Mausam, (1983), **34**, 3, 267-274

550.341 : 534.647(544.1)

Crustal studies along Indore-Khandwa section of Narmada basin by deep seismic sounding

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(*Received 30 November 1981*)

सार – गंभीर भूकपी परिज्ञापनों का उपयोग करके मध्य प्रदेश के इन्दौर-खंडवा क्षेत्र की परिच्छेदिका का अध्ययन किया गया है। विस्फोटों के आंकड़ों को अंकित करने के लिए परिच्छेदिका के चारों ओर आठ वेधशालाएं स्थापित की गई। उनमें उच्च प्रवर्धन भूकंप रेखियों का उपयोग किया गया। उपयोग में लाए गए विस्फोटकों का परिमाण 50 कि० ग्रा० से 1200 कि० ग्रा० तक था। अपवर्तन संबंधी अध्यनों से पता चला है कि उस क्षेत्र की भूपपंटी द्विस्तरी है। उसमें 18 कि० मी० तक ग्रेनाइट और 20 कि० मी० तक बैसाल्ट है और इस प्रकार मऊ में कुल गहराई 38 कि० मी० है। बाद में इस तथ्य की पुष्टि परावर्तन अध्ययनों से भी हुई।

शोधपत्र में विकसित वेग निदर्श का उपयोग करके सूक्ष्म भूकम्पों के अधिकेन्द्री प्राचलों का निर्धारण किया गया है। निष्कर्षतः प्रेक्षणों की अवधि में उस क्षेत्र की भूकम्पी सक्रियता अति अल्प थी।

ABSTRACT. The area along Indore-Khandwa profile in the M.P. region has been studied using the deep seismic sounding techniques. A total of eight observatories were set up along the profile to record the explosions data, using high magnification seismographs. The quantity of explosions used for the purpose ranged from 50 kg to 1200 kg. Refraction studies have revealed that there is a two layer crust consisting of 18 km of granite and 20 km of basalt in the region; that is giving a depth of Moho as 38 km. This has been further confirmed from the reflection studies.

Using the velocity model deduced in this paper, the epicentral parameters of micro earthquakes have been determined. It has been found that the seismic activity in the region has been very low during the period of observations.

1. Introduction

During the year 1980-81, deep seismic sounding experiments were carried out along Ujjain-Indore-Khandwa profile by the National Geophysical Research Institute (NGRI). As in the past, India Meteorological Department also participated in the project and set up 8 field seismological observatories to record the explosions.

The main object of this study was the participation in the project CRUMANSONATA (Crust Mantle Studies of the Sone-Narmada and Tapti Lineament Zone) of the Geological survey of India. Out of these, electromagnetic seismometers (vertical component) were installed at four of the observatories, while at the other four, microearthquake instruments (Sprengnether MEQ 800) were employed to study the crustal structure of the region. A total of 37 explosions were recorded by our seismographs. Special arrangement was made with NGRI recording system for knowing the absolute timings of the explosions. During the field operations, 10 shot points were operated with changes varying from 50 kg to 1200 kg. The data so collected during the two months period of our participation was analysed and the results so obtained from refraction, reflection and coda studies have been discussed in the paper. In addition to the explosion records, the high gain seismographs have enabled us to study the seismic activity in the region.

2. Geological set up

In earlier geological times, the area now occupied by *Narmada* and *Tapti* rivers was a part of Arabian Sea which was subsequently filled up by deposition of sediments in the sea and successive earth movements. During that period, *Narmada* was in confluent with *Tapti,* but subsequently due to evolution of Satpuras, they were drifted apart. As the upper part of the region was filled up with alluvium deposits, the lower part still remained unfilled and there appeared to be a rift below. Krishnan (1953) considered the "E-W" direction of flow of these rivers unlike others, as an anomaly and suggested that they occupy two rifts formed by "Sag" faulting or bending of northern Peninsula at the time of upheaval of Himalayas.

West (1962) was of the opinion that there-exists a rift below *Narmada* extending up to Moho or further below. This concept was supported by Qureshi (1963) who indicated Satpura region to represent a "horst". The Narmada-Sone valleys have been considered to be the site of an ancient premontory which marked the limits of sedimentation of the Vindhyan bed (Precambrian-early Cambrian) to the north and at a latter stage the Permian-Cretaceous Gondwana beds to the south. Auden (1969) opined that the faulting along Narmada had been initiated during the Pliocene which continued into the Pleistocene. Due to this, the alluvium of the river valleys had been carried down to very great depth. This has been supported by drilling and ground water surveys.

Yellur (1968) considered that the course of Narmada and its tributaries are controlled by ENE-WSW or E-W main rift fault with several sympathetic faults. Landsat imageries and aerial photographs of the regions confirmed these features.

Pal and Bhimsankaram (1976) have reported from Paleomagnetic studies on the Deccan trap flows on both sides of Narmada-lineament across Asirgarh-Indore section that the polarity reversal has taken place at least 5 times during the period of outpour of Deccan trap lava flows. This has been attributed to be due to Wrench faulting or step faulting. It is surmised that the lineament is genetically associated with the post-Jurassic drift of the Indian plate, the Himalayan orogeny and the Deccan Trap volcanism. The concentration of hot springs, anomalous heat flow, and seismotectonic mainfestations in the *Narmada-Tapti* Graben have been attributed to the abnormal crust-mantle relationship (Krishnaswamy 1976). This lineament has been considered by Crawford (1978) as a deep narrow fault in the Indian Peninsula extending into Malagary-Somalia region on the basis of technomagnatic evidences.

Observational network and data

In order to record the explosions, eight observatories were set up along the profile (Fig. 1),

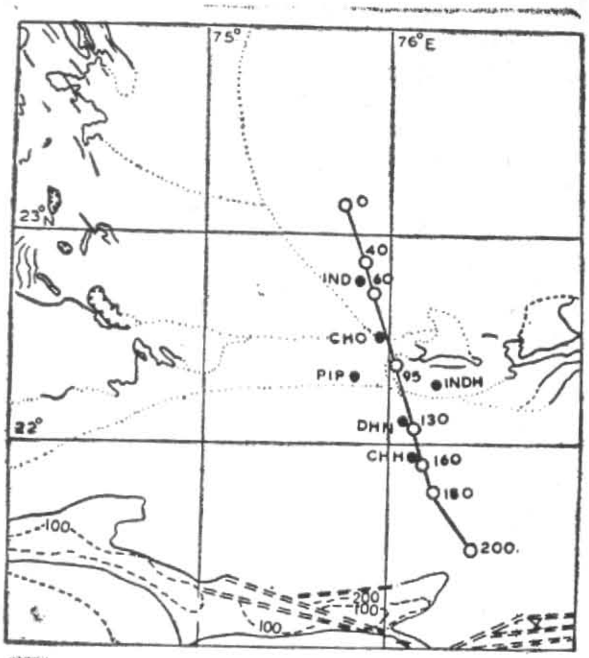

Fig. 1. D.S.S. profile across *Narmada* along with shot points and recording stations

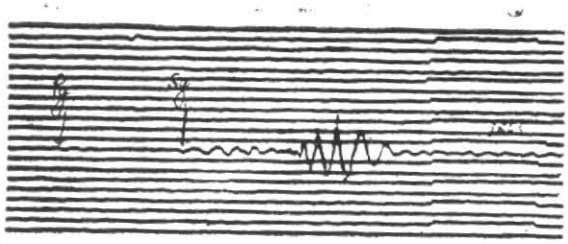

Fig. 2(a). Records of explosions taken on EM charts indicating various phases

one each at Indore, Choral, Piplia, Indhawari, Dhangaon and Chhaigaon. At four stations, highly sensitive IMD electromagnetic seismographs were installed while at the other four stations, micro-earthquake instruments (MEQ 800) were commissioned. The station coordinates and the type of instruments along with their magnifications are given in Table 1.

For time measurements, all the stations were provided with accurate timing system. In order to identify different seismic phases properly, IMD seismometers were connected with fast run recorders with a speed of 1 cm per second.

During the current field season, charges ranging from 50 kg to 1200 kg were detonated from ten shot points. The locations of the shot points are given in Table 2. The depth of the shot holes varies from 9 to 17 metres.

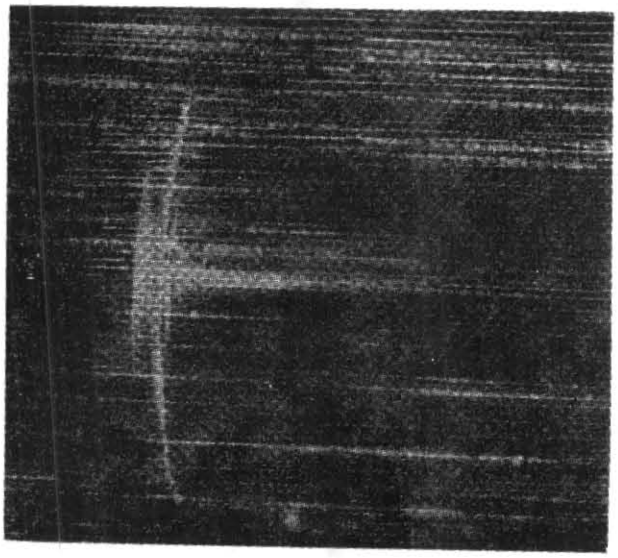

Fig. 2(b). Records of explosions taken on MEQ indicating various phases

TABLE 1

Coordinates of observatories and the type of instruments with magnification

S. No.	Station	Code	Lat. (N)	Long. (E)	Instrument installed	Magnification/ Gain
1	Indore	IND	22° 41′59.4″	75° 51′ 49.8″	(*i*) Electromagnetic (Z) (*ii*) MEQ 800	75K 72db
2	Choral	CHO	22° 26′ 11.4″	75° 57′ 55.2″	MEQ 800 (Sprengnether	78/72db
3	Piplia	PIP	22° 14′ 1.8″	75° 51′ 40.8″	Electromagnetic (Z)	75K
4	Indhawari	INDH	22° 13′ 24.0″	76° 14′ 55.2″	MEQ 800	84db
5	Dhangaon	DHN	22° 05′ 52.2	76° 07′ 07.2″	(*i*) Electromagnetic (Z) (*ii*) MEQ 800	50K 78/72db
6	Chhaigaon	CHH	21° 49′ 42.0″	76° 12′ 56.4″	Electromagnetic (Z)	75K

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 *Sn* was recorded by a few of our stations. Two typical seismograms of electromagnetic and MEQ instruments are shown in Figs. 2 (a) and (b) respectively. It was also possible to identify some reflected phases from intermediate layer and Moho on the seismograms with confidence as they were discernible in separate groups (not shown).

Seismic activity along the Narmada rift

Seismic activity in the region assumed more importance after the Broach (1970) earthquake in which about 26 persons were killed and another 200 people suffered injuries due to collapse of buildings. The damage caused by this earthquake was mainly along the *Narmada* river over a 10 to 15 km wide belt. The general direction of the ground fissures was east north-east with some isolated ones aligned north-south. Chandra (1977) has summarised the fault plane solutions reported by different workers for this earthquake and found thrust faulting. This is contrary to the results obtained along the bordering main faults of the rifts in other part of the world, which are always of normal type (tensional). The eastward striking nodal plane showed a component of left lateral motion which agreed with the trend of *Narmada* and *Girnar* seismic zones.

During the period of present observations, only 3 local events were recorded. Hypocentral parameters were calculated with the help of the IBM computer in the India Meteorological Department using a fortran IV programme : Hypo 71 (U.S. Geological Survey). The velocity model for the determination of hypocentral parameters was taken from the blast experiments deduced in the next section. Comparison of the seismic activity with the other rifts of the world suggests that the intensity and frequency of seismic events along the Narmada rifts is much smaller in comparision to the seismic activity along the East African rift system or the Rhine graben. The Baikal rift which is the deepest intra-continental rift has the highest seismicity. Although Brahmam and Negi (1973) have drawn a similarity between these continental rifts and Narmada or Koyna rifts, the low level of seismic activity observed, suggests

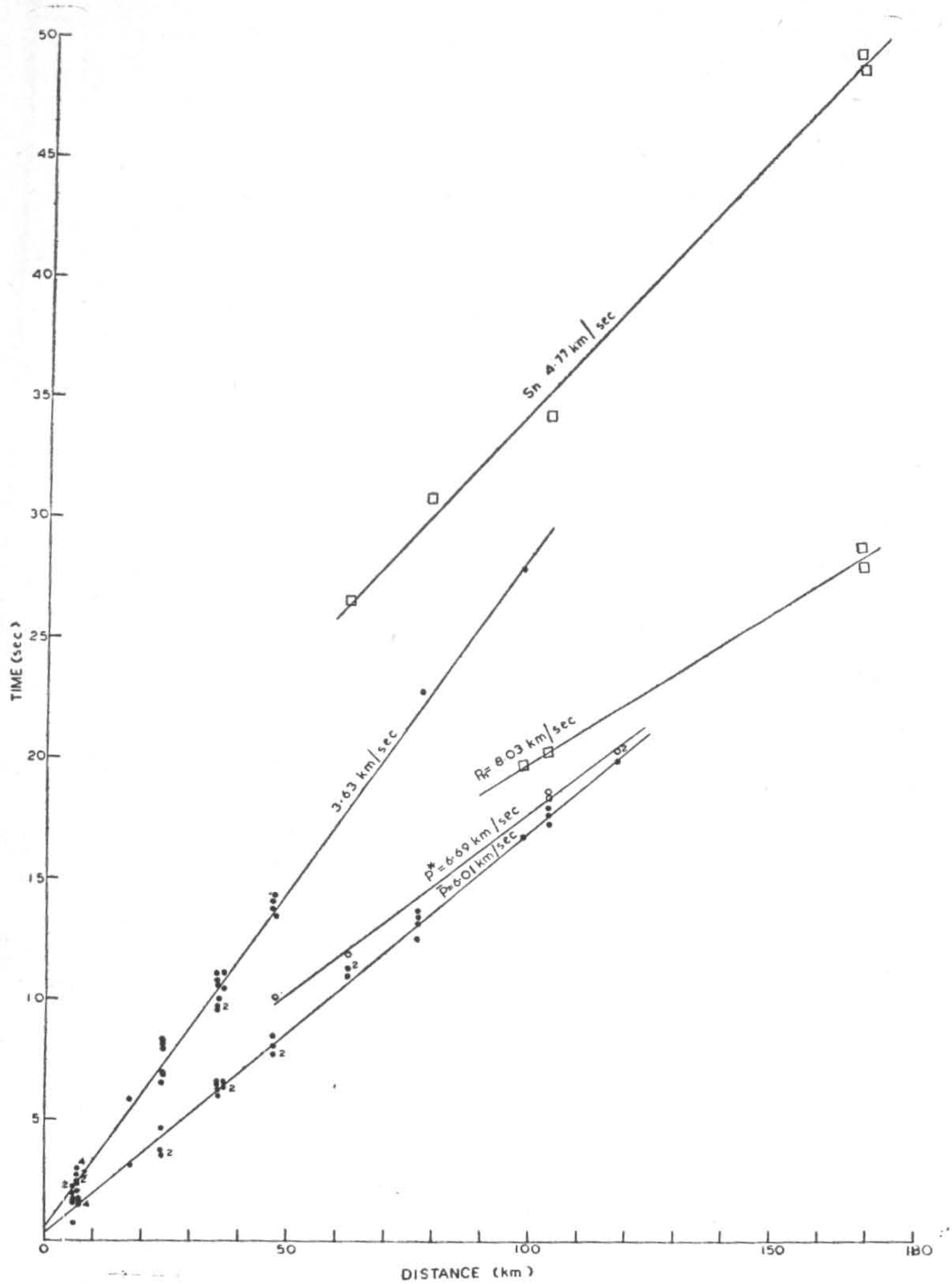

Fig. 3. Time distance curves from refraction data

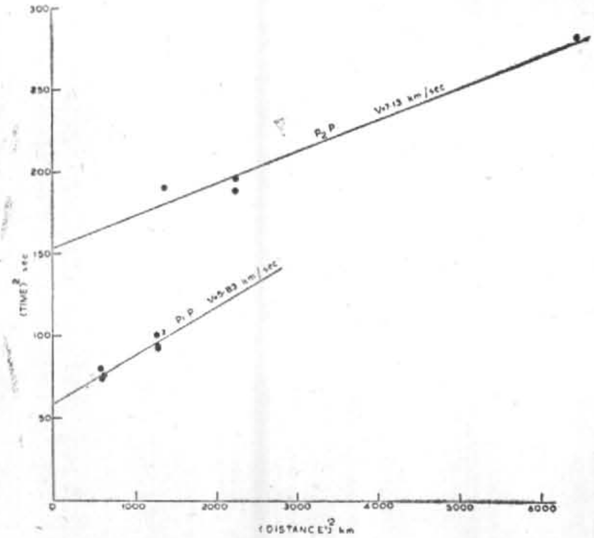

Fig. 4. T^2 *vs* $\triangle^2$ plot from reflection data

TABLE 2

DSS Profile : Ujjain-Nepanagar-Mahan Shot-points Coordinates

Shot- point	Latitude	Longitude
S P-0	23° 08′ 21.3″	75° 47′ 14.3″
S P-40	22° 49′ 09.5″	75° 50′ 46.5″
S P-60	22° 37′ 42.3″	75° 53′ 01.6″
S P-95	22° 17′ 00.1″	76° 00′ 52.0″
S P-135	22° 02′ 07.5″	76° 08′ 06.6″
S P-160	21° 46′ 49.2″	76° 13′ 44.6″
S P-180	21° 38′ 16.3″	76° 19′ 41.6″
S P-200	21° 26′ 50.0″	76° 25′ 56.7″
S P-245	21° 04′ 25.7″	76° 43′ 08.7″
S P-320	20° 30′ 00.0″	77° 08′ 58.7″

TABLE 3

Results obtained from refraction and reflection studies

	Refraction studies			Reflection studies	
	Velocity *P*-wave (km/sec)	Velocity *S*-wave (km/sec)	Thickness from *P*-wave (km)	Average velocity (km/sec)	Thickness in km (corrected)
Granitic layer	6.01	3.63	18.0	5.83	20.1
Basaltic layer	6.69	—	19.9	—	19.7
Crust as a whole	—	—	—	7.13	—
Upper Mantle	8.03	4.77	—	—	—
Depth of Moho	—	—	37.9	—	39.8

that its genesis is different from the other continental rifts of the world.

3. Results

(a) Refraction data

Travel time curves for P_g, P^*, P_n, S_g and S_n were made by plotting the transit times of the wave against the distance of the recording station from the shot points (Fig. 3). All the plotted points were found to lie on 5 straight line segments. The velocities of different phases were computed using the equations given below. Assuming a two layered crust, the depth to

TABLE 4

(Standard deviations/standard errors in wave velocities and intercept times

Phase	V	σV	S.E.	a	σa	S.E.
P_g	6.01	0.051	0.008	0.24	0.442	0.071
P^*	6.69	0.077	0.027	2.63	0.399	0.141
P_n	8.03	0.295	0.147	7.26	1.265	0.632
S_g	3.63	0.051	0.008	0.62	0.637	0.105
S_n	4.77	0.174	0.078	13.29	2.031	0.908

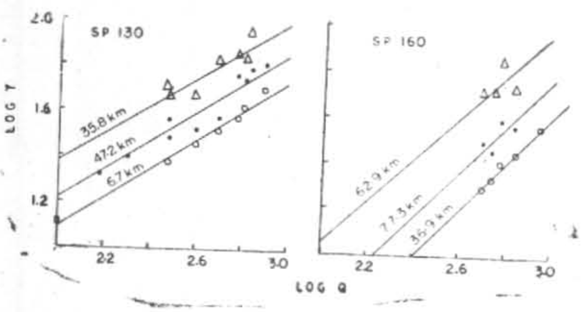

Fig. 5. Variation of coda duration with charge keeping △ constant

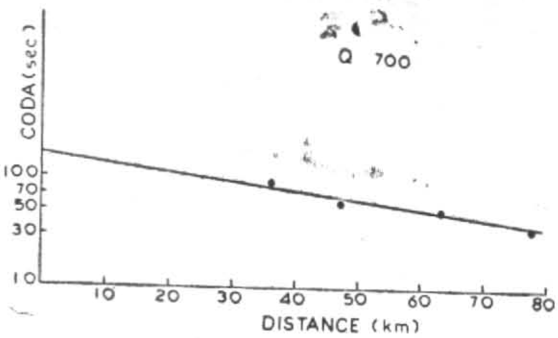

Fig. 6. Variation of coda duration with distance (△) keeping Q constant

Conrad (H_1) and Moho (H_2) can be calculated from the following relations :

$$Tp_g = I + \frac{\triangle}{Vp_g} \quad \text{In case of direct waves } I = 0$$

$$Tp^* = 2\,H_1 \left(\frac{1}{Vp_g^2} - \frac{1}{Vp^{*2}}\right)^{\frac{1}{2}} \qquad [\text{Focus} = 0]$$

$$Tp_n = 2\,H_1 \left(\frac{1}{Vp_g^2} - \frac{1}{Vp_n^2}\right)^{\frac{1}{2}} + + 2\,H_2 \left(\frac{1}{Vp^{*2}} - \frac{1}{Vp_n^2}\right)^{\frac{1}{2}}$$

where Tp^* and Tp_n are the intercept times of P^* and P_n waves respectively. The result obtained are summarised in Table 3. The limits of error are given in Table 4. The thickness of the top most granitic layer has been found to be 18 km while that of basaltic layer as 20 km thus giving the total thickness of the crust as 38 km.

(*b*) *Reflection data*

Some prominent phases reflected from the two major reflectors in the crust (Conrad and Moho discontinuities) have been collected. A plot of T^2 = *versus* $\triangle^2$ for the reflected phases from the intermediate layer and Moho has been shown in Fig. 4, from which structure has been worked out.

The travel time of a wave reflected from a layer is given by

$$T^2 = I + K$$

$$\text{where,} \qquad I = \left(\frac{2\,H}{V}\right)^2$$

(V being the average velocity in a layer of thickness H). Table 5 gives the velocities in the layers and thickness of the layers. According to Stewart (1968), the velocity and the thikness obtained from reflection studies are higher than those obtained from refraction studies and these may be corrected. The depth of these discontinuities were found to be 20 km each giving the total thickness of the crust as 40 km. The results are in fairly good agreement with the results obtained from refraction studies. The average velocity of the P wave in the granite layer has been found to be 5.83 km/sec while that in the crust as a whole as 7.1 km/sec.

(*c*) *Signal duration* (*coda*)

'Coda' has been defined in this paper as the time when the signal returns to the noise level present before the arrival of P wave. The total duration of the coda (T) was measured from MEQ records in the frequency range 5-30 Hz and plotted against the amount of charge (Q) keeping the distance constant (Fig. 5). It was observed that the slope of the straight lines obtained do not change appreciably with the change of distance (*i.e.*, distance of shot points from recording station). However, the intercept varies. The signal duration T is connected with the charge Q by the relations given below :

S.P. 130

Dhangaon	$T = 0.66\ Q^{0.63}$...(1)	($\triangle$ = 6.7 km)
Pipliya	$T = 1.44\ Q^{0.61}$...(2)	($\triangle$ = 35.8 km)
Choral	$T = 0.83\ Q^{0.64}$...(3)	($\triangle$ = 47.2 km)

S.P. 160

Dhangaon	$T = 0.03\ Q^{1.02}$...(4)	($\triangle$ = 36.9 km)
Pipliya	$T = 0.14\ Q^{0.95}$...(5)	($\triangle$ = 62.9 km)
Choral	$T = 0.06\ Q^{1.00}$...(6)	($\triangle$ = 77.3 km)

The variation of the coda duration was also studied with the distance of the shot point from recording station keeping the charge constant (Q=700 kg) and the following relation has been obtained (Fig. 6) :

$$T = 172.94\ e^{-0.0086\,\triangle} \tag{7}$$

(*d*) The parameters of the microearthquakes using HYPO 71 and the velocity model deduced from the blast data are given in Table 5. It may be seen that the events originate, not far away from the Narmada rift and were located with in the crust.

TABLE 5

Epicentre parametres

Date (1981)	Time	Lat. (°N)	Long. (°E)	Depth (km)	Magnitude*
30 Dec	00 00 59.00	21° 21.41′	75° 57.28′	33.57	4.07
15 Jan	18 24 2.43	22° 31.42′	76° 42.45′	15.00	—
24 Jan	07 13 32.72	21° 59.88′	74° 45.71′	01.88	3.43

*Magnitude may be on higher side by 0.5 units.

4. Discussions

The average crustal structure of the region as determined from refraction studies is in good agreement with the results of other workers for peninsular India such as Arora (1971), Dube *et al.* (1973), Tandon and Chaudhury (1968). The reflection studies also support the results. The general agreement in the crustal thickness with that of the Koyna region or Cuddapah basin does not enable us to draw any firm inference about the mechanism of the Narmada rift system. It may be mentioned in this connection that Brahamam and Negi (1973) have observed marked similarity between the fractures associated with the Narmada, Koyna, Kurduvadi and Godavari rifts in the peninsular India. However, it may be worthwhile to await the results of deep seismic sounding technique employed by the National Geophysical Research Institute, Hyderabad which will give a finer structure. The velocity model derived here may nevertheless be used to improve the locations of future seismic events in the region.

The microearthquake activity in this zone across Narmada Khandwa section of the rift is low. Their foci lay in the granitic layer. According to Chaubey (1971), the Sone-Narmada line is a mantle lineament which has been tectonically active since the Precambrian times and guided the deposition of the Vindhyan and Gondwana sedimentation. The activity of the mantle is however not reflected through the microearthquake survey where *Pg* and *Sg* phases were recorded showing the location of their foci in the granitic layer.

5. Conclusions

The present study has brought out the following results :

(1) The depth of the Moho is 38 km from refraction data comprising of 18 km of granitic layer and 20 km of basaltic layer.

(2) The *P*-wave velocities in the granitic and basaltic layers are 6.01 and 6.69 km/sec respectively and in the upper mantle as 8.03 km/sec. The corresponding *S* wave velocities in the granitic and upper mantle are 3.63 and 4.77 km/sec respectively.

(3) The reflection studies show a total crustal thickness in the region as 40 km with 20 km thickness of granite and basalt each. The average P-wave velocity in the granitic layer is 5.83 km/sec.

(4) Seismic activity in the region is considerably low. The events occur at a shallow depth and do not represent manifestations of mantle activity.

Acknowledgement

The authors are grateful to Shri H. M. Chaudhury, Deputy Director General for encouragement and advice during the planning of the field observations and to Dr. S. N. Chatterjee, Meteorologist for the analysis of microearthquake activity. The authors are also indebted to Dr. K. L. Kaila, Assistant Director, National Geophysical Research Institute for making special arrangements to record the origin times of the blasts during the deep seismic sounding project.

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