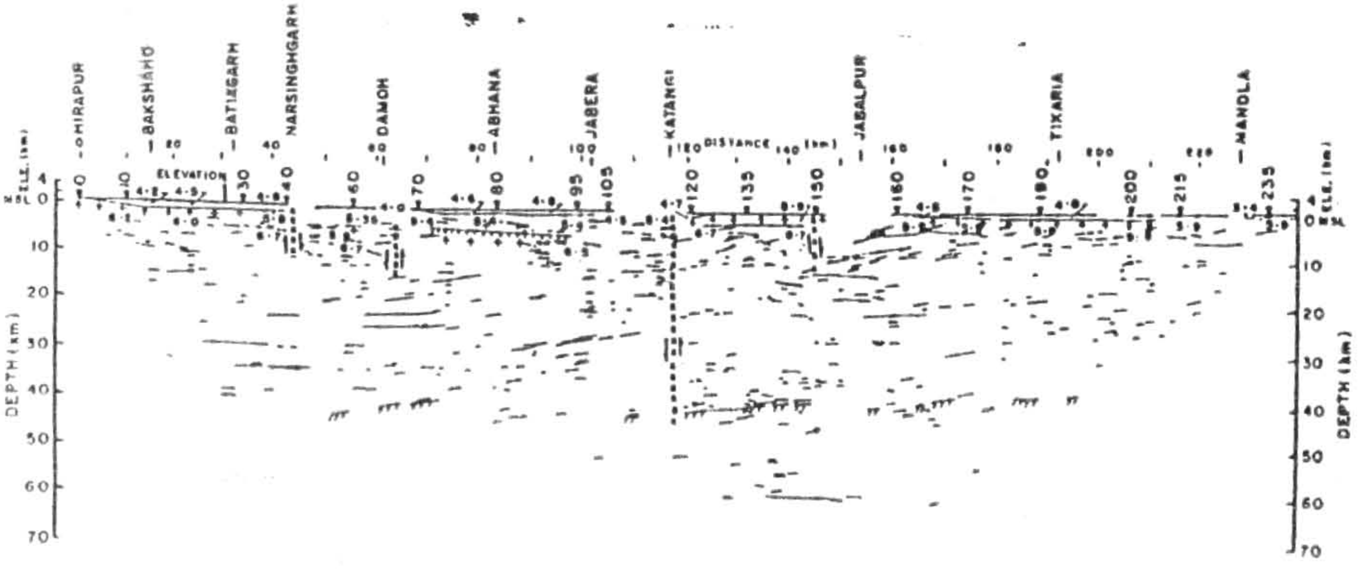

Fig. 1(b). D.S.S. results (Kaila *et al.* 1987)

earthquakes and a few moderate ones have originated in the Vindhyan/Satpura ranges near this area. The known events from the earliest times with their origin in this area are given in Table 1.

4. Observational network and data

Four temporary seismological observatories were set up at Jabalpur, Niwas, Shikara and Mandla [Fig. 1 (a)]. At all these stations portable micro-earthquake instruments (Sprengnether MEQ 800 type) were installed while at Jabalpur I.M.D. electromagnetic (Z component) seismograph with photographic recording system was also installed. The purpose of electromagnetic seismograph was to record the explosions on high speed recorders designed indigeneously in I.M.D. with the speed of 10 mm=1 sec so that the times of onset of various waves generated by explosion can be more accurately read. For maintaining time accuracy, all the stations were provided with crystal clocks with facility to impinge time signals on the record from a radio receiver. The portable seismographs were also used to monitor the micro-earthquake activity in the region. The station coordinates and the type of instruments along with their magnifications are given in Table 2.

The explosion charges ranging from 50 to 1000 kg were detonated by National Geophysical Research Institute from shot points whose locations are given in Table 3. Analysis of events indicates the presence of crustal phases 'P_g' and 'S_g' as the first arrivals in most of the cases in *P* and *S* groups. The refracted phases P^* and P_n were also recorded in a few cases. However, the phase S^* could not be identified clearly on the records. The phase S_n was recorded by only a few of our stations. The results using D.S.S. technique are given in Figs. 1 (a) & (b) [Kaila *et al.* 1987].

5. Velocity model

(a) *Refraction data*

The travel time curves for P_g, P^*, P_n, S_g and S_n were drawn by plotting the transit time (T) of the wave against the distance ($\triangle$) of the recording station from various shot points (Fig. 2). Assuming a two-layered crustal model, velocities and thickness of the layers were calculated for different phases using the following formula :

$$T_p{}^* = 2H_1 \left(\frac{1}{VP_g{}^2} - \frac{1}{VP^{*2}} \right)^{1/2} \quad \text{(Focus = 0)}$$

$$T_{P_n} = 2H_1 \left(\frac{1}{VP_g{}^2} - \frac{1}{VP_n{}^2} \right)^{1/2} + 2H_2 \left(\frac{1}{VP^{*2}} - \frac{1}{VP_n{}^2} \right)^{1/2}$$

where, T_{P^*} and T_{P_n} are the intercepts made by the refracted waves from the Conrad and Moho boundaries respectively and H_1 and H_2 the thicknesses of first and second layer respectively. The average thickness of the crust as computed from *P* phases was found to be 39 km, with 23 km of granitic layer and 16 km of basaltic layer. The results obtained are summarised in Table 4. The limits of the error are given in Table 5.

(b) *Micro-earthquakes*

The micro-earthquake activity around the seismological stations may be seen in Fig. 3 where histogram of total number of events *versus* epicentral distance has been shown. The histograms of the number of micro-earthquakes show that the maximum number has been recorded as below :

Mandla	75-100 km
Jabalpur	0-25
Shikara	25-50 km
Niwas	25-75 km

The epicentral distances corresponding to the above have been drawn in Fig. 1 (a). Assuming statistically that the maxima at the various stations relate to a common source, the zone west of Jabalpur (shown hatched) appears to be such source. The earthquakes in the past which have occurred thrice (Table 1) near Jabalpur also confirm the activity of the zone.

Only a few of the above earthquakes were recorded by three or more stations so as to determine hypocentres of these micro-earthquakes. Seven such hypocentres have been obtained with the help of IBM computer in IMD, New Delhi using Fortran IV programme Hypo 71 using 3 layered velocity model with a sedimentary layer of 2.5 km thickness as discussed later. Magnitudes (M) of the earthquakes were obtained using coda length (T) in sec and using formula :

$$M = -1.67 + 2 \log T + 0.0035 \triangle$$

where, $\triangle$ (km) is epicentral distance.

The list of earthquakes is given in Table 6. Fig. 4 shows the micro-earthquakes plotted on the lineament map of the region. It may be noticed that the micro-earthquakes are originating in the following zones :

(*i*) Son lineament extension northeastward and features parallel to it.

(*ii*) Tapti lineament and features parallel to it close to Ambikapur.

No seismic activity close to Tattapani hot springs in Madhya Pradesh has been detected inspite of operating the instrument at 90 db gain (I.M.D. Report on Seismic Survey Tattapani, unpublished, 1986). However, epicentres of a few micro-earthquakes detected from the survey have also been shown in Fig. 4.

6. Discussion

(a) *Crustal structure*

Table 7 shows the comparison of crustal thickness as determined from D.S.S. explosions in different parts of the country. It may be noticed that the thickness of the granitic layer appears to generally increase from Peninsular India to Jabalpur region. However, since error analysis was not done in the earlier studies, this inference may be taken as tentative. Compared to the P_g and S_g wave velocities in the neighbouring Narmada region close to Bhopal-Hoshangabad and Indore-Khandwa profiles, there is a slight decrease in the velocities over Jabalpur region. The seismic wave velocities were, however, found to be the lowest in the Koyna region (Srivastava *et al.* 1984).

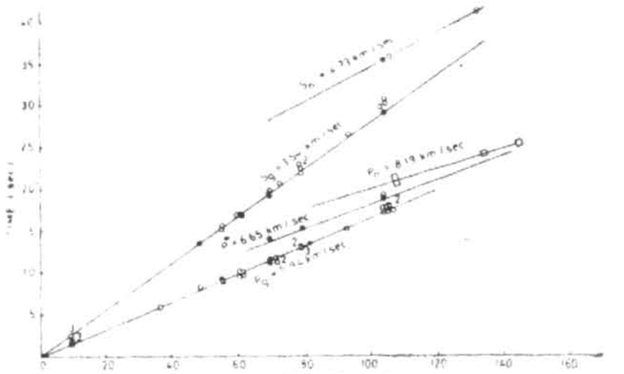

Fig. 2. Travel-times of seismic waves

TABLE 6

Epicentral parameters of micro-earthquakes

S. No.	Date (Mar 1984)	0. Time (GMT) *h*	*m*	*s*	Epicentre	Mag.	Depth (km)
1	6	18	28	15.86	23°10′ .84 N, 79°54′ .39 E	2.3	32
2	11	20	29	13.47	22°37′ .93 N, 80°19′ .43 E	2.7	20
3	11	21	11	52.18	22°45′ .99 N, 80°18′ 95 E	2.4	15
4	14	12	50	12.49	22°02′01 N, 79°08′41 E	3.2	4
5	16	13	05	26.81	24°32′02 N, 82°55′.01 E	3.1	5
6	21	12	43	51.79	21°52′47 N, 80°29′95 E	2.6	4
7	24	12	44	56.7	22°16′.0 N, 82°45′.5 E	3.3	5

Note — The magnitude of the seismic events may in error by half unit as the above relationship has not yet been standardised with reference to W.A. seismographs due to paucity of data

TABLE 7

Comparison of crustal thickness by various workers in the Indian Peninsula using D.S.S. explosion data

Authors	Region studied	Crustal thickness (km)		
		Granitic layer	Basaltic layer	Depth of Moho
Present authors	Jabalpur-Mandla	23.0	16.0	39.0
Chaudhury *et al.* (1984)	Kaveli to Udipi	22.4	16.2	38.6
Srivastava, Verma and Verma (1982)	Indore-Khandwa	18.0	19.9	37.7
Srivastava, Verma and Chaudhury (1982)	Koyna region	17.5	18.8	36.3
Srivastava, Verma and Verma (1982)	Peninsular India	21.6	16.7	38.3

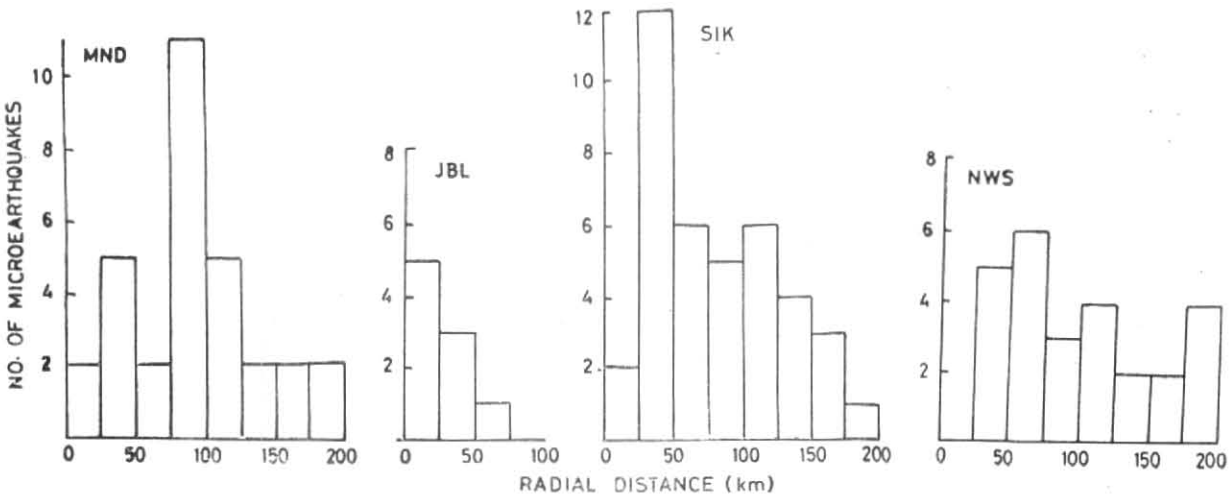

Fig. 3. Histograms of micro-earthquakes

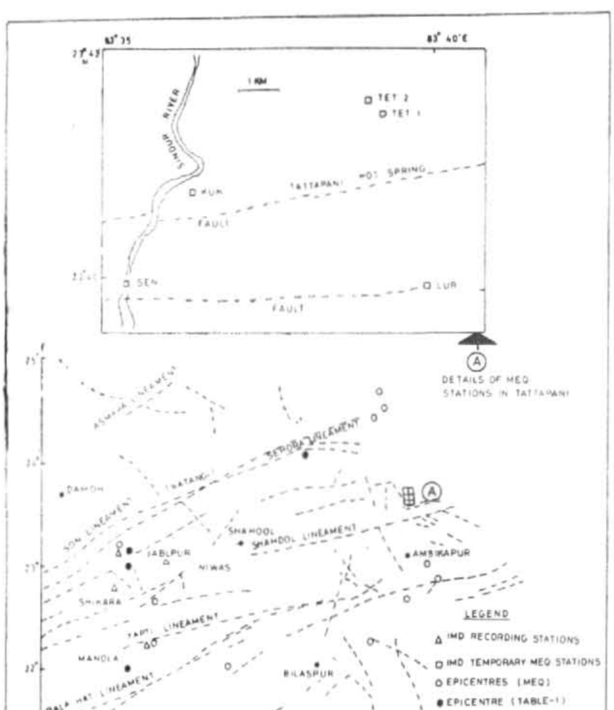

Fig. 4. Micro-earthquakes and lineaments

Although a number of minor and major lineaments through land-sat imagery have been identified in the region, the seismic activity which is shallow focus and confined to crust could be correlated with the features parallel to the extensions of Son and Tapti lineaments. The epicentres of earthquakes (Table 1) also corroborate this result but the dipping of the faults could not be studied due to lack of data.

Kaila *et al.* (1987) have presented detailed crustal structure in this region based on D.S.S. data. They have found that the sediments in the Vindhyan basin have a maximum thickness of about 1.5 km at Bakshaho with *P* wave velocity of 4.5 km/sec. The lower Vindhyan sediments deposited north of Narmada-Son lineament between Katangi and Narsinghgarh had a velocity of 5.4 km/sec. The thickness of the lower Vindhyans increases north to south towards Katangi and the depth to the basement reaches 5.5 km near Jabera. They have inferred a horst feature between Katangi and Jabalpur representing Narmada-Son lineament. The *P* wave velocity in the Gondwana (about 40 km east of Jabalpur) and Tràp rocks (between Jabalpur and Mandla) are reported as 3.8 km/sec and 4.5 to 4.8 km/sec respectively. In view of large variations in the seismic wave velocities and the thickness of sediments/traps, an averaged thickness and velocity for the top layer could better be obtained from very short period dispersion of surface waves for inclusion in the *P* and *S* wave two layered velocity model deduced in this paper for determining the epicentral parameters of micro-earthquakes. As averaged top layer thickness and wave velocities over this area were not available, the best velocity model used in Hypo 71 programme was obtained by varying the thickness from 2 to 3 km and the wave velocities from 4.5 to 4.6 km /sec (using more representative values from Kaila *et al.* 1987), keeping the velocities and thickness the same as given in Table 4. The ratio of V_P/V_S was taken from P_G and S_G velocities as 1.68 from our study. The following model, which gave lowest RMS and ERZ in the Hypo 71 programme may be taken for epicentral determination:

Layer (km)	*Velocity (km/sec)*	
0	4.55	
2.5	5.94	V_P/V_S=1.68
20.5	6.65	
39.0	8.19	

It may be mentioned that the depth of Moho reported by Kaila *et al.* (1987) from D.S.S. technique was found to vary from 39.5 near Tikaria to 45 km at Narsinghgarh and the Moho velocity as 8.0 km/sec as compared to averaged depth of 39 km and velocity of 8.19 km/sec from the present study. Taking into consideration, the order of errors involved, paucity of observations and the different techniques deployed, the results of crustal thickness appear to agree although an interpretation of lower Moho velocity of 8.0 km/sec by Kaila *et al.* (1987) needs to be given, when compared with the results from other regions of Peninsular India (Chaudhury *et al.* 1984, Srivastava *et al.* 1984, I.M.D. Technical report on Crumansonata region 1980 - 82). Our P_g and P^* velocities of 5.94 km/sec and 6.65 km/sec, however, agree fairly well with those reported from D.S.S. data. The velocities of S_g and S_n obtained in this study provide additional data to understand the physical properties of the underlying crust.

(b) *Micro-earthquake activity vis a vis D.S.S. results*

Kaila *et al.* (1987) have reported from D.S.S. data a basement uplifted fault zone in the form of a horst between Katangi and Jabalpur and have associated with the Narmada-Son lineament (Fig.1 b). They also observed highly complicated seismic wave fields indicating that this area is badly disturbed and is a zone of weakness. The concentration of micro-earthquake activity west of Jabalpur almost coincides with this zone. It is also shown by D.S.S. results that the fault zone near Katangi, about 30 km northwest of Jabalpur, is the deepest over the whole profile extending to about 50 km below the ground level. However, lack of micro-earthquake epicentres does not enable us to delineate the dip of of the fault plane.

(c) *Seismic risk near Jabalpur*

The region west of Jabalpur could be identified as a pocket of higher seismicity on the basis of past earthquake data as well as contemporary micro-earthquake observations [(Fig. 1 (a)]. The largest magnitude of the earthquake which occurred in 1846 was 6.5 near Jabalpur (close to Damoh). Since then three more earthquakes of intensity III to VI M.M. have occurred in the same region in addition to the micro-earthquake activity detected through this survey.

Srivastava and Rama Chandran (1985) have found from historical catalogue of earthquakes that moderate earthquakes have a tendency to recur in the Peninsular India where seismic activity is occasionally observed in the past. In view of this and the concentration of micro-earthquake activity, recurrence of an earthquake of magnitude 6 to 6.5 is not ruled out near Jabalpur which needs to be considered for designing important structures in the region.

7. Conclusions

From the present investigations following conclusions have been drawn :

(*i*) A two layered crustal model has been interpreted for this region from refraction studies. The average thickness of the granitic and basaltic layers from P wave data have been found to be 23 km and 16 km respectively. The model needs to include a sedimentary layer of 2.5 km thickness with P wave velocity of 4.55 km/sec.

(*ii*) The velocities of P_g, P^* and P_n waves in Jabalpur region as computed from refraction data are 5.94, 6.65 and 8.19 km/sec in granite, basalt and Moho respectively. The corresponding S_g and S_n velocities are 3.54 and 4.73 km/sec.

(*iii*) Seismic activity in the region with origin in an area towards west/northwest of Jabalpur in the vicinity of Katangi fault delineated from D.S.S. data is indicated. The micro-earthquakes were found to occur at a shallow depth and do not represent manifestation of mantle activity.

References

Chowbey, V.D., 1971, "Superimposed folding in the transition rocks (Precambrian) and its influence on the structure of the southeastern margin of the Vindhyan Basin, Jabalpur, Madhya Pradesh", *J. geol. Soc. India*, **12**, 142-151.

Chaudhury, H.M., Srivastava, H.N., Kamble, V.P., Dube, R.K., Verma, R.K. and Verma, G.S., 1984, "Crustal investigations from explosion data along Kaveli-Udipi section of Peninsular India", *Mausam*, **35**, pp. 157-164.

IMD Technical Report (1980-1982), On crustal investigations and Microearthquake Survey in Crumansonata Region (Unpublished Report).

Kaila, K.L., Murty, P.R.K., Mall, D.M., Dixit, M.M. and Sarkar, D., 1987, "Deep Seismic Soundings along Hirapur-Mandla profile, Central India", *Geophys. J.R. astr. Soc.*, **89**, 399-404.

Srivastava, H.N. and Rama Chandran, K., 1985, New catalogue for historical earthquake over Peninsular India, *Mausam*, **36**, pp. 351-358.

Srivastava, H. N., Verma, R. K. and Verma, G. S., 1982, Crustal structure of Peninsular India using chemical explosions, Read at Seminar, Exp. Geophysics (B. H. U.).

Srivastava, H.N., Verma, R.K., and Verma, G.S., 1983, Crustal studies along Indore-Khandwa section of Narmada basin by deep seismic sounding, *Mausam*, **34**, 3, pp. 267-274.

Srivastava, H.N., Verma, R.K., Verma, G.S. and Chaudhury, H.M., 1984, "Crustal studies of the Koyna region using explosion data from deep seismic sounding", *Tectonophysics*, **110**, 61-72.