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39. P-Wave Travel Time Anomaly in Asia and the Southwestern Pacific.

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Abstract

The regional variation of the P-wave travel time residual is investigated. USCGS and Soviet data are used for this study. The selected epicenters are determined by at least thirty readings at various stations distributed widely in azimuth and distance. The residual is studied at stations located on the concave and convex sides of the arcs in order to find the dependence of the residual on the seismic activity and the tectonic nature of the arcs. The same study was carried out at stable regions such as the Arabian shield and Central Asia. The residual is compared with that corresponding to various well-known models derived mainly from explosion seismology. It is concluded that the residual is closely related to seismotectonic movements and the seismic activity as well. It is also found that the P-wave residual is abnormally negative on the convex side of the arcs and normal or slightly positive on the concave sides. A larger negative residual is observed on the convex side of the arc of which the seismic activity is higher than that of any other one. The P-wave velocity in the upper mantle under the Arabian shield is less than that of the J-B model, while it is higher than that of J-B in the upper mantle under Central Asia. The attenuation is low wherever the residual is negative.

1. Introduction

The body wave velocity is considered as the most significant tool in exploring the earth's interior. Since the construction of the J-B travel time curves (1939) there have been many efforts, using more and more accurate data, to improve the accurracy of the travel time curves, on one hand and on the other, to get a more precise and detailed picture of the earth's fine structure (Gutenberg, 1953, 1959, Carder and Bailey, 1958, Kogan, 1960, Jeffreys, 1962, Lehmann, 1962, 1964, Anderson and

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Toksöz, 1963, Niazi and Anderson, 1965, Carder *et al.*, 1966, Roller and Jackson, 1966, Kanamori, 1967, Julian and Anderson, 1968, Herrin, 1968). A regional variation of the P-wave velocity in the upper mantle was discovered by Herrin *et al.* (1968). The dependence of the the P-wave velocity on the azimuth of approach at the seismic stations has been noted by Ritsema (1959), Bolt (1966), Cleary and Hales (1966b), Niazi (1966), Otsuka (1966), Utsu (1967), Kanamori (1968), Kebeasy (1969, 1970), Mizoue, Tsujiura and Kebeasy (1969), and Nuttli and Bolt (1969). The velocity anisotropy in the upper mantle was introduced to explain the P-wave travel time delay (Morris *et al.* 1969, Raitt *et al.* 1969, Mooney, 1970). This delay was partially attributed to an anomalous heat flow and density by Hales and Doyle, 1970 and Horai and Simmons, 1968.

The purpose of this paper is to investigate the P-wave travel time anomaly in terms of seismotectonic movements and seismic activities around the arcs and also at stable regions. The residual will be compared with that of various models derived mainly from explosion data.

2. Data

The data were collected from the Earthquake Data Report (EDR) of the U. S. Coast and Geodetic Survery (USCGS), for the period from Jan. 1965 to Dec. 1969. Only earthquakes with a body wave magnitude greater than 5.1 or earthquakes with hypocenters determined from more than 30 readings at different stations distributed around the epicenter in the distance range from 0° to 90°, were used for the analysis. All these epicenters are believed to be fairly accurate. The earthquakes selected for the present work are shallow ($H \leq 70$ km) except the Tonga—Kermadec region for which shallow, intermediate and deep earthquakes are treated. The used epicenters are plotted in Fig. 1, for the southwestern Pacific region and in Fig. 2 for Asia. For

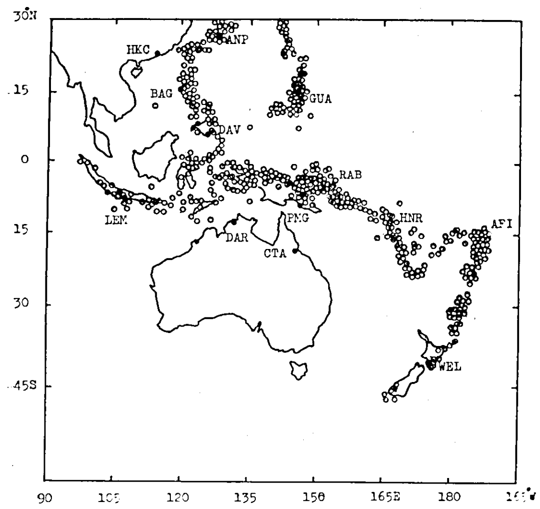

Fig. 1. Epicenters used for the southwestern Pacific region ($H \leq 70$ km, $m_b \geq 5.1$, No. of stations used for each epicenter location$\geq$30 stations). The stations used for the present analysis are also shown.

Central Asia, five earthquakes in Pamir were chosen. They are listed in Table 1 together with their relocation results. All stations used, including Soviet stations, are given in Table 2.

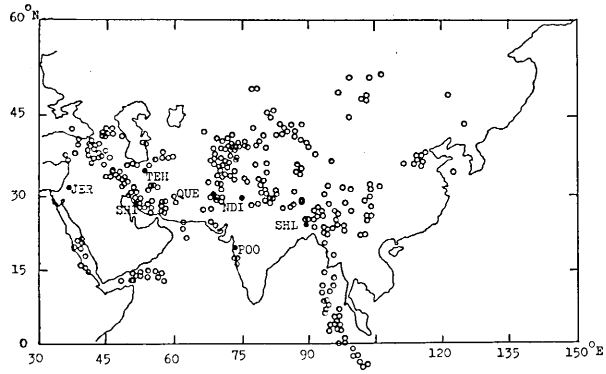

Fig. 2. The epicenters used for southern Asia, selected on the same basis as those in Fig. 1. Stations used for this region are shown.

3. Procedure

The P-wave travel time residual from J-B curves around each station, in the distance range from 0 to 40°, were classified according to azimuth into eight

Table 1. A list of five earthquakes used to investigate the P-wave travel time residuals in Central Asia. The locations made by the USCGS and the Soviet net-work and that made by both the Soviet and the USCGS data together, are given.

Date	Data	Origin Time	Epicenter		Depth (km)	Magnitude
670105	USCGS	100758.3	39.4°N	72.9°E	11	5.3
	Soviet	100802	39.3	72.7	—	5¼
	Both	100802.2	39.3	72.7	43	—
670202	USCGS	073754.9	39.7	75.5	39	5.3
	Soviet	073758	39.7	75.3	—	5
	Both	073757.2	39.7	75.3	54	—
670424	USCGS	085110.9	37.4	72.7	31	5.6
	Soviet	085111	37.3	72.6	8	5¼—½
	Both	085111.5	37.3	72.6	41	—
670511	USCGS	145058.8	39.4	73.8	21	5.6
	Soviet	145101	39.3	73.8	—	6
	Both	145101.2	39.3	73.8	38	—
670514	USCGS	090054.8	39.2	73.9	33	5.0
	Soviet	090055	39.2	73.9	—	5¼
	Both	090055.6	39.2	73.9	37	—

Both means that hypocenters are relocated using all available date of USCGS and Soviet net-work.

Table 2. A list of stations used in the present work. Soviet stations are taken from the seismological bulletin of the Soviet net-work stations. Heights of these stations are not given. The given code was made by the present author to facilitate the calculations.

Code	Name	Latitude	Longitude	Height
		Southwestern Pacific		
AFI*	Afiamalu	13.908° S	171.78°W	706M
WEL*	Wellington	41.29 S	174.77 E	122
HNR*	Honiara	9.43 S	159.95 E	85
RAB*	Rabaul	4.19 S	152.17 E	184
PMG*	Port Moresby	9.48 S	147.15 E	70
DAR	Darwin	12.38 S	130.83 E	6
LEM*	Lembang	6.83 S	107.62 E	1241
DAV*	Davao	7.09 N	125.58 E	85
BAG*	Baguio	16.41 N	120.58 E	1507
HKC*	Hong Kong	22.33 N	114.19 E	27
ANP*	Anpu	25.18 N	121.52 E	836
		South Asia		
SHL*	Shillong	25.57 N	91.90 E	1600M
NDI*	Delhi	28.68 N	77.22 E	230
QUE*	Quetta	30.19 N	66.95 E	1713
TEH	Tehran	35.74 N	51.38 E	1360
SHI*	Shiraz	29.81 N	52.86 E	1595
JER*	Jerusalem	31.77 N	35.13	770
		Soviet		
ANR		40.75°N	72.37°E	
AAP		67.55	33.33	
AWX		37.95	58.35	
XKP		41.73	43.52	
XEK		40.38	49.90	
XPS		57.85	114.20	
TPM		39.00	70.32	
TPC		39.50	46.33	
AWO		38.57	68.77	
EPE		40.18	44.50	
TKX		50.38	103.28	
NPX		52·27	104.32	
KDX		39.20	56.27	
KPS		40.58	46.33	
KWH		47.02	28.87	
KPA		37.90	69.75	
PIB		49.82	24.03	
MKH		43.01	47.43	
MHP		51.68	100.98	

* WWSSS station of USCGS.

(to be continued)

Table 2.

(Continued)

Code	Name	Latitude	Longitude	Height
MCX		55.73°N	37.93°E	
MRX		38.37	73.93	
HPE		41.43	76.00	
PAP		42.48	78.40	
PPK		59.77	30.32	
CBP		56.80	60.63	
CMY		50.40	80.25	
CMX		44.95	34.12	
CIH		43.58	39.72	
TPR		43.27	77.38	
TWK		41.33	69.30	
TKC		71.63	128.87	
TNX		41.72	44.80	
YDT		51.57	94.08	
YXR		48.63	22.30	
FAP		42.83	74.62	
XPR		37.48	71.53	
YDY		50.10	88.35	
RKE		62.01	129.72	

groups with 90° intervals overlapping each other by 45°. In relation to the epicentral distance, the residual data were averaged for every 2° distance intervals. The mean residuals are plotted against the mean epicentral distance for all available data at every station. The standard deviation was also calculated for each point and indicated by vertical lines. An open circle is an average of less than three data in the assigned range, while the closed one is an average of more than three. The residuals were then joined by a smooth line, paying more attention to the points which are averages of a large number of data.

For Central Asia, five earthquakes with epicenters in the Pamir are selected to investigate the P-wave travel time residual from the J-B curves. The hypocenters and origin times of these earthquakes were determined by USCGS and the Soviet net-work independently. However, Soviet stations are located only to the north of those epicenters while the USCGS stations are located to the south. In the present work, Soviet and CGS data were used together to relocate the focal coordinates of those five earthquakes (cf. Fig. 3). The locations determined by the CGS and the Soviet net-works separatly and those from both data groups together are given in Table 1. The travel time residuals at Soviet stations along the two profiles extending from Pamir to Eastern Siberia and to Carpathia through the Caucasus, will be studied to find the de-

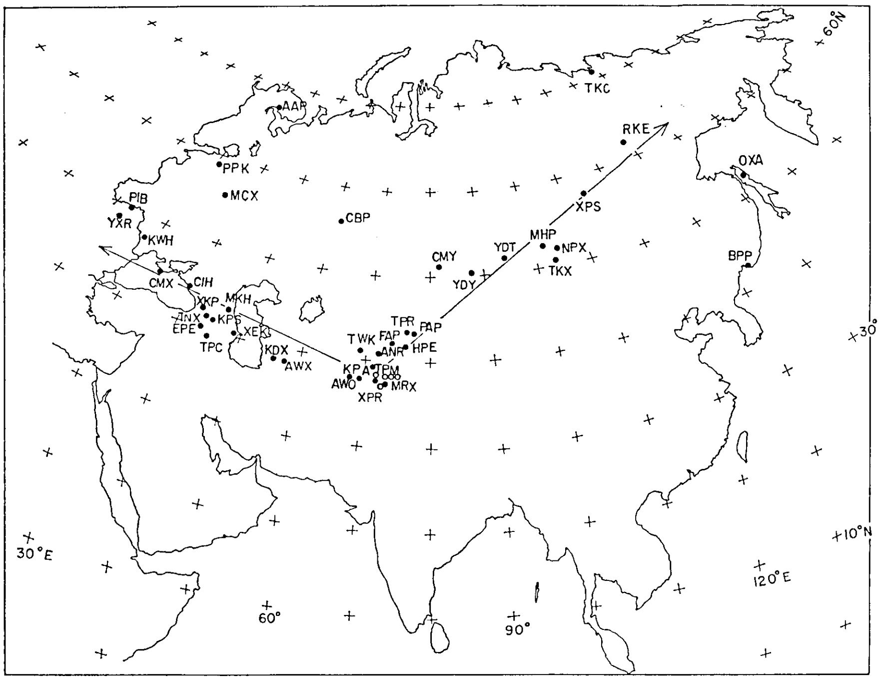

Fig. 3. Soviet stations used for Central Asia (closed circles) and five earthquakes selected for this region (open circles). North-east (NE) and north west (NW) profiles are also shown.

viation of the upper mantle structure under Central Asia from that of the J-B model.

The travel time residual from the J-B curves for various known models such as the Gutenberg model (1959), the CIT11CS3 model (1965), Kanamori's preliminary model (1967), and Herrin model (1968), were calculated in the distance range from 0 to 40° and are shown in Fig. 4. These differences will be used to compare the observed residuals. It should be mentioned that in these models the regionality or heterogeneity of the upper mantle is not specifically considered.

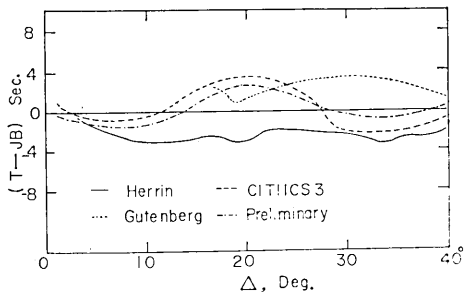

Fig. 4. P-wave travel time residuals for Gutenberg, Herrin, CIT11CS3 and Kanamori's preliminary models with respect to the J-B model.

4. The Tonga—Kermadec Island Arc

The features of this arc have been found by Gutenberg and Richter (1954) and Sykes (1966) through the studies on seismicity and volcanic activities. Shallow, intermediate and deep earthquakes show the features of the arc which bends sharply to the west at its northern end. AFI is located on the convex side of the island arc, while WEL is located to the south-west of that arc (cf, Fig. 5). Ten vertical cross sections perpendicular to the island arc are included in the same figure. The interval between every two profiles is 2° latitude and all earthquakes which occured within one degree to the north and one degree to the south of the cross section are projected in one profile. These cross sections represent the seismic plane where earthquake foci are located. These sections show the island arc structure.

The P-wave travel time residuals at AFI and WEL for shallow, intermediate and deep earthquakes which occurred in the Tonga—Kermadec region are given as a function of the epicentral distance in Fig. 6. The residual of shallow earthquakes at HNR is also given in the same figure. The observed residual at AFI for shallow earthquakes is very large in the negative sense indicating abnormally early arrivals. The standard deviation is large because of the wide depth range ($0 \leq H \leq 70$ km). The average residual is about -8.0 seconds in the distance range from 4 to 14°. At distances greater than 14°, the residual decreases till it becomes -1.8 seconds at $\Delta=20.4°$. In the case of intermediate earthquakes, the residual increases as distance increases till it reach -11.0 seconds at $\Delta=13.8°$, and then decreases till it becomes normal at $\Delta=20.8°$. For deep earthquakes the average residual is about -4.0 seconds in the distance range from 7.4 to 15°. It decreases as the distance increases till it becomes -1.2 seconds at $\Delta=19°$. At WEL the largest negative residual for shallow earthquakes is -5.0 seconds observed at $\Delta=9°$. The residual is normal at $\Delta=15°$. Although the available data at WEL for intermediate earthquakes are few, the average residual is about -6.0 seconds in the distance range from 6 to 15° and then the residual becomes normal at $\Delta=21°$. Deep earthquakes have not been observed to the south of latitude 33°S. The available data showed a negative residual of about -4.0 seconds, on the average, in the distance range from 9.8 to 13°. The residual is more or less normal in the distance range from 15.8 to 23°. HNR is far away to the west of the Tonga—Kermadec arc and the residual from earthquakes to the southeast (SE) of this station appears to be normal all along the distance range investigated here. The residual at this station might have been affected by the structure of the New Hebrides island arc. The seismic

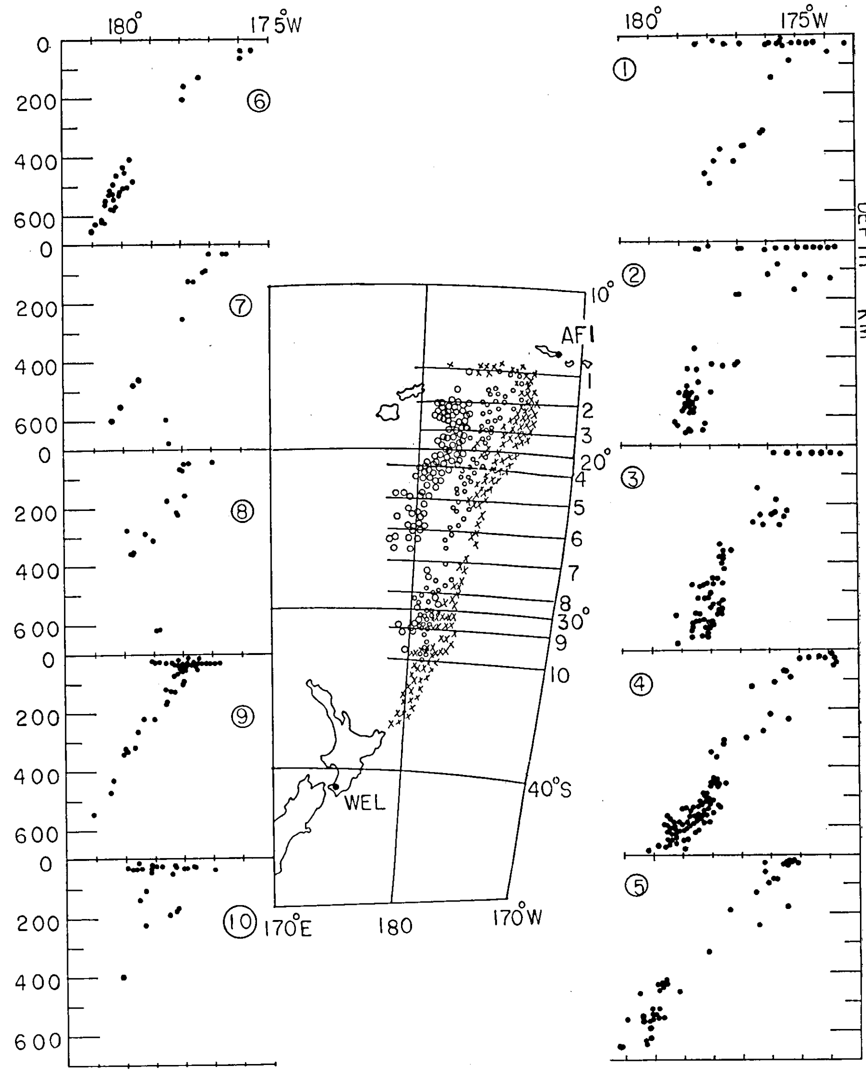

Fig. 5. Epicenters used for the Tonga—Kermadec Island arc (x; shallow earthquakes, o; intermediate earthquakes, 0; deep earthquakes). Ten vertical cross sections perpendicular to the island arc are also shown and arranged from 1 through 10 as from north to south.

plane under the latter island arc is vertical (Gutenberg and Richter, 1954).

The largest negative residual at AFI for shallow, intermediate and deep earthquakes of the Tonga—Kermadec region is observed at $\Delta \simeq 14°$. To locate the anomalous region which is responsible for this abnormally negative residual, the cross section No. 6 in Fig. 5 which is located about 14° to the south west of AFI, is considered. The ray paths, according to the J-B model, for shallow (33 km), intermediate (180 km) and deep (500 km) earthquakes from this plane to AFI are calculated and projected in the same plane as shown in Fig. 7. It can be seen that, in all cases, the ray takes off from the seismic plane and travels to AFI in a narrow region outside the seismic plane and on the oceanic of the arc. Accordingly, the P-wave velocity in that region should be greater than that of J-B. Since the negative residual is observed at $\Delta \leq 2°$, the upper boundary of this anomalous region is very shallow and may reach the surface. The crustal thickness is of the order of 15 km or less (oceanic crust), and its effect may be neglected. The fact that deep earthquakes take place as deep as 700 km suggests that the lower boundary of this region may reach that depth. As an evidence for the lower boundary of this region, a negative residual from deep earthquakes is observed till $\Delta = 19°$. The width of this region can not be determined from the present observations. Nevertheless, we believe that the width is within the order of few hundred kilometers. A slab model like that proposed by Oliver and Isacks (1967) may also explain the observed P-wave travel time residual

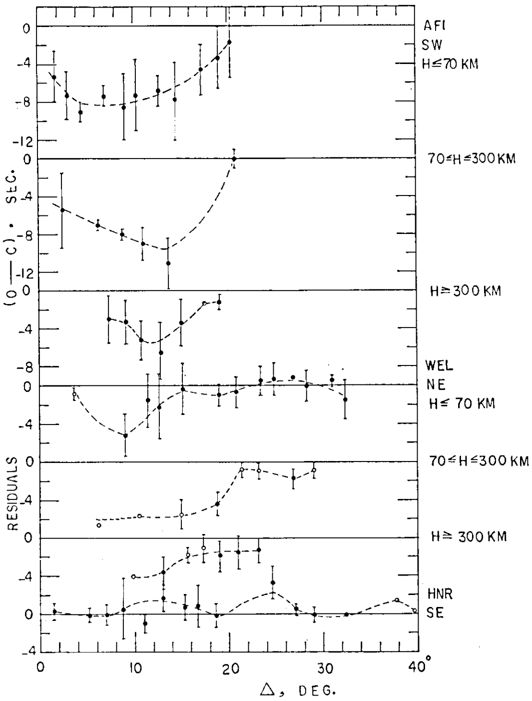

Fig. 6. P-wave travel time residuals at AFI and WEL for shallow, intermediate and deep earthquakes which took place in the Tonga—Kermadec region. Residuals for shallow earthquakes recorded at HNR are also shown.

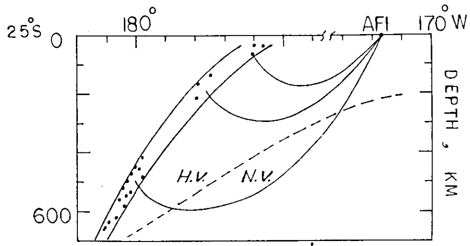

Fig. 7. Vertical cross section No. 6 and AFI (at latitude 13.9°S) projected on one plane at latitude 25°S. Ray paths for shallow (33 km), intermediate (180 km) and deep (500 km) earthquakes to AFI, based on the J-B model are also projected. AFI is about 14° away from this plane.

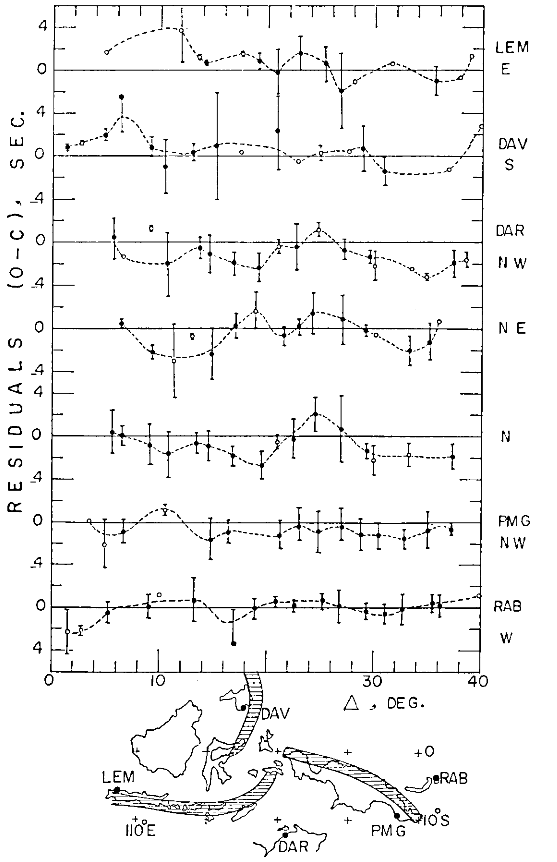

Fig. 8. P-wave travel time residuals in the region of Indonesia and the Philippine. The island arcs in this region are also shown.

in that region. From the geothermal point of view, Watanabe (personal communication) thinks that the oceanic side of the island arc is cold. It should be mentioned that the Tonga—Kermadec island arc is very young and its seismic activity is high at the present time.

5. Taiwan—Philippine and Indonesia Regions

The seismo-tectonic nature of the Taiwan—Philippine regions has been investigated by Katsumata and Sykes (1969). Also the New Guinea-Solomon Islands region is studied by Denham (1969). According to these studies, the features of the island arc structure in those regions are traced. They are shown in Figs. 8 and 9. The P-wave travel time residual as a function of distance at stations located in those two regions is given in the same two figures. Data are very much scattered and no conclusion can be derived. However, this scatter indicates that the island arc structure in these regions is very complicated. Nevertheless, we can notice that the residuals from east (E) of LEM are positive in the distance range from 5 to 19°. LEM is on the concave side of the Sunda and Philippine arcs. Residuals from north-west (NW) of PMG and from west (W) of RAB are normal.

6. Burma—Sumatra Island Arc

According to Gutenberg and Richter (1954) intermediate and deep earthquakes occur on the concave side of the island arc making the seismic plane dipping toward the continental side of the arc. NDI and SHL, and LEM were selected to investigate the P-wave travel time residual on the convex and concave side respectively. The P-wave residual from shallow earthquakes which occurred within this arc at the stations as a function of distance is shown in Fig. 10. The residual from southeast (SE) of NDI is negative in the distance range from 2 to 20°. At SHL, the residual is abnormally large and negative in the distance range from 8 to 23°. From 23 to 40°, the residual is normal. The residual from northwest (NW) of LEM is slightly positive at $\Delta \leq 18°$ and slightly negative in the distance range from 20 to 28°. It is to be noted that the P-wave travel time residual is negative at stations located on the convex side of the arc (e. g. NDI and SHL) and slightly positive or normal at the station located on the concave side of the arc (e. g. LEM). This observation is consistent with that found at TSK and DDK for the Kurile arc (Kebeasy, 1969) and also with that at COL and BIG for the Alaskan Island arc (Kebeasy, 1970), although the residual magnitude is different from one arc to another. This difference can be attributed to the seismic activity around each arc.

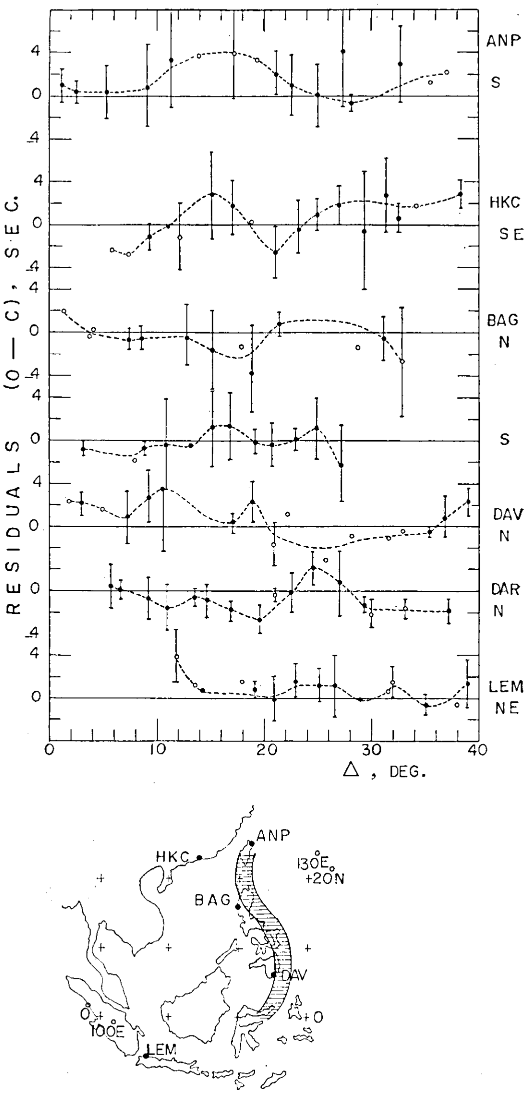

Fig. 9. P-wave travel time residuals for the region of Taiwan and the Philippines. The island arcs of this region are also shown.

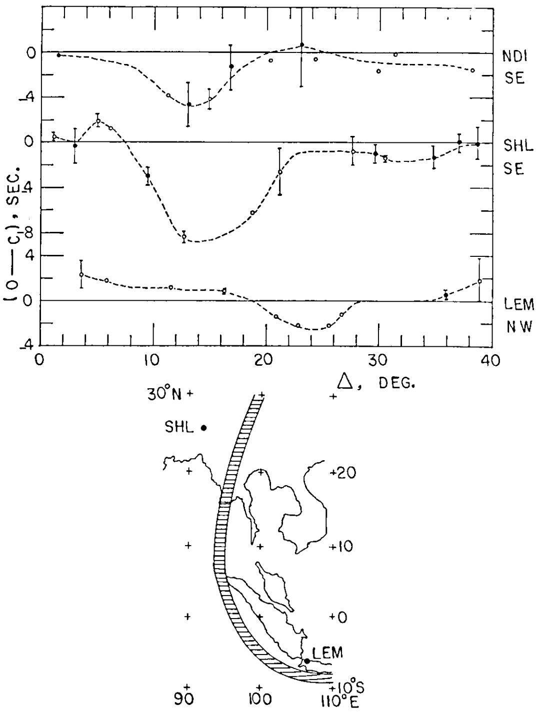

Fig. 10. P-wave travel time residuals at NDI, SHL and LEM for shallow earthquakes which occurred within the Burma—Sumatra island arc. NDI and SHL are located on the convex side of the arc, while LEM is on the concave side.

7. The Himalayan Arc

The Himalayan arc is tectonically well developed and faces the stable region of the Indian plateau (Gutenberg and Richter, 1954), even though only shallow and intermediate earthquakes are reported to have taken place in the arcuate region. Intermediate earthquakes are few and the seismic planc of this arc seems to be curved and dipping toward Tibet. The P-wave travel time residual at QUE, NDI and SHL from shallow earthquakes which took place within the Himalayan arc or to the north-east, are shown in Fig. 11. All these stations are located to the south and on the convex side of this arc. Residual from earthquakes which occurred north-east (NE) or east (E) of QUE show abnormally large negative values in the distance range from 9 to 18°. NDI is located closer to the arc and the observed residual from north-east (NE) of this station is about −1.5 seconds in the distance range from 6 to 21°. The observed residuals from east (E) of NDI and from north-west (NW) of SHL indicate abnormally large negative values in the distance range from 6 to 22° at NDI, and from 8 to 21° at SHL. This large negative residual is due to the tectonic nature of the arc structure which significantly differs from the upper mantle structure of the J-B model. These observations are consistent with the previous cases of the Kurile Island arc, the Tonga—Kermadec Island arc, the Alaska Island arc and the Burma—Sumatra island arc. Seismic activity and geological age differ from arc to arc and the residual magnitude is also found to be different from one arc to another.

8. The Persian Region and the Baluchistan Arc

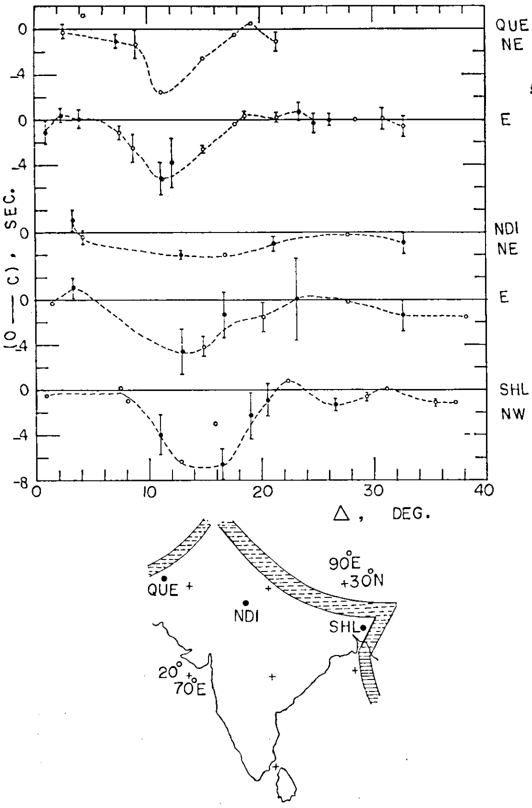

Fig. 11. P-wave travel time residuals at QUE, NDI and SHL for shallow earthquakes which occurred within the Himalayan arc. All these stations are on the convex side of the arc. The Himalayan arc is also shown.

Shallow earthquakes do often occur in the Persian region, but they do not follow a specific seismotectonical trend. The Baluchistan arc faces this region from the east. Intermediate earthquakes are observed to the west of this arc (Gutenberg and Richter. 1954 and USCGS, 1966 through 1968). The location of shallow earthquakes suggests that the Baluchistan arc curved to north-west and the location of intermediate earthquakes suggests also that the seismic plane under this arc is dipping in the same direction. The observed P-wave travel time residual is studied at QUE and NDI on the convex side of this arc and at TEH and SHI on its concave side. It is shown in Fig. 12. The residuals from north (N) of QUE and from north-west (NW) of NDI are negative in the distance range from 6 to 21° at QUE and from 6 to 18° at NDI. TEH and SHI are far away to the west and the observed residuals at these stations at distance less than 19° are due to the upper mantle structure under the Persian region. The residual is more or less normal at SHI and TEH in the distance range from 5 to 19°. At $20° \leq \Delta \leq 30°$, the residual is positive at both stations. This may be attributed to the time which the seismic ray spent under the concave side of the Baluchistan arc. Earthquakes occur as deep as 300 km to the west of that arc.

9. The Arabian Shield and the Iran-Iraq-Turkey Arc

Gutenberg and Richter (1954) have considered the Arabian region as

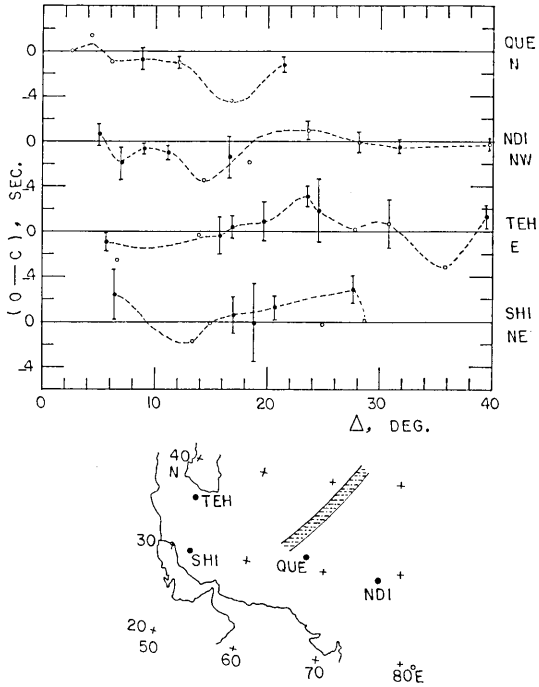

Fig. 12. P-wave travel time residuals at QUE, NDI, TEH and SHI for shallow earthquakes which occurred within the Baluchistan arc or in the Persian region. QUE and NDI are on the convex side of the island like arc. TEH and SHI are on the concave side, but rather far from the arcuate region.

an outlying part of the African stable mass and separated from it by the active zones of the Red Sea. No earthquakes so far have been observed in that region. The P-wave travel time residual at JER from earthquakes which occurred in the Red Sea, the Gulf of Aden and the Iran-Iraq-Turkey arc, is about +1.5 seconds on the average, in the distance range from 9 to 40° (c. f. Fig. 13). This indicates that the P-wave velocity in the upper mantle under this shield is a little less than that of the J-B model. Large and shallow earthquakes have been observed very frequently nowadays in north-western Iran and eastern Turkey. This arc is rather old and intermediate and deep earthquakes have not been observed in that region. The P-wave travel time residual at TEH and SHI, as a function of distance is given in Fig. 13. The residual from west (W) of TEH is positive, in the distance range from 5 to 19°, while it is negative at SHI in the distance range from 8 to 24°. TEH is located on the concave side of the arc, while SHI is located inside the arc.

10. Central Asia

The method used for the previous regions can not be used for this part of central Asia because of the rare occurrence of earthquakes. However, due to the distribution of the Soviet stations, we have been able to investigate P-wave travel time residuals along two profiles. One is from Pamir along the country border of USSR to north east Siberia. The second one is from Pamir to the north west till the Caucasus and Carpathian region. As mentioned before, we have selected five shallow earthquakes which took place in Pamir and relocated their hypocenters using all available data of the USCGS and the Soviet net-works. The residual as a function of distance along the two profiles is given in Fig. 14. The upper two profiles show the observed residual based on Soviet location, while the lower two profiles show that based on the relocation result. It can be seen that both of them are nearly identical. Nevertheless the latter one is shifted toward positive values. The observed residual based on the relocated hypocenters, along (NE) and (NW) is nearly similar to the residual of the Herrin model with respect to the J-B model, except that the former is shifted toward positive values. Moreover, the residual magnitude along the NW profile is larger than that of the Herrin model, in the distance range from 6 to 16°, and smaller in the distance range from 20 to 40°. The residual in the later distance rangeis normal. This observation implies that the P-wave velocity in the uppermost part of the upper mantle is higher than that of the J-B and the Herrin models.

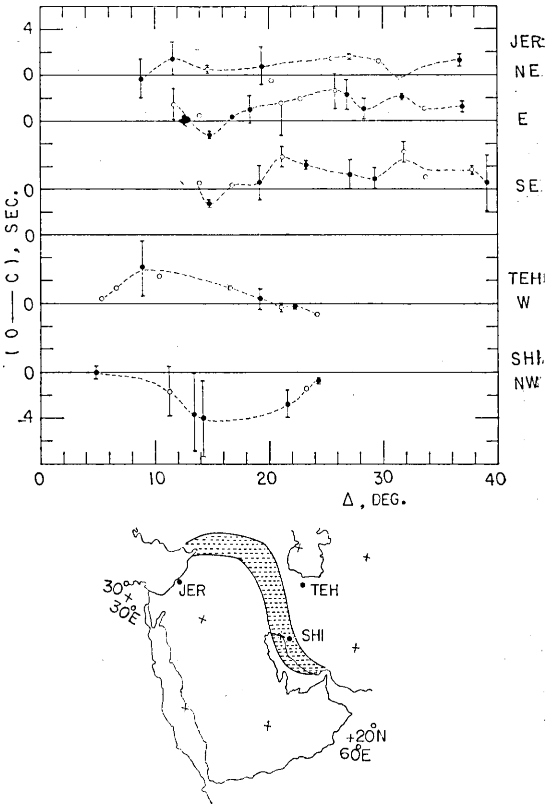

Fig. 13. P-wave travel time residuals at JER, TEH and SHI for various azimuthal direction from shallow earthquakes which occurred in the Red Sea, Gulf of Aden, western Iran and eastern Turkey. The feature of the Iran-Iraq-Turkey arc is also given.

11. P-wave Residual and Seismic Activity

The observed P-wave travel time residual as a function of distance is shown in Fig. 15, for the Tonga—Kermadec, Kurile—Japan, Alaska, Burma—Sumatra and the Himalayan arcs. These residuals have been observed at station located on the convex side of the above mentioned arcs. The abnormally negative residual is usually observed at distances

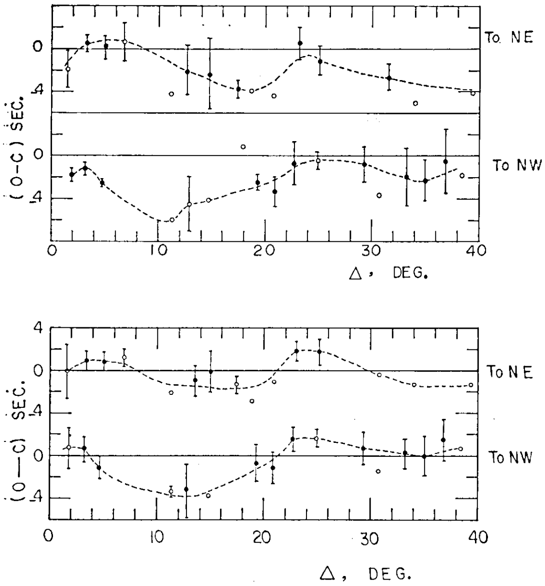

Fig. 14. P-wave travel time residuals along two profiles, northeastern (NE) and northwestern (NW), in Central Asia. The upper part shows the residuals based on the Russian locations. The lower part shows the residuals based on the relocated hypocenters made in the present work using all available data of the USCGS and the Soviet net-work.

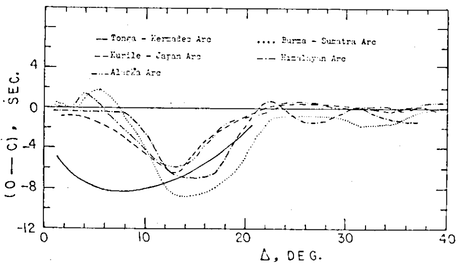

Fig. 15. P-wave travel time residual as observed at stations located on the convex side of the Tonga-Kermadec, Kurile-Japan, Alaska, Burma-Sumatra and the Himalayan arcs.

less than 20°. The start of this abnormal residual at a certain distance depends upon the station location with respect to the arcuate region. The amount of the residual is different from one arc to another. It seems to be closely related to the seismic activity around each island arc. The higher the seismic activity in the arcuate region the larger is the negative residual. The large negative residual observed on the convex side of the Tonga—Kermadec arc is a strong evidence for that fact. This region is considered to be a very active seismic region (Gutenberg and Richter, 1954). About one third of the world's deep earthquakes occur in that region. The Himalayan arc is less active and the magnitude of the residual is smaller than that observed for the Tonga-Kermadec Island arc. At distances greater than 20°, the residual is more or less normal and independent of azimuth, distance and regionality.

12. Attenuation and Seismic Velocity in the Upper Mantle

A summary of the quality of S_n-propagation as determined by Molnar and Oliver (1969) based on some 1.500 paths to various seismic stations all around the world is represented in Fig. 16. According to this representation, S_n propagates with high efficiency on the convex side of

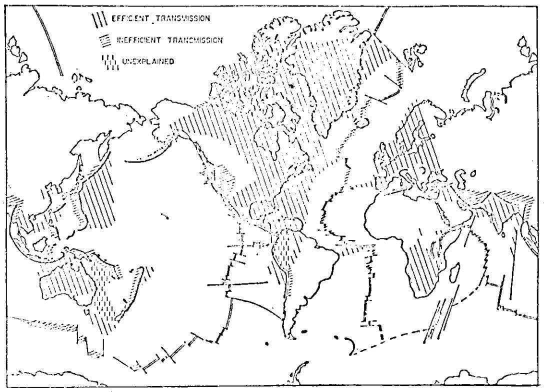

Fig. 16. Summary of the quality of S_n-propagation as determined by Molnar and Oliver (1969). The hatched area indicates the regions studied, the orientation of hatching gives the quality according to legend.

the arcs. In the present study, it has been found that the P-wave travel time residual at stations located on the convex side of the arcs is usually negative. This implies that the P-wave propagates with a higher velocity than that expected from the J-B model. In general, wherever the attenuation is low, the P-wave velocity is found to be high. The investigation of the P-wave travel time residual is more advantagious than the attenuation method. The P-wave velocity is affected only by the path while the attenuation is affected not only by path but also by the earthquake mechanism. Moreover it is easier to find the residual difference from one arc to another than to find the frequency change of the P or S-waves.

13. Conclusion

From the present study, the following conclusions could be derived:—

1. The observed P-wave travel time residual is abnormally large and negative at stations located on the convex side of the arcs.
2. The observed P-wave travel time residual is normal or slightly positive at stations located on the concave side of the arcs.
3. The magnitude of the negative residual of the P-wave travel time at stations located on the convex side of the arc is different from one arc to another. The younger the arc and the higher the seismic activity, the larger the observed negative residual is.
4. The P-wave velocity in the upper mantle along the oceanic side of the island arcs is higher than that along the continental side.
5. The P-wave velocity in the upper mantle under the Arabian shield is normal or a little lower than that of the J-B model, while it is higher under Central Asia.
6. In regions of low attenuation, a large and negative P-wave travel time residual is observed.

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39. アジアと南西太平洋における P 波の走時異常

地震研究所 R. M. KEBEASY

P波の走時偏差の地域的な差異を調べた．このために USCGS と Soviet によるデータを使った．この研究のために使った地震の震央は，どれも，次の事柄を満たしている．(1) 震央は 30 以上の観測点でのP波の到達時刻によって決められている．(2) それらの観測点は，震央のまわりに，方位震央距離共に広く分布している．

Arc の地震活動，tectonic nature に，この走時偏差がどれだけ依存しているかを調べるために，この走時偏差は，Arc の convex side にある観測点と concave side にある観測点で調べられている．同じような研究を Arabian-shield と，中央アジアの安定な地域についても行った．

この走時偏差は，主に爆破地震学から得られているようなよく知られた速度構造モデルと比較されている．

走時偏差は seismotectonic movement や，地震活動とかなりの関係があるということが結論される．つまり，P 波の走時偏差は arc の convex side で異常に負であり，concave side では normal 又は幾分正であることがわかる．地震活動がより活発な arc はそれだけ走時偏差も大きな負となっている．

Arabian shield の下の上部マントルでの P 波の速度は J-B モデルに比べて小さいが，中央アジアにおいては，それは，J-B に比べて大きい．減衰は，偏差が負である所はどこでも，低くなっている．