SEISMIC MODEL OF CENTRAL AND EASTERN LESSER HIMALAYA OF NEPAL

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सरांश

मध्य तथा पूर्वी नेपालको मध्य पहाडी प्रदेशमा जुन प्रकारले स्थानीय भूकम्प तरङ्गको प्रत्यक्षवेगको वितरणको आधारमा तीन विभिन्न वेगयुक्त तह भएको भू–पृष्ठको प्रतिरूप बनाउन सकिन्छ। यस प्रतिरूपको प्रथम तहमा भूकम्प तरङ्गको वेग. ६ कि.मी. प्रति सेकेण्ड, दोश्रों तहमा ६.५ कि. मी. प्रति सेकेण्ड र तेश्रो मोहो विच्छेदयुक्त तहमा ८.१ कि.मी. प्रति सेकेण्ड छ। प्रतिरूपको प्रथम २० देखि २३ कि. मी- बाक्लो तथा भू–पृष्ठ ५५ कि. मी. बाक्लो भएको अनुमान विभिन्न स्थानीय अवस्थानका भूकम्प तरङ्गको प्रयम आगमनसंग मेल खान्छ। भूकम्पको तथ्य विन्दुहरू प्रथम तहमा मात्र सिमित छन्।

१९८१ को अक्टोवर ६ तारिखमा गएको भूकम्पको तरङ्गको पहिलो आगमनहरूको अध्ययन मोहो विच्छेदबाट परावर्तित तरङ्ग हरूको अध्ययनको आधारमा बनाइएका भुकम्प तरङ्गको वेगको प्रतिरूपले पनि माथि उल्लेखित तीन तह युक्त प्रतिरूपको पुस्ट्याई गर्दछ।

तथापी, पोखरा, उदयपुर जोड्ने रेखाबाट दक्षिण पट्टि जुन प्रकारले स्थानीय भूकम्प तरङ्गको प्रत्यक्ष बेगको बितरण भएको छ त्यो तीन तहयुक्त प्रतिरूप अनुरूपको सैद्धान्तिक वेग बितरणसंग मेल खाएको देखिदैन। यस प्रकारको अनमेल वेग वितरण कि त (क) भूकम्पीय नामीहरू दोश्रो तहमा मात्र सिमित भएकोले हुनु पर्दछ या कि त (ख) त्यहां मोहो विच्छेद ३५ देखि ४० कि. मी. को गहराईमा अवस्थित छ (इन्डियन पेनिन सूलाकोभू–पृष्ठको मोटाई बरावर)

जस्ले गर्दा माथि भनिएको भूकम्प तरङ्ग वेगमा आधारित भू-पृष्ठ प्रतिरूपमा केही फरक हुन गयो।

ABSTRACT

The apparent velocity distribution of the local seisms of lesser Himalaya of central and Eastern Nepal allows to derive a three layered local seismic velocity model with first layer velocity of 5.6 Km/Sec. second layer of 6.5 Km/sec. and Moho discontinuity with 8.1 Km/sec. The first arrivals of different local phases of seismic waves are consistent with 20-23 Km thickness of the first layer and with crustal thickness of 55Km. The seismic events are confined to the first layer.

Local velocity model derived after the seismic event of 6 Oct 1981, origin time 19 hr 18 mn 17 sec. by modelling the first arrivals and PMP (Moho reflection) arrivals within the interval of distance 138-218 Km confirms the velocity model derived from apparent velocity distribution.

However, apparent velocity distribution of local seismic events occuring south of the line joining approximately Pokhara to Udayapur in plan does not seem to fit the theoretical distribution corresponding to the above three layered model with events within first layer. The apparent velocity of these

events may be explained either (a) by the confinement of the focus of the events to the second layer or, (b) by the variation of the seismic velocity model with Moho depth at 35-40 Km. i.e. with a normal Indian peninsular crust thickness.

1.1 INTRODUCTION

The Kathmandu seismic Network comprising three vertical component shortperiod telemetric stations is located in the vicinity of Kathmandu to form nearly an equal sided triangular array with side length of approximately 30 Km. The stations are being operated by Department of Mines and Geology since March 1981 in collaboration with Laboratoire de Geophysique Applique, Paris University.

The need of an appropriate velocity model for the localization of local events has been strongly felt since the very begning of the operation of the stations. In this connection the first attempt for velocity determination was made in 1981 based on the data from Kulekhani quarry blasts. The obtained P wave velocity equal to 5.58 Km/sec. had been assigned to the first layer, probably represented by metasediments of Lesser Himalaya (Pandey 1981, Bouvier 1982). In this paper an attempt has been made to derive the local velocity model on the basis of apparent veocity distribution as a function of S-P time intervel.

2.1 MATERIALS AND METHODS

The apparent velocity and the azimuth of wave approach are computed from first arrivals of local phases recorded at the three stations of Kathmandu Seismic Network. The rms error of onset time reading is estimated to be 0.3 km/sec. The local velocity computation corresponding to 0.1 sec. rms error of events are also localised with tentative velocity models (Fig. 6).

The apparent velocity vs S-P time interval graph is shown in Fig. 1 for the local events of central and Eastern Nepal. The apparent velocity values are confined between 5.4 and 9.0 km/sec. for 4 to 33 sec. of S-P time interval. However, the distribution seems to be quite chaotic. If we consider the events of lesser Himalaya only and further limit these events by their epicentre locations occuring north of the line joining Pokhara to Udayapur, the apparent velocity vs. S-P time interval plot exhibits a surprisingly low dispersion and therefore may be interpretated in terms of local seismic velocity-depth model (Fig. 2). We shall call this interpretated model as normal model.

The events which are anomalous in the sense of apparent velocity in relation to this normal model represented by velocity distribution of Fig. 2 can be explained either by model difference or by other hypocentre parameter variation or by

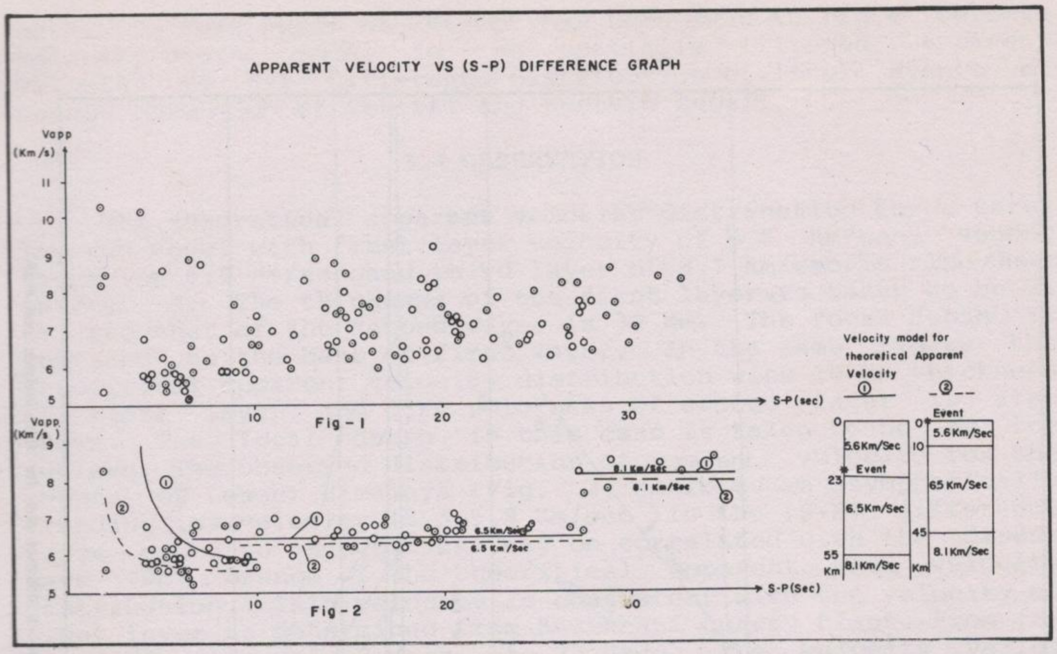

Fig. 1. Apparent velocity vs (S—P) difference plot for the events of Lesser Himalaya.
Fig. 2. Apparent velocity vs (S—P) difference plot for the events of Lesser Himalaya north of the line joining approximately Pokhara to Udayapur. The theoretical graphs are shown for (1) 20 km. depth of focus (2) surface focus.

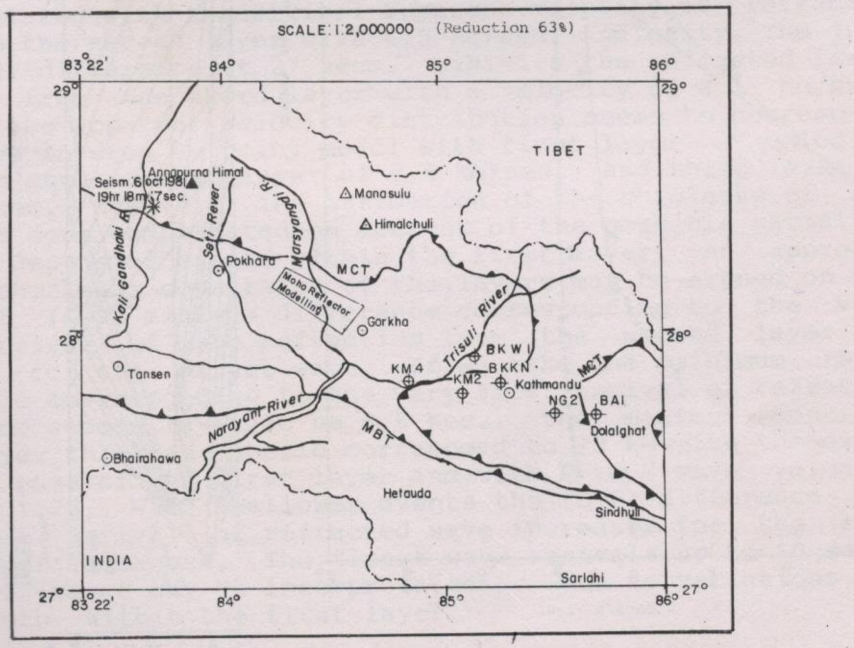

Fig-3 The locations of the stations recording the seism of 6 oct·1981 with estimated origin time at 19h.18m.17s. is presented The Moho modelled area corresponding to assumed epicentre and station locations is also shown.

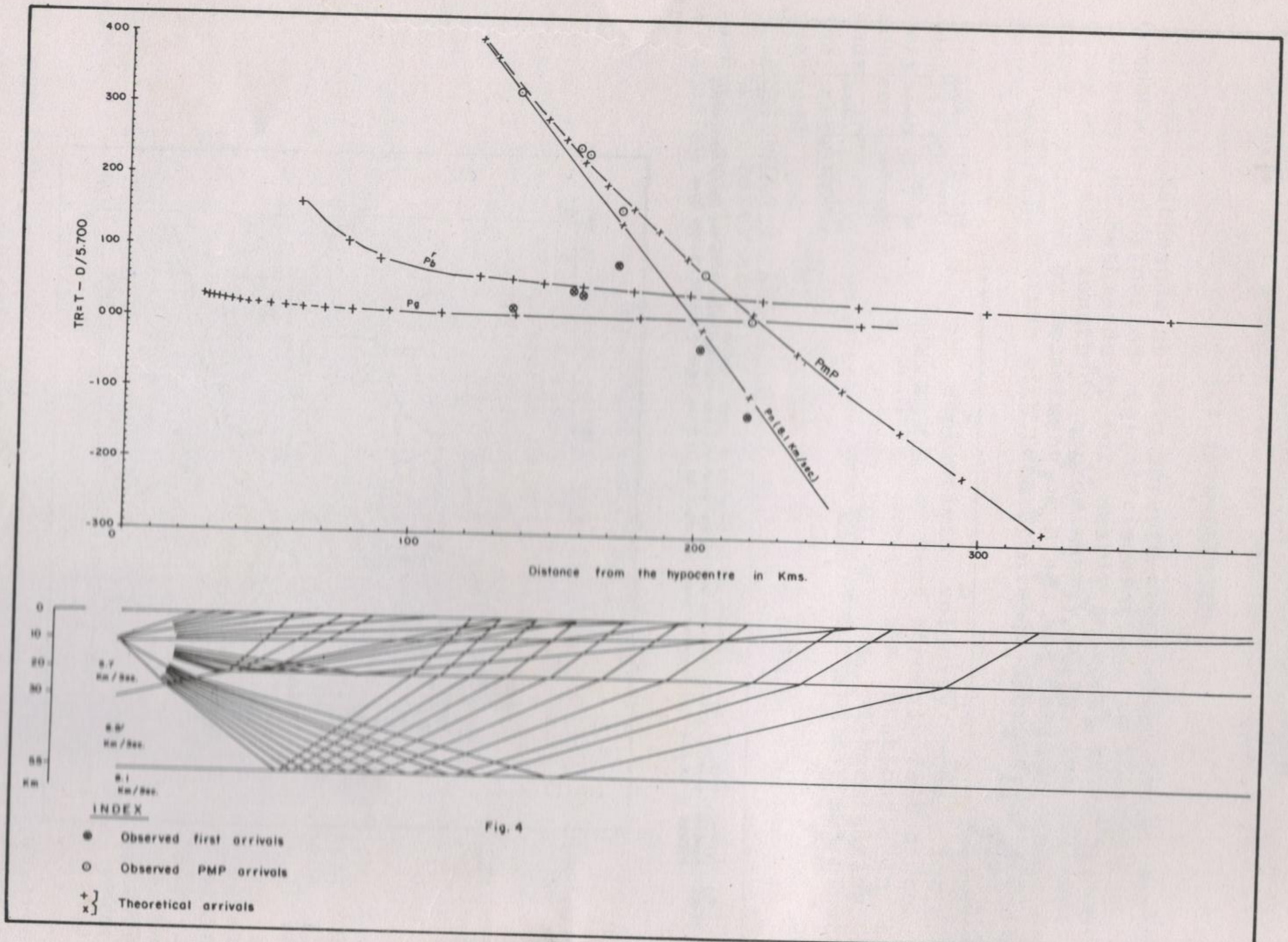

Fig.4. Ray tracing model and reduced theoretical and observed arrival times vs distance plot for first arrivals and PmP arrivals. The station and the events are shown in Fig. 3.

both. In this paper an attempt has been made to fit a seismic velocity-depth model to the spatially filtered apparent velocity vs S-P difference distribution of local events of Lesser Himalaya of Central and Eastern Nepal.

3.1 OBSERVATION

The theoretical apparent velocity distribution for a three layered model with first layer velocity of 5.6 km/sec, second layer of 6.5 Km/sec. and third layer of 8.1 km/sec. is also shown in Fig. 2. The thickness of the first layer is taken to be 23 km and that of the second layer is 32 km. The focal depth is confined to the base of first layer. In the same figure the theoritical apparent velocity distribution with 10 km thickness of first layer and 35km thickness of second layer is also shown. The focal depth in this case is taken to be at the surface. The observed distribution of apparent velocity for the events of Lesser Himalaya (Fig. 2) exhibits an asymptotically trending low velocity (5.5-5.9 Km/sec) in the (S-P) difference range of 5 to 10 sec. and may be correlated with the direct wave (Pα) branch of the theoritical apparent wave velocity distribution. This velocity is consistent with the velocity of first layer as determined from Kulekhani quarry blast. From (S-P) difference of 7 secs. to 27 secs. the velocity varies between 6.1 to 6.9 km/sec. with an average value of 6.5 km/sec. Taking into consideration of the root mean square error of velocity determination to be 0.3 Km/sec., this distribution may be coorelated with theoritical apparent velocity of refracted wave from the second layer with 6.5 Km/sec. velocity. The jump near (S-P) difference of 27 secs. exhibits the refracted first arrivals from the third layer with a velocity of 8.1 km/sec. This way the apparent velocity distribution seems to correspond to a three layered velocity model with first layer velocity of 5.6 Km/sec, second layer of 6.5 km/sec. and third layer of 8.1 km/sec. However, the estimation of the thickness of the layer is more complicated on account of the possible variation of focal depths of events within the first layer. An approach to the thickness constraint of the layers may be argued on the basis of (S-P) minimum difference corresponding to the very first arrival of the refraction from the second layer in relation to the direct wave. If we take the minimum (S-P) difference corresponding to the very first arrival of refracted wave from second layer to be 6.6 sec., the maximum possible first layer thickness should correspond to 23 km with the event at the base of the first layer and with P to S wave velocity ratio of 1.75. With shallower events the (S-P) difference for the first arrival of refracted wave increases for the same first layer thickness. The direct wave arrivals up to 10 secs. (S-P) difference may be interpretated due to variations of focal depth within the first layer.

The estimation of the second layer is more direct when the first layer thickness and the focal depth is estimated. The third layer refraction arrival at 27 secs. gives the estimate

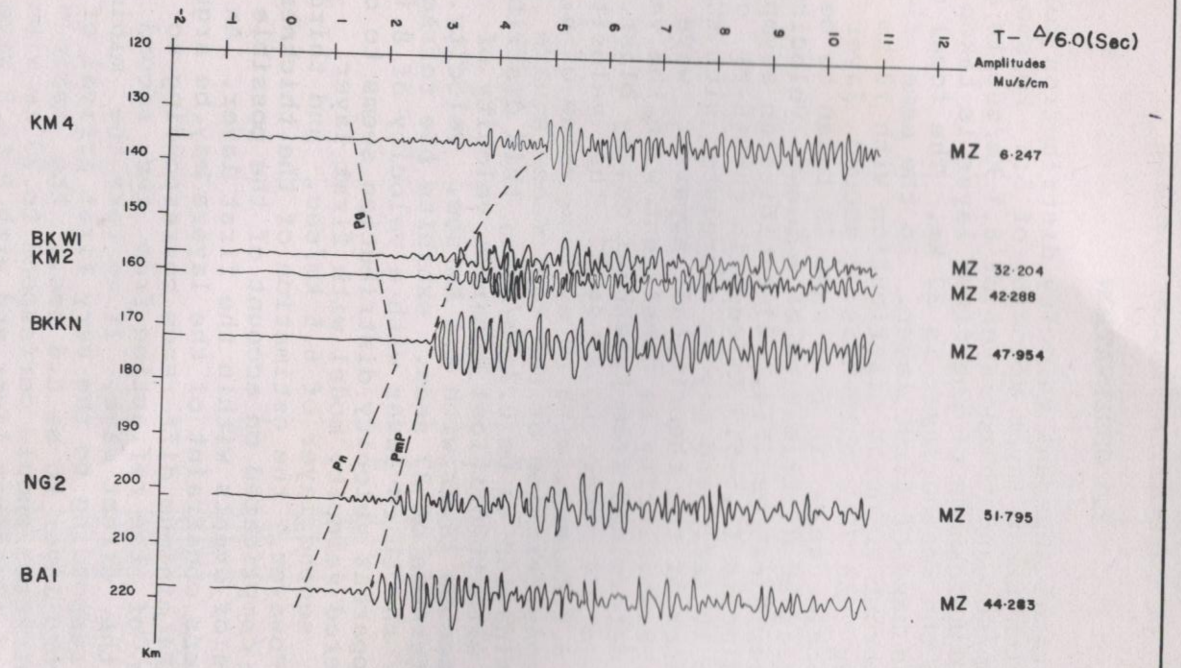

Fig.5

Fig. 5. Composite seismogramme for the stations shown in Fig. 3. The reduction velocity is 6.0km/sec. The first arrivals (Pg) correspond to direct wave arrivals and refracted wave arrivals from Moho discontinuity is denoted by (Pn). (PmP) arrivals are the reflection arrivals from Moho discontinuity.

of 32 km for the second layer corresponding to 23 km thickness of first layer with the event at the base of the first layer.

In the same way the maximum (S-P) difference corresponding to the first arrival of the direct wave gives the other limit of the first layer thickness. Considering it to be 10 secs. the first layer thickness is estimated to be greater than 10 kms corresponding to surface focus of the event. The third layer refraction corresponding to surface focus and 10 km thickness of first layer should arrive at 28.6 sec.of (S-P) difference for 35 km thickness of the second layer. The second layer refraction arrives at 6 secs. of (S-P) difference for a focus of 6.5 km depth and the third layer refraction corresponding to 35 km of second layer thickness arrives at 27 secs. of (S-P) difference.

This way the first layer thickness seems to be constrained between 10 and 23 kms. while the second layer thickness lies between 35 to 32 kms.

As we have seen the thickness of the first layer and second layer and consequently the thickness of crust have some trade offs with the assumed focal depth in the model. The focal depth of microseismic events in the near vicinity of tne Kathmandu network reveals a most frequent depth of 15 km. The estimate of first and second layer thickness corresponding to focal depth of 15 km, and fitting the apparent velocity distribution of fig 2 is 20 and 34km respectively. The foci of microseismic events are confined to the first layer with 5.6 km/sec.velocity.

The apparent velocity of the events with epicentres occuring south of the demarkation line joining Pokhara to Udayapur are anomalous to the discussed apparent velocity distribution of(Fig 2. Fig.6). These events are characterised by higher apparent velocity between 7.2 to 9.0 km/sec. which is greater than the second layer velocity of the above discussed model plus two times the rms error of velocity computation. In fig. 1 these events comprise the velocity distribution from 13 to 20 secs. of S-P time interval. These anomalous events may be explained either by variation of the focal depth of the events within the frame work of above discussed velocity model or by the variation of the velocity model itself. One explanation may be the focal depths confined to second layer with 6.5 km/sec. velocity with the same above discussed velocity depth model prevailing in this area as well. However, a shallower Moho (Indian Peninsular Moho) at a depth of 35-40 km can give rise to Pn first arrivals starting nearly from 14-15 secs. of S-P time interval when the focal depth is in the range of 15-20 km and the thickness of second 6.5 km/sec velocity layer is reduced. The anomalous arrivals may be considered as Pn arrivals. The second interpretation would imply that the Pokhara - Udayapur line tectonically divides the Lesser Himalaya into two domains with 55 km. crushal thickness in the north and 35-40 km crushal thickness on the south of this line.

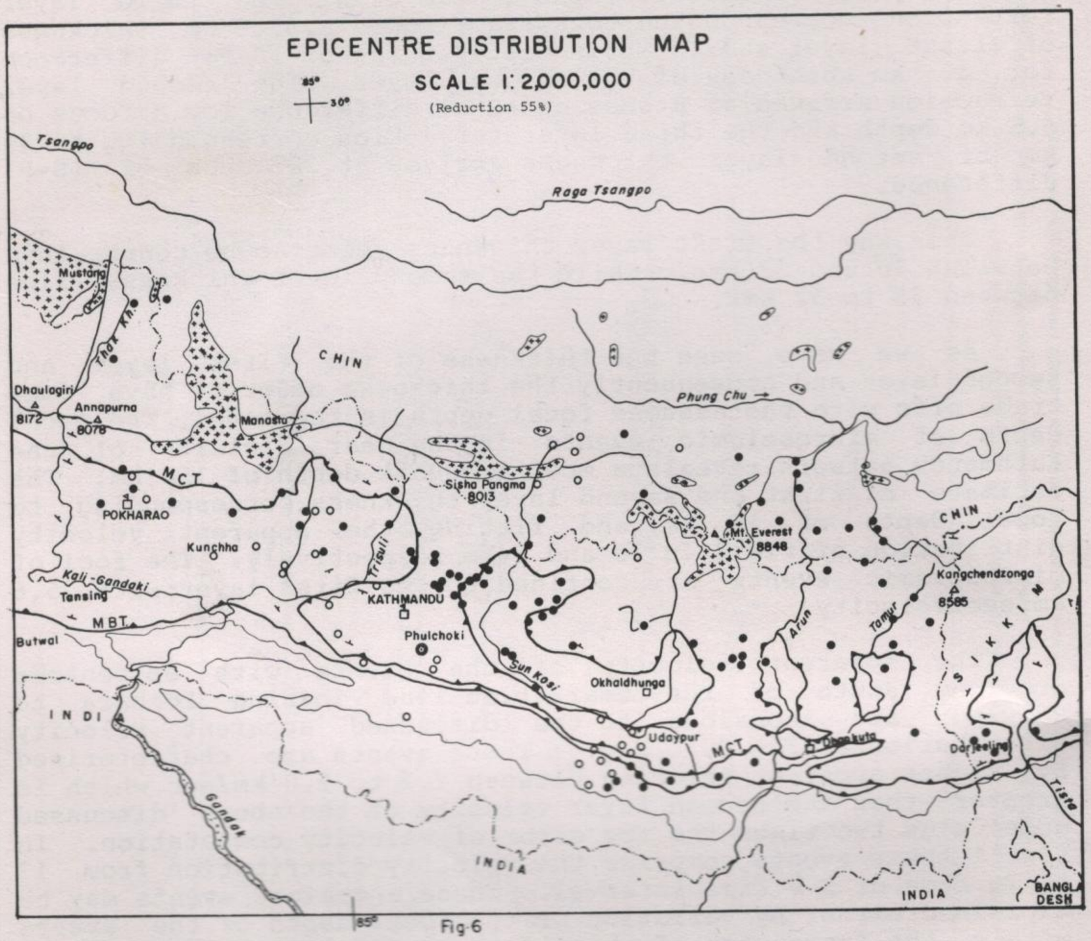

Fig 6

Fig·6· Epicentres determined after the arrivals of P and S phases at Phulchoki, Daman and Kakani stations of the Kathmandu seismic network for the periods 1980 March to 1981 December. The black circles correspond to the events with apparent velocity distrbution as shown in fig·2· The open circles represent the events which do not fit the apparent velocity distributions of Fig.2.

The anomaly in the near vicinity with smaller S-P time interval may also be related to different model domains. However, the domain mapping is out of the scope of this paper.

3.2 MODELLING AFTER SEISMIC EVENT OF 6 OCT 1981
Origin time 19 hr 18 mn 17 sec.

The seismic event of 6 Oct. 1981, origin time 19 hr 18mn 17 sec. has been recorded by the Kathmandu Seismic Network and 7 portable stations of Institute de physique du Globe, Paris University under the Experimental Seismological Observation Programme, a joint venture of Department of Mines and Geology and Institute de Physique du Globe, Paris University which was carried out during Sept.-Oct. 1981. The field recording in portable stations was carried out in magnetic tapes in station d' Enregistrement Seismologique, IPGP and the seismometer employed was a three component seismometer. The locations of the stations are shown in Fig. 3.

The localisation of the event has been carried out by HYPO 71 programme in the computer of IPG, Paris University. The first hypocentre trial solutions revealed a fairly consistent origin time using velocity model deducted from apparent velocity data as discussed above. It was also noted that the relative distances of the station from the epicentre were fairly consistent in different hypocentre solutions corresponding to different initial departure depth in HYPO 71 programme. The consistency of the origin time as well as small residuals for S waves indicated the constraint on the total path of the wave propogation. For example for Pn waves any incriment of time in the crust propogation should be compensated by the same incriment of time of propogation along the layer below the Moho discontinuity. This, on the other hand gave a oppertunity to model the velocity structure after PmP (Moho reflection) arrivals with constrained total time of propogation to fit the first arivals.

For the model comparision the event was localized with equivalent two layered model and the rsulting epicentre-station distances, focal depth and origin time of the event were considered for comparision of observed arrivals with computed ones. In other words, for each model to be tasted a two layered equivalent model with first layer velocity of 5.7 km and second layer velocity of 8.1 km/sec. was computed so that the time of propogation of the first arrivals (Pg and Pn) is the same as for the three layered model to be tested with 5.7, 6.5 and 8.1 km/sec. velocity interfaces at the modellging depths. The result of the hypocentre solution with such equivalent model was supposed to replace the seismic event by an artificial blast. The final fit of the model was made on first arrivals (Pg, Pn) and PmP (Moho reflection) arrivals.

The computation of the theoritical arrivals was made by ray tracing programme in the computer of IPG, Paris University.

The reduction velocity is taken to be 5.7 km/sec. (Fig. 4). The observed first and second (PmP) arrivals are also shown in the same figures. The observed arrivals comprise the interval of distance from 136 to 218 km from the source.

The three first arrivals up to distance 160 km seem to fit the direct wave Pg arrivals where as the later three first arrivals fit the theoritical Pn arrivals within 0.2-0.3 sec. deviation. This deviation is consistent with the uncertainity of onset time reading in the seismogramme for the first arrivals. The observed PmP arrivals fit very well the computed PmP arrivals within an accuracy of 0.1/sec. The selection of the final model is based on the match of PmP arrivals and of first arrivals, the PmP arrivals constraining the depth of Moho and the first layer thickness, while the first arrivals constrain the time of propogation within the crust and below the Moho discontinuity.

In Fig.5, the composite seismogramme record from different stations is presented. The velocity of reduction is 6.0 km/sec. The Pg and Pn branch of first arrivals and the PmP arrivals are distinctly evident.

The discussed model matching has been possible basically due to two observed consistencies of HYPO 71 solution, namely the consistency of origin time and the consistency of enterstation distances in relation to the epicentre. The former consistency says that there is a tradeoff between crustal propogation time (consequently the crustal thickness) and the epicentre distance and upper mantle propogation time constraining the model. The second consistency limits the curvature of the reflected hodograph which is a function of depth of the Moho reflector and the source distance. Any of these two catogories of arrivals (first arrivals and PmP) could be fitted to varities of models as much as the epicentre localization precision is quite low. However, the joint fitting of both these catagories of arrivals imposes a fairly narrow constraint on the variation of model. On the basis of actual computation a reasonable fitting of 2-3 km of Moho depth variation could be achieved.

This way, ray tracing model based on seismic events of 6 Oct 1981, origin time 19 hr 18 mn 17 sec. confirms the seismic model derived from apparent velocity observations. The seismic velocity model for Lesser Himalaya (with the above mentioned demarkation) seems to be a three layered model with first layer velocity equal to 5.6 km/sec. and second layer velocity of 6.5 km/sec. with the second layer interface at 20 km. The third layer interface (Moho discontinuity) seems to be at a depth of 55 km and has a velocity of 8.0-8.1 km/sec.

4.1 CONCLUSIONS

The Lesser Himalaya of Central and Eastern Nepal can be divided into two regions roughly along the line joining Pokhara to Udayapur on the basis of apparent velocity of first arrivals of seismic waves at the stations of Kathmandu Seismic Network. On the north of the demarkation line focal depths of events seem to be shallow and less than 20 to 23 km. The Moho depth seems to be 55km. The first layer with a velocity of 5.6 km/sec. and thickness of 20 to 22 km probably represents the upper crust where as the 6.5 km/sec. velocity may be attributed to the lower crust velocity.

The line joining Pokhara to Udayapur roughly correlates in east with the axis of Mahabaharat synclinorium. South of this the apparent velocity of the events can be explained in two ways, (a) The focus of the events is confined to the lower crust with a velocity of 6.5 km/sec. In such case the Mahabharat synclinorium seems to be characterised by deeper events and the difference of focal depths in northern and southern region seems to be correlated with anticlinorium and synclinorium. These two belts seem to intersect at near Pokhara. (b) Alternatively apparent velocity of the events of southern region may be interpreteted as due to reduced crustal thickness with Moho depth at 35-40 km. south of Pokhara - Udayapur axis. The margin of the Indian Peninsular crust probably follows roughly Pokhara Udayapur axis. The focal depths of the events may be the same order of depth as in the northern region.

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