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9. *Residuals of Teleseismic P-wave Travel Times Observed in Japan.*

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Abstract

Anomalies in teleseismic P-wave travel-times observed at stations in Japan have been studied by using 8920 arrival time data of 223 distant earthquakes. Earlier arrivals are observed at stations on the Pacific side of Northeast Japan, and later arrivals are observed at stations in Southwest Japan and on the Japan Sea side of Northeast Japan. Exceptionally early arrivals are observed at stations in the Chugoku region, Southwest Japan. The geographical distribution of the station anomalies in the teleseismic travel times is consistent with the features of seismic activity, Bouger gravity anomaly, heat-flow and attenuation of seismic waves.

Sinusoidal variations of the teleseismic travel-time residuals with azimuth are observed. Especially at high-sensitivity stations in the Kanto region the time differences of up to 2 seconds are observed between the earliest and latest arrivals. These azimuthal variations can not be explained only by the regional variation in the crustal structure directly beneath the stations. Mean residuals of the teleseismic travel times at each station are more in conformity with the station corrections of travel-times determined by the joint hypocenter determination (JHD) method for the mantle earthquakes rather than for the crustal earthquakes. Regional and lateral variations of the travel-time anomaly are mainly interpreted by the presence of a high-velocity zone in the upper mantle, associated with the descending slab beneath the Japanese Islands from the Pacific side.

A negative correlation is observed between the mean residuals of teleseismic travel times and the Bouguer gravity anomalies at each station. Lateral variation of the velocity and density is suggested from the negative correlation of azimuthal variation of teleseismic residuals and the Bouguer gravity anomaly around some stations. A tendency of separation of stations into two groups with earlier and later arrivals is observed in the relation of the station anomalies with the station corrections of travel times and earthquake magnitude, and the Bouguer gravity anomaly. Regional differences of the attenuation of seismic waves seem to be consistent with the station anomalies of teleseismic travel times.

1. Introduction

For a more accurate determination of earthquake hypocenters in and around the Japanese Islands adequate station corrections of travel times are required. Station anomalies of travel times in Japan have been observed from nearby deep and shallow earthquakes, as extensively reviewed by UTSU (1971). It is not easy to separate the causes of station anomalies from the neighbouring effects around stations due to grazing incidences for nearby earthquakes. Teleseismic travel times make it possible to isolate the relative station anomaly, because of nearly vertical incidences to stations.

Travel-time data of deep and shallow earthquakes at short distances are strongly affected by the mislocation of hypocentral coordinates (UTSU, 1971, 1975). Teleseismic travel times observed in a limited region have the advantage of being less affected by the mislocation of hypocenters. A further advantage of teleseismic travel times is a good azimuthal coverage around stations, which makes it possible to study the lateral variation of structure around stations by their azimuthal variation.

Systematic differences of travel times from the standard times have been indicated from the world-wide studies by CLEARLY and HALES (1966a), CARDER *et al.* (1966), HERRIN and TAGGART (1968), LILWALL and DOUGLAS (1970), GIBOWICZ (1970), LOMNITZ (1971), JULIAN and SENGUPTA (1973), MAKI (1974), VEITH (1975), SENGUPTA and JULIAN (1976).

Teleseismic residuals have been used for detecting the temporal variation of velocities in the source regions (WYSS and HOLCOM, 1973; WYSS and JOHNSON, 1974; SUTTON, 1974; CRAMER and KOVACH, 1974, 1975; KANAMORI and CHUNG, 1974; BOORE *et al.* 1975; WYSS 1975a, b; CRAMER, 1976; ROBINSON and IYER, 1976; PROZOREV, 1977).

For studying the anomalous structure of the upper mantle associated with the descending lithospheric plate under the Japanese Islands, teleseismic travel times have been analyzed (UTSU, 1967, 1971; KANAMORI, 1968; KEBEASSY, 1970; AOKI and TADA, 1973; NAGAMUNE, 1973a; HAMADA, 1973).

Azimuthal variations of the teleseismic travel-time residuals have been studied for the crust and upper mantle structure beneath the stations (RITSEMA, 1959; BOLT and NUTTLI, 1966; OTSUKA, 1966a, b; CLEARLY and HALES, 1966b; CLEARLY, 1967; HALES *et al.*, 1968a; HERRIN and TAGGART, 1968; DAVIES and MCKENZIE, 1969; NUTTLI and BOLT 1969; MITRONOVAS and ISACKS, 1971; JACOB, 1972; PAYO, 1972; NAGAMUNE 1973a; SPENCE, 1974; ENGDAHL, 1975; ROBINSON, 1976; AGARWAL *et al.*, 1976; SENGUPTA and JULIAN, 1976; RAIKES, 1976; VEITH, 1978).

Although the general description of the anomalous structure around the deep seismic zone has been made, further studies of regional and lateral variations of the crust and uppermost mantle structure are needed. In this paper the regional variation of travel-time anomalies will be studied by using teleseismic travel times observed in Japan. The lateral variation of the upper mantle structure beneath stations will be studied from azimuthal variation of teleseismic travel-time residuals. Station anomalies of travel times will be geographically correlated with the gravity anomaly and attenuation of seismic waves.

2. Materials

In order to determine the usable range of epicentral distances of the teleseisms, the variation of incident angles to the earth's surface with epicentral distance is studied at first. Fig. 1 shows the variation of incident angle with distance for the surface and deep focus (h=794 km) earthquake. The values of incident angle are determined for the crustal velocity of 6.35 km/sec and $dT/d\Delta$ obtained by numerical differentiation of the JEFFREYS-BULLEN travel times (JEFFREYS and BULLEN, 1940, 1958). A large difference in the incident angles between these focal depths is observed at distances less than 30°. For distances greater than 30°, the difference of incident angles does not exceed 2°. Incident angles from any focal depths can then be regarded to be the same for epicentral distances greater than 30°.

Travel-time data from distant earthquakes are compiled from the

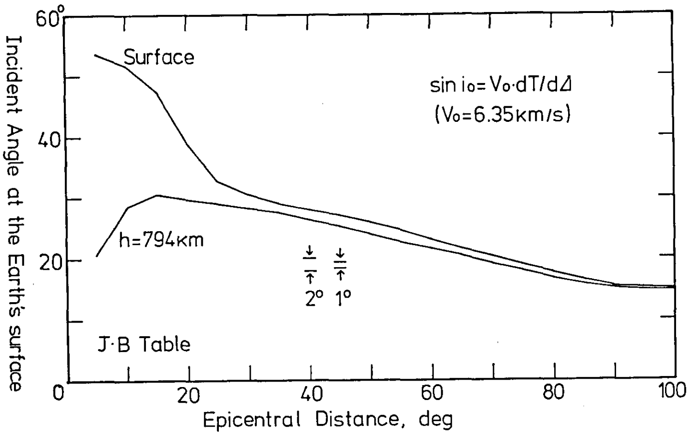

Fig. 1. Variation of the incident angle at the earth's surface with epicentral distance for the surface and deep-focus (h=794 km) earthquakes. The values of $dT/d\Delta$ are obtained by the numerical differentiation of the JEFFREYS-BULLEN travel times and assuming a crustal velocity of 6.35 km/sec.

JMA Data File, which includes the focal coordinates by the USGS for distant earthquakes and arrival times during the period from 1963 to 1976. For the years after 1976, travel-time data for distant earthquakes are not reported in the JMA Data File.

Only the P-wave arrival times which are read to the nearest tenth of a second are used in the present study. Two hundred and twenty-three distant earthquakes were observed by more than 10 stations whose travel-time residuals are less than 5 seconds at epicentral distances greater than 30°. The lowest magnitude of these earthquakes were 5.0. Travel-time residuals are obtained from the JEFFREYS-BULLEN Travel-Time Table (JEFFREYS and BULLEN, 1940, 1958) by correcting the earth's ellipticity and the height of stations (BULLEN, 1937a, b). The number of travel times used in the present study reaches 8920 and about 20% of

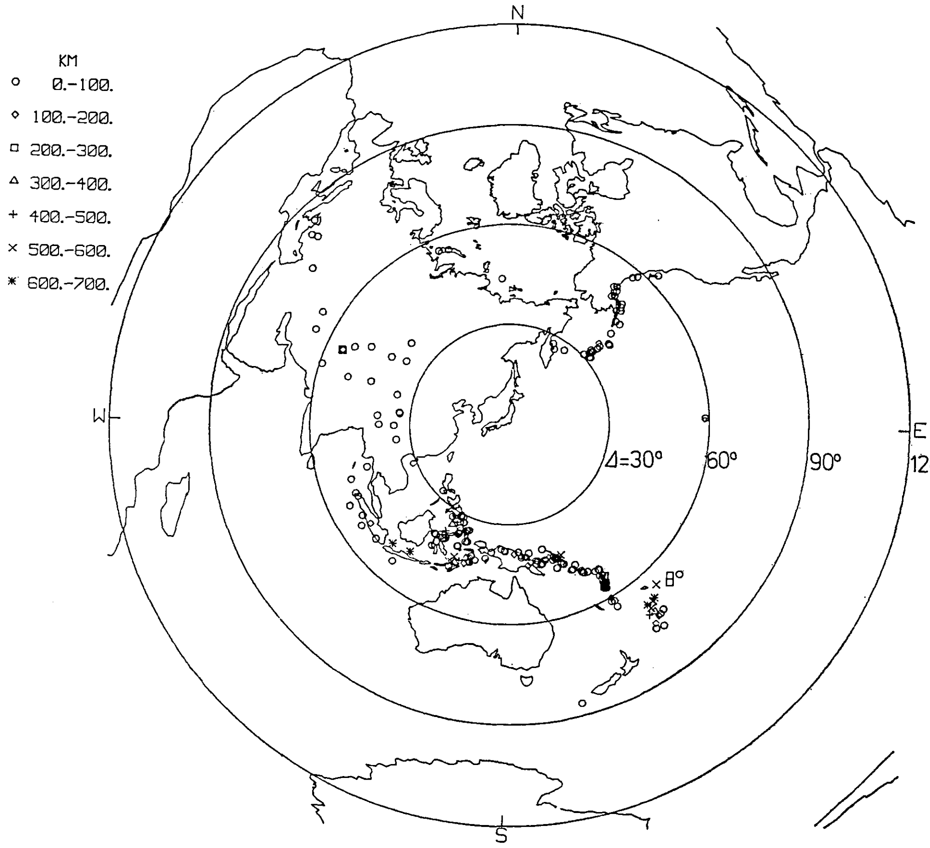

Fig. 2. Azimuthal coverage of the epicenters used in this study, on the azimuthal equi-distance projection with the center of location (36°N, 140°E). Focal depths are shown by different symbols for every 100 km interval. Equi-distances of 30° to 120° are also shown by circles.

them are supplemented by the high-sensitivity stations of several universities.

The hypocenter locations and origin times of the 223 distant earthquakes used in this study are listed in the Appendix. The focal coordinates of earthquakes in the year of 1963 are taken from the USGS, and others after 1964 are from the ISC. Errors of focal coordinates and origin times are not given for the earthquakes of 1963. In Fig. 2 the epicenters of 223 earthquakes are represented on the azimuthal equidistance projection about the location (36°N, 140°E), with different symbols for every 100 km of focal depths. A good coverage of azimuths around the stations is seen. Travel-time data are collected also from some explosions whose time and location of the detonations are announced.

3. Teleseismic travel-time residuals observed in Japan

Residuals of travel times are caused by the following effects, (1) misdetermination of hypocentral coordinates and origin times, (2) systematic departure of observed travel times from the standard ones in use, and (3) regional differences in the crust and uppermost mantle structure beneath the stations. Travel-time residuals from nearby-deep earthquakes cannot be easily separated into these components. However, in the case of teleseismic travel times it is easy to separate them into these components.

Misdeterminations of epicentral coordinates, focal depths and origin times are produced not only by inadequate data sets or bad coverages of distance and azimuth of observational stations, but also by regional variations in velocity structure around the sources. But the effects of the errors of hypocentral locations on travel-time residuals are small for teleseismic data observed within a narrow range of distance and azimuth.

Recent observations from nuclear explosions and well-located earthquakes show the systematic departure of travel times from the Jeffreys Bullen times as a function of distance (HUSEBYE, 1965; CARDER *et al.*, 1966; CLEARLY and HALES, 1966a; CLEARLY, 1967; HALES *et al.*, 1968b; HERRIN *et al.*, 1968b; LILWALL and DOUGLAS, 1970; LOMNITZ, 1971; SENGUPTA and JULIAN, 1976; HALES and MÄKI-LOPEZ, 1980). According to these studies, a base line correction of up to 2 or 3 seconds from the Jeffreys-Bullen times is required and a significant undulation is also observed. Earlier arrivals are observed around the distances $\Delta=30°$ and 60°, and later arrivals around $\Delta=40°$ and 80°. Such systematic departures have been also observed in Japan (KANAMORI, 1968; NAGAMUNE, 1973a; AOKI and TADA, 1973).

The effects of the mislocation of hypocenters and the systematic departure from the Jeffreys-Bullen times on the teleseismic residuals can be removed by subtructing the mean values and the systematic trend of residuals. But in the present study the systematic trend of teleseismic residuals cannot be estimated because of the narrow range of distances.

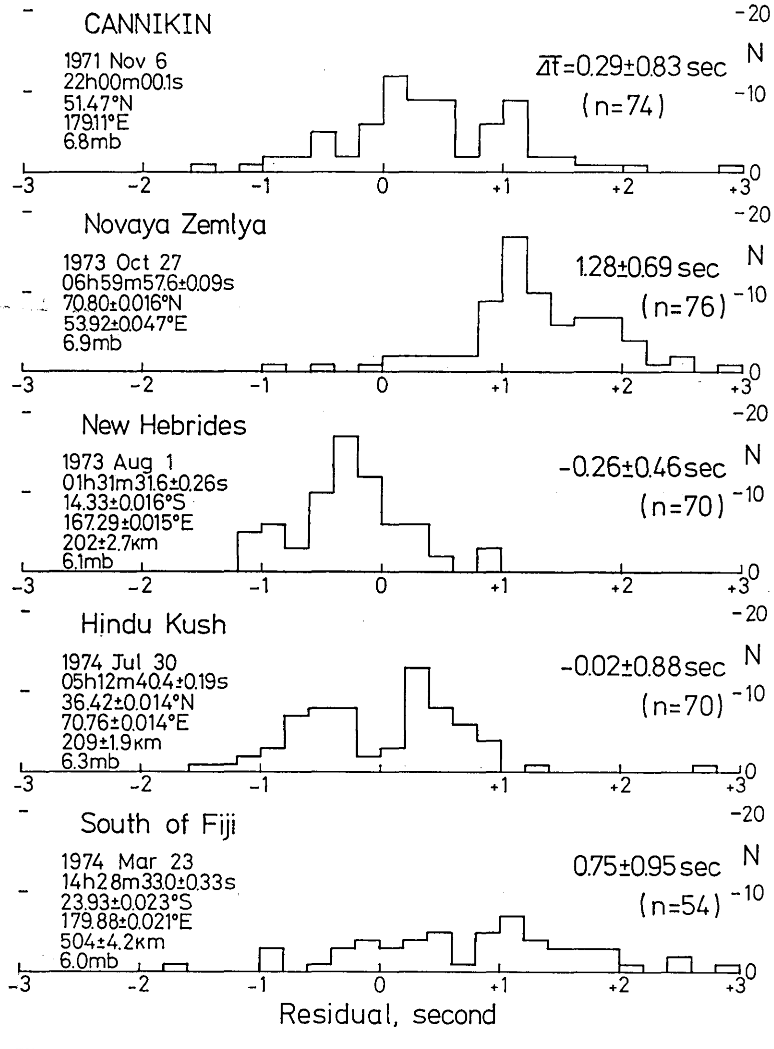

Fig. 3. Histograms of the teleseismic residuals for individual earthquakes observed in Japan, (a) the CANNIKIN explosion, (b) an explosion at Novaya Zemlya, (c) an intermediate-depth earthquake which occurred below the New Hebrides, (d) an intermediate-depth earthquake which occurred below Hindu Kush, and (e) a deep-focus earthquake which occurred below South of Fiji. The mean and standard deviations of teleseismic residuals are shown with the data number.

LOMNITZ (1971) showed a large variation of 2134 travel-time residuals for the Nevada nuclear explosions with the standard deviation of $\sigma=2.1$ seconds. HERRIN *et al.* (1968b) showed $\sigma=1.2$ second for the surface focus earthquakes, and SENGUPTA and JULIAN (1976) obtained $\sigma=0.6$ second for the deep earthquakes.

The existence of a high velocity zone in the upper mantle with a contrast of several percent is derived from the travel-time residuals of teleseismic and nearby-deep earthquakes (KATSUMATA, 1960; UTSU, 1967, 1971, 1975; KANAMORI, 1968; DAVIES and MCKENZIE, 1969; MITRONOVAS and ISACKS, 1971; TADA, 1972; NAGAMUNE, 1973b; ICHIKAWA, 1969). Even after removing the mean residuals for individual earthquakes, the large effects of regional variation of the crust and upper mantle structure beneath the Japanese Islands are left as a wide variation of residuals.

Fig. 3 represents examples of the histograms of teleseismic residuals. Separations into earlier and later arrivals are observed for the CANNIKIN explosion (top) and an intermediate-depth earthquake in Hindu Kush (fourth). Such separations are caused by the regional variation of the crust and upper mantle structure beneath the Japanese Islands. However, a large shift of the residuals (+1.2 sec) for an explosion in Novaya Zemlya (second) is due to the erroneous focal coordinates and origin time which are determined seismologically.

Fig. 4 shows the geographical distributions of teleseimic residuals classified according to the departure from the mean values. Earlier and later arrivals relative to the mean are shown by open and solid symbols, respectively. Lines of equal distance from the epicenters (or detonations) are also shown. A predominant feature is the regional variation of teleseismic residuals, rather than the dependence on distance. Earlier arrivals are observed on the Pacific side of Northeast Japan and later arrivals are seen in Southwest Japan. Earlier arrivals in the Chugoku region are also observed, and the existence of a high velocity zone beneath the Chugoku region is expected.

Fig. 5 represents the composite travel-time residuals from the Jeffreys-Bullen times. Systematic differences of the recent observations are also shown by lines (CARDER *et al.*, 1966; SENGUPTA and JULIAN, 1976). Lines of "1968-JB+3.0" denote the times compensated by 3 seconds for the differences of the 1968 P times (HERRIN *et al.*, 1968a) from the Jeffreys-Bullen times. A trend of increasing with distance for the CANNIKIN explosion (Fig. 5a) has also been indicated by NAGAMUNE (1973a). Four extremely earlier arrivals (squares and triangles in Fig. 4b) around $\Delta=50°$ for the explosion in Navaya Zemlya are observed at stations in the Hokkaido region and also at $\Delta=53$ to $56°$ in the Chugoku-Shikoku region. A small variation of residuals is observed for the intermediate-depth

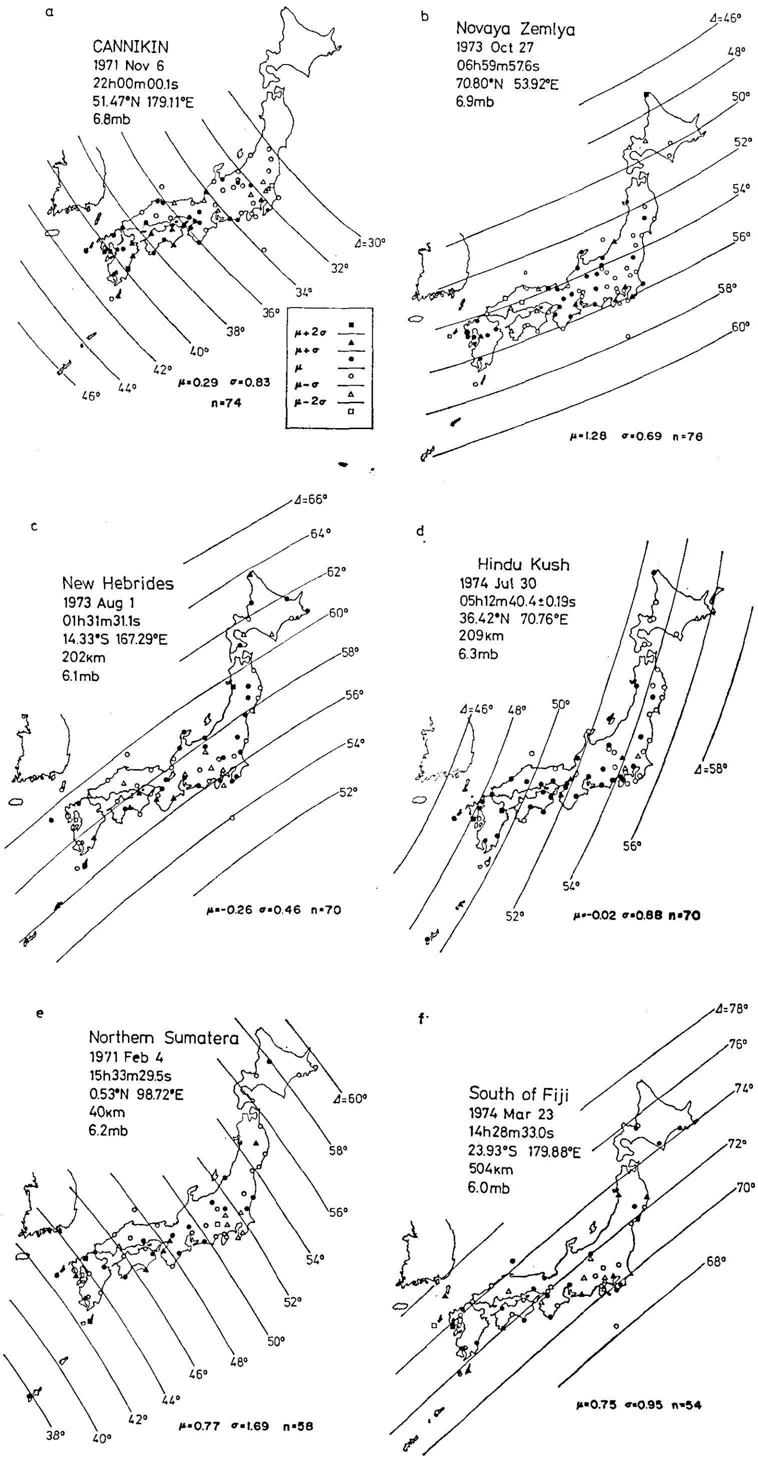
a
CANNIKIN
1971 Nov 6
22h00m00.1s
51.47°N 179.11°E
6.8mb
Δ=30°
32°
34°
36°
38°
40°
42°
44°
46°
μ+2σ ■
μ+σ ▲
μ ●
μ−σ ○
μ−2σ △
□
μ=0.29 σ=0.83
n=74
b
Novaya Zemlya
1973 Oct 27
06h59m57.6s
70.80°N 53.92°E
6.9mb
Δ=46°
48°
50°
52°
54°
56°
58°
60°
μ=1.28 σ=0.69 n=76
c
New Hebrides
1973 Aug 1
01h31m31.1s
14.33°S 167.29°E
202km
6.1mb
Δ=66°
64°
62°
60°
58°
56°
54°
52°
μ=−0.26 σ=0.46 n=70
d
Hindu Kush
1974 Jul 30
05h12m40.4±0.19s
36.42°N 70.76°E
209km
6.3mb
Δ=46°
48°
50°
52°
54°
56°
Δ=58°
μ=−0.02 σ=0.88 n=70
e
Northern Sumatera
1971 Feb 4
15h33m29.5s
0.53°N 98.72°E
40km
6.2mb
Δ=60°
58°
56°
54°
52°
50°
48°
46°
44°
42°
40°
38°
μ=0.77 σ=1.69 n=58
f
South of Fiji
1974 Mar 23
14h28m33.0s
23.93°S 179.88°E
504km
6.0mb
Δ=78°
76°
74°
72°
70°
68°
μ=0.75 σ=0.95 n=54

Fig. 4. Geographical distributions of the teleseismic travel-time residuals for (a) the CANNIKIN explosion, (b) an explosion at Novaya Zemlya, (c) an intermediate-depth earthquake which occurred below the New Hebrides, (d) an intermediate-depth earthquake which occurred below Hindu Kush, (e) a shallow earthquake which occurred at Northern Sumatera, and (f) a deep-focus earthquake which occurred below South of Fiji. Residuals are represented by different symbols according to the departure from the mean residuals. Open and solid symbols denote earlier and later arrivals, respectively. Equal distances from epicenters are also shown by the curved lines.

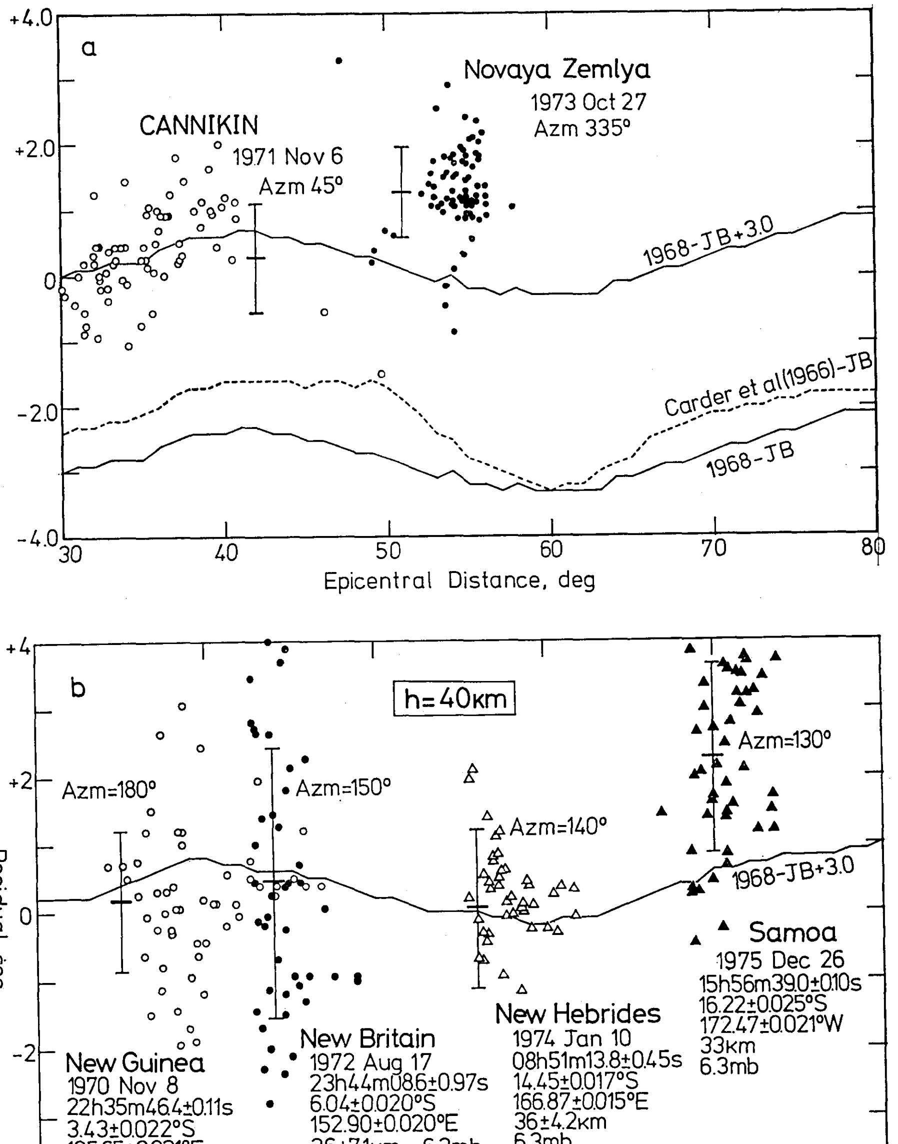

Fig. 5 (to be continued).

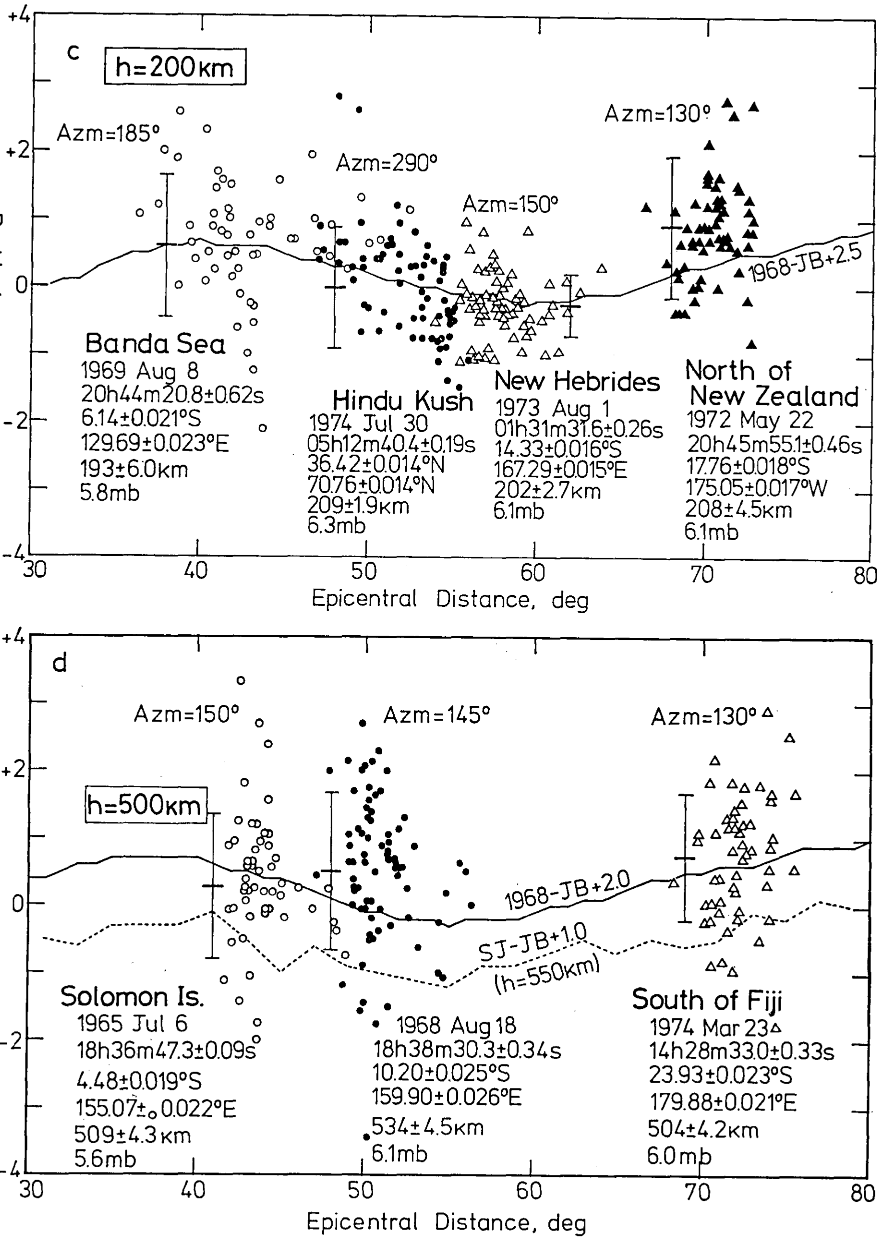

Fig. 5. Composite travel times for (a) two explosions, the CANNIKIN at the Aleutian Islands (open circles), and the 1973 event at Novaya Zemlya (solid circles), (b) four shallow earthquakes, (h=40 km), (c) three intermediate-depth earthquakes, and (d) three deep-focus earthquakes. Systematic differences from the Jeffreys-Bullen travel times are also shown by "1968-JB", "1968-JB+3.0" and so on. The values "AZM" mean azimuths of seismic waves coming to the station.

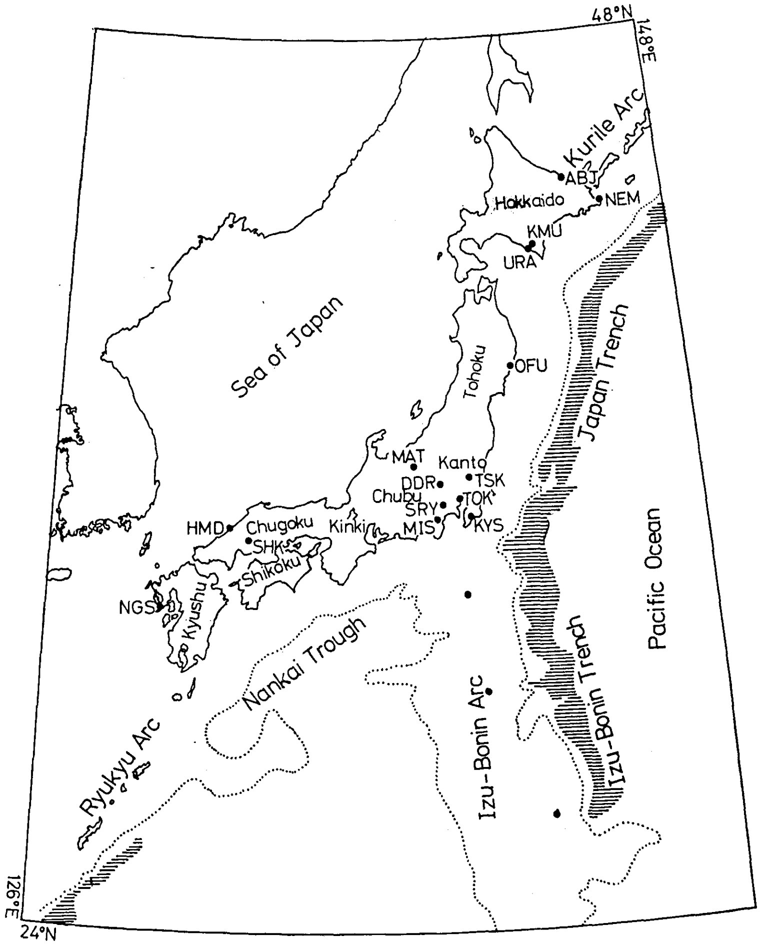

Fig. 6. Location map of the observational stations quoted in this paper.

earthquakes (h=200 km) (Fig. 5c) and shows the systematic undulation, accompanying earlier arrivals around $\Delta=60°$ and later ones around $\Delta=40°$ and 80°.

The mean and standard deviation of travel-time residuals for individual earthquakes are listed in the last column of Appendix. The mean residuals of these 223 earthquakes range from -0.5 to $+1.5$ seconds, and the standard deviations are as large as 2.0 seconds. In this paper relative residuals will be used by substracting the mean residuals for the individial earthquakes.

4. Station anomalies of the teleseismic travel times in Japan

Only a few studies of teleseismic travel-time residuals have been

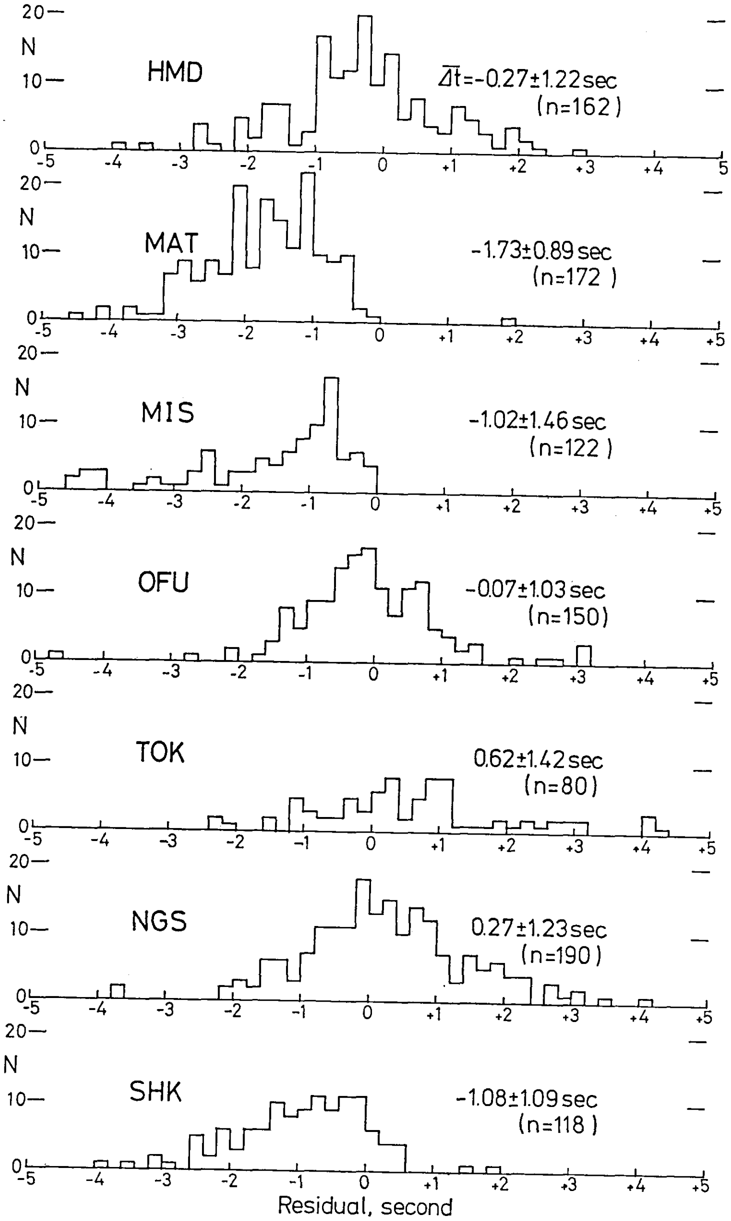

Fig. 7. Histograms of the teleseismic travel-time residuals at each station, (a) Hamada (HMD), (b) Matsushiro (MAT), (c) Mishima (MIS), (d) Ofunato (OFU), (e) Tokyo (TOK), (f) Nagasaki (NAG) and (g) Shiraki (SHK). The mean and standard deviations of the teleseimic residuals are also shown.

made in Japan. Azimuthal dependence was observed for the slowness anomalies at the Uppsala array stations (KULHANEK and BROWN, 1974).

However, the earth's structure derived from the apparent velocity (KANAMORI, 1967; FUKAO, 1977) and the temporal variation of velocities around the source regions could not be accomplished without clarifying the causes of teleseismic travel-time anomalies at each station.

In Fig. 6 the location of stations discussed in this study is displayed. Fig. 7 shows examples of the histograms of teleseismic residuals observed for individual stations. Some stations with less sensitive seismographs of the Japan Meteorological Agency (JMA) tend to show a large variation in the residuals. A majority of the stations have the mean residuals ranging from −0.5 to +1.0 second and standard deviations of up to 2.0 seconds.

The table summarizes the station anomalies of teleseismic residuals at 124 stations in Japan, together with the number of observations, mean residual, standard deviation, and amplitude and phase shift of sinusoidal variation with azimuth (measured clockwise). At each station an extremely large number of earthquakes was observed compared to the previous studies for nearby deep and shallow earthquakes.

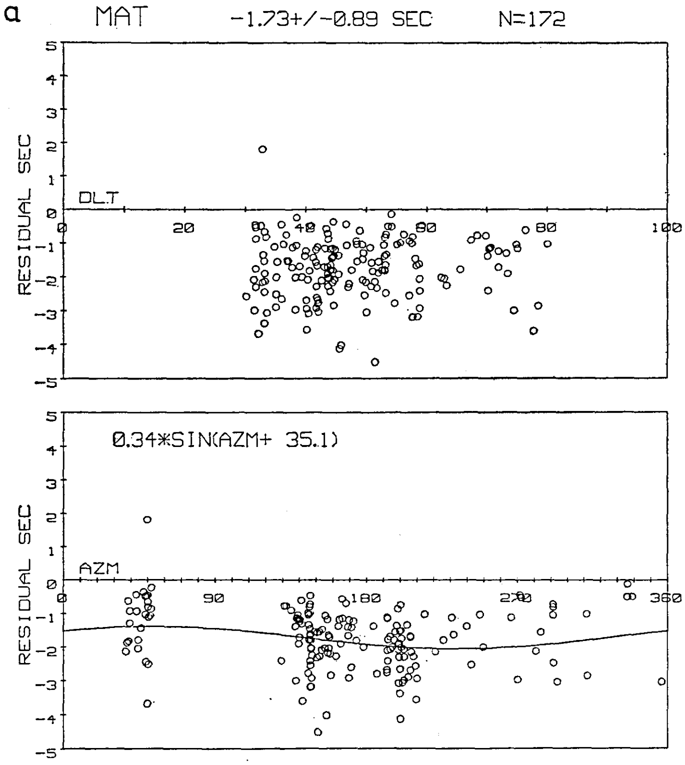

Fig. 8 (to be continued).

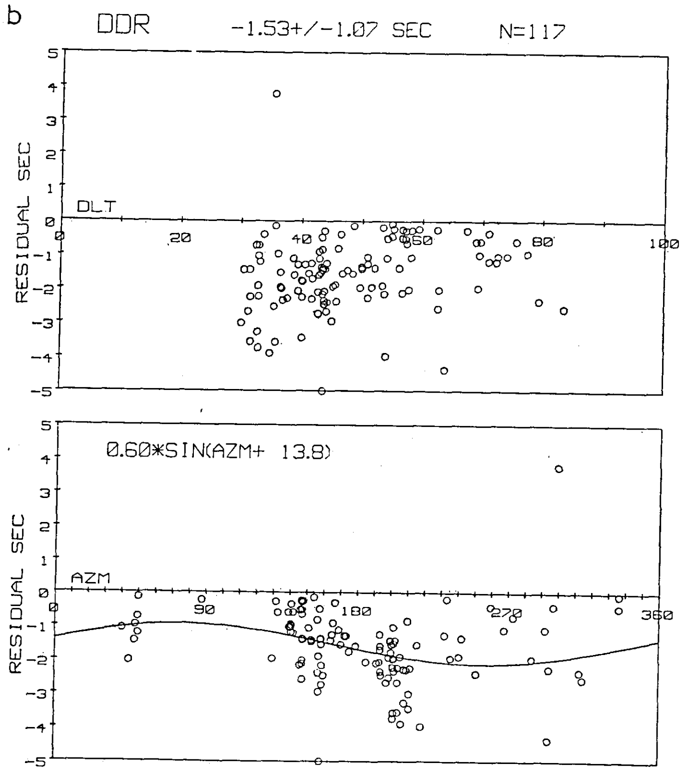

Fig. 8. Variation of the teleseismic residuals with distance (DLT, top) and azimuth (AZM, bottom), at stations (a) Matsushiro (MAT), (b) Dodaira (DDR). Lines of sinusoidal variation with azimuth are fitted by the least-squares method by reducing the mean residuals (shown in the uppermost part).

Fig. 8 shows the variations of teleseismic residuals with epicentral distance and azimuth of approach for stations Matsushiro (MAT) and Dodaira (DDR). No clear tendencies are observed in the variation with epicentral distance, but the azimuthal dependence of teleseismic residuals can be recognized. A sinusoidal variation of teleseismic residuals with azimuth of approach (line and formula in the bottom of Fig. 8) can be obtained by the least-squares method. Thus, some parts of teleseismic residuals can be interpreted as the azimuthal variation.

Fig. 9 shows the running averages of teleseismic residuals for the epicentral distance and azimuth of approach, with the standard deviation shown by error bars. Averaging is made over the window of 10° for distance and 15° for azimuths. For the station Abashiri (ABJ) in Hokkaido, earlier arrivals are observed for azimuths of approach around $\phi=80°$, though the Pacific lithospheric plate of high velocity descends to the northwest. The decrease of teleseismic residuals with distance around

Table. Mean (μ) and standard deviation (σ), azimuthal term (amplitude, a and phase, ϕ) of teleseismic residuals at each station. N means the number of observations.

Sta.	N	μ/σ	Azm. term a ϕ
ABJ	62	0.16±1.45	0.77/195.0
ABU	116	−0.67±1.24	0.29/252.1
AIK	105	−0.35±1.07	0.30/142.9
AJI	49	−0.80±1.11	0.32/ 85.4
AKI	109	0.72±1.22	0.21/ 98.8
AOM	38	0.53±1.67	0.57/341.1
ASA	60	0.48±1.07	0.36/118.4
ASJ	8	0.34±0.83	0.51/256.7
ASZ	107	0.60±1.33	0.34/239.3
CHJ	57	0.18±1.75	0.15/140.0
CHO	27	−0.24±1.29	0.04/168.2
DDR	117	−1.53±1.07	0.60/ 13.8
FKJ	86	0.67±1.42	0.18/194.4
FKK	152	0.11±1.25	0.08/199.2
FKS	95	0.25±1.29	0.19/260.7
FUK	26	0.66±1.01	0.36/312.4
FUN	68	0.53±1.43	0.28/ 45.7
GIF	54	0.54±1.31	0.09/317.1
HAC	115	−0.58±1.09	0.11/ 93.7
HAK	122	−0.59±1.13	0.33/214.6
HIK	98	1.34±1.31	0.36/184.5
HIM	33	1.12±1.07	0.23/315.0
HIR	98	0.02±1.32	0.10/322.8
HJJ	35	0.39±1.87	0.93/182.8
HMD	162	−0.27±1.22	0.17/ 18.0
HMM	76	0.31±0.96	0.34/356.2
HOJ	6	0.25±1.41	1.31/174.9
IID	75	−0.08±1.03	0.14/271.0
ISI	37	0.98±1.16	0.35/ 9.9
ISN	126	−0.34±1.10	0.16/222.8
IZU	23	0.45±0.91	0.28/199.0
KAG	121	1.08±1.52	0.07/230.1
KAK	8	−1.58±1.26	0.79/ 55.9
KAM	49	0.90±1.40	0.52/ 32.9
KAN	66	0.74±1.18	0.19/ 84.8
KMG	103	−0.12±1.53	0.40/306.9
KMU	96	−0.19±1.00	0.20/261.9
KOB	16	1.09±1.71	0.15/ 43.7
KOC	52	0.53±1.14	0.24/242.2
KOF	140	−0.08±1.27	0.39/ 49.9
KUM	89	0.67±1.36	0.20/ 87.5
KUS	102	−0.50±1.36	0.47/246.2
KYO	154	0.16±1.18	0.26/222.4
KYS	92	−0.08±1.68	1.14/ 16.7
MAE	66	−0.17±1.57	0.32/327.0
MAI	11	0.74±1.99	0.47/ 5.9
MAT	172	−1.73±0.89	0.34/ 35.1
MIS	122	−1.02±1.46	0.14/ 36.2
MIT	55	−0.26±1.20	0.04/172.0
MIY	40	0.02±0.84	0.26/131.7
MIZ	104	0.62±1.36	0.28/ 31.6
MRK	136	−0.42±1.31	0.27/236.8
MRR	15	−0.77±1.20	0.25/111.9
MRT	128	0.63±1.19	0.27/201.1
MTM	51	0.35±1.40	0.29/357.4
MTS	24	0.79±1.50	0.28/155.6
MTY	107	0.76±1.38	0.24/242.1
MYZ	130	0.65±1.43	0.46/122.6
NAG	132	0.13±1.05	0.33/194.7
NAH	57	0.83±1.22	0.52/233.2
NAR	21	0.60±0.85	0.59/348.1
NEM	82	−1.12±1.01	0.30/106.0
NGN	161	0.15±1.33	0.15/ 73.6
NGS	190	0.27±1.23	0.38/346.6
NII	57	0.85±1.44	0.08/133.0
NOB	13	0.22±1.21	0.32/173.7
OBI	13	0.56±1.12	0.60/101.4
OFU	150	−0.07±1.03	0.11/215.0
OIC	52	−1.25±1.10	0.84/ 24.1
OIS	41	−1.17±1.05	0.29/180.8
OIT	83	1.10±1.70	0.23/ 14.7
OKA	71	−0.32±0.95	0.21/351.4
OMA	38	0.42±1.67	0.10/ 70.0
ONA	106	0.37±1.34	0.32/ 11.9
OSA	125	0.26±1.16	0.20/229.4
OSH	66	−0.45±1.46	0.32/278.8
OWA	112	−0.14±1.39	0.12/329.6
OYM	38	−1.22±0.82	0.62/ 49.5
RMJ	15	0.10±0.91	0.51/ 52.8
SAG	63	1.48±1.89	0.23/242.7
SAI	121	−0.18±1.47	0.17/236.2
SAK	26	1.26±1.00	0.64/231.6
SAP	111	−0.66±1.22	0.36/217.1
SEN	118	−0.22±0.85	0.17/193.8
SHJ	117	0.08±1.60	0.16/188.7
SHK	118	−1.08±1.09	0.25/ 90.6
SHN	70	0.15±1.17	0.62/184.7
SHR	34	−0.38±1.02	0.15/193.9
SHZ	137	0.02±1.35	0.41/311.1
SRY	100	−1.88±1.09	0.83/ 30.4
SUM	92	−0.25±1.21	0.19/ 98.9
SUT	7	−0.24±0.94	0.62/173.6
TAJ	52	1.42±1.38	0.80/230.8
TKD	53	0.39±1.58	0.12/244.7
TKM	142	0.17±1.14	0.21/246.4
TKS	42	1.08±1.27	0.10/286.1
TKY	21	−0.05±1.70	0.88/325.5
TMS	59	−0.14±1.55	0.18/ 80.4
TOK	80	0.62±1.42	0.43/ 50.7
TOR	34	−0.34±1.97	0.69/278.4
TOT	27	−0.40±1.06	0.60/333.0
TOY	32	−0.01±1.08	0.28/210.6
TSK	110	−1.72±1.26	1.25/ 5.4
TSR	24	−0.12±0.97	0.72/197.2
TSS	12	2.07±1.31	1.03/148.1
TSU	28	1.38±1.07	0.34/200.3
TYK	144	0.38±1.32	0.30/239.7
UNZ	5	−0.10±1.87	1.73/ 65.6
URA	94	1.00±0.97	0.27/221.2
URS	31	−0.24±0.99	0.27/173.3
UTS	42	−0.79±1.19	0.40/ 39.4
UWA	10	0.50±1.02	0.97/161.7
WAJ	60	0.51±1.14	0.30/ 1.6
WAK	45	0.86±1.11	0.51/333.4
WKU	19	0.03±0.85	0.50/188.5
WKY	59	0.99±1.48	0.40/208.3
YAM	59	−0.23±0.80	0.09/226.0
YKS	54	−0.11±1.39	0.68/173.5
YOK	41	0.48±1.61	0.43/ 15.5
YON	24	−0.06±0.95	0.22/ 83.0
NZJ	12	1.09±1.42	0.99/202.0
TTZ	8	−1.26±1.04	1.08/ 21.2
HSS	27	−0.49±1.66	0.79/242.1
OIW	88	−0.29±1.00	0.32/ 70.2

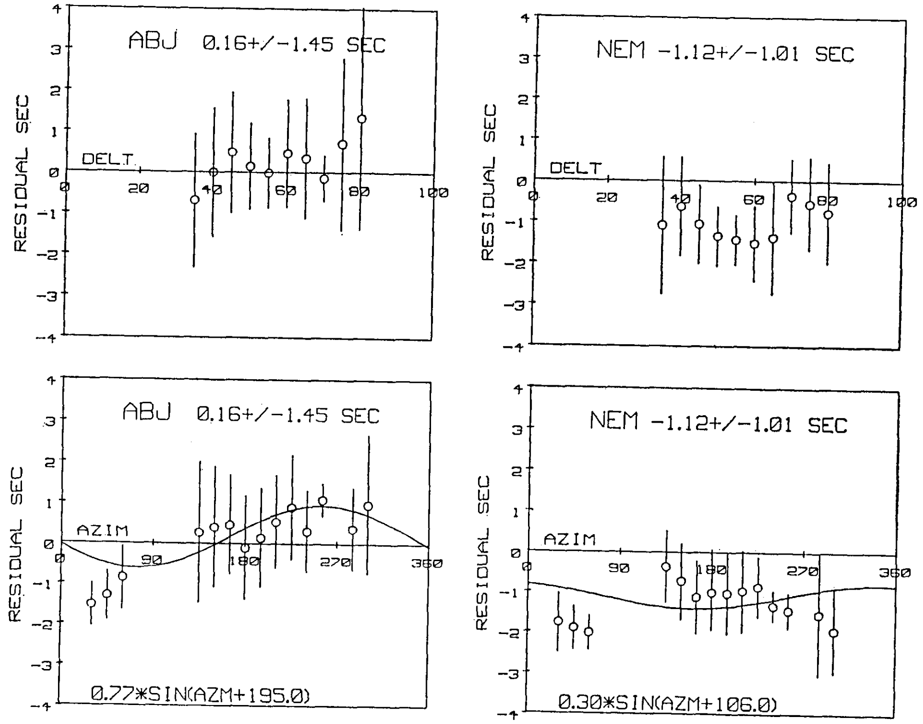

Fig. 9. Variation of the running average (circles) and standard deviation (bars) of teleseismic residuals with distance and azimuth at stations, (a) Abashiri (ABJ) and (b) Nemuro (NEM). Sinusoidal curves are fitted to the raw residual data.

$\Delta=60°$, observed at the station Nemuro (NEM), corresponds to the systematically earlier arrivals shown by the recent studies.

Fig. 10 shows the geographical distribution of mean residuals at each station. The mean and standard deviations for all stations equal to $\mu=+0.10$ and $\sigma=0.73$ seconds. Stations are represented by open and solid symbols for earlier and later arrival classified according to departure from the mean value. Stations on the Pacific side of Northeast Japan show earlier arrivals, and later arrivals are observed in Southwest Japan and on the Japan Sea side of Northeast Japan. Exceptionally earlier arrivals in the Chubu and Chugoku region in Southwest Japan are another feature, although a thicker crust underlays in the Chubu region (KANAMORI, 1963; KAMINUMA and AKI, 1963; KAMINUMA, 1964; KURITA, 1970) and the Chugoku region is located in a high heat-flow region (UYEDA, 1972).

Geographical distribution of station anomalies of the teleseismic residuals has a common feature with some geophysical implications, such as the Bouguer gravity anomaly, the heat-flow and the decaying factor of

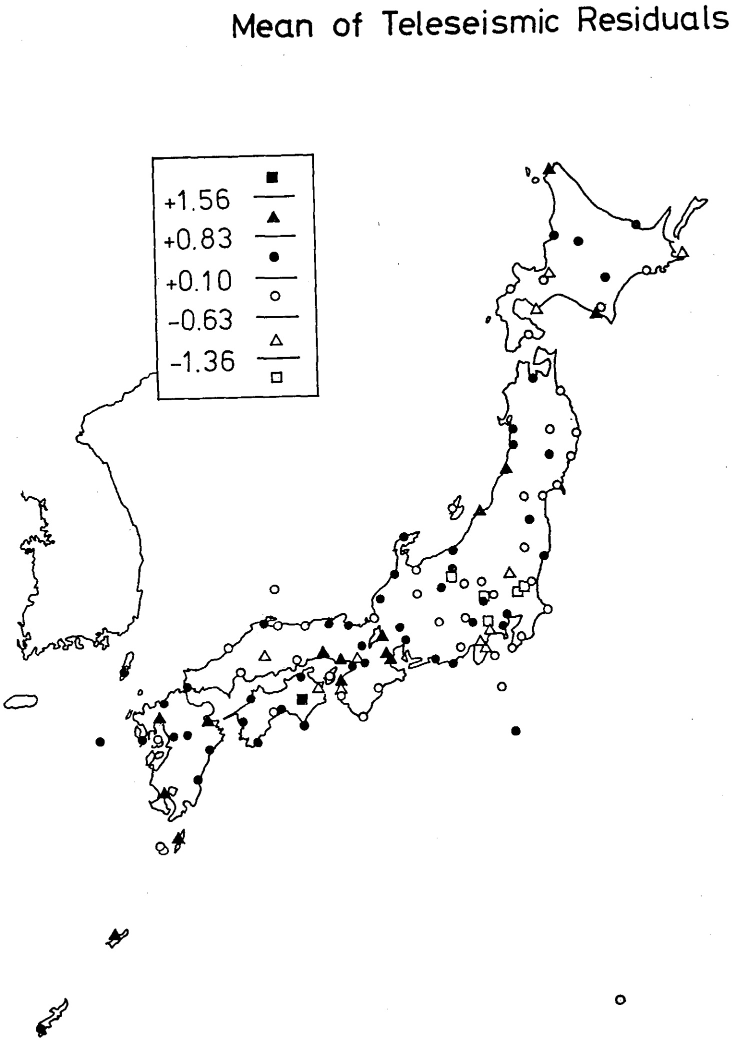

Fig. 10. Geographical distribution of the mean residuals of the teleseismic travel times. Open and solid symbols show earlier and later arrivals, which being represented by the different symbols according to the amount of the departure from the mean residuals.

seismic amplitude. From such geographical correlation earlier arrivals on the Pacific side of Northeast Japan can be interpreted by the existence of a high velocity zone associated with the descending Pacific plate.

The sources of station anomalies can be elucidated by the regional variation of the crust or upper mantle structure. In Fig. 11 the mean residuals of the teleseismic travel times are compared with the residuals and station corrections obtained in the previous studies. Fig. 11a repre-

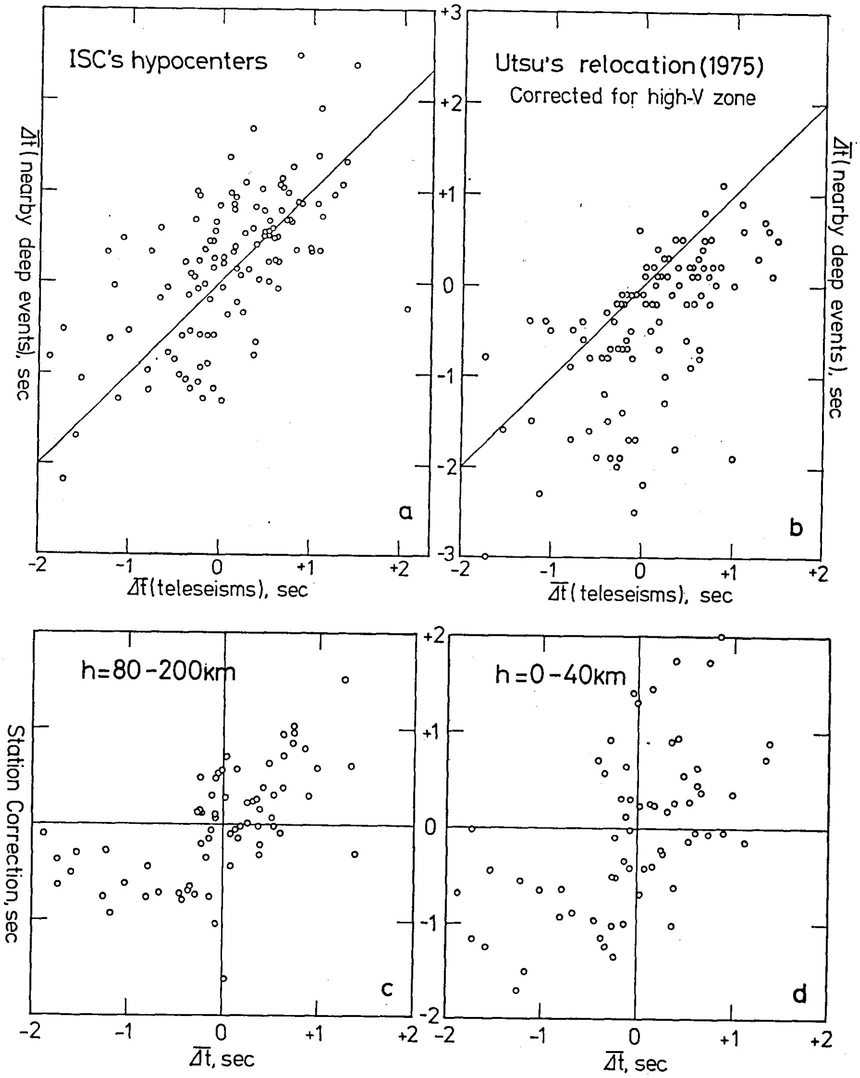

Fig. 11. Comparison of the mean residuals of teleseismic travel times at each station, with (a) the mean residuals for the nearby-deep earthquakes which occurred around Japan (Maki, 1977), (b) the mean residuals for the relocated ones by Utsu (1975), which are obtained by taking account of the velocity contrast within and around the deep seismic zone, (c) the station corrections of the travel times for the mantle earthquakes (h=80-200 km) in the Kanto region, determined by the JHD method (MAKI, 1979), (d) station corrections for the crustal earthquakes ($h \leqq 40$ km) in the Kanto region determined by the JHD method (MAKI, 1979).

sents comparison of the mean residuals at each station for the teleseismic travel times with those for nearby-deep earthquakes (MAKI, 1977). These hypocenters are free from the anomalous structure of the upper mantle

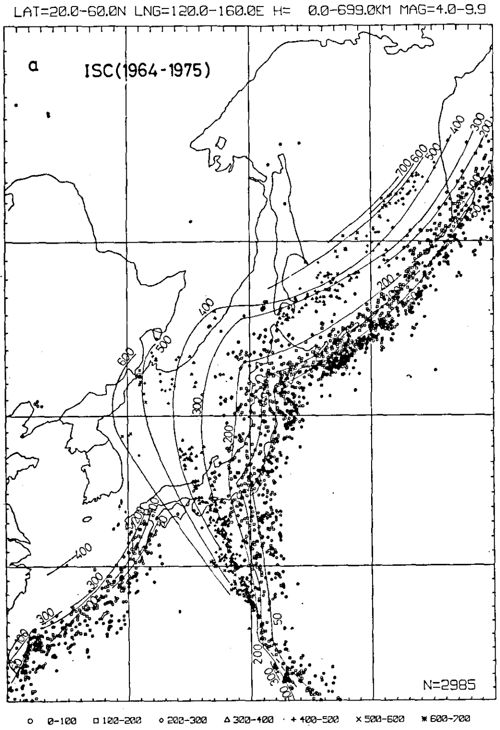

Fig. 12a. Depth contours of hypocenters from the ISC's Historical File during the period from 1964 to 1975. Epicenters of earthquakes with magnitudes of 4.0 or greater for earthquakes deeper than 100 km, and earthquakes with magnitudes of 5.0 or greater with depths shallower than 100 km, located by using 10 or more stations.

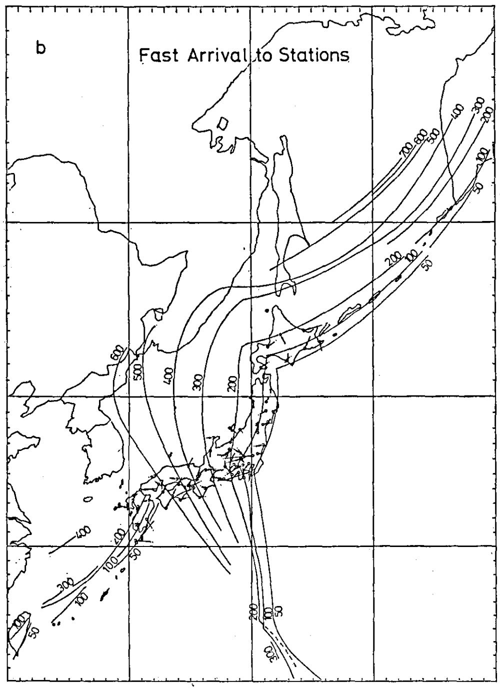

Fig. 12b. Direction of approach of the earliest arrivals which is obtained from the azimuthal variation of residuals. Lengths of the arrows show amplitude of the sinusoidal variation with azimuth.

near the sources because the hypocenters are determined mainly by distant stations in the world. These teleseismic residuals are then affected by the anomalous structure of the upper mantle rather than by the near-source anomaly. Fig. 11b shows the comparison of mean residual at each station for 47 nearby-deep earthquakes, located by taking account of the velocity contrasts within and around the deep seismic zone (UTSU, 1975). From these comparisons most parts of the station anomalies for teleseismic travel times in the pesent study are caused by the anomalous structure of the upper mantle near stations.

The mean residuals of teleseismic travel times are also compared with the station corrections determined by the joint hypocenter determination (JHD) method for the mantle earthquakes (Fig. 11c) and crustal earthquakes (Fig. 11d) in the Kanto region (MAKI, 1979). A better cor-

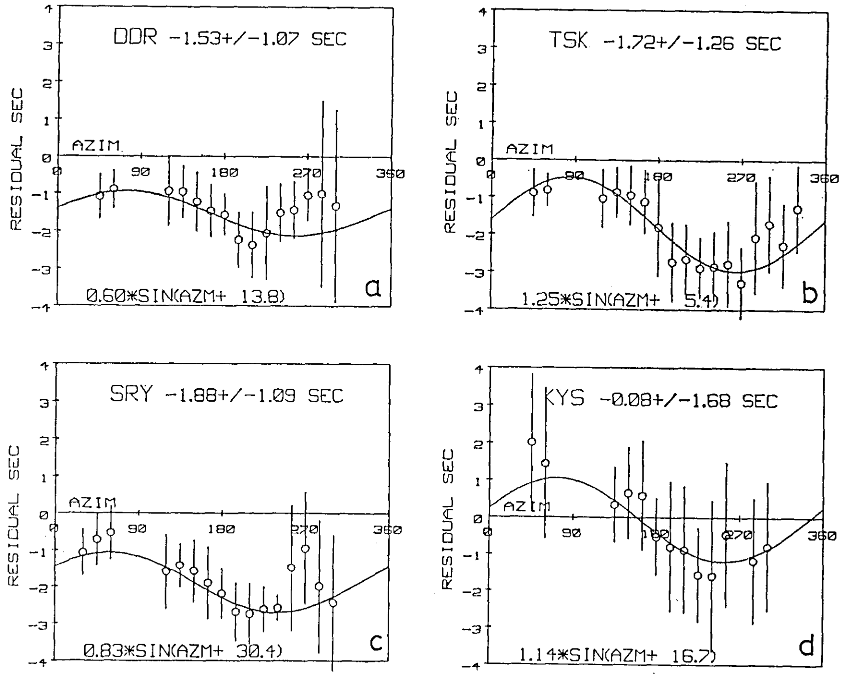

Fig. 13. Azimuthal variation of the running averages of teleseismic travel-time residuals at high-sensitivity stations in the Kanto region, (a) Dodaira (DDR), (b) Tsukuba (TSK), (c) Shiroyama (SRY) and Kiyosumi (KYS). Sinusoidal curves are fitted to raw data.

relation is observed for the mantle earthquakes. A large scatter observed for the crustal earthquake is caused by the local variation in the crustal structure. A tendency to separate into two groups of stations with earlier and later arrivals is observed in the relation to the station correction for the mantle earthquakes.

The amplitude of sinusoidal variation of teleseismic residuals with azimuth is less than 0.4 seconds at most stations. From the frequency distribution in azimuth intervals of 30° predominent phases of the sinusoidal variation with azimuth are separated into two groups around $\phi=0°$ and 210°. Thus earliest arrivals are observed for two directions, or the northwest and southeast. These azimuths of earlier and later arrivals will be compared with the features of the deep seismic zone of the high velocity. Fig. 12a represents the epicenters by the ISC in and around the Japanese Islands during the period from 1964 to 1975. The depth contours are smoothly drawn on the epicenter map for every 100 km of focal depth. In Fig. 12b the azimuths of approach with the earliest arrival at each station (shown by arrows) are compared with the depth contours. Only stations with an amplitude larger than 0.4 sec are shown. The length of arrows means the amplitude of sinusoidal variation with

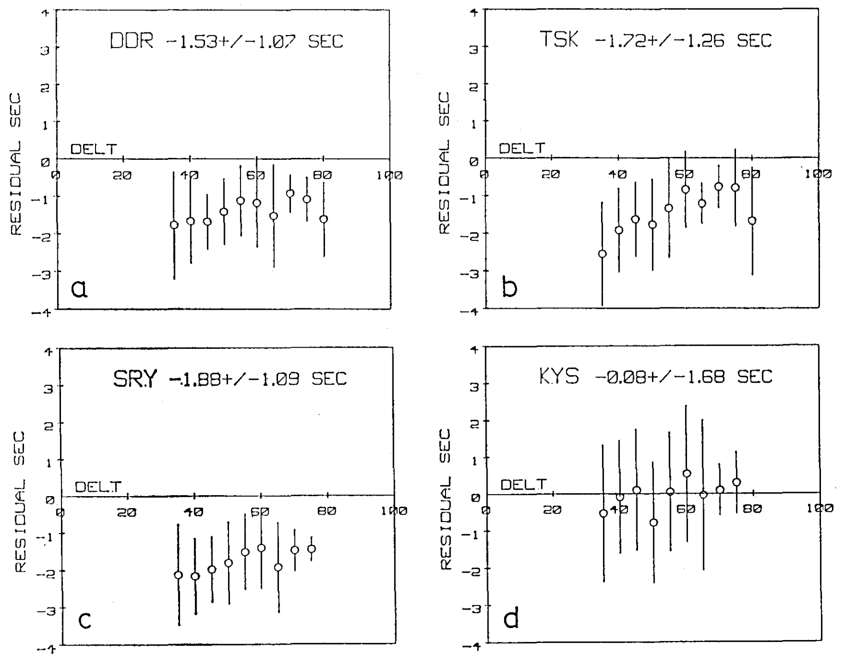

Fig. 14. Distance variation of the running averages of teleseismic travel-time residuals at the high-sensitivity stations in the Kanto region, (a) Dodaira (DDR), (b) Tsukuba (TSK), (c) Shiroyama (SRY) and Kiyosumi (KYS).

azimuth. Complicated patterns of direction of earliest arrivals in relation to the strike or dipping direction of the deep seismic zone are observed. The direction of the earliest arrival at Kushiro (KUS) in Hokkaido is parallel to the strike of the deep seismic zone. Such complicated patterns for the earliest arrivals are due to the nearly vertical incidences to the deep seismic zone.

The high-sensitivity stations in the Kanto gegion have a large amplitude of the sinusoidal variation with azimuth of up to 1.2 seconds, and they have the earliest arrivals from the west and the latest arrivals from the east. Fig. 13 shows azimuthal variations of teleseismic residuals at the stations of the Dodaira Micro-earthquake Observatory. Variations of teleseismic travel-time residuals with distance are also shown in Fig. 14.

Fig. 15 gives a rough estimation of time differences for paths coming from the west and the east. The high velocity zone is formed at the deep seismic zone along the section connecting the points (135°E, 34°N) and (144°E, 37°N). The focal coordinates were sorted out of the Historical File of the ISC for the period from 1964 to 1975. Velocities of 8.2 km/sec and 7.7 km/sec are assumed for the high velocity zone and

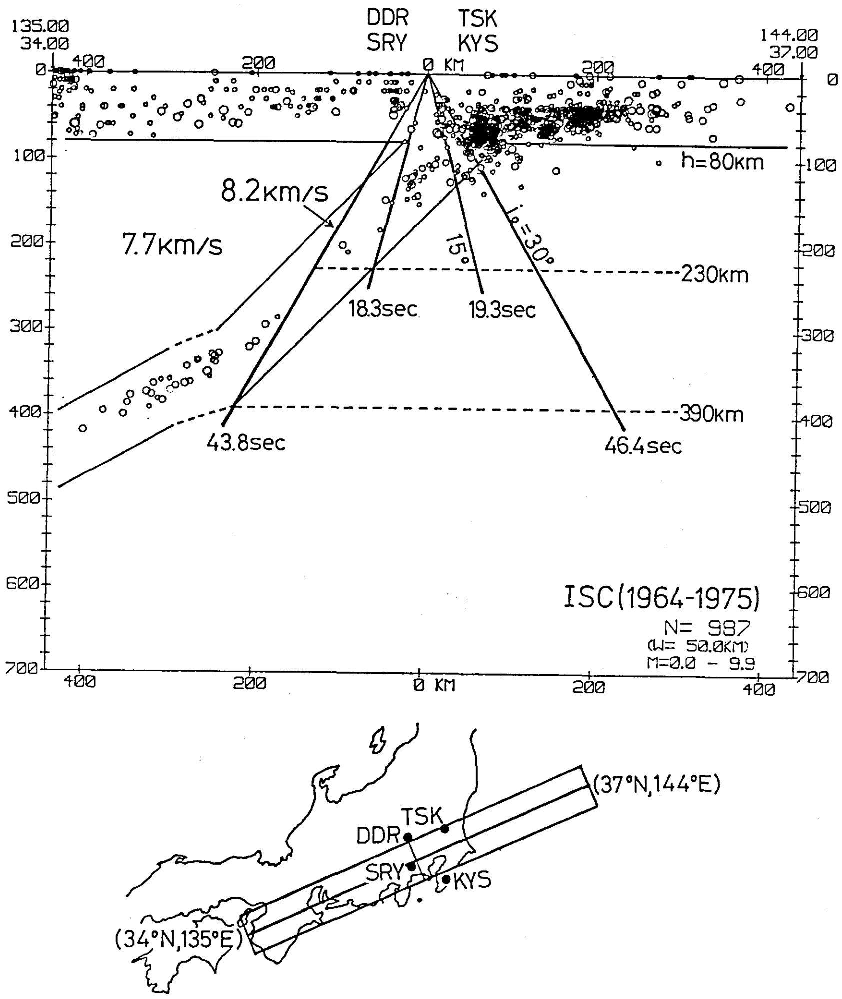

Fig. 15. Comparison of the travel times through paths with earlier and later arrivals in the Kanto region. Vertical distribution of hypocenters (ISC's hypocenters during the period from 1964 to 1975) is shown along a section passing two points A (34°N, 135°E) and B (37°N, 144°E), within the width of 50 km on the both sides shown in the inset. Heavy lines show paths incident to the central point, '0', with the angle of $i_0=15°$ and 30°. Times travelling along these paths are obtained by assuming a velocity of 8.2 km/sec and 7.7 km/sec within and around the deep seismic zone, respectively.

surrounding mantle (UTSU, 1967).

Differences of travel times along paths which are schematically approximated by thick lines are estimated as $\Delta t=1.0$ sec for the incident angle of $i_0=15°$, and $\Delta t=2.6$ sec for $i_0=30°$. Even such a rough estimate satisfies the observed time differences between the earliest and latest arrivals. Thus the station anomalies observed in the Kanto region can be interpreted by the anomalous structure in the upper mantle besides the crust.

5. Geographical implications related to the travel-time anomaly

The station anomalies of teleseismic travel times have been explained by the regional and lateral variations of the crust or upper mantle structure beneath stations. What parts of the crust and upper mantle produce the station anomaly cannot be uniquely solved.

NUTTLI and BOLT (1969) showed that the teleseismic residuals observed in California (BOLT and NUTTLI, 1966) could not be explained merely by the variation of crustal structure (thickness, velocity and dipping of interfaces). They interpreted these residuals to be caused by the regional variation of the low-velocity zone in the upper mantle beneath California, but recently teleseismic travel-time anomalies have been explained by the existence of an fossil lithospheric slab with high velocity (KOIZUMI *et al.* 1973; SOLOMON and BUTLER, 1974; RAIKES, 1976).

The physical implication of the travel time anomaly has been studied by correlating to some geophysical features (HALES and DOYLES, 1967). Travel-time anomalies in Japan will be compared with the regional variations of seismic activity, crustal structure, Bouguer gravity anomaly, heat-flow and decaying factor of seismic waves.

The effects of crustal structure on the travel-time anomaly are shown for the possible variation of travel times through the crust. MIKUMO (1966) proposed 27 possible models of the crustal structure in Japan, which are composed of a granitic layer ($v_1=5.50$ km/sec), a basaltic layer ($v_2=6.00\text{–}6.50$ km/sec), an intermediate layer ($v_3=7.50$ km/sec) and the uppermost mantle ($V_m=7.7\text{–}8.00$ km/sec). Vertical travel times through the common thickness of 50 km vary from 7.26 to 7.83 sec for these possible models, and the time difference reaches only 0.57 sec. KURITA (1969a, b, 1970) showed the azimuthal variation of crustal structure around stations Shiraki (SHK), Matsushiro (MAT) and Tsukuba (TSK) through the study of spectra of long-period body waves from distant earthquakes. The maximum difference of vertical travel times through the common paths for his structure of the crust reaches only $\Delta t=0.11$ sec (common thickness of $h=64$ km) for SHK, $\Delta t=0.14$ sec ($h=63$ km) for MAT and $\Delta t=0.34$ sec ($h=51$ km) for TSK.

Less correlation between the station anomaly and the crustal thickness and large azimuthal variation of teleseismic residuals are favourable for the opinion that the travel-time anomaly could not be explained merely by the regional variation of the crustal structrue. MARSHALL *et*

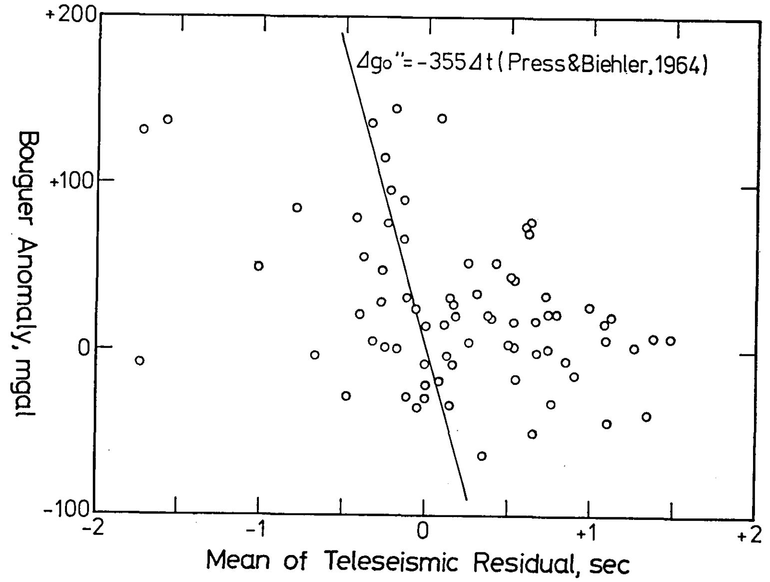

Fig. 16. Correlation of the Bouguer gravity anomaly to the mean residuals of teleseismic travel times. The straight line shows the relation given by PRESS and BIEHLER (1965) for California-Nevada region.

al. (1979) showed the negative correlation of the station anomaly with the Pn velocity around stations in the United States. A better correlation of the station anomaly has been obtained for the station corrections for the mantle earthquakes rather than for the crustal earthquakes.

The negative correlation of the station anomaly of travel times with the Bouguer gravity anomaly has been shown by PRESS and BIEHLER (1964), FAIRHEAD and REEVER (1977), UTSU (1975) and OKADA *et al.* (1979). Such a negative correlation is consistent with the experimental positive correlation of the velocity and density. In Fig. 16 the Bouguer gravity anomalies at each station are compared with the station anomalies of the teleseismic travel times, based on the table by the GEOGRAPHICAL SURVEY INSTITUTE (1944, 1957, 1964, 1965 and 1966). The relation presented by PRESS and BIEHLER (1964) is also shown by a line. The figure shows a tendency of separation into earlier and later arrivals rather than a simple negative linear relation. Such a separation is observed also in Fig. 11c, showing the relation between the station anomalies and station corrections for the mantle earthquakes.

Fig. 17 shows the variation of the Bouguer gravity anomaly with distance and azimuth around station Matsushiro (MAT). The data of the Bouguer gravity anomaly are taken from the HAGIWARA File (HAGIWARA, 1967), which are corrected for the terrestrial effects around the observa-

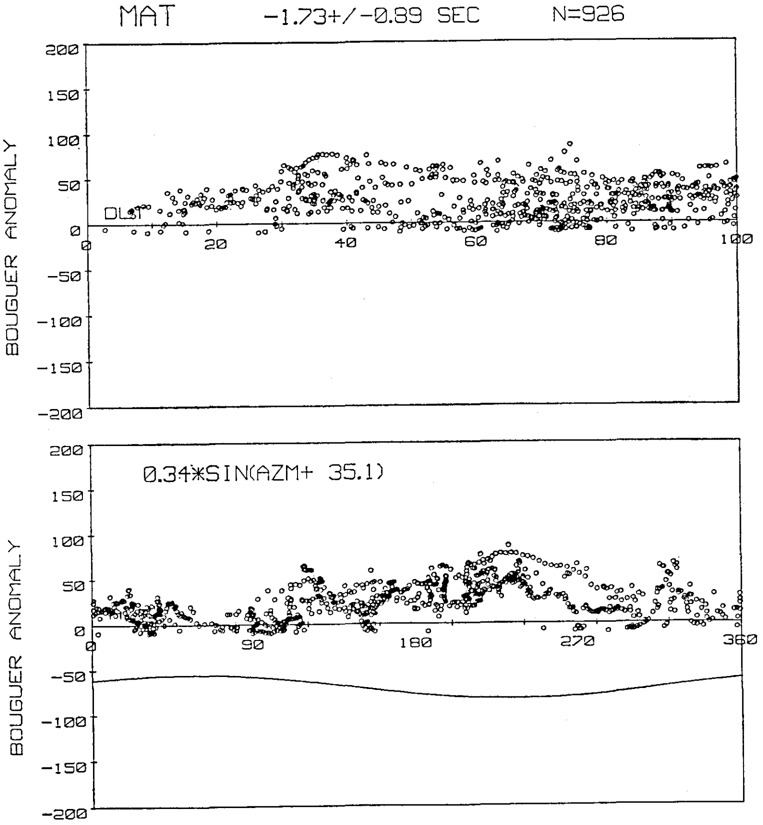

Fig. 17. Variation of the Bouguer gravity anomaly (after HAGIWARA, 1967) with distance and azimuth around station Matsushiro (MAT). A sinusoidal variation with azimuth is the one obtained for the teleseismic residuals (Fig. 9a).

tional locations. In Fig. 18 the azimuthal variations of running averages of the Bouguer gravity anomaly are compared with the teleseismic residuals. A negative correlation is observed for all azimuths around Matsushiro station but for some azimuths around Shiraki and Tsukuba. Such azimuthal correlations suggest that the lateral variation of the velocity around stations is consistent with the density variation.

McGINLEY and ANDERSON (1969) discussed the relation of seismic attenuation and Poisson's ratio by using the relative amplitude of the P and S waves observed at stations in the United States. For the stations with higher attenuation and higher Poisson's ratio, later arriavls were also observed. MARSHALL *et al.* (1979) studied the relation of magnitude correction to Pn velocity and attenuation around stations in the United States.

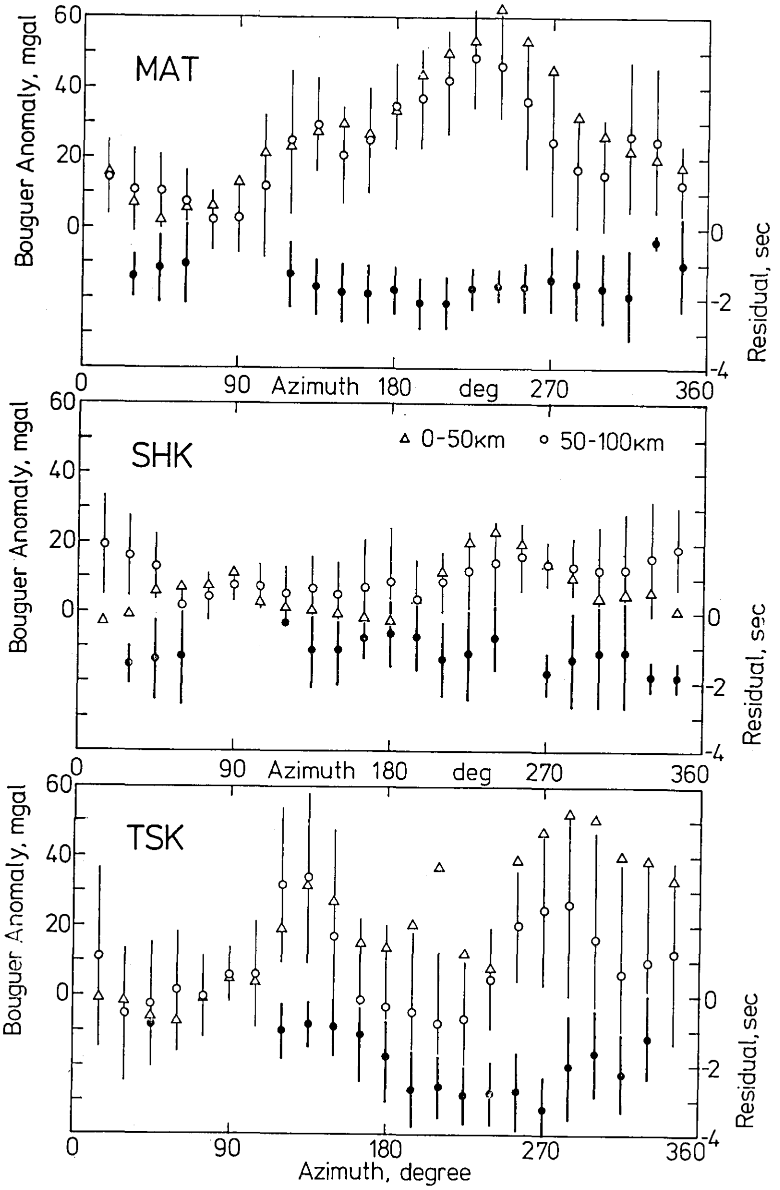

Fig. 18. Azimuthal variation of the running averages of the Bouguer gravity anomaly (open triangles and circles) and teleseismic residuals (solid circles) around Matsushiro (MAT), Shiraki (SHK) and Tsukuba (TSK). Gravity data are separated into two groups by distance, less than 50 km (triangles) and less than 100 km (open circles).

The regional variation of the decaying factor of maximum amplitude in formulae for determining the earthquake magnitude are shown by

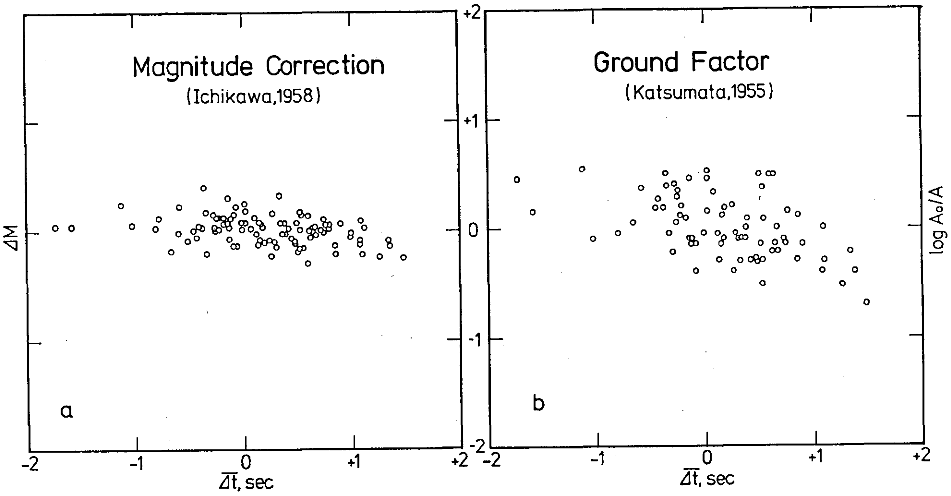

Fig. 19. Comparison of the magnitude correction by ICHIKAWA (1958) and the ground factor by KATSUMATA (1955) with the mean residuals of the teleseismic travel times obtained in this study.

HAYATSU (1955) and MAKI (1963). The geographical correlation of the decaying factor of maximum amplitude with the Bouguer gravity anomaly and seismic activity was pointed out by HAYATSU (1955). In Fig. 19a the station corrections of earthquake magnitude given by ICHIKAWA (1958) are compared with the station anomalies of the teleseismic travel times. Some negative relation is seen for later arrivals, which is more apparent in the relation to the ground factor by KATSUMATA (1967) in Fig. 19b.

Assuming that the anomalies of earthquake magnitude and teleseismic travel times are produced by common paths, the difference of earthquake magnitude is represented by,

$$\delta M = -0.4343\frac{\pi}{T}\left(\frac{t'}{Q'}-\frac{t}{Q}\right)$$

where Q and Q' denote the quality factor of attenuation, t and t' denote the travel times, and T means the period of waves. Then for an equal value of Q and Q', the magnitude difference is proportional to the time difference. Fig. 20 shows the relation of the magnitude anomaly to the travel time anomaly for various values of attenuation factor. Because different types and periods of seismic waves are used for determining earthquake magnitude and for measuring travel times, observed data show great ambiguity. Some systematic differences of attenuation by one order of Q value are observable between stations with earlier and later arrivals.

The separation of station anomalies into earlier and later arrival is seen from the correlation to the station correction for the mantle earth-

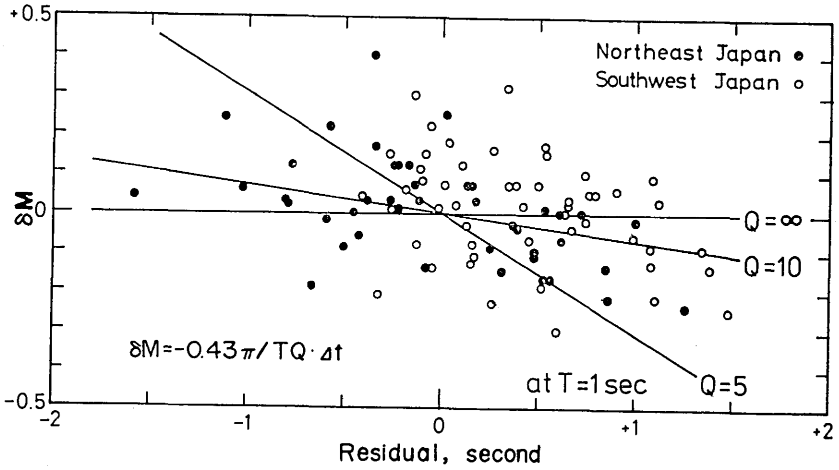

Fig. 20. Difference of attenuation factor (Q) between Northeast and Southwest Japan, derived from the relation of station anomaly of the earthquake magnitude and teleseismic travel time. Stations are classified into the ones in Northeast Japan (solid circles) and in Southwest Japan (open circles).

quakes, the Bouguer gravity anomaly and the magnitude correction. Such later arrivals are caused by anomalously small velocity which is produced by the exceedingly high temperature associated with the high heat-flow. KANAMORI (1968) explained the P-wave velocity contrast of 0.4 km/sec in the upper mantle beneath the Japanese Islands by the temperature difference of about 500°C and including a partial melting of 20%.

6. Conclusion

The regional variation of the travel-time anomaly was studied by 8920 teleseismic travel-time residuals of the P-waves observed in Japan, from 223 distant earthquakes, including nuclear explosions, deep and shallow earthquakes. The following conclusions were obtained;

(1) Systematic departures from the JEFFREYS-BULLEN travel times are observed also in Japan, earlier arrivals around the distances of $\Delta=60°$, and later arrivals around $\Delta=40°$ and 80°. Such systematic departures agree to the unduration with distance observed by CARDER *et al.* (1966), HERRIN *et al.* (1968b), LILWALL and DOUGLAS (1970), and SENGUPTA and JULIAN(1976).

(2) Station anomalies are observed in the teleseismic travel times in Japan. Station biases, especially the azimuthal variation at each station, suggest the presence of lateral variation of physical properties of the crust and upper mantle structure. The mean residuals at each station range from -1.8 to $+1.4$ sec, and the amplitude of sinusoidal variation

with azimuth up to 1.2 sec.

(3) The regional variation of mean residuals at each station is observed for the teleseismic P wave travel times. Nearly vertical incidences of teleseisms make it possible to isolate the structural difference directly beneath the station. Earlier arrivals are observed on the Pacific side from the Hokkaido to Kanto region. Later arrivals are observed at the stations in Southwest Japan and on the Japan Sea side of Hokkaido and Northeast Japan. Exceptionally earlier arrivals are observed in the Chugoku region as pointed out in several studies (NAGAMUNE, 1973a; AOKI and TADA, 1973; UTSU, 1975; MAKI, 1977).

The regional variation of station anomalies is interpreted by the presence of the high velocity zone associated with the descending lithospheric plate. The high velocity zone beneath the Chugoku region is to be studied in more detail.

(4) Teleseismic travel-time anomalies have a better correlation with the mean residuals for the nearby-deep earthquakes (UTSU, 1975; MAKI, 1977) rather than the station corrections for the crustal earthquakes in the Kanto region (MAKI, 1979). The variation of travel times passing through possible crustal structures cannot interpret such observed residuals.

(5) Azimuthal variations of teleseismic residuals are observed at most of the Japanese stations. Stations in the Kanto region have amplitudes over 1.0 second in the sinusoidal variation of residuals with azimuth, and the time difference between the earliest and latest arrivals exceeds 2 seconds. Such azimuthal anomalies were explained by the tentative upper mantle structure with the high velocity zone along the deep seismic zone. Some stations in the Hokkaido region show the earliest arrivals in the direction parallel to the strike of the deep seismic zone.

(6) Separation of stations into two groups with earlier and later arrivals is recognized from the relation of the mean teleseismic residuals to the station corrections for the mantle earthquakes, the Bouguer gravity anomaly and the station corrections of earthquake magnitude. This separation means the possibility of dividing into the high-V, ρ, Q and low-V, ρ, Q regions. The regional variations of velocity, density and the attenuation factor seem to be caused by the regional variation of temperature and constituent of materials in the crust and uppermost mantle.

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9. 日本で観測される遠地地震の P 波走時残差

地震研究所　牧　　　正

223 個の遠地地震（震央距離 30°～100°）に対して観測された 8920 個の到着時データ（気象庁・大学等）を用いて走時異常が調べられた．Jeffreys-Bullen の標準走時に対する系統的傾向として，東北日本の太平洋側で速い走時，日本海側で遅い走時が観測され，又西南日本では一般に遅い走時が観測される．中国・四国地方の一部では例外的に速い走時が観測される．遠地地震に対する走時異常の地理的分布は，地震活動・重力異常・熱流量・地震波減衰係数の分布とも調和する．

観測点のまわりの方位に対し，遠地地震の走時残差は sin 変化を示す．特に関東地方の高感度観測点では，速い走時と遅い走時の間に 2 秒の差がみられる．この大きな差は，観測点直下の地殻構造の地域的変化だけでは説明できない．各観測点の平均残差は，複合震源決定法（JHD）で求められた観測点補正値の内で地殻内地震に対するよりもマントル地震に対するものと良く対応する．遠地地震に対する走時異常の地域性や方位変化は主として，日本列島下に沈み込む太平洋プレートの構造によって説明される．

遠地地震に対する平均残差と重力異常値，及び残差と重力異常の方位変化には負の関係がみられる．又遠地地震の平均残差の，マントル地震に対する観測点補正値・マグニチュード補正値・重力異常値に対する関係では，直線関係と共に，2 つのグループに分かれる傾向がみられる．

Appendix. List of hypocentral coordinates (origin time, epicenter and focal depth) of the distant earthquakes used in the present study of the teleseismic travel-time residuals. Number of observations, mean and standard deviation at each station are also shown. NFE means the number of the source regions defined by FLINN and ENGDAHL (1965).

NO	Y	M	D	H	M	SECOND	LATITUDE φ°N		LONGITUDE λ°E		DEPTH km	MAG	NFE	OBS	MEAN/S.D. sec
1	1963	JAN	1	23	39	9.50	56.60	N	157.50	W	80		12	33	−0.248±0.756
2	1963	JAN	28	12	12	19.90	2.60	S	149.90	E	32		190	14	1.537±1.690
3	1963	JAN	28	13	0	48.10	54.70	N	161.70	W	14	6.5	12	33	2.192±1.700
4	1963	FEB	13	18	13	54.90	9.90	S	160.70	E	30	6.0	193	17	1.269±1.678
5	1963	FEB	14	7	4	42.20	7.40	S	128.20	E	197	5.3	280	24	0.246±1.693
6	1963	FEB	26	20	14	7.00	7.50	S	146.10	E	156		207	83	1.460±1.115
7	1963	MAR	26	9	43	20.30	29.70	S	177.90	W	48	5.9	178	33	2.908±1.621
8	1963	APR	7	22	36	3.60	4.80	S	103.30	E	70		274	35	1.297±1.607
9	1963	APR	16	1	29	15.90	0.90	S	128.20	E	6	5.0	267	26	2.117±2.251
10	1963	APR	19	7	35	22.70	35.70	N	96.90	E	33	5.4	325	16	0.126±2.732
11	1963	APR	30	0	58	19.20	0.90	S	128.80	E	33	5.0	267	24	2.001±1.726
12	1963	MAY	31	10	3	20.20	19.00	S	168.90	E	142	6.2	186	15	0.910±1.430
13	1963	JUN	19	9	9	4.00	4.70	N	126.50	E	83	6.2	263	16	1.516±2.321
14	1963	JUN	24	4	26	37.90	59.50	N	151.70	W	52	5.7	14	24	−0.452±1.831
15	1963	JUL	4	10	58	13.20	26.30	S	177.70	W	158	6.5	171	41	−0.016±1.065
16	1963	AUG	22	19	52	25.00	9.40	S	158.00	E	33	6.1	193	37	1.033±1.671
17	1963	AUG	25	12	18	12.50	17.50	S	178.80	W	565	6.1	181	70	0.995±0.829
18	1963	SEP	15	0	46	54.10	10.30	S	165.60	E	43	6.3	184	68	0.458±1.211
19	1963	SEP	17	19	20	8.20	10.10	S	165.30	E	17	6.1	184	59	2.091±2.000
20	1963	NOV	4	1	17	8.90	6.80	S	129.60	E	80		280	64	1.850±1.338
21	1963	NOV	6	2	13	16.80	2.60	S	138.40	E	33	5.7	201	23	1.344±1.820
22	1963	DEC	15	19	34	45.50	4.80	S	108.00	E	650	6.4	275	66	0.337±1.552
23	1963	DEC	18	0	30	2.60	24.80	S	176.60	W	46	6.5	171	64	0.335±1.797
24	1964	JAN	28	14	9	15.90±0.10	36.48±0.020	N	70.95±0.023	E	197± 2.5	6.6	718	21	−0.383±1.432
25	1964	FEB	6	13	7	23.10±0.11	55.72±0.032	N	155.95±0.042	W	13± 3.7	6.4	17	49	1.520±2.274
26	1964	MAR	28	3	36	13.90±0.09	61.05±0.021	N	147.48±0.043	W	23± 2.6		2	89	0.006±1.790
27	1964	MAR	28	11	30	11.30±0.13	0.40±0.032	N	122.11±0.037	E	160± 8.8	6.1	265	37	−0.369±1.057
28	1964	MAR	28	14	47	37.30±0.13	60.36±0.032	N	146.61±0.061	W	12± 1.0	6.0	2	25	1.209±2.045
29	1964	MAR	28	20	29	8.20±0.10	59.79±0.025	N	148.67±0.044	W	35± 2.8	6.2	14	41	−0.234±1.700
30	1964	MAR	30	2	18	6.80±0.15	56.65±0.041	N	152.82±0.059	W	22± 1.8	5.8	13	30	−0.509±2.335

(to be continued)

Appendix (Continued)

NO	Y	M	D	H	M	SECOND	LATITUDE φ°N	LONGITUDE λ°E	DEPTH km	MAG	NFE	OBS	MEAN/S.D. sec
31	1964	APR	2	1	11	48.60±0.22	5.75±0.079N	95.42±0.071E	65±27.0	5.6	706	32	2.087±1.519
32	1964	APR	4	17	46	9.00±0.09	56.30±0.024N	154.40±0.034W	24± 1.2	5.8	13	33	0.099±2.199
33	1964	APR	23	3	32	51.00±0.13	5.42±0.028S	133.99±0.033E	33± 0.0	6.5	204	53	0.682±1.641
34	1964	APR	24	5	56	9.80±0.12	5.07±0.032S	144.20±0.032E	99± 7.3	6.3	202	68	0.834±1.901
35	1964	JUN	30	13	46	18.50±0.29	0.50±0.200S	122.61±0.078E	15±27.0	5.8	265	24	1.879±2.572
36	1964	JUL	8	11	55	41.10±0.11	5.54±0.027S	129.79±0.029E	189± 8.5	6.5	280	78	1.180±1.156
37	1964	JUL	9	16	39	50.00±0.14	15.56±0.029S	167.62±0.034E	127± 5.1	6.4	186	53	0.185±1.780
38	1964	AUG	13	0	31	15.00±0.10	5.48±0.022S	154.25±0.025E	392± 3.5	5.8	193	76	0.871±1.246
39	1964	AUG	25	13	47	19.30±0.10	78.15±0.023N	126.65±0.095E	34± 2.8	6.2	654	46	0.712±2.056
40	1944	SEP	5	2	53	49.70±0.12	5.78±0.024S	154.14±0.027E	57± 6.3	5.7	193	13	2.415±1.934
41	1964	SEP	12	22	7	3.20±0.24	48.95±0.042S	164.46±0.067E	33± 0.0	6.1	16	20	1.230±1.759
42	1964	SEP	15	15	29	38.80±0.11	8.90±0.028N	93.03±0.026E	89± 6.7	6.3	704	57	0.919±1.136
43	1964	OCT	2	13	0	37.00±0.13	10.42±0.028S	162.42±0.031E	41± 8.3	5.9	193	38	0.386±1.108
44	1964	OCT	11	21	15	6.20±0.13	0.62±0.029S	121.68±0.031E	55± 8.3	5.7	265	27	0.503±1.538
45	1964	OCT	12	15	42	55.10±0.15	3.02±0.034N	126.50±0.040E	62±10.0	5.5	263	23	1.000±1.548
46	1964	OCT	18	12	32	24.90±0.16	7.17±0.099S	123.86±0.043E	585± 9.4	5.8	280	73	1.323±1.826
47	1964	OCT	21	23	9	19.00±0.12	28.04±0.028N	93.75±0.029E	37± 0.0	5.9	313	15	0.217±2.526
48	1964	NOV	17	8	15	41.10±0.11	5.75±0.022S	150.74±0.024E	60± 0.0	6.3	192	51	1.096±1.547
49	1964	NOV	18	14	34	55.40±0.11	5.99±0.020S	148.18±0.023E	61± 5.7	5.5	192	22	1.615±1.053
50	1964	NOV	19	23	35	6.40±0.14	6.00±0.027S	150.75±0.031E	3± 0.0	5.9	192	27	3.048±1.361
51	1964	DEC	28	16	16	8.70±0.11	22.13±0.026S	179.62±0.031W	577± 4.8	5.7	171	29	1.316±1.421
52	1965	JAN	24	0	11	12.00±0.12	2.40±0.026S	125.98±0.029E	6± 0.0	6.5	270	73	2.852±1.311
53	1965	FEB	4	5	1	21.60±0.12	51.29±0.038N	178.55±0·035E	36± 2.7	6.1	6	24	0.831±1.999
54	1965	FEB	4	8	40	42.10±0.16	51.39±0.046N	179.59±0.054E	40± 0.0	6.1	6	28	0.305±2.191
55	1965	MAR	14	15	53	6.20±0.09	36.42±0.021N	70.73±0.020E	205± 2.6	6.4	718	64	0.437±1.566
56	1965	MAR	30	2	27	3.40±0.08	50.32±0.024N	177.93±0.026E	20±11.0	6.5	6	49	2.474±1.337
57	1965	MAY	20	0	40	9.80±0.16	14.60±0.032S	167.41±0.040E	31± 9.0	5.9	186	38	2.081±1.825
58	1965	JUL	2	20	58	38.10±0.08	53.03±0.021N	167.55±0.024W	40± 7.7	6.7	9	76	0.424±1.274
59	1965	JUL	6	18	36	47.30±0.09	4.48±0.019S	155.07±0.022E	509± 4.3	5.6	193	54	0.282±1.080
60	1965	JUL	29	6	29	21.80±0.10	51.11±0.030N	171.30±0.031W	18± 0.9	6.3	9	59	0.685±1.597
61	1965	AUG	11	3	40	55.50±0.15	15.47±0.029S	166.91±0.032E	14± 0.0	5.9	186	30	2.134±1.515
62	1965	AUG	11	22	31	49.10±0.11	15.75±0.026S	167.12±0.026E	31±11.0	6.2	186	56	0.747±1.144
63	1965	AUG	13	12	40	8.20±0.24	15.88±0.046S	166.83±0.052E	26±19.0	5.4	186	20	1.290±2.672
64	1965	AUG	20	5	54	50.60±0.09	5.74±0.017S	128.63±0.024E	328± 6.4	6.1	280	64	0.813±1.147
65	1965	OCT	1	8	52	1.90±0.07	50.02±0.022N	178.28±0.022E	55±11.0	6.2	6	18	2.584±1.256

(to be continued)

Appendix (Continued)

NO	Y	M	D	H	M	SECOND	LATITUDE φ°N	LONGITUDE λ°E	DEPTH km	MAG	NFE	OBS	MEAN/S.D. sec
66	1965	NOV	13	4	33	50.60±0.07	43.87±0.017N	87.74±0.019E	29± 6.6	6.2	332	39	0.141±1.151
67	1966	APR	23	0	9	33.00±0.29	0.78±0.057S	122.22±0.063E	27± 1.5	6.0	265	42	2.059±1.961
68	1966	JUN	6	7	46	15.60±0.22	36.43±0.018N	71.12±0.018E	214± 2.2	6.1	717	67	−0.178±1.127
69	1966	JUN	13	18	8	36.60±0.45	12.23±0.021S	167.02±0.021E	242± 4.5	6.0	184	34	0.174±0.987
70	1966	JUN	15	0	59	46.10±0.16	10.43±0.030S	160.89±0.037E	34± 0.0	6.0	193	56	0.051±2.044
71	1966	JUN	22	20	29	5.30±0.60	7.21±0.025S	124.69±0.032E	523± 7.6	6.1	280	58	1.041±1.233
72	1966	JUL	4	18	33	38.70±0.19	51.99±0.045N	179.95±0.051E	16± 1.0	5.9	6	40	−0.058±2.656
73	1966	AUG	1	21	3	0.90±0.21	30.08±0.040N	68.62±0.035E	40± 2.4	5.7	710	40	1.792±2.103
74	1966	AUG	7	2	13	4.30±0.10	50.57±0.023N	171.22±0.023W	29± 1.3	6.3	16	46	0.860±1.317
75	1966	SEP	8	21	15	52.30±0.87	2.34±0.022N	128.40±0.026E	90± 7.9	6.6	267	68	−0.572±1.342
76	1966	SEP	28	14	0	21.00±2.50	27.53±0.035N	100.08±0.029E	12±15.0	5.7	318	14	0.337±0.867
77	1966	DEC	23	15	50	21.30±0.54	7.11±0.020S	148.31±0.023E	46± 5.0	6.1	207	66	−0.149±0.959
78	1966	DEC	31	18	23	8.80±0.65	11.89±0.026S	166.38±0.027E	73± 6.1	5.5	184	22	−0.248±1.542
79	1966	DEC	31	22	15	17.10±0.60	12.10±0.110S	165.70±0.130E	36± 2.9	5.2	184	19	1.573±2.696
80	1967	FEB	14	1	36	4.00±2.80	13.75±0.039N	96.47±0.030E	13±17.0	5.6	703	23	0.903±2.006
81	1967	APR	12	4	51	41.80±0.17	5.16±0.035N	96.31±0.027E	63± 3.9	6.1	706	40	0.671±1.459
82	1967	MAY	21	18	45	13.20±0.92	0.95±0.019S	101.39±0.018E	184± 8.4	6.2	274	53	0.320±1.143
83	1967	JUL	22	16	56	58.00±0.15	40.67±0.027N	30.69±0.023E	33± 3.3	6.0	366	47	0.563±2.445
84	1967	AUG	30	4	22	5.10±0.10	31.61±0.023N	100.26±0.018E	24± 3.0	6.1	307	13	0.052±2.020
85	1967	OCT	9	17	21	46.20±0.33	21.10±0.022S	179.18±0.019W	605± 4.6	6.2	172	87	0.433±1.047
86	1967	DEC	25	1	23	33.30±0.70	5.25±0.025S	153.70±0.030E	55± 6.5	5.8	190	52	−0.201±1.611
87	1968	JAN	19	6	4	36.00±2.10	9.29±0.028S	158.46±0.028E	13±12.0	6.0	193	30	1.112±1.380
88	1968	FEB	12	5	44	45.10±0.90	5.54±0.027S	153.36±0.030E	46± 8.2	6.2	190	64	0.322±1.047
89	1968	FEB	19	22	45	42.40±0.16	39.40±0.027N	24.94±0.028E	7± 0.0	6.0	365	19	2.384±2.047
90	1968	MAR	3	22	55	36.60±0.64	1.57±0.027N	122.53±0.031E	433± 7.3	5.5	265	28	0.404±1.329
91	1968	MAY	28	13	27	19.80±0.78	2.98±0.026S	139.34±0.028E	73± 7.2	6.2	197	68	0.651±1.063
92	1968	JUN	7	11	57	31.00±2.10	1.86±0.031S	120.10±0.035E	27±15.0	5.9	268	31	−0.675±1.092
93	1968	AUG	10	2	7	0.00±2.60	1.38±0.026N	126.24±0.030E	1±15.0	6.3	266	69	1.835±1.508
94	1968	AUG	10	5	51	49.00±1.20	1.40±0.027N	126.27±0.033E	41±10.0	6.1	266	37	−0.258±1.285
95	1968	AUG	14	22	14	20.10±0.18	0.06±0.037N	119.73±0.041E	22± 1.0	6.1	265	53	0.816±2.479
96	1968	AUG	18	18	38	30.30±0.34	10.20±0.025S	159.90±0.026E	534± 4.5	6.1	193	77	0.523±1.167
97	1968	AUG	31	10	47	41.30±0.28	34.15±0.053N	59.01±0.045E	25± 0.8	5.9	348	39	1.703±2.208
98	1968	SEP	16	13	55	35.70±0.57	6.08±0.030S	148.77±0.033E	49± 5.5	5.9	192	52	0.706±1.417
99	1968	SEP	27	3	58	58.00±1.20	6.89±0.022S	129.21±0.031E	151±11.0	5.9	280	28	0.732±1.126
100	1968	OCT	23	21	4	42.90±0.11	3.38±0.019S	143.29±0.026E	21± 1.0	6.2	200	38	0.851±1.535

(to be continued)

Appendix (Continued)

NO	Y	M	D	H	M	SECOND	LATITUDE φ°N	LONGITUDE λ°E	DEPTH km	MAG	NFE	OBS	MEAN/S.D. sec
101	1968	DEC	7	4	57	57.20±0.35	3.63±0.064 S	146.18±0.068 E	74± 4.3	5.6	203	16	−0.942±1.473
102	1968	DEC	17	12	2	14.80±0.47	60.15±0.020 N	152.82±0.037 W	82± 4.3	6.0	2	34	0.079±1.001
103	1969	JAN	5	13	26	42.80±0.63	8.03±0.028 S	158.94±0.025 E	71± 6.0	6.2	193	57	−0.196±1.403
104	1969	JAN	6	15	39	1.30±0.14	10.57±0.028 S	164.46±0.027 E	32± 0.0	6.2	183	37	−0.181±1.609
105	1969	JAN	19	18	50	52.40±0.37	14.89±0.021 S	167.22±0.018 E	114± 3.6	6.2	186	58	−0.044±0.874
106	1969	JAN	24	2	33	3.40±0.29	21.87±0.023 S	179.54±0.021 W	587± 4.0	5.9	181	43	0.534±0.769
107	1969	JAN	30	10	29	40.30±0.94	4.77±0.029 N	127.50±0.032 E	72± 8.5	5.9	263	47	1.059±1.865
108	1969	FEB	3	21	41	43.40±0.11	4.81±0.023 N	127.54±0.025 E	46± 4.2	6.1	263	39	−0.162±1.440
109	1969	FEB	10	22	58	3.30±0.38	22.75±0.030 S	178.76±0.031 E	635± 5.8	6.0	171	73	0.421±0.996
110	1969	FEB	11	22	16	11.50±0.94	6.76±0.032 S	126.74±0.048 E	425±10.0	6.0	280	76	0.988±1.696
111	1969	FEB	23	0	37	2.00±1.30	3.17±0.035 S	118.91±0.033 E	53±12.0	5.8	268	42	0.589±1.185
112	1969	MAR	27	12	41	36.30±0.12	4.72±0.025 N	127.65±0.028 E	32± 0.0	5.8	263	25	0.378±2.012
113	1969	MAY	14	19	32	55.00±1.10	51.29±0.019 N	179.85±0.023 W	22± 7.6	6.2	7	33	1.157±0.778
114	1969	AUG	4	17	19	20.50±0.41	5.71±0.020 S	125.42±0.020 E	531± 5.3	6.3	280	73	0.738±1.069
115	1969	AUG	5	2	13	8.00±1.30	1.26±0.020 N	126.23±0.021 E	21± 9.4	6.1	266	53	0.920±1.114
116	1969	AUG	8	20	44	20.80±0.62	6.14±0.021 S	129.69±0.023 E	193± 6.0	5.8	280	57	0.595±1.045
117	1969	NOV	21	2	5	35.40±0.14	1.94±0.034 N	94.61±0.027 E	20± 0.9	6.4	705	49	1.436±1.539
118	1969	NOV	22	23	9	39.20±0.09	57.70±0.019 N	163.56±0.032 E	51± 2.1	6.2	218	14	−0.291±2.317
119	1970	JAN	4	17	0	39.40±0.20	24.12±0.045 N	102.49±0.036 E	15± 1.1	5.8	318	12	0.186±2.806
120	1970	JAN	10	12	7	8.60±0.64	6·80±0.021 N	126.75±0.023 E	68± 5.8	5.9	259	29	−0.214±1.534
121	1970	JAN	20	7	19	51.40±0.81	25.85±0.027 S	177.29±0.026 W	82± 7.3	6.2	171	59	−0.345±1.140
122	1970	FEB	13	15	43	26.90±0.30	5.96±0.022 S	113.03±0.022 E	616± 4.2	5.7	275	53	−0.465±1.156
123	1970	FEB	28	10	52	31.10±0.39	52.59±0.021 N	175.04±0.026 W	161± 3.7	6.0	7	66	1.082±1.358
124	1970	MAR	27	18	36	47.00±2.20	0.28±0.024 N	119.37±0.027 E	11±13.0	6.0	265	44	1.943±1.346
125	1970	MAR	28	21	2	23.50±0.57	39.21±0.017 N	29.51±0.017 E	18± 4.2	6.0	366	42	1.275±1.284
126	1970	MAR	30	16	46	46.20±0.63	6.78±0.024 N	126.66±0.027 E	82± 5.6	5.8	259	15	0.067±1.546
127	1970	MAY	15	17	13	12.50±0.09	50.19±0.018 N	91.24±0.022 E	12± 0.9	5.9	333	26	0.829±2.193
128	1970	JUN	5	4	53	7.40±0.10	42.48±0.019 N	78.71±0.021 E	24± 1.7	5.9	330	29	0.236±1.127
129	1970	JUN	24	13	9	11.30±0.17	51.77±0.027 N	130.76±0.049 W	22± 0.7	5.7	22	24	−0.944±2.240
130	1970	JUN	28	1	30	13.80±0.83	8.75±0.028 S	124.04±0.025 E	50± 7.6	6.2	289	30	0.844±0.902
131	1970	JUL	29	10	16	20.40±0.57	26.02±0.019 N	95.37±0.015 E	68± 5.2	6.4	287	54	−0.922±1.258
132	1970	JUL	30	0	52	20.30±0.17	37.85±0.032 N	55.94±0.027 E	22± 2.4	5.7	341	15	1.306±1.559
133	1970	AUG	11	10	22	20.00±2.40	14.13±0.049 S	166.56±0.041 E	20±17.0	6.1	186	28	0.839±2.072
134	1970	OCT	31	17	53	10.50±0.18	4.97±0.032 S	145.45±0.038 E	45± 2.9	6.0	200	58	−0.332±1.439
135	1970	NOV	8	22	35	46.40±0.11	3.43±0.022 S	135.65±0.021 E	33± 1.1	6.2	196	54	0.187±1.041

(to be continued)

Appendix (Continued)

NO	Y	M	D	H	M	SECOND	LATITUDE φ°N	LONGITUDE λ°E	DEPTH km	MAG	NFE	OBS	MEAN/S.D. sec
136	1970	DEC	28	20	3	25.50±0.45	5.23±0.021 S	153.59±0.023 E	63± 4.2	6.2	190	21	−0.406±2.136
137	1970	DEC	29	2	26	11.80±0.51	10.58±0.018 S	161.39±0.020 E	70± 4.8	6.0	193	28	0.462±1.227
138	1971	JAN	10	7	17	4.70±0.67	3.21±0.021 S	139.69±0.025 E	41± 6.2	6.5	201	73	1.023±1.325
139	1971	FEB	4	15	33	29.50±0.89	0.53±0.025 N	98.72±0.024 E	40± 7.8	6.2	706	58	0.774±1.689
140	1971	FEB	7	2	29	29.10±0.19	51.47±0.040 N	176.81±0.053 W	40± 1.4	5.8	7	33	−1.232±2.144
141	1971	APR	7	4	59	37.00±1.00	2.45±0.017 N	129.13±0.019 E	29± 7.2	6.3	267	50	1.005±1.474
142	1971	MAY	2	6	8	26.90±0.42	51.42±0.020 N	177.21±0.024 W	38± 3.7	6.0	7	36	0.151±1.780
143	1971	MAY	22	16	43	59.30±0.13	38.85±0.024 N	40.52±0.021 E	3± 0.0	5.9	366	12	1.903±0.807
144	1971	JUN	11	13	58	37.60±0.14	51.67±0.028 N	176.04±0.036 E	19± 0.9	5.8	6	12	0.040±3.123
145	1971	JUL	8	19	7	7.30±0.81	7.03±0.026 S	129.70±0.027 E	92± 7.5	6.1	280	24	0.446±1.573
146	1971	JUL	14	6	11	28.90±0.55	5.52±0.023 S	153.96±0.022 E	43± 5.1	6.0	190	67	−0.135±1.627
147	1971	JUL	19	0	14	45.20±0.69	5.78±0.026 S	153.80±0.027 E	37± 6.4	5.9	190	15	0.943±2.202
148	1971	JUL	26	1	23	21.20±0.60	4.93±0.023 S	153.18±0.024 E	43± 5.6	6.6	190	63	0.029±1.358
149	1971	SEP	25	4	36	13.70±0.25	6.54±0.014 S	146.64±0.016 E	111± 2.3	6.3	207	63	−0.120±0.783
150	1971	OCT	27	17	58	37.90±0.54	15.57±0.026 S	167.24±0.023 E	49± 5.2	6.3	186	33	−0.174±1.880
151	1971	OCT	28	15	13	37.20±0.80	5.57±0.043 S	153.99±0.045 E	107± 7.9	5.8	190	18	1.508±3.668
152	1971	NOV	6	22	0	0.10±0.0	51.47±0.0 N	179.11±0.0 E	0± 0.0	6.8	6	74	0.288±0.834
153	1971	NOV	21	5	57	12.00±0.36	11.87±0.016 S	166.55±0.015 E	119± 3.5	6.5	184	57	−0.117±0.638
154	1971	DEC	15	8	29	56.60±0.09	56.04±0.018 N	163.17±0.032 E	39± 1.1	6.2	219	13	−0.338±1.223
155	1972	JAN	18	21	55	15.00±1.50	4.84±0.031 S	145.10±0.031 E	23±11.0	5.8	200	24	1.487±2.051
156	1972	JAN	19	15	1	1.20±0.24	4.84±0.043 S	145.14±0.046 E	100± 0.0	5.9	200	31	−0.770±1.380
157	1972	JAN	23	21	17	52.60±0.82	13.18±0.033 S	166.32±0.030 E	33± 7.1	5.8	186	31	−0.649±1.307
158	1972	FEB	14	23	29	51.60±0.47	11.43±0.020 S	166.37±0.019 E	101± 4.6	6.2	184	43	1.594±1.847
159	1972	MAR	7	7	45	20.70±0.41	28.25±0.022 S	178.27±0.020 W	181± 4.1	6.1	177	39	0.590±0.765
160	1972	MAR	30	5	34	50.40±0.31	25.69±0.019 S	179.58±0.023 E	479± 3.8	6.1	171	43	0.793±1.462
161	1972	APR	4	22	43	6.70±0.43	7.47±0.019 S	125.56±0.018 E	375± 4.7	6.1	280	52	1.056±1.236
162	1972	APR	25	19	30	8.00±0.52	13.38±0.016 N	120.34±0.018 E	38± 4.5	6.4	250	10	−0.637±1.465
163	1972	APR	28	23	32	10.60±0.24	5.13±0.017 S	154.23±0.018 E	413± 2.8	6.0	193	52	0.232±1.053
164	1972	MAY	4	7	48	17.60±0.30	15.94±0.016 S	167.53±0.016 E	46± 2.9	6.3	186	34	−0.111±0.766
165	1972	MAY	22	20	45	55.10±0.46	17.76±0.018 S	175.05±0.017 W	208± 4.5	6.1	176	63	0.903±1.037
166	1972	JUN	11	16	41	2.70±0.55	3.86±0.023 N	124.26±0.026 E	336± 5.7	6.2	262	59	0.876±2.291
167	1972	JUL	30	21	45	15.80±0.16	56.77±0.028 N	135.91±0.054 W	29± 1.8	6.2	19	40	−0.375±1.428
168	1972	AUG	17	23	44	8.60±0.97	6.04±0.020 S	152.90±0.020 E	26± 7.1	6.3	192	46	0.463±1.993
169	1972	SEP	5	17	18	29.50±0.56	1.90±0.017 N	128.20±0.021 E	154± 5.3	5.9	267	27	−0.210±1.222
170	1972	SEP	24	20	9	36.20±0.15	6.22±0.030 S	131.15±0.031 E	33± 0.0	6.0	281	35	1.716±2.135

(to be continued)

Appendix (Continued)

NO	Y	M	D	H	M	SECOND	LATITUDE φ°N	LONGITUDE λ°E	DEPTH km	MAG	NFE	OBS	MEAN/S.D. sec
171	1972	NOV	2	19	55	23.30±0.49	20.03±0.020 S	168.91±0.024 E	37± 4.5	6.0	188	43	0.437±1.116
172	1972	DEC	2	0	19	52.00±1.10	6.41±0.029 N	126.62±0.031 E	73±10.0	6.0	259	13	−0.610±2.588
173	1973	JAN	18	9	28	13.70±0.34	6.88±0.017 S	150.03±0.018 E	38± 3.1	6.3	192	46	−0.154±1.036
174	1973	FEB	6	10	37	7.00±3.80	31.33±0.039 N	100.49±0.033 E	5±23.0	5.9	307	14	1.761±1.964
175	1973	MAR	9	10	6	34.00±1.00	6.32±0.017 N	127.38±0.019 E	25± 7.4	5.9	248	17	0.682±1.403
176	1973	MAR	18	11	6	14.80±0.11	2.09±0.024 N	126.55±0.026 E	33± 0.0	5.9	266	30	1.398±2.072
177	1973	JUL	1	13	33	34.40±0.09	57.86±0.016 N	137.42±0.028 W	30± 1.5	6.2	20	31	0.038±1.093
178	1973	JUL	14	4	51	20.00±0.12	35.16±0.022 N	86.40±0.023 E	22± 1.7	5.9	306	42	1.201±1.513
179	1973	AUG	1	1	31	31.60±0.26	14.33±0.016 S	167.29±0.015 E	202± 2.7	6.1	186	70	−0.263±0.463
180	1973	AUG	13	8	28	19.40±0.32	4.50±0.017 S	144.10±0.018 E	103± 3.1	5.9	200	37	−0.254±1.505
181	1973	SEP	12	6	59	54.60±0.07	73.32±0.012 N	54.97±0.044 E	0± 0.0	6.8	648	26	1.315±0.761
182	1973	SEP	20	20	43	38.50±0.36	9.23±0.024 N	123.92±0.026 E	542± 4.6	5.9	257	18	0.132±1.849
183	1973	OCT	27	6	59	57.60±0.09	70.80±0.016 N	53.92±0.047 E	0± 0.0	6.9	648	76	1.284±0.685
184	1973	NOV	6	9	36	5.90±0.64	51.64±0.022 N	175.48±0.028 W	40± 5.6	5.7	7	16	0.521±1.210
185	1973	DEC	9	19	55	46.00±1.90	19.90±0.035 S	169.67±0.043 E	26±13.0	5.9	186	20	1.138±2.018
186	1973	DEC	28	5	31	3.80±0.27	23.88±0.020 S	180.00±0.018 E	517± 3.5	6.2	182	34	1.273±1.020
187	1973	DEC	28	13	41	46.00±4.50	14.56±0.060 S	166.80±0.052 E	13±27.0	6.3	186	21	1.049±2.310
188	1973	DEC	29	0	19	30.80±0.69	15.13±0.023 S	166.92±0.021 E	43± 6.4	6.2	186	35	0.244±1.353
189	1974	JAN	10	8	51	13.80±0.45	14.45±0.017 S	166.87±0.015 E	36± 4.2	6.3	186	44	0.058±1.173
190	1974	JAN	31	23	30	5.00±1.20	7.39±0.025 S	155.92±0.023 E	32± 8.6	5.9	193	30	0.621±1.645
191	1974	FEB	1	3	12	31.00±3.90	7.28±0.051 S	155.62±0.047 E	12±24.0	6.2	193	20	2.001±2.529
192	1974	MAR	23	14	28	33.00±0.33	23.93±0.023 S	179.88±0.021 E	504± 4.2	6.0	171	54	0.754±0.947
193	1974	JUN	4	4	14	13.80±0.45	15.89±0.018 S	175.04±0.015 W	256± 4.5	6.1	173	35	0.730±1.266
194	1974	JUL	2	23	26	26.80±0.12	29.22±0.025 S	175.94±0.026 W	33± 0.0	6.5	177	48	0.884±0.927
195	1974	JUL	4	19	30	41.10±0.13	45.20±0.025 N	93.86±0.028 E	16± 0.6	5.9	334	14	1.100±2.109
196	1974	JUL	30	5	12	40.40±0.19	36.42±0.014 N	70.76±0.014 E	209± 1.9	6.3	718	70	−0.019±0.875
197	1974	AUG	11	1	13	55.00±1.30	39.34±0.018 N	73.76±0.019 E	7± 7.8	6.2	719	50	3.062±1.371
198	1974	SEP	7	20	43	15.00±0.17	9.80±0.037 S	108.49±0.035 E	60± 2.2	6.0	282	17	0.788±2.167
199	1974	OCT	23	6	14	52.00±1.60	8.40±0.035 S	154.03±0.032 E	18±11.0	6.2	194	35	0.927±1.681
200	1974	OCT	29	3	14	18.60±0.49	6.93±0.018 S	129.52±0.018 E	156± 4.7	6.3	280	54	0.811±1.105
201	1974	NOV	2	4	59	56.90±0.07	70.81±0.013 N	53.91±0.039 E	0± 0.0	6.4	648	58	1.737±0.740
202	1974	NOV	20	4	14	50.60±0.43	15.12±0.019 S	167.16±0.017 E	62± 4.0	6.2	186	40	−0.792±0.783
203	1974	DEC	3	3	6	35.70±0.16	5.04±0.031 S	129.99±0.032 E	32± 3.6	6.0	280	29	0.087±1.577
204	1974	DEC	24	6	55	47.00±0.14	2.30±0.031 S	99.01±0.027 E	32± 1.7	5.9	274	22	0.776±1.770
205	1975	JAN	14	19	37	18.10±0.16	4.93±0.031 S	130.03±0.033 E	23± 0.9	5.6	280	23	1.558±1.475

(to be continued)

Appendix (Continued)

NO	Y	M	D	H	M	SECOND	LATITUDE φ°N	LOGNITUDE λ°E	DEPTH km	MAG	NFE	OBS	MEAN/S.D. sec
206	1975	JAN	14	19	49	5.00±0.13	4.93±0.026 S	130.09±0.027 E	82± 4.5	6.0	280	41	0.371±1.031
207	1975	JAN	19	8	1	58.00±2.10	32.39±0.030 N	78.50±0.028 E	1±12.0	6.2	304	37	3.024±1.458
208	1975	FEB	7	4	51	41.00±1.10	7.24±0.017 S	149.58±0.016 E	9± 6.8	6.2	192	30	1.726±1.121
209	1975	FEB	22	8	36	6.80±0.37	51.32±0.015 N	179.44±0.019 W	42± 3.3	6.3	7	25	0.562±0.715
210	1975	FEB	22	22	4	33.50±0.55	24.98±0.028 S	178.88±0.023 W	333± 5.6	6.1	171	29	0.465±1.539
211	1975	MAR	5	0	22	17.00±2.50	2.39±0.030 S	126.15±0.031 E	7±15.0	6.1	270	18	1.872±2.000
212	1975	MAR	13	18	45	29.90±0.43	21.75±0.019 S	170.53±0.020 E	86± 3.9	6.0	189	45	0.716±1.367
213	1975	APR	13	1	34	37.40±0.45	5.66±0.019 N	125.38±0.022 E	235± 4.4	5.5	259	20	0.273±1.781
214	1975	MAY	13	21	18	42.00±0.89	1.03±0.027 N	126.02±0.031 E	37± 8.0	5.8	266	23	−0.040±1.740
215	1975	JUL	10	18	29	15.80±0.59	6.51±0.020 N	126.65±0.023 E	81± 5.3	5.9	259	18	−0.952±2.305
216	1975	JUL	20	14	37	40.60±0.48	6.64±0.021 S	155.09±0.023 E	54± 4.5	6.5	193	48	1.801±1.993
217	1975	JUL	20	19	54	29.10±0.92	7.15±0.035 S	155.21±0.033 E	49± 8.5	6.1	195	25	0.639±1.936
218	1975	AUG	2	10	18	19.70±0.10	53.48±0.020 N	161.39±0.029 W	46± 0.8	6.0	17	20	−0.831±1.201
219	1975	AUG	15	7	28	24.50±0.09	54.92±0.018 N	167.87±0.027 E	41± 0.9	5.8	4	17	0.838±1.708
220	1975	NOV	29	14	47	41.10±0.42	19.46±0.027 N	155.14±0.028 W	11± 2.7	5.9	613	22	1.921±1.983
221	1975	DEC	25	23	22	20.30±0.40	4.07±0.017 S	142.11±0.017 E	102± 3.9	6.4	202	100	0.817±1.175
222	1975	DEC	26	15	56	39.10±0.10	16.22±0.025 S	172.47±0.021 W	33± 0.0	6.3	169	50	2.258±1.391
223	1976	AUG	16	16	11	5.00±0.40	6.22±0.031 N	124.10±0.038 E	8± 4.0	6.4	259	28	0.907±1.926