Paper No. 200, Bull. ISET Vol. 16 No. 4, Dec. 1979, pp. 153—158

A COMPARISON OF UPPER MANTLE TRAVEL-TIME BRANCHES USING DATA FROM GBA, YKA AND WRA SEISMIC ARRAYS[1]

AVADH RAM

Introduction

The tectonic processes and forces which are responsible for phenomenon such as movement of lithospheric plates and mechanism of earthquakes depend very much on what we know about the structure of upper mantle and its regional variation. During the last fifteen years, a large number of upper mantle velocity models have been postulated from P-wave travel time observations and slowness data. Although, these models differ from each other in detail, most of them have shown evidence for discontinuities or large positive velocity gradients near the '400 km' and '680 km' depth ranges. In most cases, the presence of these transition zones implies that two major triplications should exist in the travel time curve for epicentral distances less than 30°. Much of the non uniqueness or variations in the published upper mantle models occur because of the great difficulties in observing and identifying the later arrivals belonging to different travel time branches. It appears from review of the literature that the main reasons for this problem are; (i) the complexity of the earthquake signal, (ii) the great variability in amplitude observations over even very closely spaced stations and (iii) the uncertainties of epicentre locations and focal depth.

Advancement of the seismic arrays and sophisticated data processing techniques have facilitated the direct and automatic measurement of travel time gradient or slowness, apparent velocity and azimuths for the incoming seismic waves crossing an array. The subtle variations in slowness and apparent azimuths for overlapping phases especially where the branches of the travel time curve are triplicated, can in many cases be resolved successfully. Such measurements provide much more detailed and refined upper mantle models of the Earth and may also remove some of the ambiguities in data interpretation. In this article, the velocity models and positions of the upper mantle travel time branches as inferred from the analyses of over 600 earthquakes from three different continents are summarized.

Processing of Array Data, Travel-Time Branches and Velocity Models

Regional upper mantle studies are essential and desirable for elucidating very fine structural variations that might be present and could be obscured while averaging the individual measurements in the final results. Further more, a region-wise comparison of the findings is utmost important for better understanding of relative motion of the subducting plates, earthquake mechanisms and nature and propagation of seismic waves. Over 600 earthquakes (distance range 12°—30°) recorded at Gauribidanur (India), Yellowknife (Canada) and Warramunga (Australia) medium aperture seismic arrays have been analysed using adaptive processing techniques. The Indian subcontinent has been divided into four zones in order to make regional studies, (i) Himalayan region (azimuth 0°—90°), (ii) Java

1 Paper No. 12 presented at Kurukshetra Symposium.

2 Department of Geophysics, Banaras Hindu University, Varanasi-221005.

trench (90°—180°), (iii) Mid-Indian Oceanic ridge (180°—280°) and (iv) Hindu Kush region (280°—360°). California and Alaska-peninsula regions were considerd using YKA data. The results of WKA data analysis are implied to the Northeastern parts of Australia.

In all these studies, slowness values as determined by an array have been used as the main diagnostic tool. Since slowness values can be affected by lateral inhomogeneities, single measurement or a series of measurements along a particular seismic trace may not always give a true picture. The inhomogeneity problem was approached by not only analysing the variations of slowness along each trace but also by looking at as many earthquakes as possible over different regions to see if any pattern emerges above the noise and scatter.

Details about the epicentral locations of earthquakes, array configurations, processing of the data, analyses and plotting of the results and methods for inversion of the slowness data can be found in the literature (Ram and Mereu, 1977; Ram et. al, 1978 and Simpson et. al, 1974). A typical upper mantle structure would produce travel time branches as shown in Fig. 1. AB, BC, CD, DE and EF are different (direct and retrograde) theoretical branches. The cusps at C and E predict high amplitude arrivals. In the cases of GBA and YKA results the position of these cusps, especially at C, is still uncertain and needs detailed investigations. This problem is being tackled by analysing large number of events particularly within 10°-14° distance range. Synthetic traces for amplitude analysis and an-elastic parameter, Q are also studied.

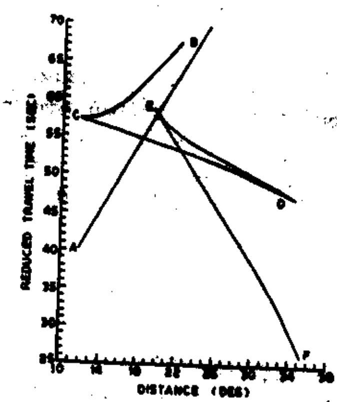

Fig. 1 AB, BC, CD, DE, and EF are (theoretical) travel-time branches corresponding to a typical upper mantle structure (Reducing velocity = 10.0 km/sec)

P-wave velocity models as postulated from the analyses of this data are shown in the form of tables for various regions. Table 1 gives velocity distribution with depth for continental and oceanic regions around India. The jump in velocities for '400 Km' and '650 Km' discontinuities can be seen in all the regions except the Himalayan region. In this region, if the latter discontinuity is replaced by a broad high velocity gradient zone; a velocity depth structure much more consistent with the observed data is found. The slope of the travel time curve of DE branch pertaining to the later arrivals is parallel with that

TABLE 1

P-wave velocities in continental and oceanic regions around India.

P-wave velocity (km/sec) Model RM-1	Depth (km) (Himalayan Region)	P-wave velocity (km/sec) Model RM-2	Depth (km) (Java trench Region)
5.50	0	5.07	0
5.50	15	5.07	1
6.50	15	6.70	1
6.50	33	6.70	5
7.90	33	7.80	5
7.90	113	7.90	95
8.13	113	8.00	175
8.13	354	7.75	175
9.55	404	7.75	352
9.55	434	9.85	427
11.34	825	9.85	574
11.34	847	11.08	705
		11.08	725
		11.18	819
Model RM-4	(Hindukush Region)	Model RM-3	(Mid-Oceanic Ridge)
5.50	0	5.07	0
5.50	15	5.07	1
6.50	15	6.70	1
6.50	33	6.70	5
7.90	33	7.80	5
7.90	113	7.90	95
8.13	113	8.00	175
8.13	362	7.75	175
9.67	412	7.75	332
9.67	542	6.69	407
10.84	644	9.69	599
10.84	678	10.75	638
11.12	822	11.29	860
		11.30	872

TABLE 2

P-wave velocity models for California (RMW-1 & RMW-3) and Alaska-Peninsula (RMW-2) regions

Model RMW-1		Model RMW-2		Model RMW-3	
Velocity (km/sec)	Depth (km)	Velocity (km/sec)	Depth (km)	Velocity (km/sec)	Depth (km)
5.50	0	5.50	0	5.50	0
5.50	15	5.50	15	5.50	15
6.50	15	6.50	15	6.50	15
6.50	33	6.50	33	6.50	33
7.95	33	7.95	33	7.95	33
8.26	199	8.22	161	8.26	199
8.26	368	8.22	333	8.26	296
9.62	418	9.19	383	8.94	366
9.62	590	9.19	518	9.07	454
11.14	696	10.33	546	9.81	471
11.14	716	10.33	566	9.92	601
11.15	753	11.01	762	9.92	683
				11.11	708
				11.14	761

TABLE 3

Upper mantle velocity model (SMAK II) for Northeastern regions of Australia

Velocity (Km/Sec)	Depth (Km)
6.20	0
6.20	20
6.50	20
6.50	35
8.10	35
8.10	85
8.25	85
8.32	175
3.32	315
8.32	315
9.20	380.0
10.13	559.6
10.16	572.6
10.16	656.9
10.16	656.9
10.71	671.3
11.46	846.4

of the EF branch comprising first arrivals (Ram and Mereu, 1977, Fig. 3a). This finding is very interesting and has necessitated the re-examination of the positioning of travel-time branches associated with '650 Km' discontinuity for this region. One of the approaches which is being carried out, is to study the area in a grid form consisting narrow azimuth and distance ranges using large number of earthquakes with good signal to noise ratio. This study can be supplemented by amplitude investigations corresponding with cusps D and E.

Table 2 illustrates velocity distribution with depth for California and Alaska-peninsula and Alaska-peninsula regions. An alternative model RMW-3 is also shown. Model RMW-1 is preferred over RMW-3 because of its simplicity. The two transition zone (discontinuties) are clearly outlined. Table 3 presents upper mantle velocity model for North-eastern parts of Australia. This model SMAK II is the refined version of an earlier model SMAK I. The Q and its effect on the observation of travel time branches has been considered (Mereu et. al, 1974). The '400 Km' and '650 Km' discontinuities are well identified in this model. Research projects involving inhomogeneity problem, scattering and attenuation of P-waves in the Indian crust and upper mantle regions are in progress and their results will be published elsewhere.

TABLE 4

A comparison of the observed uppermantle travel-time branches as inferred from the Gauribidaur (India), Yellowknife (Canada) and Warramunga (Australia) medium aperture seismic array data.

Arrays	Number of earthquakes & their source regions	Distance ranges for observed travel-time branches (Refer Fig. 1)				
		AB (°)	AB-CD Cross-over point (°)	CD (°)	CD-EF Cross-over point (°)	EF (°)
GBA	300					
(after Ram & Mereu, 1977)	Himalayan	16—23	18	16—22	Absent	22—32
	Java trench	16—19	19	18—23	24	23—36
	Mid-oceanic ridge	19—19	18	18—22	24	18—35
	Hindukush	15—24	18	20—22	23	19—35
YKA	100					
(after Ram et. al, 1978)	California	13—26	19	20—25	23.5	21—30
	Alaska-peninsula	15—17	19	19—23	20	16—30
WRA	200					
(after Simpson et. al, 1974)	Northeastern Australia	13—20	19	16—25	25	21—30

Conclusions

A detailed discussion and conclusion of results can be found in earlier paper as mentioned in the previous sections of the text. However, the major features of the three studies from different continents in terms of observed upper mantle travel time branches are summarised in Table 4.

References

Mereu, R.F., Simpson, D.W. and King, D.W., (1974) 'Q and its effect on the observation of upper mantle travel time branches', Earth and Planet. Sci. Letters, Vol. 21, pp. 439-447.

Ram, A. and Mereu, R.F., (1977) 'Lateral variations in upper mantle structure around India as obtained from Gauribidanur seismic array Geophys. data', J.R. Astron. Soc., Vol 49, pp. 87-114.

Ram, A., Mereu, R.F. and Weichert, D.H., (1978) 'The identification and interpretation of upper mantel time branches from measurements of dT/dΔ made on data recorded at the Yellowknife seismic array', Can. J. Earth Sci., Vol. 15, pp. 227-236.

Simpson, D.W., Mereu, R.F. and King, D.W., (1974) 'An array study of P-wave velocities in the upper mantle transition zone beneath northeastern Australia', Bull. Seismol. Soc. Am., Vol. 64, pp. 1757-1788.