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REVISED VELOCITY STRUCTURE IN THE UPPER MANTLE BENEATH THE JAPAN REGION

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Abstract

A preliminary model of the three-dimensional velocity structure in the upper mantle is revised by applying a method of ray tracing to the analysis of travel times for four events of shallow and intermediate focal depths.

In the lithosphere (high-V zone), P_n velocity is 2-3 per cent lower in southwest Japan than that in the northeast region. A rapid increase in velocity is particularly remarkable at a depth of 150km in the northeast. Namely, P velocity changes from 8.17km/s at 150km to 8.50km/s at 180km. The high gradient layer constituting a part of the high-V zone is quite different from other models presented to date.

Noticeable difference in velocity is also found in the asthenosphere between the inner and outer regions of the arc system : P velocity is about 3 per cent lower in the inner region.

1. Introduction

A preliminary three-dimensional velocity structure in the Japan region was obtained in Paper I (KAKUTA, 1985), by using a shooting method applicable to a complicated structure in the upper mantle. The model lowered travel time residuals for earthquakes near Hokkaido more remarkably at several stations in northeast Japan and Hokkaido than a horizontally layered model did. Nevertheless, it could not satisfactorily explain observations. For an intermediate depth event in the west off Hokkaido, residuals were systematically distributed : negative at the stations on the Pacific side of northeast Japan but positive on the side of the Japan Sea in northeast and central Japan. Large positive residuals were brought about for a shallow event in southwest Japan. We hence investigate P velocity distributions more precisely. Events are the same as analyzed in the previous study (KAKUTA, 1985): events 1, 2 and 3 occurring near Hokkaido and event 4 in southwest Japan (Fig. 1 and Table).

2. Residuals for the Starting Velocity Structure

We assume six zones roughly approximate to the complicated structure in the Japan region, as shown in a schematic profile (Fig. 2). They are almost the same as the previous

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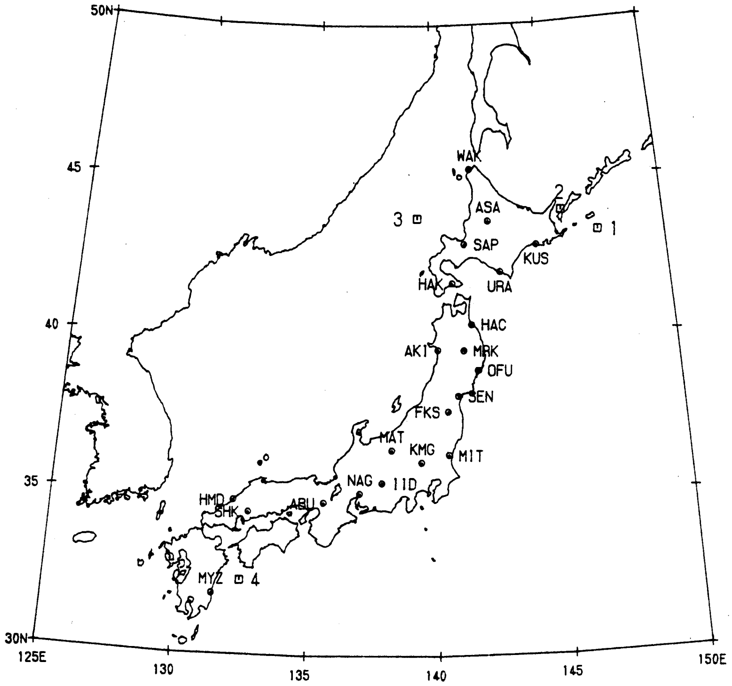

Fig. 1. Epicenters (square) and observation stations (circle) used in the present study. Integer refers to the event number.

Table. Focal parameters of the events used for ray tracing.

No	Origin Time	Latitude (°N)	Longitude (°E)	Depth (km)	
1	1964 May 31 00 h 40 m 37.8±0.1 s	43.33±0.02	147.12±0.03	47	
2	1965 Oct. 25 22 h 34 m 24.4 0.2 s	44.04 0.02	145.57 0.03	166	
3	1975 Aug. 6 21 h 37 m 39.8 0.15 s	43.90 0.015	139.33 0.022	229	ISC
4	1968 Apr. 1 00 h 42 m 03.9 0.3 s	32.38 0.03	132.46 0.02	36	

model ; zone boundaries are not modified too. The first zone corresponds to the crust and the second to the low-V mantle on the inner region (continental side) of the arc system. High-V zones involving deep seismic planes are the third and fourth : the third zone spreads over southwest Japan and the fourth zone extends from Kuril through northeast Japan to Izu-Bonin islands. Both zones cover the asthenosphere, or the fifth zone, which is divided into two : zone-5a under the third zone and zone-5b under the fourth zone. The sixth is the mesosphere. Details of the zone boundaries and quadrilateral net were already described in Paper I.

Small residuals at shorter distances for events 1 and 2 were relevant to the rays travelling only through shallow depths in the second and fourth zones, while the negative residuals for event 3 referred to the fourth zone at intermediate depths near 200km. The previous model for the fourth zone was accordingly almost fit to velocities at shallow depths but not at intermediate depths : velocities are inferred to be considerably higher at about 200km deep than the model. An evidence was probably P_r of 12.5 s/deg for an intermediate depth event (KAKUTA, 1989).

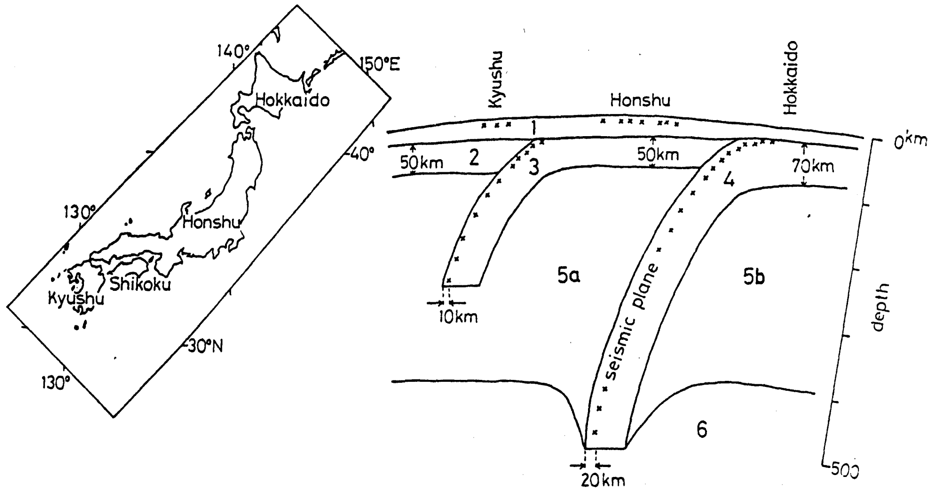

Fig. 2. Schematic cross section of the upper mantle from Kuril through Kyushu [reproduced from KAKUTA (1985)]. Integer stands for the zone number. It is almost the same as that in the previous model except the fifth zone, or asthenosphere, which is divided into 5a (inner region) and 5b (outer region).

Large positive residuals for event 4 were due to excessively high velocities in the third zone. Although the third zone in the previous model was assumed to be only slightly different in velocity structure from the fourth zone, a large difference was certainly confirmed in P_n velocity between the two zones from the correlation analysis (KAKUTA, 1989). Moreover, KAKUTA (1973) indicated on the basis of travel time analyses that Jeffreys' model was preferable to K-4-A or to Herrin's model (HERRIN, 1968) for approximating the velocity structure in southwest Japan.

The previous model also failed to explain observations at distances more than 9° for event 1 or than 7° for event 2 : especially large negative residuals at MAT and NAG. They were probably brought about by the theoretical rays diverted into deeper parts owing to excessively low velocities in zone-5b underlying the fourth zone. On the other hand, positive residuals for event 3 were attributable to excessively high velocities in zone-5a overlying the fourth zone. A large difference in velocity was consequently expected in the asthenosphere, or the fifth zone, between the inner and outer regions of the arc system.

3. Revised Velocity Structure and Travel Time Residuals

Examining travel times for four events by a trial and error procedure, we obtained revised velocity distributions depicted in Fig. 3 ; K-4-A (KAKUTA, 1973) and Jeffreys' model were shown for a reference. As easily seen from Fig. 4, travel time residuals for the revised model (open circle) were, on the whole, largely decreased as compared with those for the previous model (triangle). The large positive residuals for event 4 were reduced by 1 s or over at HMD, ABU, SEN and MRK. At MAT and NAG for event 2 as well as at MRK, SEN and FKS for event 3, the negative residuals were also considerably improved. A brief description of the velocity structures is as follows :

In the first and second zones, velocity distributions are the same as those in the previous model. P velocities increase with depth steadily from 4.9km/s at the surface, through 6.1km/s at 5km, to 6.8km/s at 30km in the first zone and almost linearly from 7.5km/s at 20km to 7.82km/s at 150km in the second zone.

The third zone, or the lithosphere in southwest Japan, is characterized by relatively low P_n velocity of 7.80km/s. The velocity distribution is very similar to Jeffreys' model : 7.96 km/s at 100km, through 8.10km/s at 170km, to 8.42km/s at 240km.

In the fourth zone, or the lithosphere in the northeast region, P_n velocity is high (8.05 km/s) and Herrin's model approximates the velocity distributions from 40 to 150km. At depths between 150 and 180km, P velocities change rapidly from 8.17 to 8.50km/s.

The fifth zone, or the asthenosphere, is classified into two. One is zone-5a on the continental side of the fourth zone and the other zone-5b underlaying the fourth zone. Zone-5a is characterized by low velocities changing from 7.70km/s at 50km, through 7.82 km/s at 150km, to 8.35km/s at 300km. In contrast, zone-5b almost agrees in velocity structure with the third zone : 7.92km/s at 80km, through 8.10km/s at 170km, to 8.58km/s at 300km. Between the two, the velocity contrast amounts to 3 percent, which is consistent with the estimate by HAMADA (1973).

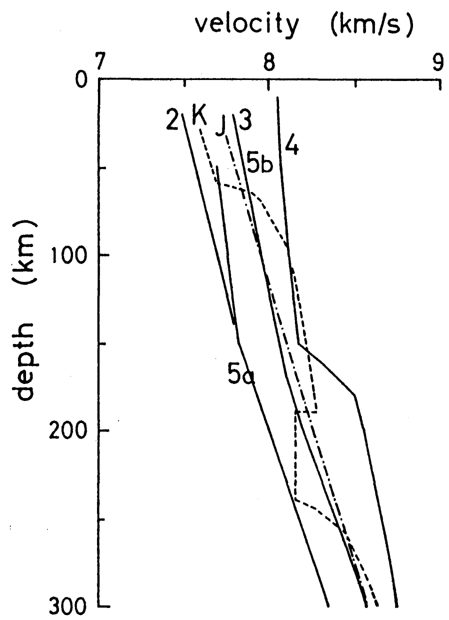

Fig. 3. Revised velocity structure in the respective zones. Integer stands for the zone number. Model K-4-A (K) and that of Jeffreys (J) are shown for reference.

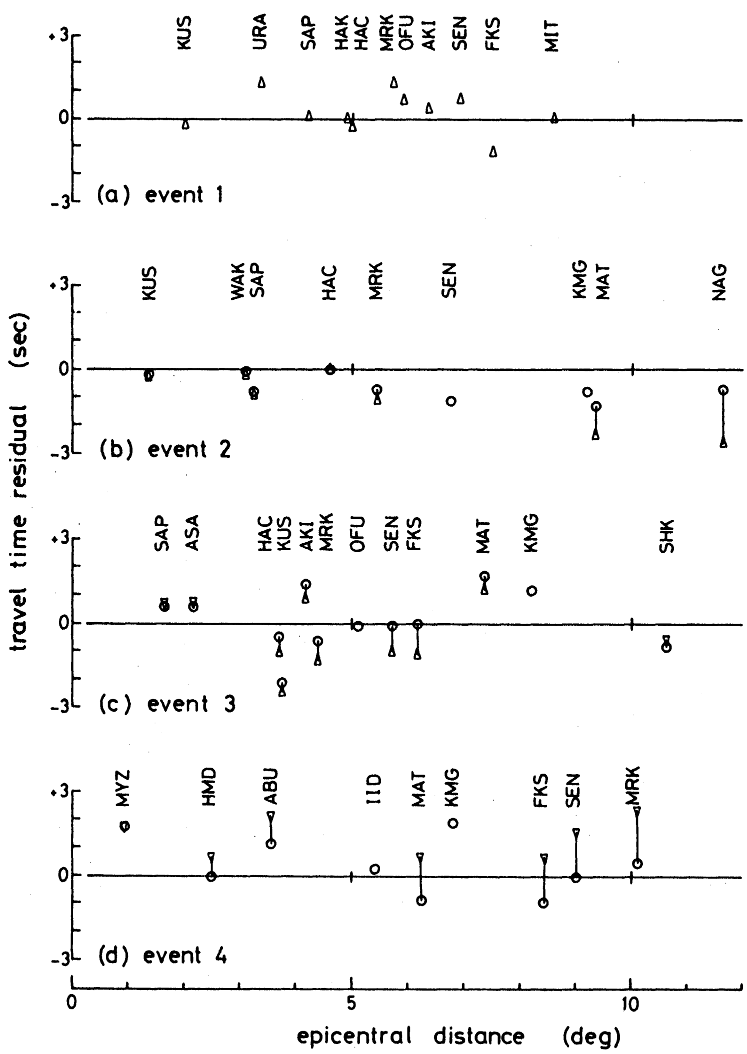

Fig. 4. Travel time residuals for the revised velocity structure (open circle) compared with those for the starting model (triangle) : (a) event 1, (b) event 2, (c) event 3 and (d) event 4. Only the residuals for the starting model were shown in (a), because the differences were very small.

On the lower surface of the fourth zone, the velocity contrast reaches its maximum of 4.4 percent at a depth of 180km and gently decreases to 2 percent at 300km. Decrease in velocity contrast with depth was concordant with the result of TADA (1972). It was also supported by velocity deviation ratios estimated from travel time residuals for earthquakes in the Kuril-Hokkaido arc (KAKUTA, 1973).

Model K-4-A approximates the velocity distribution along the Kuril-Hokkaido arc in a vertical section from the second zone (low-V zone), through the fourth (high-V lithosphere), to the fifth (asthenosphere) as seen in Fig. 3.

4. Discontinuity near 200km Depth

We found a section of velocities rapidly increasing from 8.17 to 8.50km/s at depths between 150 and 180km in the lithosphere. Such a section was approximately consistent not only in depth but also in velocity with a high velocity zone reported by many authors. In most reports, it immediately underlay a low velocity layer (JOHNSON, 1967 ; KANAMORI, 1967 ; ARCHAMBEAU *et al.*, 1969 ; HELMBERGER and WIGGINS, 1971 ; FUKAO, 1977) or a zone of negative velocity gradient (HALES *et al.*, 1970 ; LEVEN *et al.*, 1981). ANDERSON (1979) as well as DRUMMOND *et al.* (1982) suggested that the discontinuity at a depth of about 200km is a worldwide feature, while LEVEN *et al.* (1981) explained it in terms of velocity anisotropy due to decoupling of the continental lithosphere from the underlying mantle. These are all spherically symmetric layered models ; if a high-V layer sharply dips into a low-V zone, it would be explained as a rapid velocity increase overlaid (or underlaid) with a low velocity layer.

In our model, such a discontinuity exists only in the high-V lithosphere along the Kuril-Hokkaido-Northeast Japan arc but not in the surrounding zones. At depths near 200km in the Japan region, seismic activities are remarkably lowered (KATSUMATA, 1967 ; ISACKS *et al.*, 1968) and the double-planed seismic zone disappears (HASEGAWA *et al.*, 1978 ; UMINO *et al.*, 1984). Both phenomena are relevant to the deep seismic activities in the high velocity zone. Considering the coincidence in depth range, both seem to be related to the rapid velocity increase in the zone.

5. Conclusions

Using the ray tracing method presented in Paper I, we obtained velocity structures almost satisfying the observations of four events at shallow and intermediate focal depths.

In the high-V lithosphere, velocities are considerably lower in southwest Japan than in northeast Japan : Jeffreys' model approximates the velocity structure in the southwest region, while Herrin's model does that in the northeast region. The velocity contrast between the two regions decreases with depth from 3 percent at 20km to 1 percent at 150km. At intermediate depths in the northeast region, P velocity changes rapidly from 8.17km/s at 150km to 8.50km/s at 180km. The high gradient layer of 30km thick constitutes a part of the high-V zone and quite different from those as involved in several spherically symmetric models : it immediately underlies (or overlies) neither a low velocity layer nor zone of negative velocity gradient.

The uppermost mantle in the inner region of the Kuril-Hokkaido-Northeast Japan arc is a zone of very low velocities changing from 7.5km/s at 20km, through 7.6km/s at 60km, to 7.7 km/s at 100km. Between the high-V and low-V zones in the northeast region, the velocity contrast amounts to 5-7 percent, which is comparable with those known to date (UTSU, 1967 ; HAMADA, 1973). A clear difference in velocity was also confirmed in the asthenosphere between the inner and outer regions of the arc : the velocities in the inner region are about 3 per cent lower than those in the outer region.

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