Upper Crustal Structure in the Northwestern Chubu District, Japan as Derived from the Tedori-River Quarry Blasts.

By Kunihiko WATANABE and Hideaki FUKUI

(Kyoto University and Nagoya University)
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Abstract

The upper crustal structure in the northwestern Chubu region has been investigated from a number of quarry blasts at the Tedori-River Dam site, Ishikawa Prefecture.

For effective observations of seismic waves from the blasts, mobile observations have been carried out during four months from May to August, 1978, at 107 sites including permanent stations along 14 profiles extending radially from the quarry site to a distance of about 150 kilometers. The results reveal some gaps in the travel-time-distance relations and regional irregularities in the apparent velocities, suggesting complicated structures in the upper crust over this region. Since most of the profiles have not been covered by reverse observations, two different simple layered models are tentatively proposed here. These are Model II, with two layers,

1st layer: 5.3 km/sec ($0 \leq H < 2.5$km)
2nd layer: 6.15km/sec ($2.5 \leq H$ km)

and Model III with three layers,

1st layer: 5.0 km/sec ($0 \leq H < 0.5$km)
2nd layer: 5.6 km/syc ($0.5 \leq H < 4.0$km)
3rd layer: 6.4 km/sec ($4 \leq H$ km)

Spatial distribution of the differences between the observed travel times and the corresponding times calculated for Model II show that in the coastal area of the Sea of Japan there exists a low-velocity surface layer with a time delay of the order of 0.5 seconds. Lateral heterogeneities in the structure should be taken into consideration in investigating seismic activities in this region.

1. Preface

In the northwestern Chubu region, routine seismic observations have been continued since 1970 at network stations of the Hokuriku Microearthquake Observatory[1] and the Kamitakara Geophysical Observatory[2] of the Disaster Prevention Research Institute, Kyoto University, and at stations of the Inuyama and Takayama Seismological Observatories of Nagoya University[3]. Since the spring of 1976, many quarry blasts have been recorded at these stations. The shot points estimated from the observed seismic data were concentrated near the Tedori-River Dam site[4], Ishikawa Prefecture, and the magnitude of the blasts was estimated as ranging from 1 to 2.5.

In this region, traverse observations of several explosions and quarry blasts including those of Miboro[5], Atsumi-Noto[6], and Inabu[7] have already been made. These yielded information on the general features of the crustal structure. Seismic activities in this region have been investigated on the basis of the obtained velocity structures. In order to investigate seismic activities with greater accuracy, however, more detailed informations on the upper crustal structure are inevitably required. For this purpose, we planned to make extensive observations of the quarry blasts at the Tedori-River Dam site, by setting temporary observation sites in addition to the routine seismic stations. In addition, possible temporal variations in seisimic P-wave velocity were also tested, for which purpose more than one thousand guarry blasts have been carefully recorded for about three years. These results have been reported in separate articles (Ando et al, 1978[8] ; Hirano et al, 1979[9]).

In October 1978, several explosions were detonated for geophysical explorations of Lake Biwa, which constitute a part of a reverse profile to the Tedori quarry blasts. Since the results have been given by Matsumura et al (1979)[10], this article deals only with the Tedori quarry blasts in order to discuss the upper crustal structure in northwestern Chubu region.

The present observations and analyses were made by the Research Group*) for the Tedori-River Quarry Blasts, which involves the members of the Disaster Prevention Research Institute, Kyoto University and the Faculty of Science, Nagoya University.

2. Quarry blasts and determination of the shot points and shot times

The quarry blasts at the Tedori-Dam site have been carried out by a bench-cut method, in two quarry sites (Mt. 1 and Mt. 2) on two low hills 600 meters apart from each other in the north-south direction. Explosives were tamped into 5-10 boreholes about 20 meters deep with a diameter of 25 or 40 centimeters. The horizontal extent of the holes reached about 50 meters, and the explosives in all holes were ignited simultaneously. Thus, a shot area usually formed a source dimension of 50 meters by 20 meters. The blasts were ordinarily detonated at noon and in the

*) Members engaged in both observations and analyses are
Kunihiko WATANABE, Takeshi MIKUMO, Fumiaki TAKEUCHI, Kazuo MATSUMURA, Hiroo WADA, Makoto KOIZUMI (Kyoto University), Hideaki FUKUI (OYO Corporation from Nagoya University), Akira IKAMI (Nagoya University).
Members engaged in observations are
Kazuo MINO, Norio HIRANO, Sigemitsu MATSUO, Masataka ANDO, Yoshinobu HOSO, Nobuo HURUKAWA, Kazuo HIRAHARA, Naoya MIKAMI (Kyoto University), Hiroshi INOUE, Isao YAMADA, Mamoru YAMADA, Takashi OKUDA, Iwao FUJII (Nagoya University).

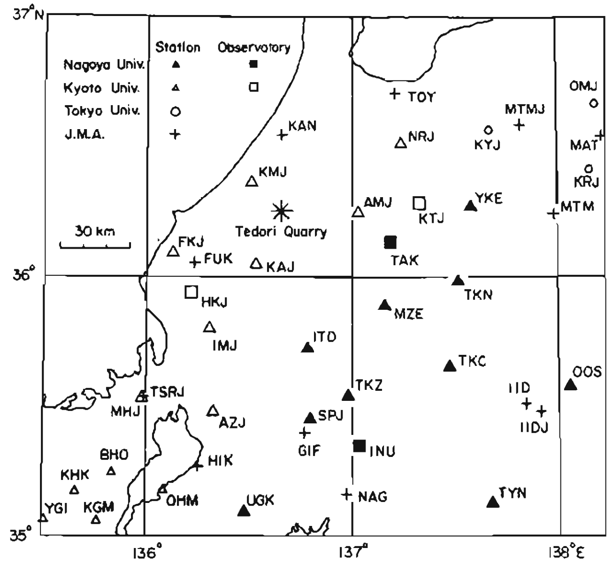


Fig. 1. Distribution of permanent stations near and around the quarry site.

evening almost every day. The amplitudes of seismic waves from the blast were so large that the initial motions were able to be easily identified at recording stations about 100-150 kilometers away from the sites (Fig. 1).

It was impossible to measure the exact location of the shot point for every blast, because the topography of the quarry sites have been deformed continuously by the successive blasts. For this reason, we assume here the center of each site estimated from a 1/25,000 map to be the representative shot points throughout the whole of the blasts. Variations in the elevation of the shot points are considered to be less than 100 meters. The difference in the location between the assumed point and each of the actual shots would yield a maximum time difference of about ±25 milli-

Table 1 Arrival times at three satellite stations from three blasts whose shot times were observed exactly. Mean difference in the arrival times for KMJ and KAJ is 1.045 sec, and the mean travel time for KMJ is 3.58 sec.

Shot No.	Shot time				Arrival time (KMJ)	Travel time (KMJ)	Arrival time (FKJ)	Arrival time (KAJ)	Difference KAJ-KMJ
1	June 20th	'78	18h29m	46s.540	50s.121	3s.581	55s.592	51s.159	1s.038
2	June 21st	'78	15h29m	37 .759	41 .335	3 .576	46 .837	42 .374	1 .039
3	July 20th	'78	18h39m	07 .594	11 .184	3 .590	16 .695	12 .243	1 .059
								Mean=	1 .045

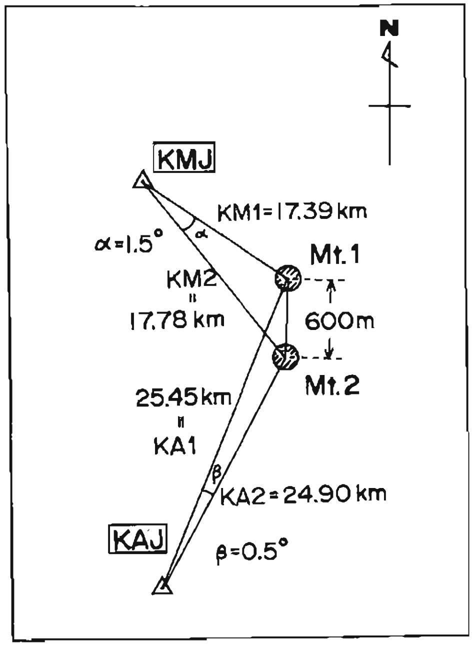


Fig. 2. Location of two quarry sites, Mt. 1 and Mt. 2, and two permanent stations, KMJ and KAJ.

seconds.

The shot time for each of the blasts was estimated in the following way. Exact shot times for three quarry blasts on Mt. 1 have been measured right on the quarry site. The arrival times of seismic waves from the three blasts observed at three satellite stations of the Hokuriku Microearthquake Observatory, and the corresponding travel times calculated from the shot times are listed in Table 1. Fig. 2 shows the location of two quarry sites, Mt. 1 and Mt. 2, and two stations, KMJ and KAJ. If we refer to more stable travel times at the KMJ station rather than those of two other stations, KAJ and FKJ, the shot time for all blasts on Mt. 1, S_1, may be approximately estimated as,

$$S_1 = P_{KM1} - 3.58 \quad \text{(sec)} \qquad (1)$$

where P_{KM1} is the arrival time at KMJ station.

For several quarry blasts which have been identified to have occurred on Mt. 2 from an explosion record, the arrival times at KMJ and KAJ are also shown in Table 2. It is found that the average travel time difference between the two stations is 0.886 seconds, while the corresponding difference for Mt. 1 was 1.045 seconds. Therefore, a comparison between the two arrival time differences may provide information to identify at which site, Mt. 1 or Mt. 2, each of the quarry blasts could have been carried out.

Table 2 Travel time differences between KMJ and KAJ for the blasts at Mt. 2. Mean difference is 0. 886 sec.

Shot		Arrival time (KMJ)	Arrival time (KAJ)	Difference KAJ-KMJ
July 4th '78	12h33m	50s. 922	51s. 801	0s. 879
July 12th '78	18h31m	28 . 879	29 . 770	0 . 891
July 13th '78	18h33m	11 . 740	12 . 629	0 . 889
July 24th '78	18h33m	31 . 121	32 . 001	0 . 880
July 29th '78	12h51m	00 . 439	01 . 328	0 . 889
			Mean=	0 . 886

We shall next estimate the shot time for the the blasts on Mt. 2. Fig. 2 indicates that the difference between the epicentral distance from Mt. 1 to KMJ and that from Mt. 2 to KMJ is 0. 394 km and that the corresponding difference for KAJ is 0. 552 km. If we denote the travel time differences for the two epicentral distances as Δt for KMJ and $\Delta t'$ for KAJ, then, the apparent velocities V^*_{KM} and V^*_{KA} should be $0.394/\Delta t$ and $0.552/\Delta t'$ respectively. If we further assume that seismic wave velocity near the shot area is almost uniform, V^*_{KM} and V^*_{KA} may be taken to be equal, and thus we have

$$\Delta t' = (0.552/0.394)\,\Delta t = 1.40\Delta t$$

From this relation and the difference in the mean values given in Table 1 and 2, $\Delta t - \Delta t' = 1.045 - 0.886$, we have

$$\Delta t = 0.066 \quad \text{(sec)} \tag{2}$$

and the apparent velocity becomes $V^*_{KM} = V^*_{KA} = 5.96$km/sec. This may be reasonable for the upper crustal velocity. Then, the shot time for the blasts on Mt. 2, S_2, may be estimated from Eqs (1) and (2),

$$\begin{aligned} S_2 &= P_{KM2} - 3.58 - 0.066 \\ &= P_{KM2} - 3.65 \qquad \text{(sec)} \end{aligned} \tag{3}$$

where P_{KM2} is an arrival time at KMJ for a blast at Mt. 2. The shot times thus estimated for all the relevant blasts are given in Table 4.

Next, the errors in the estimated shot times will be examined. Possible mislocation of the shot points may involve errors of ± 25 milliseconds in the travel times. The P-wave initial motions on the seismograms recorded at the KMJ station, which were used as a reference for the estimation of the shot times, always have a sharp and clear onset. Beside these, the timing accuracy in routine observations of microearthquakes at network stations depends on the sampling frequencies of the data in A/D converters (195 cps for the Hokuriku Observatory, and 100 cps for the Kamitakara Observatory and Nagoya University), time delays in telemetering, and the accuracy of the main X'tal clocks. Taking all these conditions into consideration, the estimated shot times may be accurate to 0.05 seconds.

3. Observations

The present observations have been carried out during the period from May to August in 1978. Mobile observation sites have been chosen to be aligned along fourteen profiles extending radially from the quarry site to a distance of 150 km. In order to analyze later phases, many observation sites were closely distributed in the southeastern direction from the quarry site. The total number of the observation sites including permanent stations amounted to 107, and 109 data were finally obtained. These 107 sites on the 14 profiles can be grouped into A- to N-lines, as shown in Fig. 3 and listed in Table 3. The observation at most of the mobile stations was made by using a 1-Hz-vertical component pickup with a portable data-recorder. At the other sites, a high-speed ink-writing recorder was operated. For details of routine microearthquake observations, refer to the published articles by the respective observatories[1)2)3)].

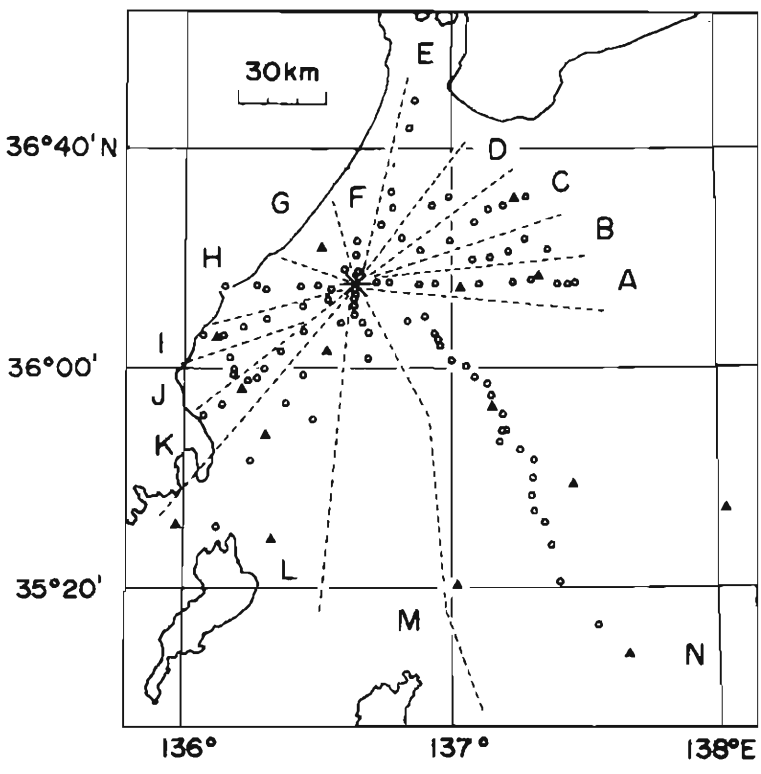


Fig. 3 Distribution of the observation sites classified into 14 profiles.
▲ denotes permanent stations and ○ denotes mobile sites.

Table 3 Locations, profiles, distances from the quarry site (* denotes the distance from Mt. 2) and the observation system at all observation sites. Letter "K" in the system column means the observation carried out by the Kamitakara Observatory; "H" Hokuriku; and "N" Nagoya University. The numerals attached to each letter mean as follows; K1, H1, N1: permanent satellite stations, K2, H2, N3: mobile stations with FM data recorders, N2: mobile stations with PCM data recorders, K3: mobile stations with pen-writing recorders, N4: stations with long-time FM data recorders.

Profile	Code	Station Name	Latitude (N)	Longitude (E)	Height	Distance	System
A 1	IRN	Ichirino	36°15′49.3″	136°43′16.2″	560m	6.86km*	N1
A 2	CGO	Chuguonsen	36 15 36.1	136 46 2.0	720	10.85	K2
A 3	MGR	Magari	36 15 13.9	136 52 53.2	740	21.14*	K2
A 4	AMT	Amotoge	36 15 32.2	136 56 20.6	915	26.29	K2
A 5	AMJ	Amo	36 14 50.4	137 1 42.0	500	34.33	K1
A 6	IBK	Ibukitoge	36 15 20.4	137 6 31.1	600	41.53	K2
A 7	KBR	Kambaratoge	36 15 34.1	137 14 13.0	840	53.06	K2
A 8	OAM	Ooamamidani	36 16 20.6	137 18 11.1	830	59.02	K2
A 9	KTJ	Kamitakara	36 16 48.8	137 19 37.8	760	61.21	K1
A10	SMD	Shiramizudani	36 15 26.1	137 24 14.8	660	68.08	K2
A11	OIM	Oimo	36 15 13.4	137 26 30.1	700	71.46	K2
A12	KSD	Kasadani	36 15 32.4	137 28 13.7	760	74.05	K2
B 1	FTY	Futatsuya	36°19′38.8″	137° 4′57.8″	865m	39.96km	K2
B 2	NSN	Nishinobu	36 20 15.5	137 8 55.7	540	46.00	K2
B 3	SGN	Suganuma	36 21 8.6	137 13 19.2	870	52.76	K2
B 4	NUY	Nishiurushiyama	36 23 33.4	137 16 55.2	360	59.01	K2
B 5	AOK	Aokitoge	36 23 32.8	137 22 0.0	860	66.39	K2
C 1	KZU	Kozu	36°21′28.9″	136°52′57.8″	500m	23.99km	K2
C 2	NKG	Nakaguchi	36 23 19.9	136 59 31.3	620	34.30	K3
C 3	HSH	Higashihara	36 26 32.9	137 5 17.7	555	44.67	K3
C 4	RSH	Ryoshigahara	36 28 50.6	137 8 24.2	430	51.09*	K3
C 5	KSG	Kufusugawa	36 29 39.7	137 11 44.3	300	55.87	K2
C 6	NRJ	Nirehara	36 30 48.5	137 14 18.0	220	60.24	K1
C 7	DSR	Daisorei	36 31 7.5	137 16 54.4	420	63.97	K2
D 1	SMK	Shimokoya	36°23′36.9″	136°49′ 0.0″	560m	21.52km	K2
D 2	MNY	Minoya	36 29 36.3	136 55 43.7	230	36.47	K2
D 3	TCH	Tochihara	36 31 7.7	136 59 21.1	360	42.30	K3
E 1	KMB	Kumabashiri	36°27′21.0″	136°42′59.0″	300m	22.94km	H2
E 2	ITG	Itagaya	36 29 1.0	136 46 41.1	220	27.78	H2
E 3	TSM	Tanoshima	36 32 7.8	136 46 10.7	220	32.82	H2
E 4	KRS	Kurisu	36 43 38.4	136 50 20.2	120	54.97	H2
E 5	ICS	Ichinoshima	36 48 39.8	136 51 42.4	70	64.43	H2
F 1	MTY	Mitsuyano	36°19′ 2.6″	136°38′37.5″	310m	6.71km	H2
F 2	YSN	Yoshino	36 20 35.9	136 38 3.5	240	9.64	H2
F 3	NNM	Nakanomi	36 23 11.8	136 38 24.4	160	14.39	H2

G 1	KZS	Kazuse	36°17′52.0″	136°35′46.4″	290m	6.40km	H2
G 2	KMJ	Komatsu	36 21 52.3	136 30 20.6	70	17.39	H1
H 1	MRY	Maruyama	36°14′40.4″	136°32′45.3″	440m	9.15km	H2
H 2	OSG	Oosugi	36 15 12.3	136 29 38.7	160	13.71	H2
H 3	ART	Aratani	36 15 6.5	136 25 37.0	95	19.74	H2
H 4	UNE	Une	36 14 37.5	136 18 3.8	100	31.09	H2
H 5	HYM	Hiyama	36 15 25.0	136 15 43.9	20	34.54	H2
H 6	SAK	Saki	36 14 59.2	136 8 45.2	0	45.00	H2
I 1	HTT	Hanatate	36°12′31.4″	136°32′10.0″	590m	11.28km	H2
I 2	KTN	Kutani	36 11 17.0	136 26 27.3	280	20.01	H2
I 3	MOK	Maruoka	36 8 56.9	136 18 2.5	155	33.32	H2
I 4	HRE	Harue	36 7 26.4	136 12 43.8	6	41.76	H2
I 5	FKJ	Fukui	36 5 38.9	136 7 24.0	90	50.42	H1
I 6	HND	Hondo	36 3 44.6	136 8 23.4	75	50.45	H2
I 7	GDS	Godaishi	36 3 55.8	136 3 47.0	195	56.64	H2
〃	〃	〃	〃	〃	〃	56.39*	〃
J 1	TJR	Tajiri	36° 1′46.7″	136° 9′52.3″	10m	50.18km	H2
J 2	YN1	Yoneoka 1	35 59 22.9	136 10 55.6	70	51.26	H2
J 3	YN2	Yoneoka 2	35 59 23.2	136 10 43.3	90	51.51	H2
K 1	IWY	Iwaya	36° 6′33.4″	136°26′30.9″	195m	24.65km	H2
K 2	EHJ	Eiheiji	36 2 45.7	136 21 27.1	240	34.99	H2
K 3	KDN	Kidonouchi	35 59 41.5	136 17 55.4	80	42.74	H2
K 4	MKD	Mukaide	35 58 1.3	136 15 56.3	85	47.02	H2
K 5	OCI	Ochii	35 57 35.5	136 14 11.1	40	49.50	H2
K 6	HKJ	Hokuriku	35 56 15.0	136 12 45.0	20	52.77	H1
K 7	HRS	Hirose	35 53 12.6	136 8 19.7	60	61.47	H2
K 8	NKY	Nakayama	35 51 9.5	136 3 52.7	160	69.01	H2
L 1	TZD	Tanizuido	36° 8′ 0.6″	136°34′50.8″	785m	14.93km	H2
L 2	KAJ	Katsuyama	36 2 55.2	136 31 41.3	300	25.45	H1
L 3	HGM	Higashimata	35 58 51.2	136 26 26.0	180	35.81	H2
L 4	TGC	Taniguchi	35 53 27.8	136 22 33.2	335	47.36	H2
L 5	SHR	Suhara	35 50 41.1	136 28 23.3	600	48.34	H2
L 6	IMJ	Imajo	35 47 53.4	136 18 10.0	240	59.60	H1
L 7	HST	Hashitate	35 43 2.0	136 14 34.5	240	70.08	H2
L 8	AZJ	Azai	35 28 38.0	136 19 26.0	370	91.30	H1
L 9	ORJ	Ooura	35 31 1.7	136 7 10.9	140	94.88	H2
〃	〃	〃	〃	〃	〃	94.35*	〃
L10	MHJ	Mihama	35 31 50.2	135 58 44.2	260	100.64	H1
M 1	KNM	Kurinuma	36°14′26.1″	136°38′30.8″	375m	1.87km	N2
M 2	FKS	Fukase	36 13 53.9	136 38 1.9	465	3.04	N2
M 3	NJM	Nishijima	36 12 43.7	136 37 55.3	450	5.15	N2
M 4	BKD	Byakkodan	36 11 27.7	136 38 9.0	510	7.38	N3
M 5	KTK	Katarashikita	36 9 58.4	136 38 9.0	565	10.12	N2
M 6	KTS	Katarashi	36 8 23.6	136 39 48.1	620	13.08	N3

M 7	INS	Ichinose	36 6 30.6	136 41 19.9	770	16.91	N2
M 8	HGY	Hatogayu	36 1 48.3	136 40 59.6	550	25.39	H2
N 1	OSR	Ooshirakawa	36° 8′39.2″	136°50′19.3″	1145m	21.34km	N2
N 2	HIR	Hirase	36 9 31.5	136 54 1.4	655	25.30	N2
N 3	OGM	Ogami	36 6 26.1	136 56 20.0	765	31.11	N3
N 4	IWK	Iwasekita	36 5 18.3	136 56 54.2	765	32.98	N2
N 5	IWS	Iwase	36 4 6.3	136 57 36.7	775	34.80*	N2
N 6	MKW	Miokawa	36 1 19.7	136 59 56.0	925	41.05	N2
N 7	MSM	Mugishima	36 0 28.5	137 3 21.9	1005	46.08	N2
N 8	NTN	Naratani	35 58 31.0	137 5 11.6	900	50.46	N2
N 9	KOR	Kaore	35 57 26.7	137 8 8.9	690	55.19	N2
N10	KIS	Kuroishi	35 55 15.8	137 9 3.5	675	58.77	N2
N11	MZE	Maze	35 53 28.1	137 9 19.0	590	61.22	N1
N12	HWD	Hiwada	35 51 58.8	137 11 30.6	710	65.52	N2
N13	NMD	Nishimura-dam	35 48 49.6	137 11 31.8	455	69.55	N2
N14	NMR	Nishimura	35 48 59.8	137 12 19.5	660	70.18	N3
N15	ATN	Atsutani	35 46 56.6	137 11 4.8	390	71.60	N2
N16	THR	Takehara	35 45 17.1	137 15 31.2	470	78.03*	N2
N17	HNO	Hebinoo	35 43 28.5	137 18 35.8	595	83.68*	N3
N18	SAM	Sami	35 40 16.0	137 18 26.8	610	88.21	N3
N19	KSM	Kusumi	35 37 5.7	137 18 36.3	440	92.78	N2
N20	SKW	Shirakawa	35 34 17.2	137 18 52.1	740	97.06	N3
N21	TKC	Tsukechi	35 39 12.2	137 27 58.2	690	99.77	N1
N22	HKT	Hirukawatoge	35 32 16.6	137 21 5.6	670	102.06	N2
N23	INU	Inuyama	35 20 58.8	137 1 42.8	132	106.43	N1
N24	ENA	Ena	35 28 18.1	137 22 38.5	290	109.31	N2
N25	YOK	Yamaoka	35 21 33.6	137 24 41.2	500	121.24	N4
N26	INB	Inabu	35 13 47.3	137 33 13.9	690	140.45	N4
N27	OOS	Ooshika	35 34 46.8	138 2 55.5	805	147.19	N1
N28	TYN	Toyone	35 7 58.5	137 40 10.4	650	155.33	N1
	Mt. 1	Tedori-quarry 1	36°15′25.2″	136°38′47.5″	350m	-	
	Mt. 2	Tedori-quarry 2	36 15 5.8	136 38 46.5	400	0.60*	

Table 4 List of observed data: * denotes shot time of less accuracy. Letters in the arrival time column denote accuracy of the arrival time, as follows; A≦ 0.02 sec, 0.02<B≦0.05, 0.05<C≦0.1, 0.1<D. t_h means elevation correction. The mark "′" denotes later phases.

Pro-file	Code	Station Name	Mt.	Shot time M	D	h m s	Arrival time	Δt_h (s)	P-O-Δ/6-Δt_h (s)
A 1	IRN	Ichirino	2	May	24	18h 30m 45s.09	46s.52A	0.08	0.21
A 2	CGO	Chuguonsen	1	July	11	18 27 55.80	57.84A	0.09	0.14
A 3	MGR	Magari	2	July	13	18 33 08.09	12.02A	0.10	0.31
A 4	AMT	Amotoge	1	Aug.	21	18 28 35.81	40.68A	0.11	0.38
A 5	AMJ	Amo	1	July	12	12 34 13.20	19.37A	0.07	0.38
A 6	IBK	Ibukitoge	1	July	16	18 29 07.84	15.11B	0.08	0.27

A 7	KBR	Kambaratoge	1	July	20	18 39 07 .60	16 .72B	0.10	0.18
A 8	OAM	Ooamamidani	1	Aug.	26	18 31 22 .41*	32 .55A	0.10	0.20
A 9	KTJ	Kamitakara	1	July	11	18 27 55 .80	66 .35A	0.10	0.25
A10	SMD	Shiramizudani	1	July	27	18 30 23 .63	35 .23B	0.09	0.16
A11	OIM	Oimo	1	Aug.	20	18 29 01 .83	14 .39D	0.09	0.56
A12	KSD	Kasadani	1	July	28	18 36 35 .00*	47 .44C	0.10	0.00
B 1	FTY	Futatsuya	1	July	26	18h 43m 47s. 63*	54s. 57A	0.11	0.17
B 2	NSN	Nishinobu	1	Aug.	30	18 29 11 .63	19 .52A	0.08	0.14
B 3	SGN	Suganuma	1	July	31	18 36 05 .73	14 .75B	0.11	0.12
B 4	NUY	Nishiurushiyama	1	Aug.	28	18 28 00 .83	10 .99B	0.06	0.26
B 5	AOK	Aokitoge	1	July	29	18 35 35 .39	46 .81C	0.11	0.24
C 1	KZU	Kozu	1	July	17	18h 38m 46s. 98	51s. 41A	0.07	0.36
C 2	NKG	Nakaguchi	1	July	12	12 34 13 .20	19 .34B	0.09	0.33
C 3	HSH	Higashihara	1	July	14	18 44 41 .65	49 .52B	0.08	0.34
C 4	RSH	Ryoshigahara	2	Aug.	22	18 28 56 .27	64 .97B	0.07	0.11
C 5	KSG	Kufusugawa	1	Aug.	25	18 34 44 .38*	53 .97B	0.06	0.22
C 6	NRJ	Nirehara	1	July	12	12 34 13 .20	23 .64A	0.05	0.35
C 7	DSR	Daisorei	1	Aug.	23	18 44 09 .15*	19 .98B	0.07	0.10
D 1	SMK	Shimokoya	1	July	14	18h 44m 41s. 65	45s. 64A	0.08	0.32
D 2	MNY	Minoya	1	Aug.	24	18 29 44 .89*	51 .53B	0.05	0.51
D 3	TCH	Tochihara	1	July	11	18 27 55 .80	63 .19B	0.06	0.28
E 1	KMB	Kumabashiri	1	July	28	18h 36m 35s. 00	39s. 32A	0.08	0.42
E 2	ITG	Itagaya	1	July	19	18 27 42 .02	47 .22A	0.07	0.50
E 3	TSM	Tanoshima	1	July	26	18 43 47 .63*	53 .95B	0.08	0.77
E 4	KRS	Kurisu	1	July	27	12 30 03 .27	13 .24A	0.07	0.74
E 5	ICS	Ichinoshima	1	July	27	18 30 23 .81*	35 .20C	0.06	0.59
F 1	MTY	Mitsuyano	1	Aug.	8	18h 32m 30s. 94	32s. 37A	0.08	0.23
F 2	YSN	Yoshino	1	Aug.	8	18 32 30 .94	32 .95A	0.08	0.32
F 3	NNM	Nakanomi	1	Aug.	8	18 32 30 .94	33 .70B	0.07	0.29
G 1	KZS	Kazuse	1	Aug.	9	18h 38m 53s. 47	54s. 84A	0.08	0.22
G 2	KMJ	Komatsu	1	Aug.	9	18 38 53 .47	57 .05A	0.05	0.63
H 1	MRY	Maruyama	1	Aug.	9	18h 38m 53s. 47	55s. 36A	0.10	0.26
H 2	OSG	Oosugi	1	July	20	18 39 07 .60	10 .35A	0.07	0.39
H 3	ART	Aratani	1	Aug.	1	18 34 14 .47	18 .19A	0.06	0.37
H 4	UNE	Une	1	July	26	18 43 47 .63*	53 .47B	0.07	0.59
H 5	HYM	Hiyama	1	July	5	18 31 07 .02*	13 .63D	0.05	0.80
H 6	SAK	Saki	1	July	29	12 50 57 .64*	65 .89C	0.05	0.70
I 1	HTT	Hanatate	1	Aug.	9	18h 38m 53s. 47	55s. 73A	0.12	0.26
I 2	KTN	Kutani	1	July	28	18 36 35 .00	38 .68A	0.08	0.26
I 3	MOK	Maruoka	1	July	14	18 44 41 .65	47 .64A	0.07	0.37
I 4	HRE	Harue	1	Aug.	4	18 41 43 .24	51 .02C	0.05	0.77
I 5	FKJ	Fukui	1	Aug.	2	18 32 02 .31	11 .39A	0.06	0.62
I 6	HND	Hondo	1	Aug.	10	18 31 06 .01	15 .08B	0.06	0.60

I 7	GDS	Godaishi	1	July	24	19	01	49 . 46	59 . 51A	0. 08	0. 53
〃	〃	〃	2	July	24	18	33	27 . 47	37 . 45B	0. 09	0. 49
J 1	TJR	Tajiri	1	Aug.	11	18 h	28m	58 s. 12*	67 s. 00B	0. 05	0. 47
J 2	YN1	Yoneoka 1	1	Aug.	10	18	31	06 . 01	14 . 98C	0. 06	0. 37
J 3	YN2	Yoneoka 2	1	Aug.	11	18	28	58 . 12*	67 . 16C	0. 06	0. 39
K 1	IWY	Iwaya	1	July	17	18 h	38m	46 s. 98	51 s. 38A	0. 07	0. 22
K 2	EHJ	Eiheiji	1	July	25	18	48	22 . 86	28 . 96A	0. 09	0. 18
K 3	KDN	Kidonouchi	1	Aug.	24	18	29	44 . 87	52 . 34A	0. 06	0. 29
K 4	MKD	Mukaide	1	Aug.	24	18	29	44 . 87	53 . 06A	0. 06	0. 29
K 5	OCI	Ochii	1	July	31	18	36	05 . 73	14 . 32B	0. 06	0. 28
K 6	HKJ	Hokuriku	1	Aug.	2	18	32	02 . 31	11 . 45A	0. 05	0. 29
K 7	HRS	Hirose	1	Aug.	2	18	32	02 . 31	12 . 75A	0. 06	0. 13
K 8	NKY	Nakayama	1	July	12	18	31	25 . 23	37 . 52C	0. 08	0. 71
L 1	TZD	Tanizuido	1	July	11	18 h	27m	55 s. 80	58 s. 75A	0. 15	0. 31
L 2	KAJ	Katsuyama	1	July	11	18	27	55 . 80	60 . 44A	0. 08	0. 32
L 3	HGM	Higashimata	1	July	5	12	28	46 . 73	52 . 97A	0. 08	0. 19
L 4	TGC	Taniguchi	1	July	27	18	30	23 . 81	31 . 93B	0. 10	0. 13
L 5	SHR	Suhara	1	July	31	18	36	05 . 73	14 . 17A	0. 14	0. 24
L 6	IMJ	Imajo	1	Aug.	2	18	32	02 . 31	12 . 65A	0. 09	0. 32
L 7	HST	Hashitate	1	July	13	18	33	09 . 44	21 . 63C	0. 09	0. 42
L 8	AZJ	Azai	1	Aug.	2	18	32	02 . 31	18 . 18C	0. 11	0. 54
L 9	ORJ	Ooura	1	July	4	12	36	46 . 73	63 . 11D	0. 07	0. 50
〃	〃	〃	2	July	4	12	33	47 . 27	63 . 58B	0. 08	0. 50
L10	MHJ	Mihama	1	Aug.	2	18	32	02 . 31	19 . 83C	0. 09	0. 66
M 1	KNM	Kurinuma	1	June	21	15 h	29m	37 s. 75	38 s. 21A	0. 09	0. 06
M 2	FKS	Fukase	1	June	21	15	29	37 . 75	38 . 47A	0. 10	0. 11
M 3	NJM	Nishijima	1	June	21	15	29	37 . 75	38 . 87A	0. 10	0. 16
M 4	BKD	Byakkodan	1	June	21	15	29	37 . 75	39 . 34A	0. 11	0. 25
M 5	KTK	Katarashikita	1	June	21	15	29	37 . 75	39 . 83A	0. 12	0. 27
M 6	KTS	Katarashi	1	May	25	12	29	01 . 69	04 . 23A	0. 12	0. 24
〃	〃	〃	〃	〃	〃	〃	〃	〃	′04 . 46B	〃	′0. 47
M 7	INS	Ichinose	1	May	25	12	29	01 . 69	04 . 96A	0. 14	0. 31
M 8	HGY	Hatogayu	1	July	29	18	35	35 . 39	39 . 98A	0. 12	0. 24
N 1	OSR	Ooshirakawa	1	May	25	18 h	39m	03 s. 56	07 s. 45A	0. 19	0. 14
N 2	HIR	Hirase	1	July	17	18	38	46 . 98	51 . 55A	0. 13	0. 22
N 3	OGM	Ogami	1	July	21	18	26	58 . 99	64 . 67A	0. 16	0. 33
N 4	IWK	Iwasekita	1	July	21	18	26	58 . 99	64 . 97A	0. 16	0. 32
N 5	IWS	Iwase	2	July	12	12	34	13 . 21	19 . 43A	0. 17	0. 25
N 6	MKW	Miokawa	1	July	12	18	31	25 . 61	33 . 06A	0. 19	0. 42
N 7	MSM	Mugishima	1	July	13	18	33	09 . 44	17 . 76B	0. 20	0. 44
〃	〃	〃	〃	〃	〃	〃	〃	〃	′17 . 92D	〃	′0. 60
N 8	NTN	Naratani	1	July	13	18	33	09 . 44	18 . 35B	0. 18	0. 32
N 9	KOR	Kaore	1	June	19	18	44	19 . 32	29 . 10B	0. 15	0. 43
N10	KIS	Kuroishi	1	July	11	18	27	55 . 80	66 . 29C	0. 15	0. 54

N11	MZE	Maze	1	July	20	18	39	07 . 60	18 . 49C	0. 14	0. 55
N12	HWD	Hiwada	1	July	11	18	27	55 . 80	67 . 60B	0. 16	0. 72
N13	NMD	Nishimura-dam	1	June	19	18	44	19 . 32	31 . 63B	0. 12	0. 60
〃	〃	〃	〃	〃	〃	〃	〃	〃	'31 . 81C	〃	'0. 78
N14	NMR	Nishimura	1	June	19	18	44	19 . 32	31 . 74C	0. 15	0. 57
〃	〃	〃	〃	〃	〃	〃	〃	〃	'31 . 95D	〃	'0. 78
N15	ATN	Atsutani	1	June	19	18	44	19 . 32	31 . 63C	0. 11	0. 27
〃	〃	〃	〃	〃	〃	〃	〃	〃	'31 . 92C	〃	'0. 56
〃	〃	〃	〃	〃	〃	〃	〃	〃	'32 . 22C	〃	'0. 86
N16	THR	Takehara	2	May	26	18	31	55 . 18	68 . 48B	0. 13	0. 16
〃	〃	〃	〃	〃	〃	〃	〃	〃	'68 . 89C	〃	'0. 57
N17	HNO	Hebinoo	2	May	26	18	31	55 . 18	69 . 76B	0. 15	0. 48
N18	SAM	Sami	1	July	21	18	26	58 . 99	74 . 37B	0. 14	0. 54
〃	〃	〃	〃	〃	〃	〃	〃	〃	'76 . 28D	〃	'2. 45
N19	KSM	Kusumi	1	Aug.	4	18	41	43 . 24	59 . 47C	0. 12	0. 65
N20	SKW	Shirakawa	1	July	19	18	27	42 . 02	58 . 71C	0. 16	0. 35
〃	〃	〃	〃	〃	〃	〃	〃	〃	'59 . 02C	〃	'0. 66
〃	〃	〃	〃	〃	〃	〃	〃	〃	'60 . 36D	〃	'2. 00
N21	TKC	Tsukechi	1	June	19	18	44	19 . 32	36 . 81C	0. 15	0. 71
〃	〃	〃	〃	〃	〃	〃	〃	〃	'38 . 08D	〃	'1. 98
N22	HKT	Hirukawatoge	1	Aug.	10	18	31	06 . 01	23 . 77B	0. 15	0. 60
N23	INU	Inuyama	1	June	19	18	44	19 . 32	37 . 52B	0. 07	0. 39
〃	〃	〃	〃	〃	〃	〃	〃	〃	'38 . 85C	〃	'1. 72
N24	ENA	Ena	1	Aug.	8	18	32	30 . 94	49 . 65C	0. 09	0. 40
〃	〃	〃	〃	〃	〃	〃	〃	〃	'50 . 07D	〃	'0. 82
N25	YOK	Yamaoka	1	Aug.	8	18	32	30 . 94	52 . 02C	0. 13	0. 74
〃	〃	〃	〃	〃	〃	〃	〃	〃	'52 . 31D	〃	'1. 03
N26	INB	Inabu	1	Aug.	11	12	28	51 . 14	75 . 20D	0. 15	0. 50
〃	〃	〃	〃	〃	〃	〃	〃	〃	'75 . 53C	〃	'0. 83
N27	OOS	Ooshika	1	June	19	18	44	19 . 32	44 . 59D	0. 17	0. 57
〃	〃	〃	〃	〃	〃	〃	〃	〃	'44 . 99C	〃	'0. 97
N28	TYN	Toyone	1	June	19	18	44	19 . 32	45 . 60C	0. 15	0. 24
〃	〃	〃	〃	〃	〃	〃	〃	〃	'46 . 40D	〃	'1. 04

The JJY time signals were used for the timing systems at almost all the mobile stations, and the timing error at these stations was less than 0. 01 seconds. Therefore, the accuracy in the arrival time depends mainly on the sharpness in the recorded onset of seismic waves from the blasts. The degree of the sharpness is indicated by different ranks in Table 4. Later phases have not been analyzed here except for the N-line.

Corrections of the travel times for the elevation of both the shot point and the observation sites were made by assuming that wave velocity in the surface layer above the sea level is 4. 5 km/sec and that there exists a layer of 5. 5 km/sec down to 3 km overlying a layer of 6. 0 km/sec. For the A-D lines, however, a layer with 5. 5 km/sec was assumed to exist down to 3 km over that of 6. 15 km/sec, by referring to a first approximation for the travel time curve. These elevation corrections imply that both the shot point and the observation site have been pulled down to sea level. The sum of the travel time correction indicated by "Δt_h" is given in Table 4 together with the observed data. The recorded seismograms arranged for each of the profiles are shown in Figs. 4(a)-(n).

During the period from April to September in 1978, it has been reported by JMA and the Hokuriku Observatory that two remarkable earthquakes with magnitudes greater than 4 and fourteen local earthquakes with magnitudes ranging between 4

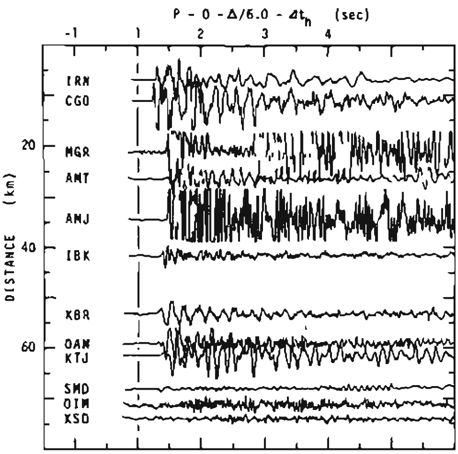
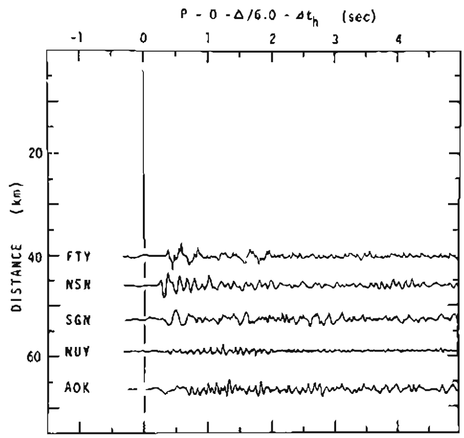
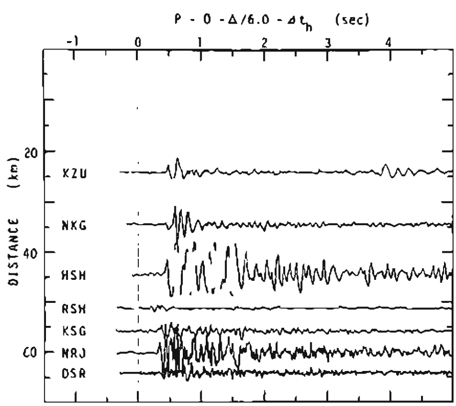


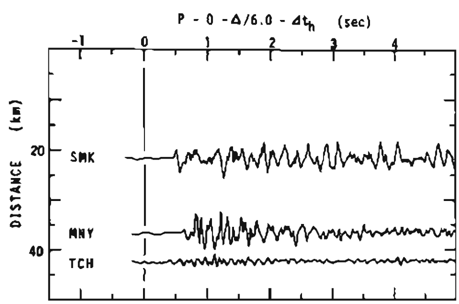
Fig. 4. (a) Recorded seismograms arranged for A-line.



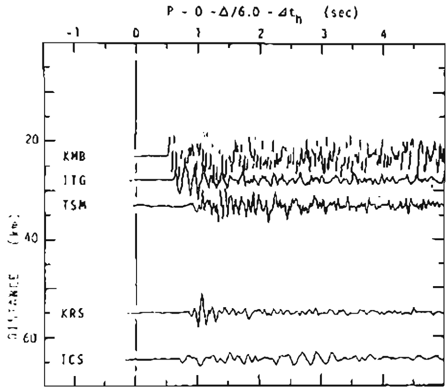
(b) Recorded seismograms arranged for B-line.



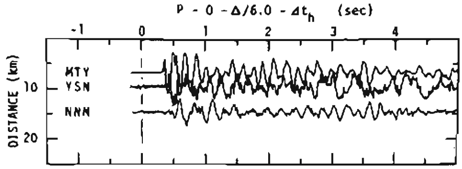
(c) Recorded seismograms arranged for C-line.



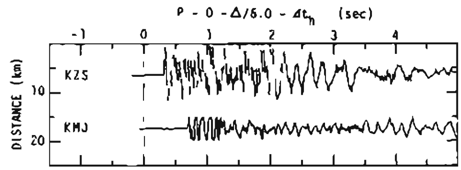
(d) Recorded seismograms arranged for D-line.



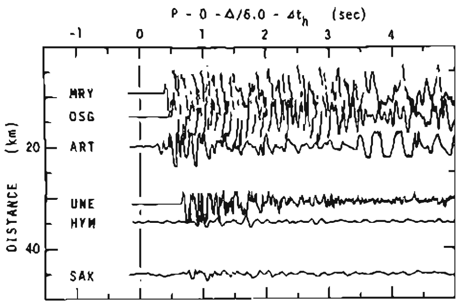
(e) Recorded seismograms arranged for E-line.



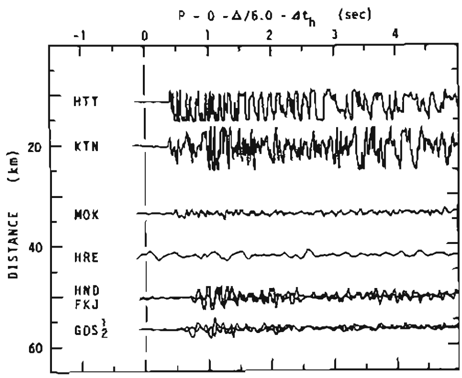
(f) Recorded seismograms arranged for F-line.



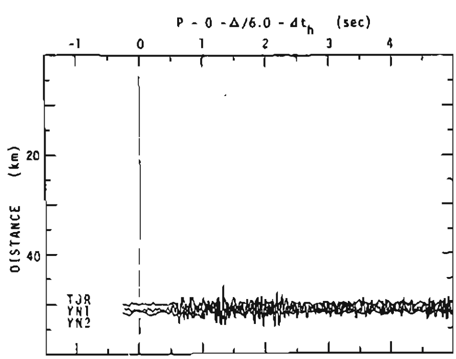
(g) Recorded seismograms arranged for G-line.



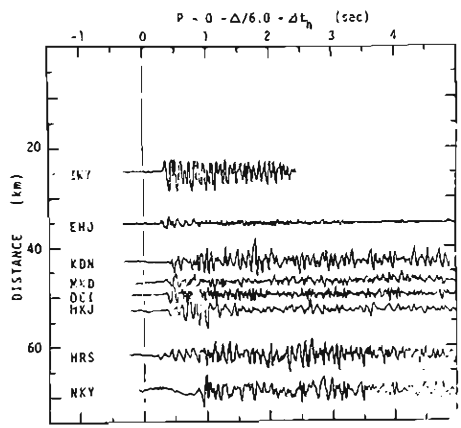
(h) Recorded seismograms arranged for H-line.



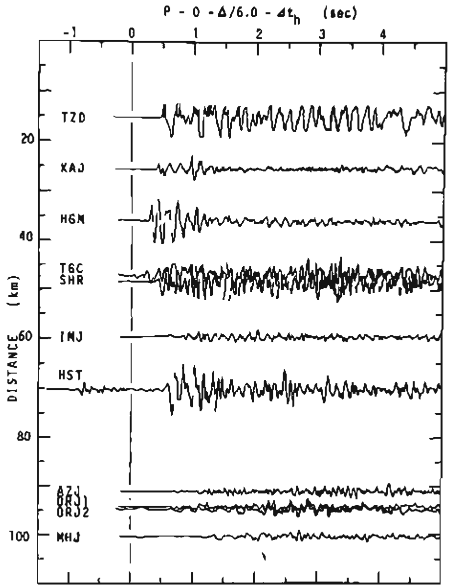
(i) Recorded seismograms arranged for I-line.



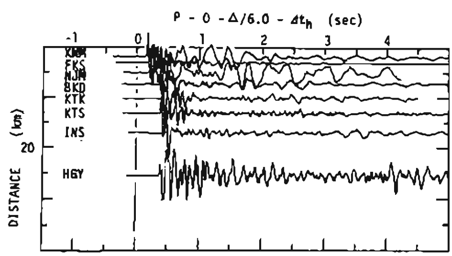
(j) Recorded seismograms arranged for J-line.



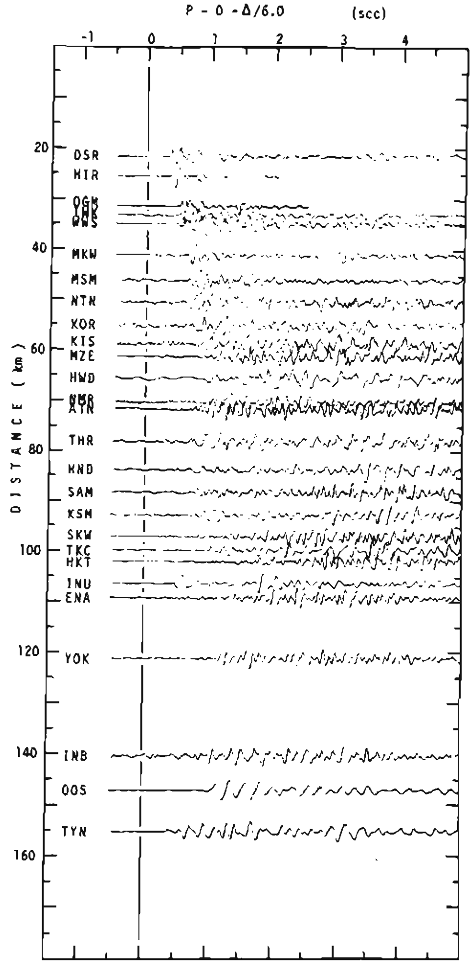
(k) Recorded seismograms arranged for K-line.



(l) Recorded seismograms arranged for L-line.



(m) Recorded seismograms arranged for M-line.



(n) Recorded seismograms arranged for N-line.

and 3 took place in the region of present interest (35°20′-36°40′N, 136°00′-137°00′E). Nine of the sixteen earthquakes occurred in April and May and four in September. It seems unlikely that the travel times observed for the various ray paths from the shot point to the observation sites are significantly affected by stress accumulation or release, in view of the low magnitudes of these earthquakes. No remarkable velocity changes exceeding the observational accuracy (~1%) have been detected for two years from 1976 to 1977, from careful investigations of routine observational data for the quarry blasts at the Hokuriku and Kamitakara Observatories.

4. Analysis

The time-distance relation for the N-line includes many observation sites extending

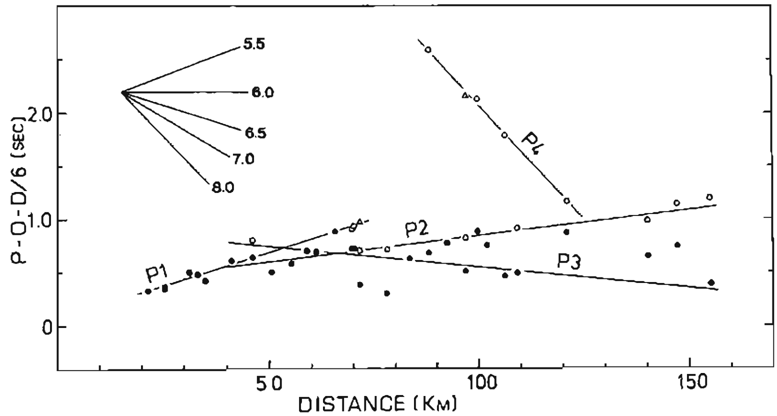


Fig. 5. Time-distance relation about N-line, which is the longest profile and includes many observation sites. Elevation corrections are not applied to this profile, because of the unsuitableness of the assumed structure. P1-P4 are indicated in Eq. 4.

up to a distance of 150 km, is shown in Fig. 5. For this profile, the method of elevation correction mentioned above seems to be unsuitable, becuase a negative intercept time comes out. Perhaps, the structure used for elevation corrections may be unsuitable for this profile. The relation without applying elevation corrections may be expressed by the following four branchs with different apparent velocities;

$$\begin{aligned} P_1 &: T=0.06+\Delta/5.58 \\ P_2 &: T=0.35+\Delta/5.83 \\ P_3 &: T=0.95+\Delta/6.15 \\ P_4 &: T=6.38+\Delta/8.09 \end{aligned} \qquad (4)$$

These apparent velocities are obtained by analyzing both initial and later phases. It is worth noticing that an apparent velocity of 5.83 km/sec is defined following an apparent velocity of 6.15 km/sec in the time-distance relation. The fact that these two apparent velocities are distinguishable provides an essential suggestion to the problem whether the granitic layer in the Chubu district consists of two layers or not.

Similar relations for the A-M lines involves somewhat scattered points and the apparent velocities estimated for the individual lines show appreciably different values. This indicates that the upper crustal structure in this region may not be uniform, but should be regarded as laterally heterogeneous. For this reason, we decided to obtain information on the average structure over several subdivided regions. All of the A-M lines were grouped into four regions; (1): A-D, (2): D-F, (3): G-J, (4): K-M, which is shown in Figs. 6(a)-(d). For region (1), the first layer is estimated to have a P-wave velocity of 5.5 km/sec down to 3 km, while the second layer would have a velocity of 6.15 km/sec, if we assume horizontally stratified layers. Careful examinations show that there is a small gap in the travel times at a distance of around 55 km,

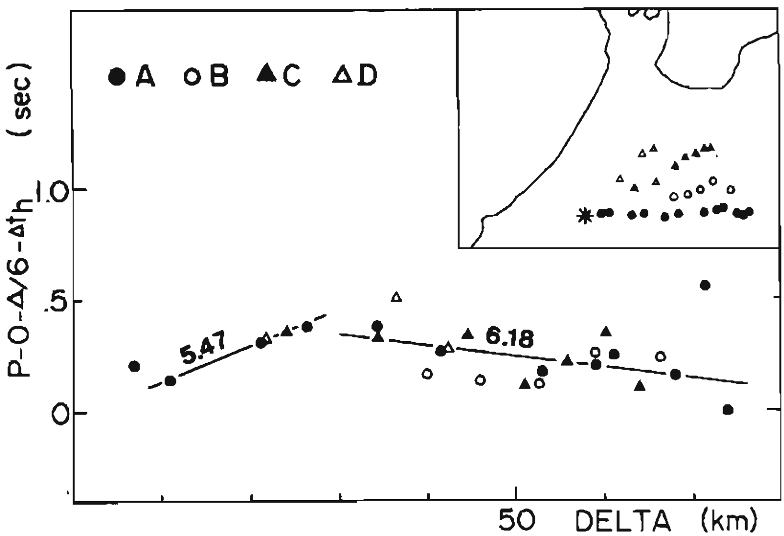
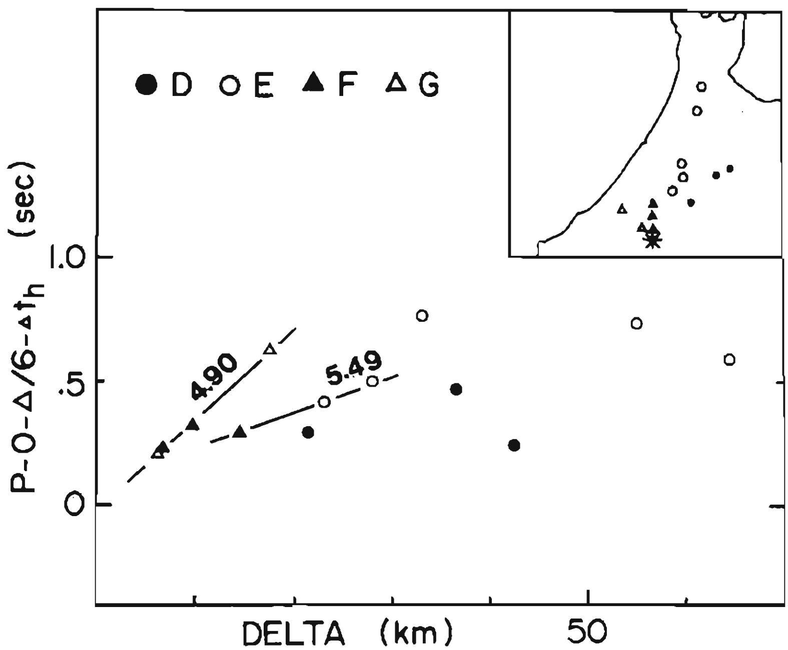
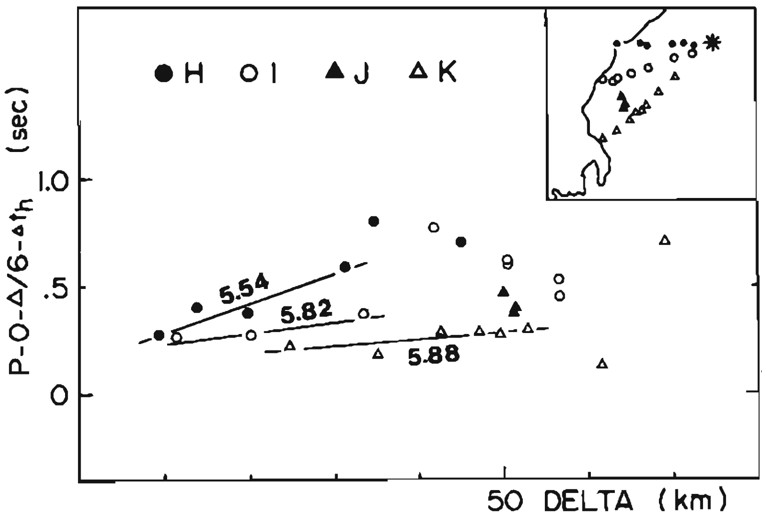


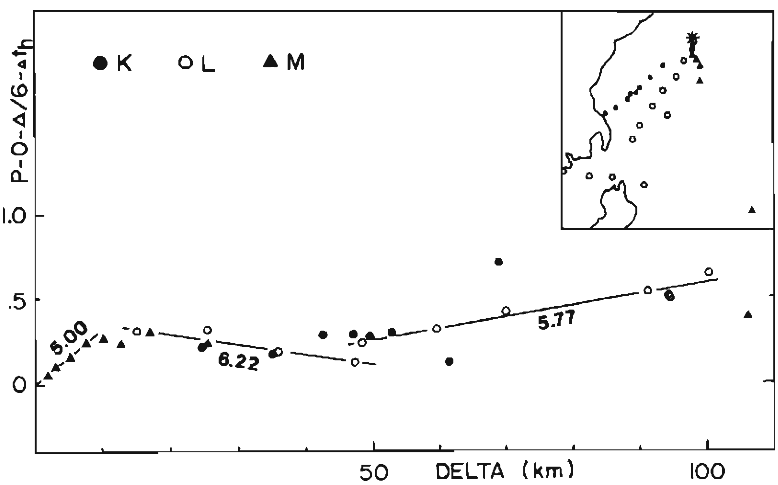
Fig. 6. (a) Time-distance relation for the group of A-D lines.



(b) Time-distance relation for the group of D-G lines.



(c) Time-distance relation for the group of H-K lines.



(d) Time-distance relation for the group of K-M lines.

but we will not raise further arguments due to the lack of reversed observations along the profile. For regions (2) and (3), similar gaps in the time-distance curves around 30 km may be recognized. If these gaps are taken into consideration, the apparent velocities would be estimated as indicated in these figures. For region (4), it may be recognized from observations near the shot point that there exists a surface layer with a velocity of 5.0 km/sec. For the L-line, explosions made for different purposes on the eastern and western coast of Lake Biwa have been used as the shots at the

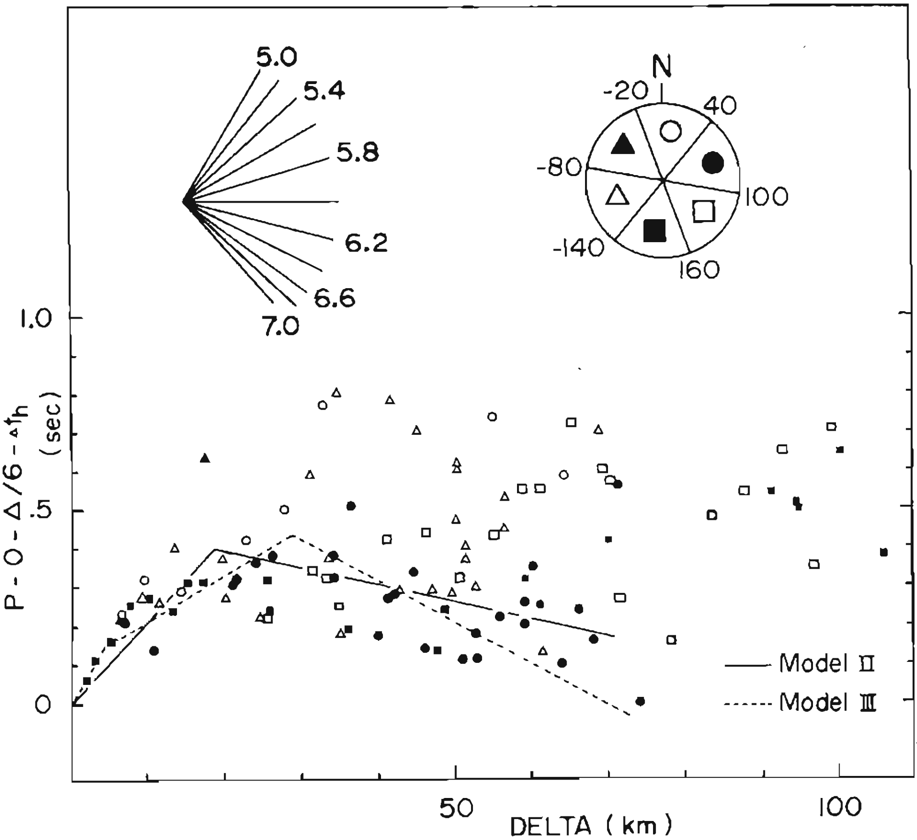


Fig. 7. Time-distance relation for all sites nearer than a distance of 110 km. They are classified into 6 groups by every 60 degrees in azimuth.

other end. The results suggest that the second layer appears to dip southwestwards by 2.3-2.5 degrees and that the layer has a vertical velocity discontinuity with a step-like structure of about 6 km. The second layer has two different velocities, namely 5.85 km/sec in the southwestern side of the discontinuity and 6.18 km/sec in the northeastern side[10].

However, since reverse observations have not been made along most of the profiles, we have to assume horizontally stratified layers for the crustal structure. To investigate preliminarily possible azimuthal dependence of the travel times, the present profiles are grouped into 6 sectors by every 60 degrees as shown in Fig. 7. It is noticed that the travel time data scatter in a wide range exceeding 0.5 seconds for distances greater than 30 km. There is a general pattern that the observation sites in the eastern profiles provide faster travel times with less scattered data, while in the northern and western sides the travel times are slower with larger scattering. These

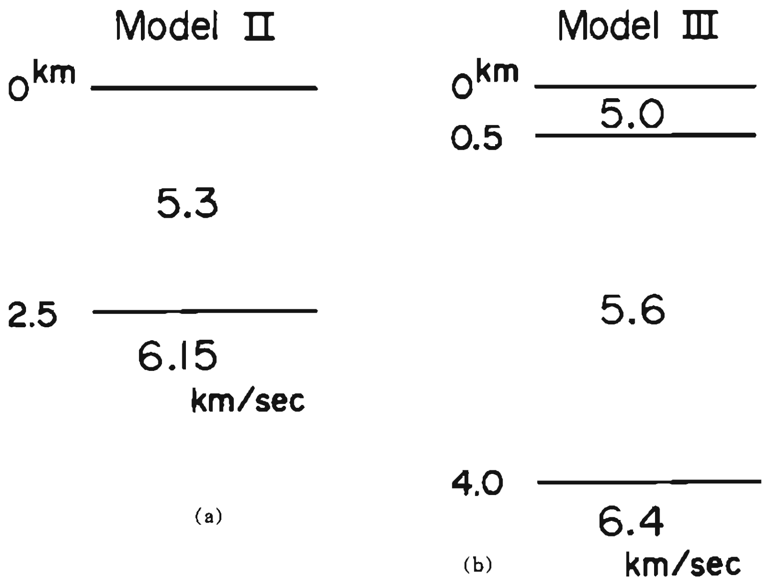


Fig. 8. (a) A proposed upper crustal structure, Model II.
(b) 〃 〃 〃 〃 Model III.

trends might be explained by the geological features in which there are thick alluvial layers in the northern and western sides and hard metamorphic rocks in the eastern side, and that there seems to exist a graben-like structure of basement rocks under the alluvial layers. The travel times at seven sites, I5-6, J1-3 and K5-6, at distances around 50 km and with azimuth of 20 degrees have remarkable azimuthal dependence, indicating a counterclockwise shortening as shown in Fig. 7. From Figs. 6(a)-(d) and Fig. 7, we propose two different models; Model II (Fig. 8 (a)) with double layers indicated by $T_{12}=\Delta/5.3$, and $T_{22}=0.48+\Delta/6.15$ and Model III (Fig. 8 (b)) with three layers given by $T_{13}=\Delta/5.0$, $T_{23}=0.09+\Delta/5.6$ and $T_{33}=0.73+\Delta/6.4$. The travel time curves for Models II and III are drawn in Fig. 7. The differences between the observed travel times (corrected for station elevation) and the corresponding times calculated for Model II are plotted in Fig. 9. It is immediately noticed that there exists abnormaly slow travel time areas along the coastal region of the Sea of Japan, particularly in the west of the Fukui plain, suggesting the existence of a low velocity surface layer in the area.

From the present observation, we have obtained some informations on the upper crustal structure in the northwestern Chubu region. This is summarized as follows:

(1) There are remarkable differences in the time-distance relations along different profiles. Because of the lack of reverse observations, two simple layered models are tentatively proposed: Model II with two layers and Model III with three layers.

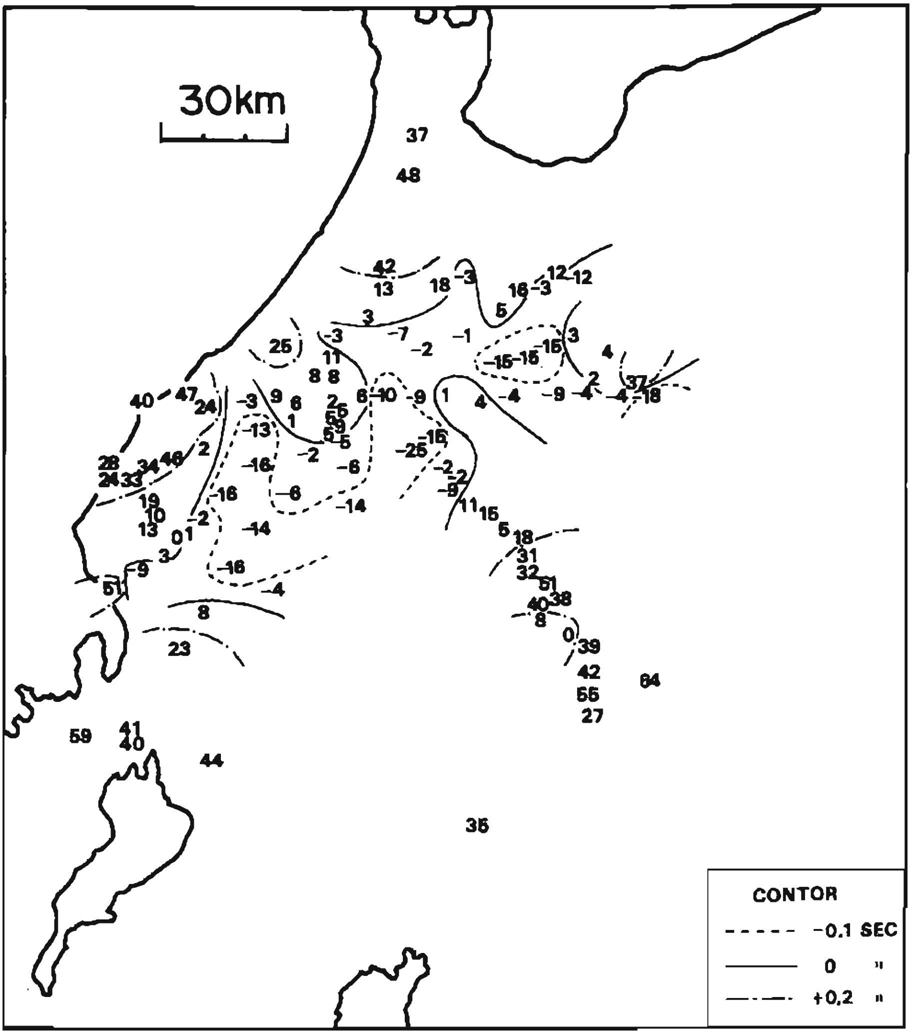


Fig. 9. Distribution of the differences between the observed travel times and the theoretical ones calculated from Model II. Numerals show the differences multiplied by one hundred.

(2) It is impossible to represent the upper crustal structure over the whole region by a horizontally layered model. Dipping layers, step-like structures and lateral inhomogeneities would have to be taken into consideration to investigate the structure in this region closely.

(3) There seem to exist extremely slow travel-time areas along the coastal regions of the Sea of Japan. It is undoubtedly necessary to synthesize data from other explosions and natural earthquakes to discuss the crustal structure in more detail.

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