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Characteristic Seismograms

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Preface

Recently, seismology has made rapid advances, and many textbooks and numerous papers have been published. However, among these publications, the selection of seismograms is only fragmentary. If there is a systematic collection of seismograms on a world-wide scale, or from shallow to deep sources its collection will be useful for better understanding of seismic phenomena.

In general, the complexity of the earth's structure causes seismograms of a great variety of waveforms and wave types. The waveform in the seismograms, especially the appearance of phases, differs from region to region even in events with similar epicentral distances, source depths and earthquake sizes. In order to clarify the local and regional characteristics of seismograms and to find unusual phenomena, the seismogram collection is made using the data of Dodaira station (DDR) over the last two decades.

The seismograms are separated into seismic regions, and are arranged along the epicentral distance, or the source depth within the region. Including special events with unusual waveform features, one hundred samples are prepared. Among these samples, some of them are already well known, however, there still includes some new phenomena.

A brief comment is attached to each sample. Seismograms contain a great variety of information. New facts will be found from this collection.

1. Introduction

In general, the complexity of the earth's structure causes seismograms of a great variety of waveforms and wave types. The waveform in the seismogram, especially the appearance of "phase" differs from region to region even in events with similar epicentral distances, source depths and earthquake sizes, and such a complexity of the seismograms gives clues in the study of earthquake phenomena.

This seismogram collection demonstrates the following points:

1) The characteristic seismograms including the phase and spectrum of earthquakes on a world-wide scale.
2) Depth-dependence of waveform and spectrum in a given seismic region.
3) Spatial behavior of seismic waves along some special zones, such as the 20°, 100°, 143° discontinuities and others.
4) Special features of seismograms of some event groups including foreshocks, main shocks, aftershocks and earthquake swarms.
5) Unusual seismograms in each region.

One hundred samples, including some special events, such as "underground explosions", are collected. Among these samples, some of them are already well known, however, there are still some new phenomena in this collection.

2. Data

The seismograms selected here were compiled from data of Dodaira Micro-earthquake Observatory (DDR) and its satellite stations. The locations of seismographic stations with their geological formations are shown in Table 1 and Fig. A.

Table 1. List of seismographic stations with local geology.

Station	Code	Location		Altitude	Formation
Dodaira	DDR	35°59′54.″0N	139°11′36.″2E	800 m	Chart
Tsukuba	TSK	36 12 39.0N	140 06 35.0E	280 m	Granite
Kiyosumi	KYS	35 11 51.6N	140 08 53.6E	180 m	Sandstone
Ohyama	OYM	35 25 12.3N	139 14 34.9E	600 m	Andesite
Shiroyama	SRY	35 30 30.0N	139 16 27.0E	254 m	Slate

All seismic signals are recorded at the Earthquake Research Institute (ERI), Tokyo by a telemetering system. DDR is the main station of our seismic network. Since 1968, three kinds of instruments, i.e., short-period (SP), medium-period (MP) and long-period (LP, LP-Low

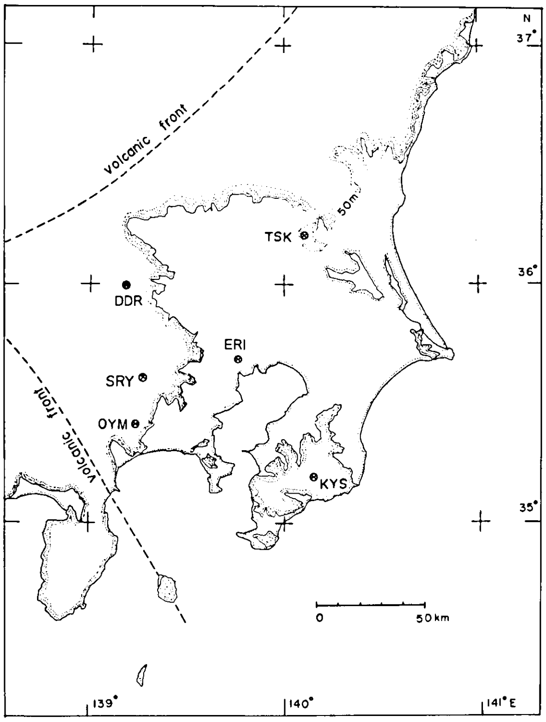


Fig. A. Distribution of seismographic stations. All seismic signals are recorded at Earthquake Research Institute (ERI), Tokyo by a telemetering system.

gain) seismographs have been in operation. Moreover, since 1973, two types of seismographs with wide-band (WB) and ultra long-period (ULP) were added in order to cover a wider dynamic range.

Figure B shows the displacement magnification curves of these seismographs. A detailed description of the seismograph system was given by TSUJIURA (1965, 1967, 1973b, 1983a).

In the recording station at ERI, all seismic signals at DDR, except for the signals of SP seismographs, have been continuously recorded on magnetic tape since the beginning of 1968. In these data, local earthquakes with magnitudes greater than about 4 have been transcribed on a commercial 1/4 inch tape together with the teleseismic events with magnitudes (Mb) greater than about 5.5, and these tapes have been preserved as a permanent data library. Using the data stored in the past two decades, the seismogram collection is made.

For the representation of this collection, the SP seismograms were copied from original seismograms recorded at a paper speed of 60 mm/min on an ink-writing chart recorder, and the seismograms of MP, WB, LP and ULP seismographs were obtained from the magnetic tape mentioned above.

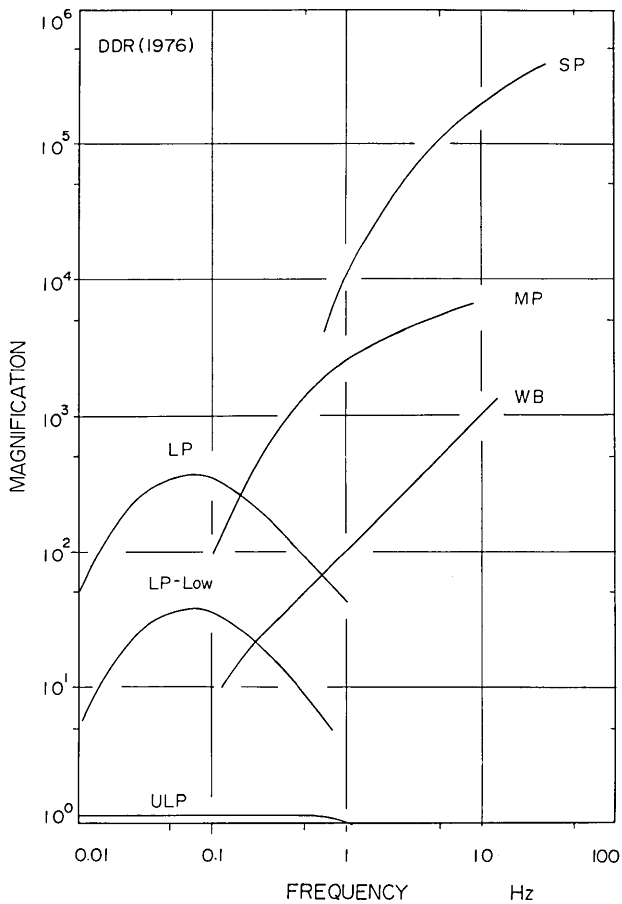


Fig. B. Magnification curves of the seismographs at DDR. SP; short-period, MP; medium-period, WB; wide-band, LP; long-period, ULP; ultra long-period seismographs, respectively. The magnifications, except for SP and LP, were changed as of Dec. 21, 1973 (see TSUJIURA, 1973b).

For better representation, the amplitudes of tape seismograms are arranged by changing the gain of play-back amplifier (G), and their paper speeds are also variable between 0.1–500 mm/sec. The magnification shown in Fig. B corresponds to 12 db gain of the play-back amplifier.

The seismograms are separated mainly according to the region proposed by FLINN and ENGDAHL (1965), except for local earthquakes within an area of few hundred kilometers. The separated seismograms in each region are selected when there are some features in wave-form, spectrum and phase appearance. Moreover, this collection includes seismograms from similar distances, but different azimuths (regions), or from similar distances, but different depths, when there is a notable difference.

3. Arrangement of seismograms

The seismograms in this collection are arranged in order of increasing distance from the station from 10 kilometers to 159 degrees. No earthquakes were observed at our stations beyond 160 degrees. One hundred samples consisting of 368 earthquakes are presented. Table 2 shows an arrangement of 100 samples, including title and epicentral data.

In Figures 1-18, the characteristic seismograms of local and near earthquakes are presented. The separation of local and near earthquakes is somewhat uncertain. We refer to earthquakes as local when their epicentral distances are less than 200 km, and near when their distances are less 10 degrees.

In Figures 19-36, the characteristic seismograms of regional earthquakes where their distances lie between 11° and 19° are presented. The regional earthquakes from DDR station cover a wide azimuth angle including the Japan Sea, Kurile-Okhotsk, Marianas and Ryukyu Islands regions.

In Figures 37-50, the seismograms of teleseismic events where their distances lie between 20° and 47° are presented. In this distance range, the earthquakes cover the regions of Aleutian, Mariana, Philippine, Celebes and Banda Sea. These seismograms contain a great variety of reflected and converted waves.

Figures 51-57 show some features of surface waves including the nature of dispersion and the dependence of source depth, and Figures from 58 to 60 show some features of the waveform and spectrum of underground explosions in the Novaya Zemlya region.

Figures 61-78 show seismograms of teleseismic events where their distances lie between 56° and 100°. These earthquakes distribute over a wide regions, Afghanistan-USSR, South Pacific Ocean, Indian Ocean and North Atlantic Ridge. These seismograms also contain a great variety of reflected waves and surface waves.

Figures 79-91 show seismograms of events beyond a distance of 101° located in the North Atlantic Ocean and Latin America. These seismograms include the spatial behavior from *P*(diffracted) waves to *PKP* waves and its 143° cusp.

Figures 92-100 show the waveform and spectral features for some event groups including earthquake swarms, foreshocks, foreshock-main shock-aftershock sequences and coda waves from local earthquakes.

Origin time, epicentral location, focal depth (h), magnitude (Mb) and epicentral distance (Δ) are based on the Bulletin of the International Seismological Centre (ISC), except for a few figures of local earthquakes. The focal parameters of local earthquakes are obtained from the Monthly Bulletin of the Japan Meteorological Agency (JMA).

Brief comments with title are held for each set to emphasize the features of seismograms, and known phases are indicated when their arrival times agree within a few seconds for the computed travel times given by the Jeffreys and Bullen (1967). Where there are unlabeled points indicated by "*i*", "*X*" or "*e*", there is still new informations to be obtained from this collection.

Table 2. Arrangement of seismograms.

No.	Title	Region	Δ (°)	Page
1	Seismograms, local earthquake....	Izu Pen.	1.1	11
2	Surface waves, local earthquakes...	Honshu	1.5	13
3	Local variation, surface wave dispersion (1)....................	Honshu	3	15
4	Local variation, surface wave dispersion (2)....................	Kyushu	7.5	17
5	Local variation of spectrum.......	Kanto	2	19
6	Depth variation of spectrum......	Off Chiba	2	21
7	Reflected wave, plate boundary....	Ibaraki	70*	23
8	Converted wave, plate boundary...	Off Kii-	4	25
9	High-frequency earthquakes.......	E. Honshu	6	27
10	Low-frequency earthquake.........	S. Honshu	5	29
11	Waveform features of earthquake swarm (1).......................	E. Honshu	5.8	31
12	Waveform features of earthquake swarm (2).......................	E. Honshu	5.8	33
13	Waveform features of earthquake swarm (3).......................	Izu Pen.	50*	35
14	*P* waveforms of large earthquakes..	Honshu	1-4	37
15	*P* waveforms of large earthquake..	Off Ibaraki	2.3	39
16	Spectral features of tsunami earthquakes (1)..................	Kurile	10	41
17	Spectral features of tsunami earthquake (2)...................	Kurile	9.6	43
18	*ScS* wave, near earthquakes.......	S. Honshu	3-7	45
19	*ScP* wave, regional earthquakes...	Okhotsk-	12-18	47
20	Multi-reflections, *ScS* waves.......	N. Korea	9	49

°: degrees of arc, *: kilometers.

Table 2. (continued)

No.	Title	Region	Δ	Page
21	*P* waveform, large deep earthquake (1)	S. Honshu	7	51
22	*P* waveform, large deep earthquake (2)	Kurile	10	53
23	*P* waveform, regional deep earthquakes	S. Honshu	12	55
24	Regional variation, *P* waveform, deep earthquakes	S. Honshu, Japan Sea	9	57
25	Low-frequency waves, deep earthquakes	Mariana, Okhotsk	18	59
26	*X* phases, deep earthquake (1)	Okhotsk	18	61
27	*X* phases, deep earthquakes (2)	Okhotsk	18	63
28	Reflected wave, 20° discon. (1)	Volcano	14	65
29	Reflected wave, 20° discon. (2)	Kurile, Volcano, Ryukyu	14	67
30	Reflected wave, 20° discontinuity	Kurile-	11-18	69
31	Reflected wave, 20° discon.	Volcano-	12-18	71
32	Reflected wave, 20° discon.	Ryukyu-	11-19	73
33	Regional variation, 20° discon.	Kurile, Ryukyu	14-15	75
34	*S* waves, 20° discontinuity	Ryukyu	15, 18	77
35	*S* waves, 20° discontinuity	Ryukyu	10-19	79
36	*S* waves—depend on depth—	Mariana	18	81
37	Reflected waves	Mariana	20	83
38	Seismograms along distance	Taiwan-	19-26	85
39	Seismograms along distance	Philippine-	29-39	87
40	Seismograms along distance	Aleutian-	33-46	89
41	Seismograms—depend on depth—	Aleutian	33	91
42	Seismograms, explosion	Aleutian	32	93
43	Seismograms—depend on depth—	Philippine	32	95
44	Seismograms—*ScSp*—	Philippine	32	97
45	Seismograms—depend on depth—	Celebes	38	99
46	Seismograms—*ScSp*—	Celebes	36	101
47	Spectral variation, *ScS* wave	Philippine-	31-38	103
48	Seismograms—depend on depth—	Banda Sea	44	105
49	Seismograms—depend on depth—	Banda Sea	43	107
50	Seismograms—*PcP*, *PcS*—	Flores Sea	46	109
51	Surface waves	W. Irian	40	111

Table 2. (continued)

Table 2. (continued)

1. Seismograms from local earthquake

Seismograms obtained from three components of MP and LP seismographs at DDR for the event in the Central Izu Peninsula (closed circle). These seismograms are reproduced from magnetic tape data. G is gain of play-back amplifier.

The facal parameters by JMA are as follows:

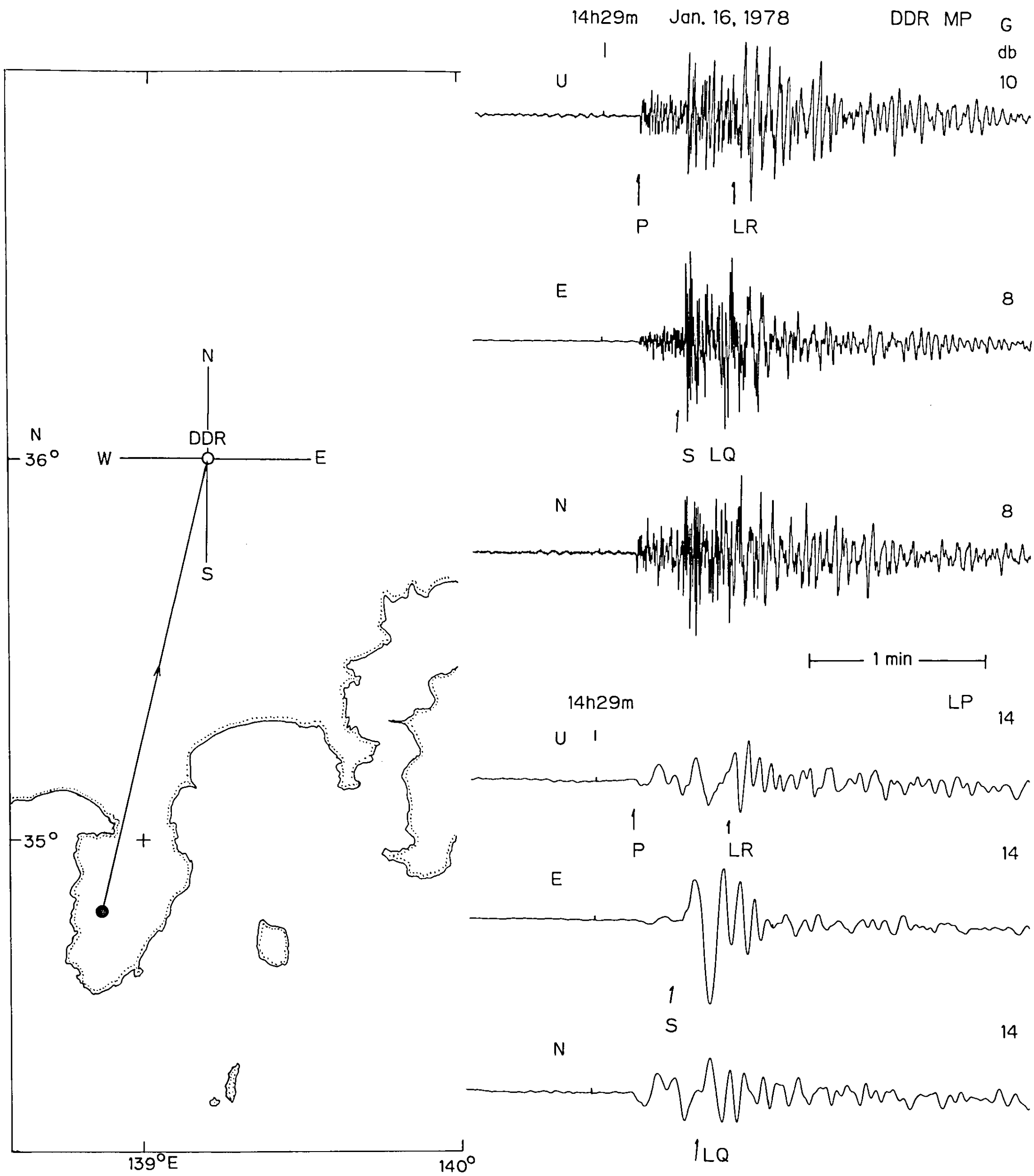
Origin Time	Epicenter		h	M	Δ
h m s	N	E	km		km
14 28 50.8*	34°.83	138°.87	0	4.7	120

*: Japanese Standard Time (UT+9h). h: source depth. M: magnitude.
Δ: epicentral distance.

Comments

1) The incidence from the SSW direction shows larger P wave amplitude in the N-S component than in the E-W component.
2) Short-period surface waves (LQ, LR) are seen on the MP and LP seismograms, especially on the MP-Z seismogram.
3) The MP seismograms passing through the low-pass filter with cut-off frequency of 0.5 Hz give a typical dispersion of LR wave starting from the period of 5 seconds.

Fig. 1


14h29m
Jan. 16, 1978
DDR MP
G
db
U
10
P
LR
E
8
S LQ
N
8
1 min
14h29m
LP
U
14
P
LR
E
14
S
N
14
LQ
N
36°
W
DDR
E
S
35°
139°E
140°

2. Surface waves from local earthquakes

Surface waves from local earthquakes obtained by MP seismographs at DDR and their epicentral locations by JMA. The event numbers on the left-hand side of the seismograms are in chronological order, and the sizes of bars show relative differences of magnification.

The focal parameters by JMA are as follows:

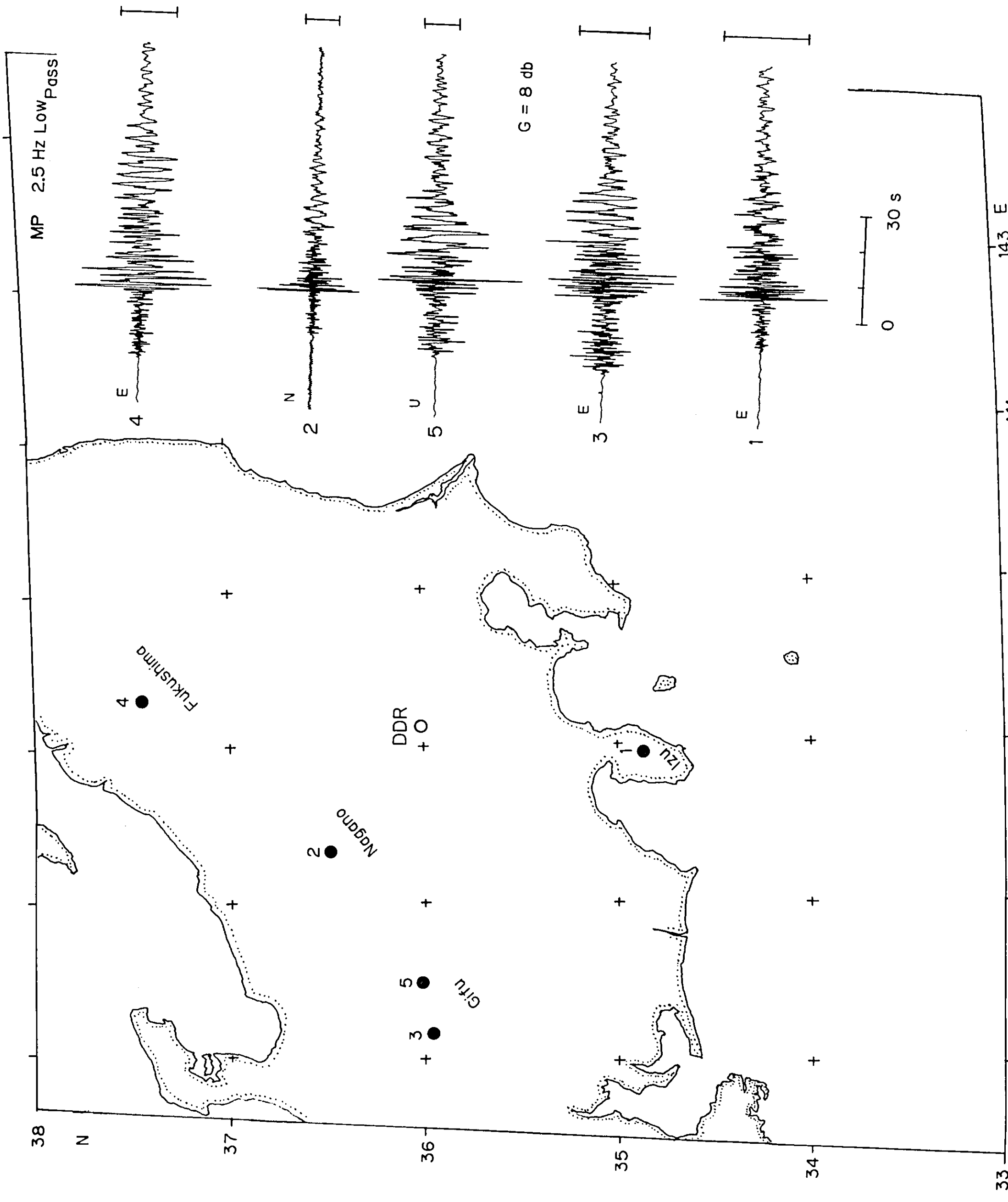
No.	Date	Origin Time*	Epicenter		*h*	*M*
		h m s	N	E	km	
1	May 11, 1974	21 44 46.6	34°.83	138°.95	10	4.0
2	Jan. 08, 1977	04 02 12.9	36.57	138.28	10	4.0
3	Oct. 06, 1983	14 20 35.2	35.92	137.21	0	4.5
4	Feb. 04, 1984	07 21 22.2	37.43	139.33	1	4.4
5	Mar. 07, 1986	03 25 33.5	36.02	137.50	4	4.9

*: Japanese Standard Time (UT+9h).

Comments

1) Short-period surface waves are seen for shallow local earthquakes ($h<10$ km).
2) Seismograms passing through the low-pass filter show the dispersion of surface waves starting from 5 sec period.
3) Local variation of the velocities of surface waves seems to exist there.
4) Medium-period seismograms (MP) are more useful for the study of local surface-wave dispersion than the SP and LP seismograms.

Fig. 2


MP 2.5 Hz Low Pass
G = 8 db
0
30 s
4 E
2 N
5 U
3 E
1 E
Fukushima
Nagano
Gifu
Izu
DDR
38 N
37
36
35
34
33
137
138
139
140
141
143 E

3. Local variation of surface wave dispersion (1)

Comparison of surface waves from two local earthquakes. The upper three traces show seismograms obtained by three components of LP seismograph at DDR for the S. E. off Boso Peninsula (A), and the lower three traces show seismograms obtained by the same instrument for the Fukui-Gifu border (B).

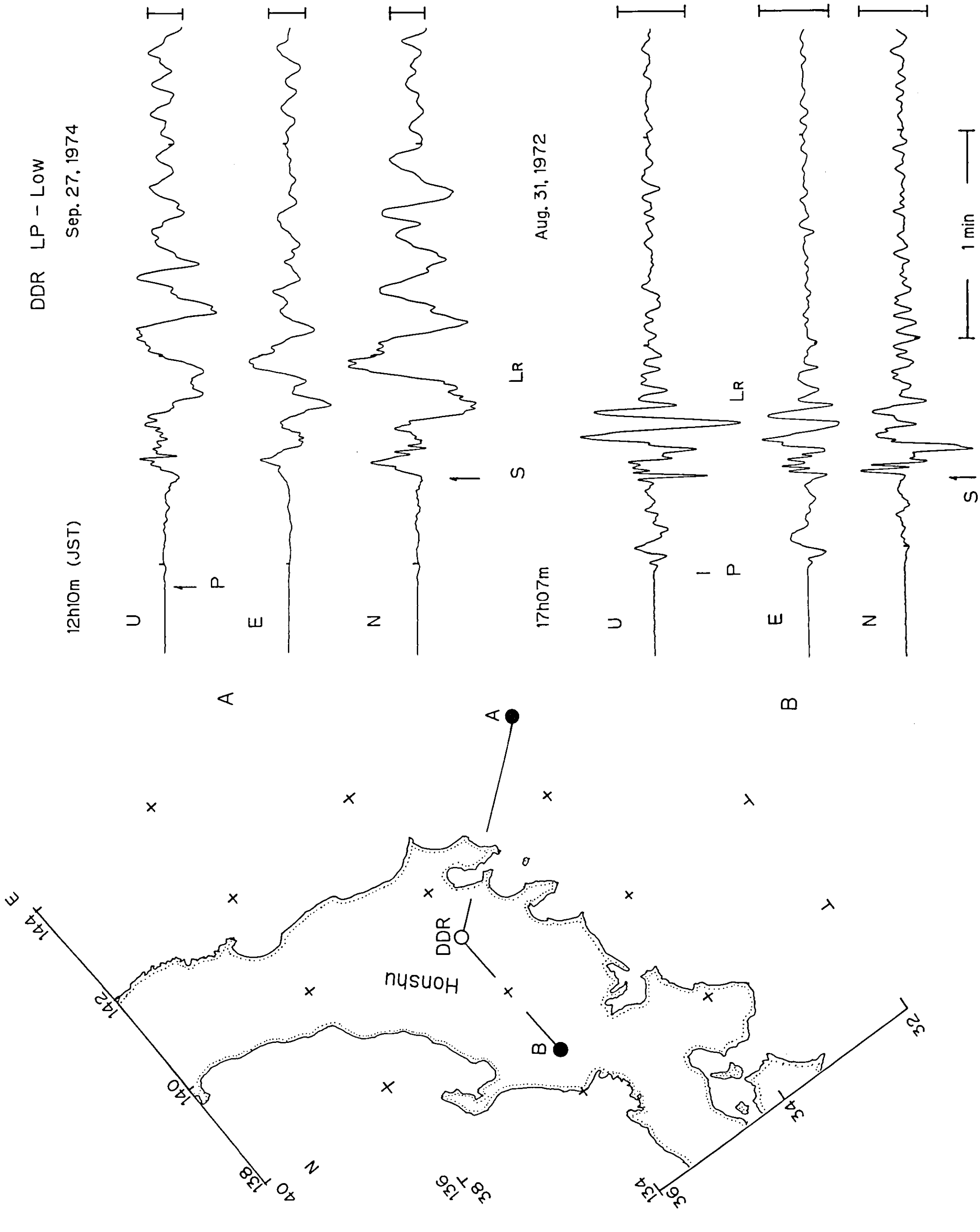
The focal parameters by JMA are as follows:

	Origin Time*	Epicenter		h	h**	M
	h m s	N	E	km	km	
A	12 10 06.2	33°.72	141°.52	60	35	6.4
B	17 07 21.0	35.88	136.77	10	36	6.0

*: JST (UT+9h). **: depth in ISC.

In spite of small differences of magnitude (0.4), source depth (ISC) and epicentral distance, clear differences of spectrum are seen between the two events. Short-period Rayleigh waves (LR) starting from 7 sec are predominant on the lower seismograms, in contrast with long-period Rayleigh waves ($T \cong 20$ sec) for upper seismograms. Such a difference of spectrum may be due to the path effect as will be discussed in a later figure.

Fig. 3


DDR LP - Low
Sep. 27, 1974
12h10m (JST)
U
E
N
P
S
LR
A
Aug. 31, 1972
17h07m
U
E
N
P
S
LR
B
1 min
DDR
Honshu
A
B
N
E
144
142
140
138
40
38
136
36
134
34
32

4. Local variation of surface wave dispersion (2)

Comparison of seismograms from two regional earthquakes obtained by LP seismographs at DDR. Upper two seismograms are for the event from inland Kyushu (1) and lower two seismograms are from near Kyushu (2).

The focal parameters by JMA and ISC are as follows:

		Origin Time*	Epicenter		h	M	Δ
		h m s	N	E	km		deg
JMA	1	04 40 51.0	33°.03	131°.13	0	5.5	
	2	06 13 11.8	31.17	131.73	40	5.6	
ISC	1	04 40 52.2	32.96	131.08	11	4.2	7.35
	2	06 13 14.8	31.35	131.46	52	5.5	7.94

*: UT.

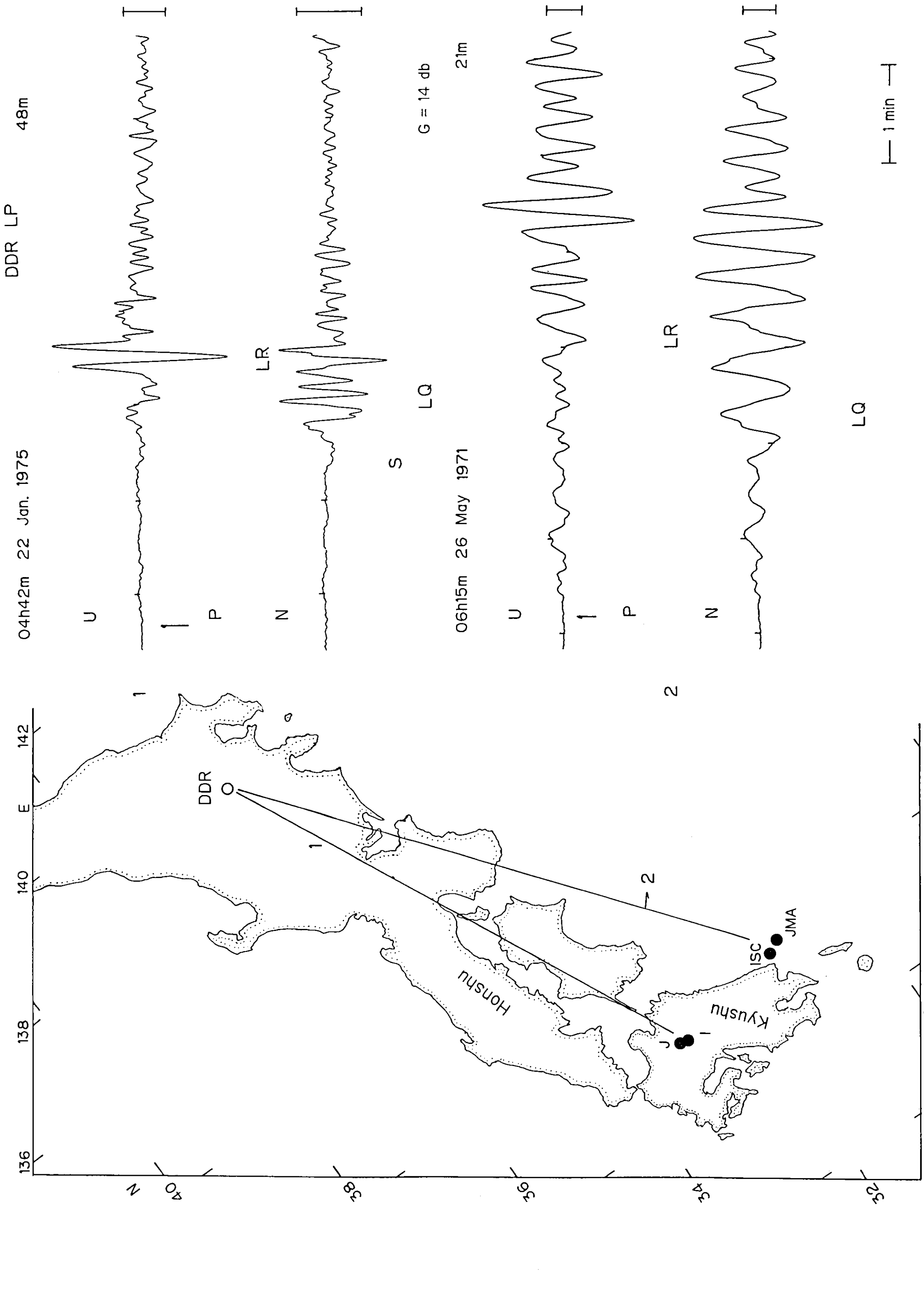
The epicenters by JMA and ISC are shown by closed circles on the map, and bars at the end of seismograms show relative differences of magnification.

Comments

Clear differences of surface-wave dispersion are seen between the two events. The Rayleigh waves (*LR*) of event No. 1 show pulse-like waveforms with short-period ($T \cong 5$ sec). On the other hand, surface wave dispersion is seen for event No. 2, especially, the Love wave (*LQ*) is well dispersed starting from 20 sec period, and such features are seen for other events in this region.

As shown in previous seismograms, the event in oceanic region shows dispersive surface wave with longer-period than that of inland region. This is a common feature in this region. The difference of waveform features therefore may be due to the path effect.

Fig. 4


DDR LP 48m
04h42m 22 Jan. 1975
U
P
N
LR
S
LQ
G = 14 db
21m
06h15m 26 May 1971
U
P
N
LR
LQ
1 min
1
2
DDR
Honshu
Kyushu
ISC
JMA
J
I
E
N
136
138
140
142
128
130
132
28
30
32
34
36
38
40

5. Local variation of the spectrum

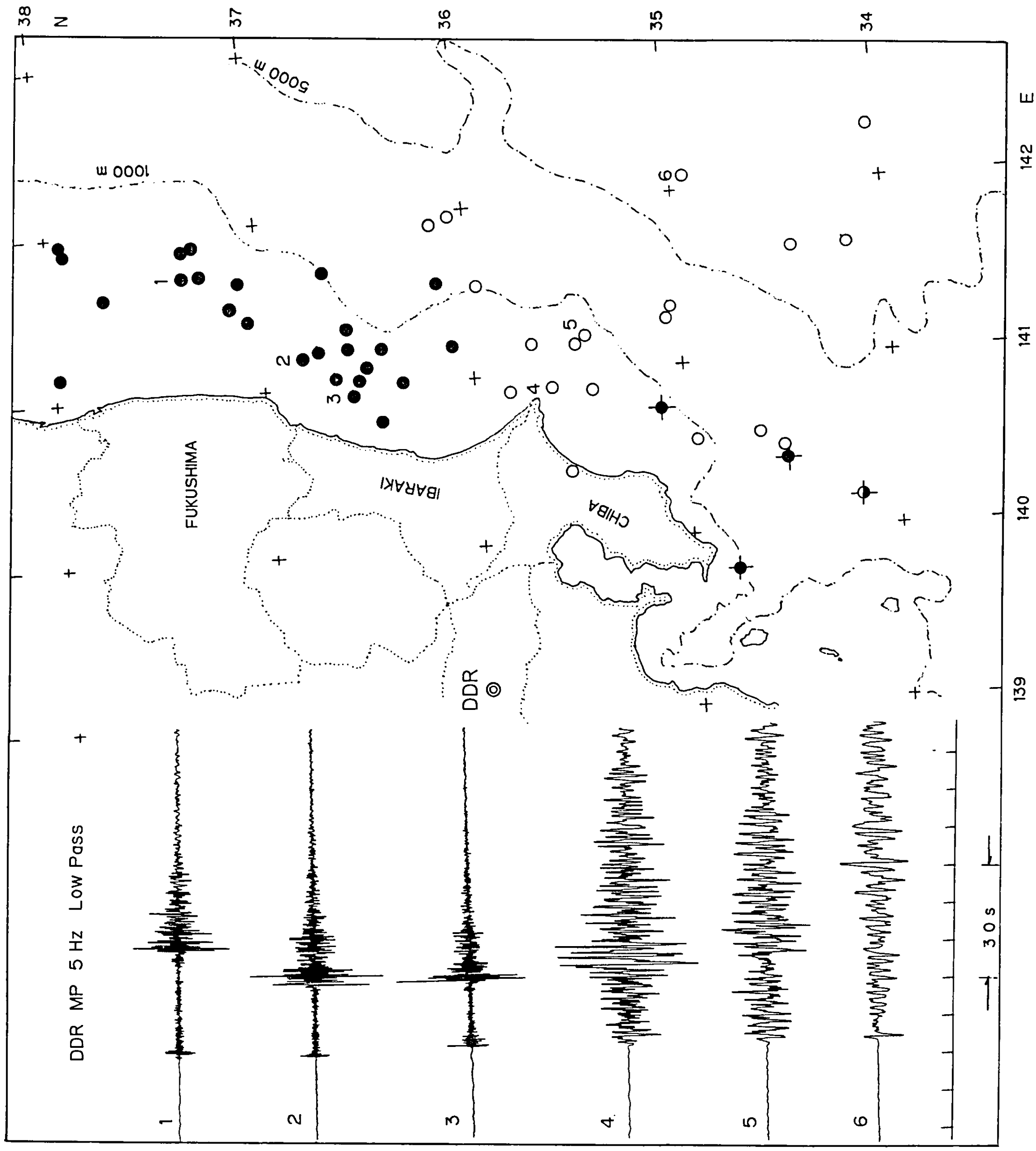
Epicenter locations of earthquakes studied for the spectrum using MP seismographs at DDR and six sample seismograms. Source depths of most earthquakes lie between 40 and 60 km, except for the circles with cross marks ($h>80$ km). Numerals from 1 to 6 on the seismograms correspond to the order number of epicenters on the map.

Comments

The spectral features of seismograms differ significantly between the upper three and lower three seismograms. The events off Ibaraki and Fukushima Prefectures contained higher-frequency components than the events off Chiba Prefecture.

From the amplitude ratios of high-and low frequencies, these events are separated into three groups of closed, half-closed and open circles. The closed circle shows the event containing large higher-frequency components than that of open circle. A detailed criterion of the separation is given by TSUJIURA (1973a). Closed- and open circles are separated at the boundary of about 36°N, but there is no difference for the deeper events ($h>80$ km) as shown later.

Fig. 5


38
37
36
35
34
N
142
141
140
139
E
1000 m
5000 m
FUKUSHIMA
IBARAKI
CHIBA
DDR
DDR MP 5 Hz Low Pass
30 s
1
2
3
4
5
6

6. Depth-variation of the spectrum

Comparison of two events with different source depths in the same region, East off Chiba Prefecture. Left traces show the seismograms obtained by WB-E, WB-N and three components of LP-Low gain seismograph at DDR, and right traces show the seismograms obtained by the same seismographs, except for the difference of the magnification of LP. The magnification of LP and LP-Low differs by a factor of 10 for the same gain of play-back amplifier (G).

I: seismic intensity by JMA.

The focal parameters by JMA are as follows:

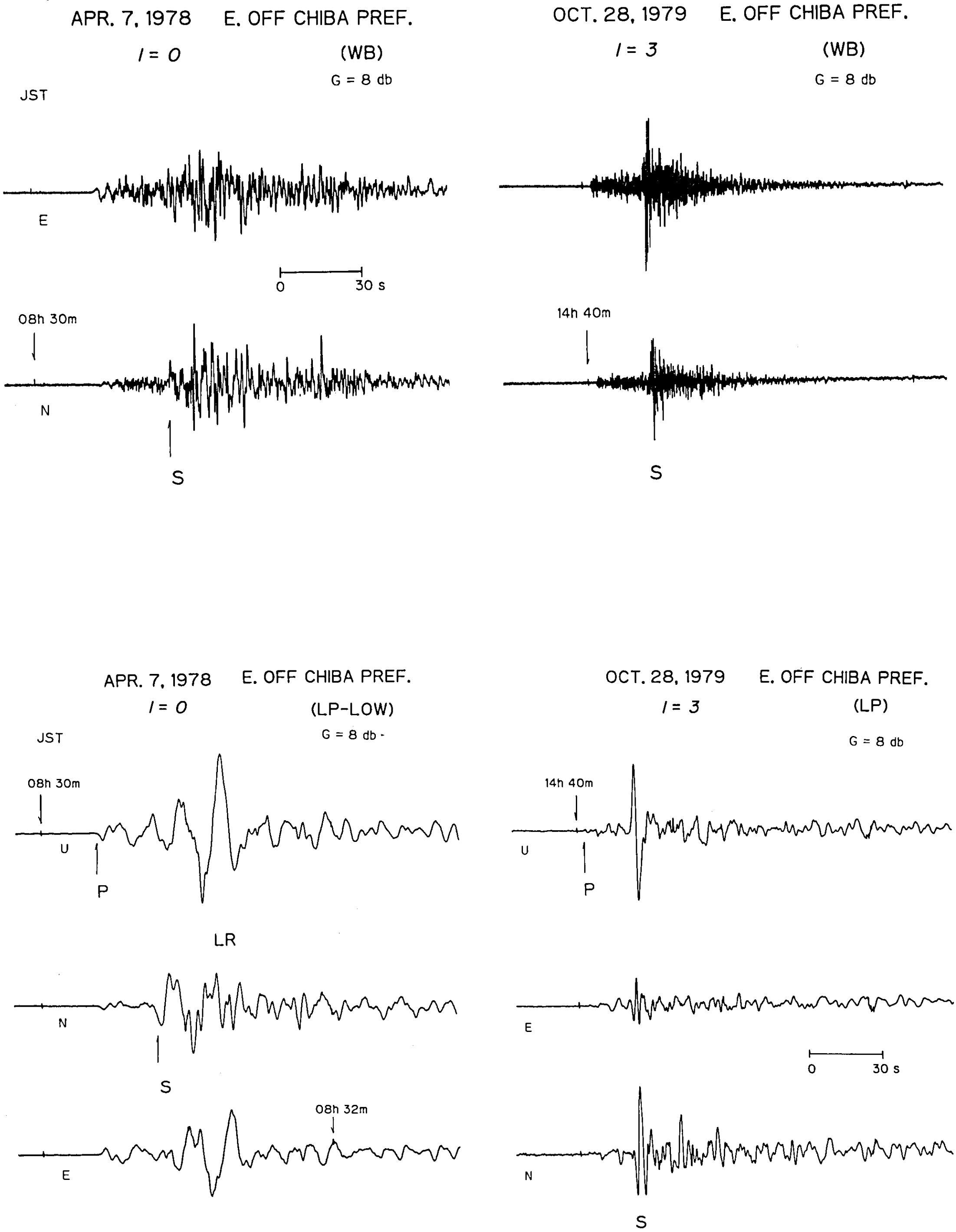
Origin Time	Epicenter		h	M	Δ
d h m s	N	E	km		km
Apr. 07, 08 29 48.9	35°.05	141°.37	30	6.1	220
Oct. 28, 14 39 35.2	35.12	140.75	90	5.5	220

Comments

1) Clear differences of waveforms are seen between the two events. The event with deep source (90 km) predominates in high-frequency components than those of shallow event (30 km), and the difference of amplitude at 5 Hz arrived at a factor of 20.
2) The seismic intensity (*I*) at Chichibu (JMA) about 10 km away from DDR was 0 (unfelt) for the former event and a value of III for the latter event.

These differences include the effects of propagation path and source spectrum. No separation is possible for the present study. However, the difference of spectrum by the source depth must be noticed, and such a difference is very important in the earthquake engineering.

Fig. 6


APR. 7, 1978
E. OFF CHIBA PREF.
l = 0
(WB)
G = 8 db
JST
E
0
30 s
08h 30m
N
S
OCT. 28, 1979
E. OFF CHIBA PREF.
l = 3
(WB)
G = 8 db
14h 40m
S
APR. 7, 1978
E. OFF CHIBA PREF.
l = 0
(LP-LOW)
G = 8 db -
JST
08h 30m
U
P
LR
N
S
08h 32m
E
OCT. 28, 1979
E. OFF CHIBA PREF.
l = 3
(LP)
G = 8 db
14h 40m
U
P
E
0
30 s
N
S

7. Reflected wave from plate boundary ?

Seismograms from S. W. Ibaraki Prefecture. The top two traces show seismograms obtained by WB-E, WB-N seismographs at DDR, and the center two traces show seismograms passed through a low-pass filter with cut-off frequency of 0.5 Hz for the top seismograms. The bottom two traces show seismograms obtained from LP-E, LP-N seismographs in the same station.

The focal parameters by JMA are as follows:

Origin Time	Epicenter		h	M	Δ
h m s	N	E	km		km
12 47 43.8*	36°.17	139°.85	60	5.0	70

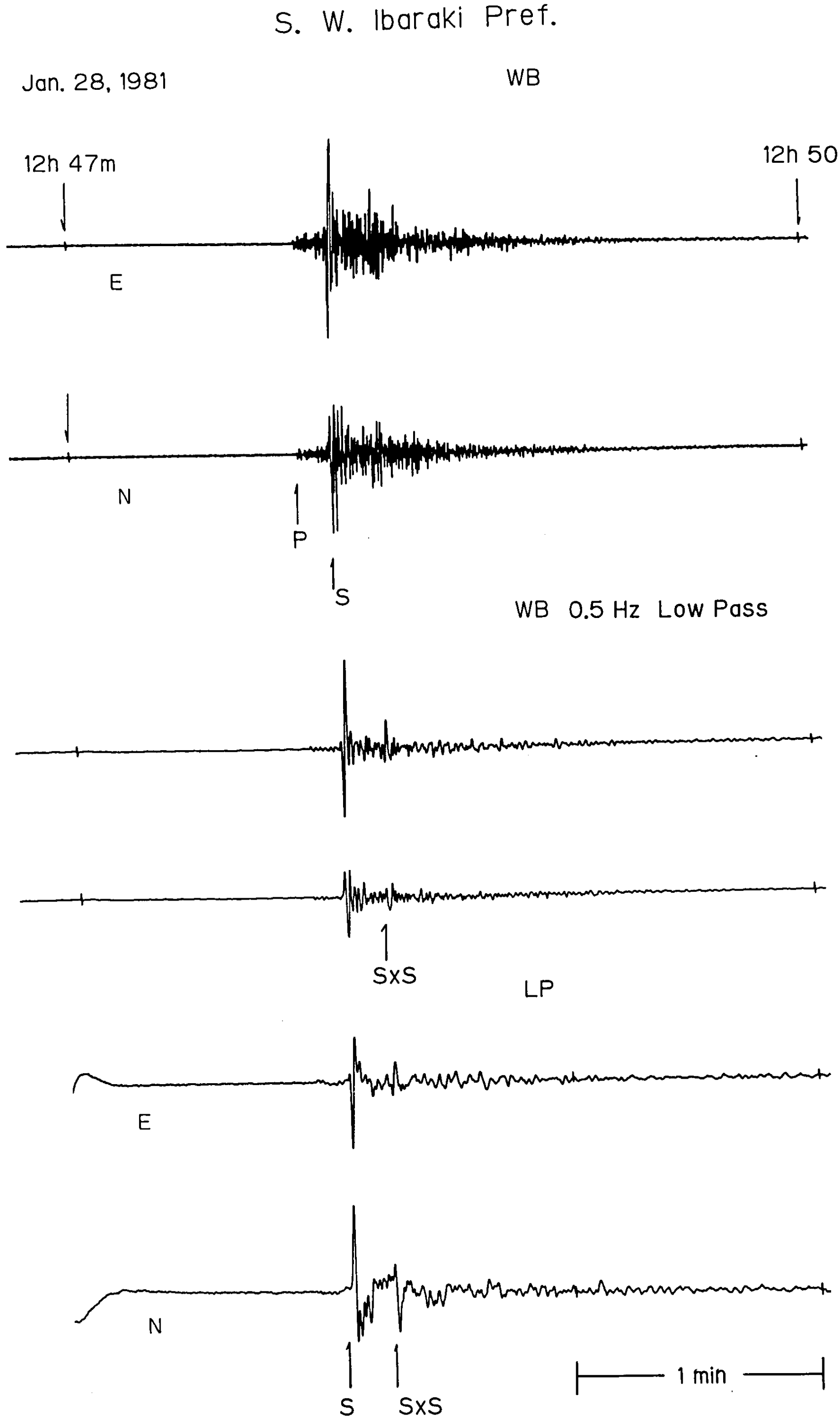
*: JST (UT+9h).

Comments

1) Clear phase indicating by *SxS* appears on the N-S component seismograms after about 10 sec from *S* wave.
2) The *SxS* phase is not clear on the vertical seismogram, though not shown here.
3) The *SxS* phase appears also for other events, though their location and source depth are limited. The ranges of source depth and epicentral distance are 50-60 km and 70-80 km, respectively.
4) The arrival time of *SxS* phase measured from *S* wave lies within a range of 9.5-10.5 sec.

A detailed analysis of *SxS* phase has not yet been made. Considering the time interval of *S* and *SxS* phases, this phase is probably the reflected wave from *S* to *S* at the lower plate boundary.

Fig. 7


S. W. Ibaraki Pref.
Jan. 28, 1981
WB
12h 47m
12h 50m
E
N
P
S
WB 0.5 Hz Low Pass
SxS
LP
E
N
S
SxS
1 min

8. Converted wave from near deep-focus earthquakes

Seismograms obtained by MP seismographs at DDR for two events in western Honshu (off Kii Peninsula and Central Nara Prefecture), and a seismogram obtained by MP seismograph at TSK for an event in western Saitama Prefecture. Note the difference in time scale between upper and bottom seismograms.

The focal parameters by JMA are as follows:

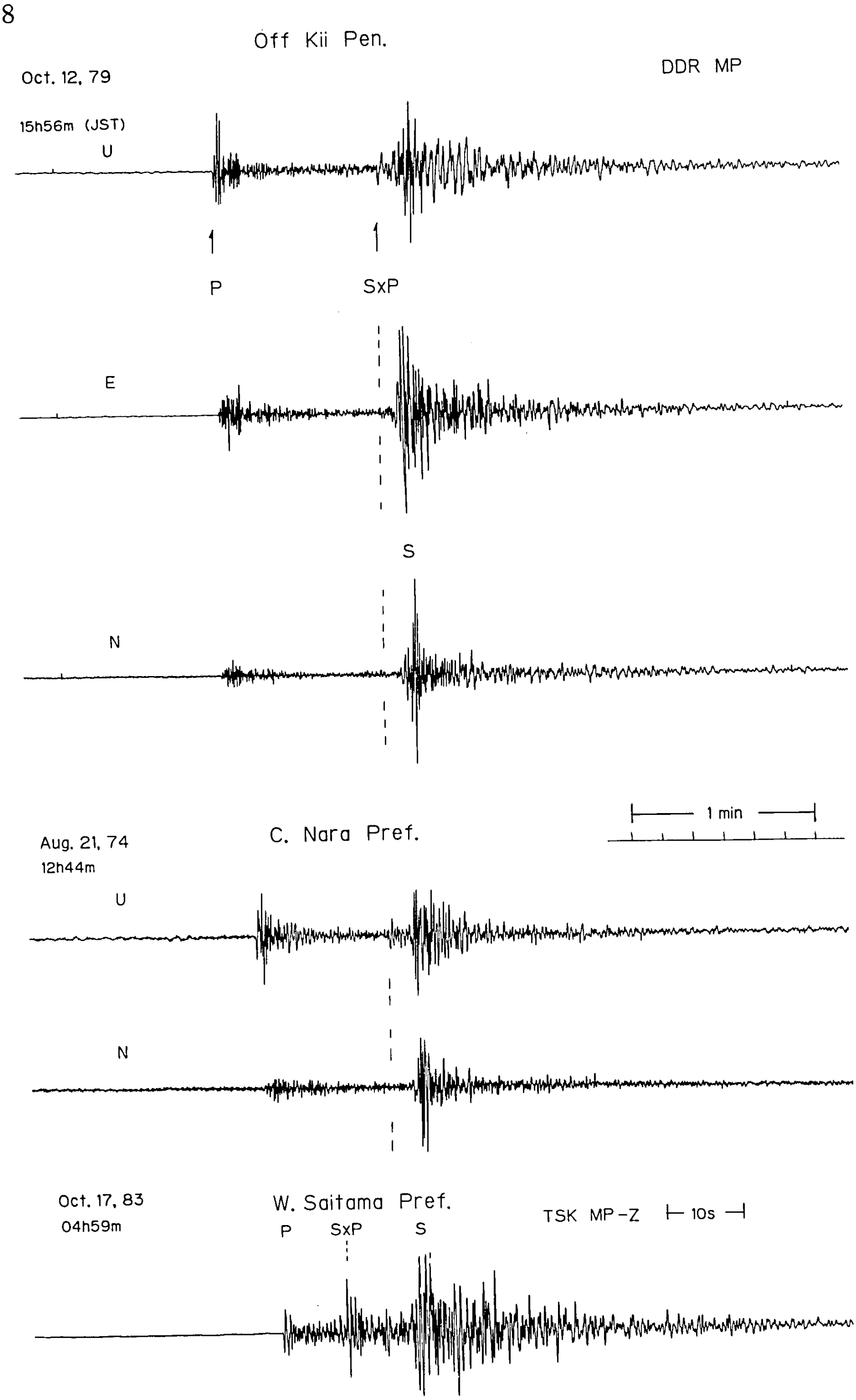
Origin Time*	Epicenter		h	M	Δ
d h m s	N	E	km		km
Oct. 12, 15 55 37.0	32°.63	136°.22	440	5.3	470
Aug. 21, 12 43 30.2	34.43	135.97	400	5.2	380
Oct. 17, 04 59 15.4	36.02	138.89	141	4.9	115

*: JST (UT+9h).

Although these earthquakes are located in different areas, a clear phase (SxP) appeared commonly on the vertical component seismogram. The time interval between SxP and S waves in each event is about 7.5, 8 and 9 sec, respectively. Such a phase is also observed for deep earthquakes ($h>100$ km) in Sagami Bay.

Considering the time interval between the two phases, this phase will be the converted wave from S to P at the plate boundary underlying the station.

Fig. 8


Off Kii Pen.
DDR MP
Oct. 12, 79
15h56m (JST)
U
P
SxP
E
S
N
1 min
Aug. 21, 74
12h44m
C. Nara Pref.
U
N
Oct. 17, 83
04h59m
W. Saitama Pref.
P
SxP
S
TSK MP-Z
10s

9. High-frequency earthquake, off the E. C. of Honshu

Seismograms obtained by MP seismograph at DDR and their epicentral locations from JMA (closed circles). Numerals on the seismograms correspond to the numbers on the map. The contour lines show the water depth.

The focal parameters by JMA are as follows:

No.	Date	Origin Time*	Epicenter		h	h**	M
		h m s	N	E	km	km	
1	Oct. 11, 1982	02 23 04.8	40°.18	143°.98	40	28	5.4
2	Jul. 26, 1979	08 11 39.4	40.18	145.03	40	59	5.1
3	Apr. 05, 1978	16 51 26.1	39.70	144.43	60	31	5.5
4	Mar. 30, 1976	14 53 09.2	39.53	143.67	30	28	5.5
5	Sep. 30, 1979	17 38 53.5	41.45	141.92	50	70	5.3
6	Jul. 29, 1981	02 00 58.5	41.63	140.23	190	180	5.6
7	Jun. 10, 1980	05 06 36.2	40.82	140.23	170	167	5.6
8	Jan. 13, 1980	00 57 01.3	41.63	143.88	60	38	6.1
9	Mar. 17, 1980	06 40 36.0	40.15	142.45	30	53	5.3

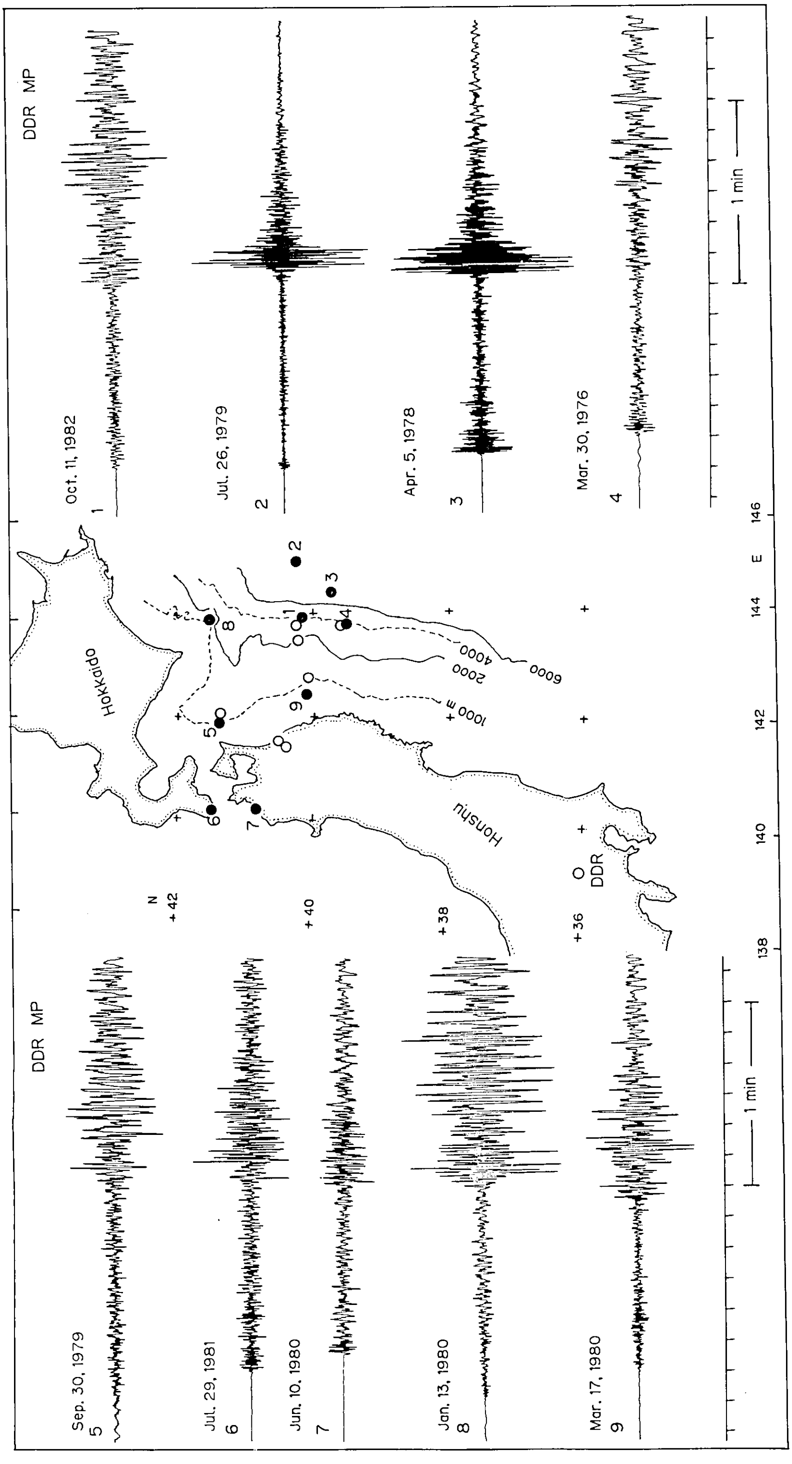
*: JST (UT+9h), **: depth by ISC.

Comments

Clear differences of waveforms are seen among the seismograms. The seismograms labeled No. 2 and No. 3 contained very high-frequency components compared with those of other events; this tendency is the same for events indicated by open circles.

As shown previously (Fig. 6), the spectrum of seismic waves differs by source depth. The source depth of events concerned here ranges from 30 km to 190 km. Events No. 2 and No. 3 with high frequencies, however, are not due to the source depth. The epicentral location is one of the most important factors determining the spectrum.

Fig. 9


DDR MP
Oct. 11, 1982
1
Jul. 26, 1979
2
Apr. 5, 1978
3
Mar. 30, 1976
4
1 min
DDR MP
Sep. 30, 1979
5
Jul. 29, 1981
6
Jun. 10, 1980
7
Jan. 13, 1980
8
Mar. 17, 1980
9
1 min
Hokkaido
Honshu
DDR
1000 m
2000
4000
6000
N
+42
+40
+38
+36
138
140
142
144
146
E

10. Low-frequency earthquake, south of Honshu

Seismograms from two events south of Honshu obtained by MP and LP seismographs at DDR. The top two traces show seismograms obtained by MP-Z and MP-N seismographs, the center two traces show seismograms obtained by LP-Z and LP-N seismographs for the same event, and the bottom trace shows the seismogram of another event in the same region obtained by MP-E. G: gain of play-back amplifier.

The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	h^*	Mb	Δ
d	h m s	N	E	km	km		deg
Mar. 30,	11 20 33.0	31°.40	140°.25	6	20	5.3	4.76
May 24,	11 24 26.9	31.34	141.80	42	50	5.6	5.13

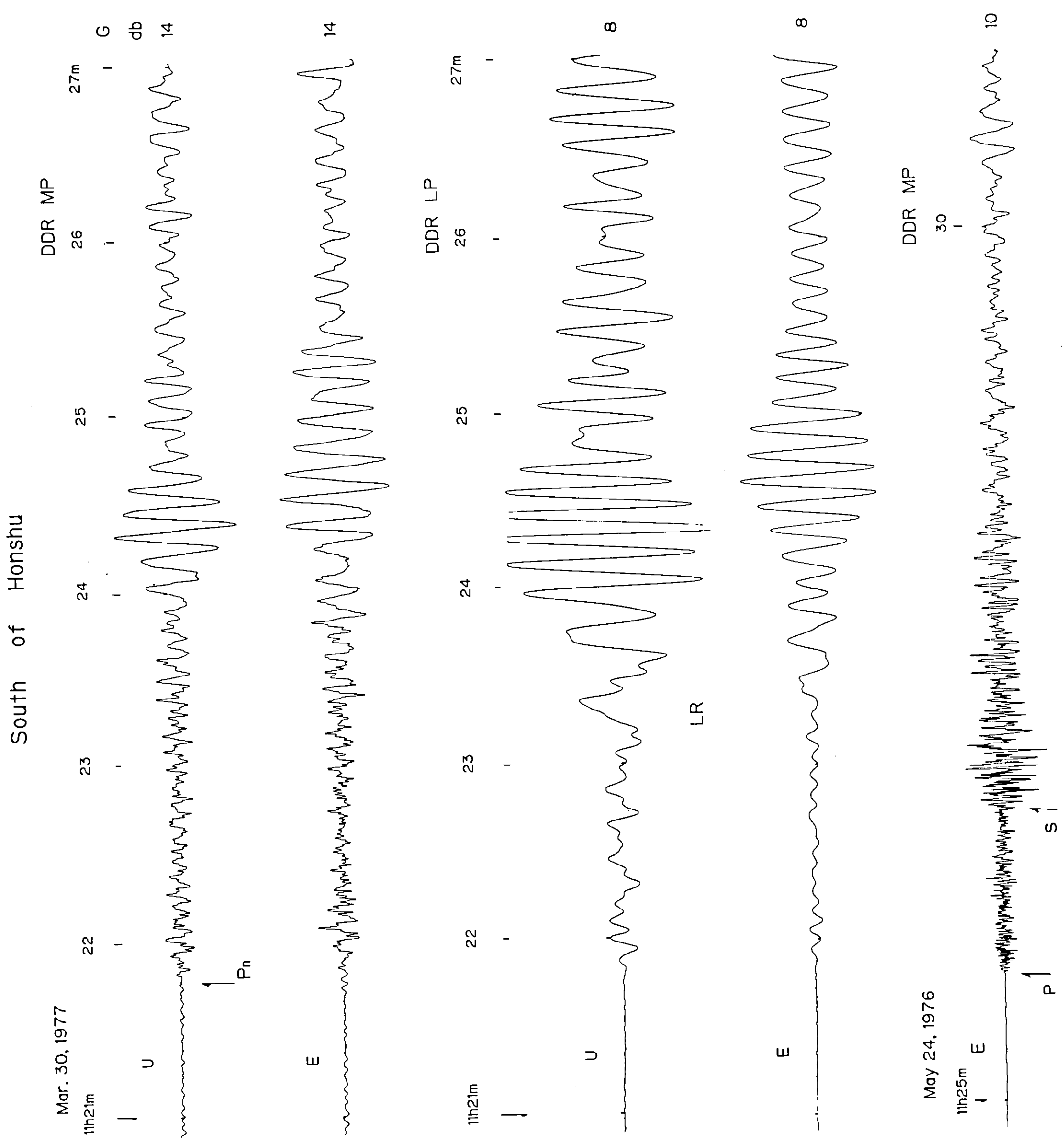
*: source depth by JMA. Mb: body-wave magnitude.

Comments

1) Low-frequency waves predominate on seismograms of the 1977 event compared with that of the 1976 event shown at the bottom.
2) The frequency of seismic waves in the 1977 event is almost constant, about 0.1 Hz, except for the beginning of *LR* wave.
3) *S* wave is not clear.
4) Bottom seismogram shows ordinary waveform features in this region.

The source depths are different between the two events. Even considering the difference of source depth, the 1977 earthquake is an unusual low-frequency event during the recent two decades.

Fig. 10


South of Honshu
Mar. 30, 1977
11h21m
DDR MP
22
23
24
25
26
27m
G
db
14
U
E
Pn
DDR LP
LR
8
May 24, 1976
11h25m
30
10
P
S

11. Waveform features of earthquake swarm (1)

The seismic activity continued for about five days off the East Coast of Honshu. The focal parameters of events with $Mb>5.0$ in the sequence by ISC are follows:

No.	Origin Time	Epicenter		h	Mb
	d h m s	N	E	km	
1	Oct. 10, 06 48 15.5	41°.05	143°.09	33	5.7
2	Oct. 10, 06 56 49.7	40.99	143.15	36	5.7
3	Oct. 12, 04 47 30.9	40.52	143.57	20	5.3
4	Oct. 12, 06 14 51.0	40.54	143.58	17	5.5
5	Oct. 14, 14 11 41.2	40.64	143.69	13	5.4
6	Oct. 15, 01 16 45.9	40.66	143.78	12	5.4

There is no specially large event. This activity therefore corresponds to ordinary swarm activity.

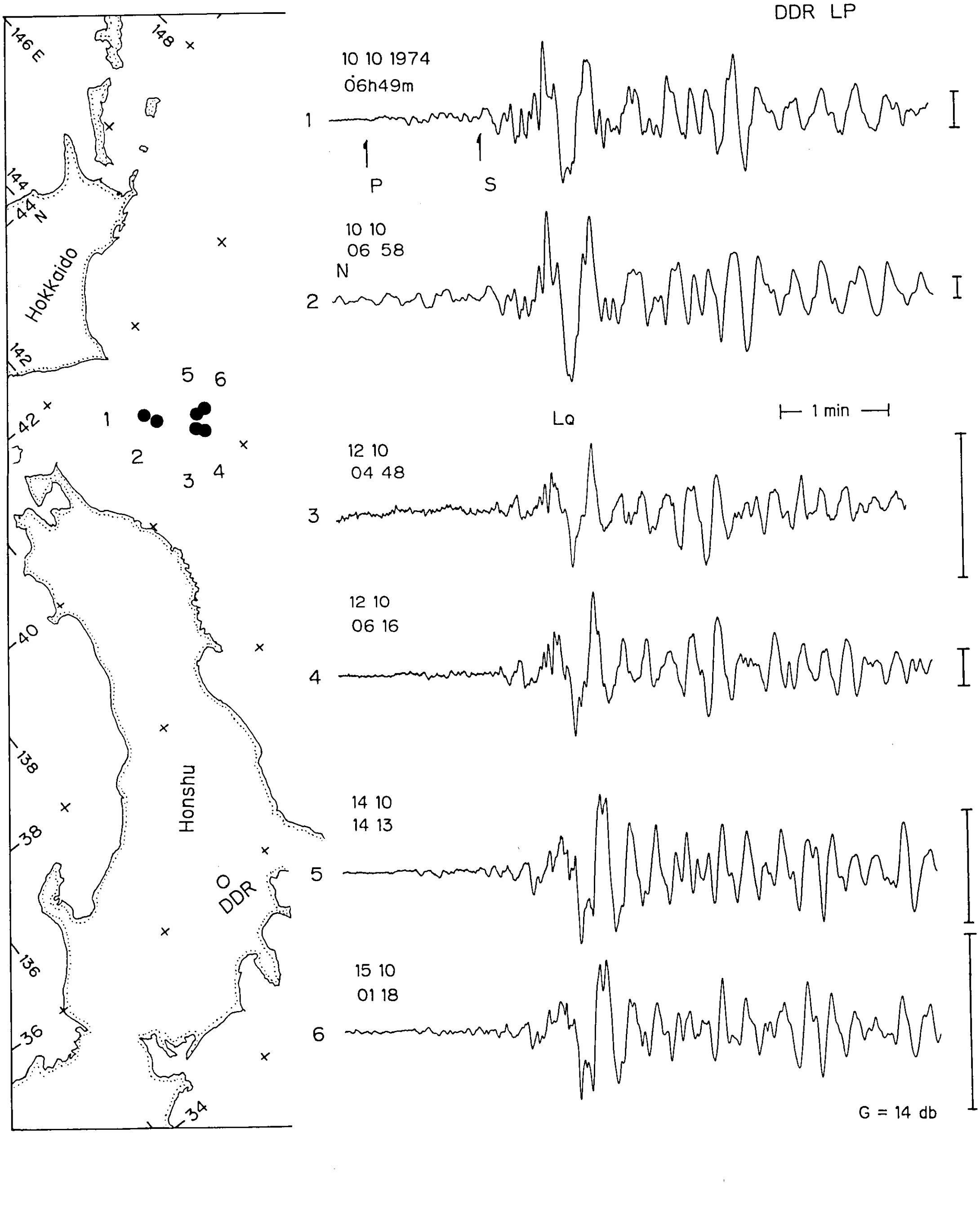
This figure shows the comparison of seismograms of six events obtained by LP-N seismograph at DDR and their epicentral locations. The sizes of bars at the end of seismograms show relative differences of magnification.

Comments

There exist three event groups with their own waveform features; events of No. 1 and No. 2 show similar waveforms. Similarly, event pairs No. 3 and No. 4 or No. 5 and No. 6 also show similar waveforms. Note that the 2nd and 3rd groups are closely located, but have different waveforms.

The existence of event groups with similar waveforms is one of the most important features of an earthquake swarm (TSUJIURA, 1979).

Fig. 11


146 E
148
144
44 N
Hokkaido
142
42
40
38
36
34
136
138
Honshu
DDR
1
2
3
4
5
6
DDR LP
10 10 1974
06h49m
P
S
10 10
06 58
N
1 min
LQ
12 10
04 48
12 10
06 16
14 10
14 13
15 10
01 18
G = 14 db

12. Waveform features of earthquake swarm (2)

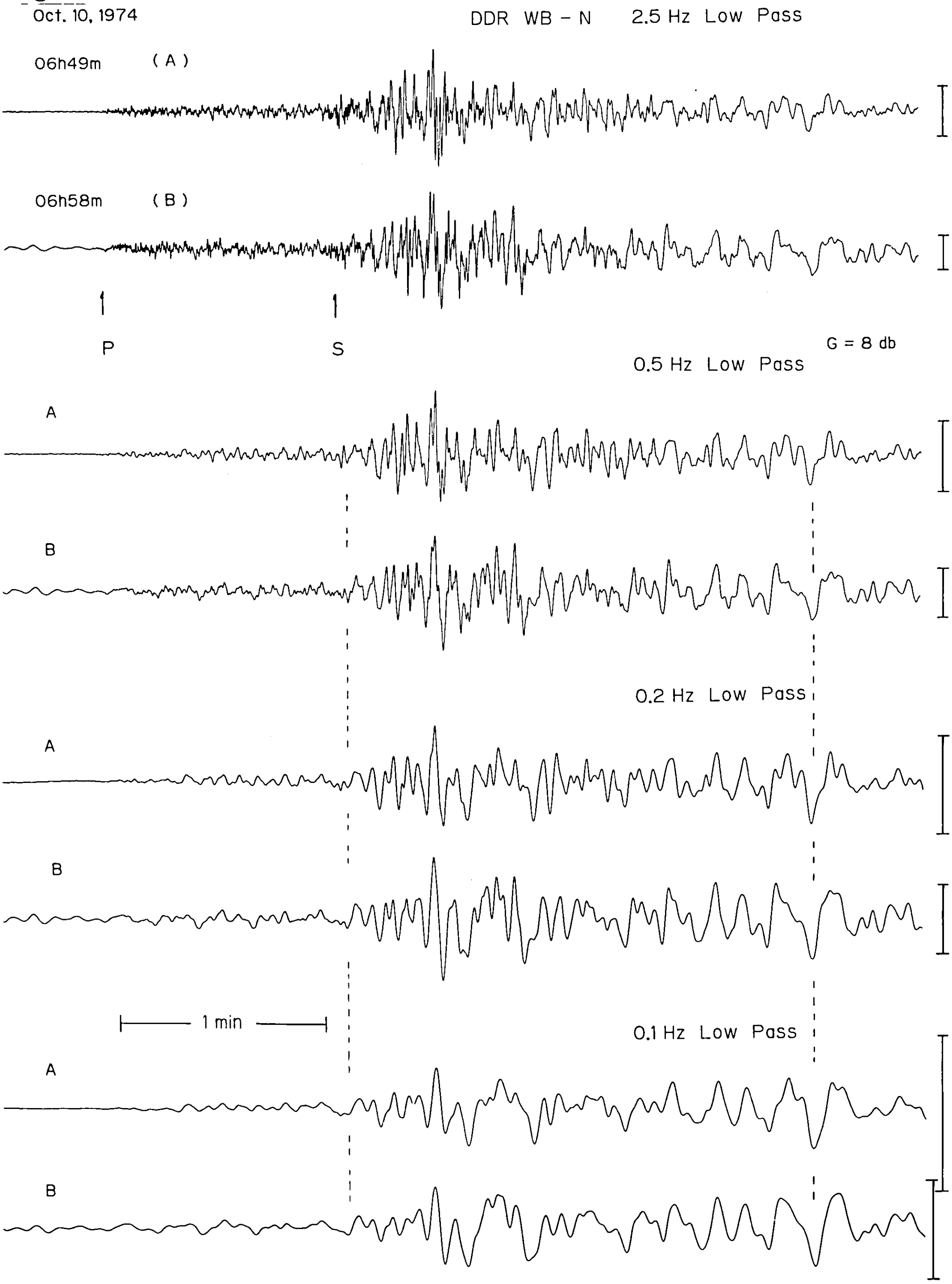
Comparison of the seismograms of event pair shown in previous figure (No. 1 and No. 2 events in Fig. 11). The top two traces (A, B) show original seismograms obtained by WB-N seismograph at DDR, and the second two traces show the seismograms passed through a low-pass filter with cut-off frequency of 0.5 Hz for the same events. The third two traces are similar seismograms with cut-off frequency of 0.2 Hz, and the bottom two traces show the seismograms with cut-off frequency of 0.1 Hz.

Comments

The similarity of waveforms in high-frequency components ($f>1$ Hz) is somewhat uncertain between the two seismograms. The similarity of waveforms increases with decreasing frequency, and seismograms with frequencies below 0.3 Hz become completely the same (bottom seismograms).

This feature suggests that the earthquakes of this event pair occurred repeatedly on the same fault plane. The disagreement in high frequencies may be due to a detailed difference in the rupture process at the source. The frequency range having similar waveforms depends on earthquake size as shown below.

Fig. 12


Oct. 10, 1974
DDR WB – N
2.5 Hz Low Pass
06h49m
(A)
06h58m
(B)
P
S
G = 8 db
0.5 Hz Low Pass
A
B
0.2 Hz Low Pass
A
B
1 min
0.1 Hz Low Pass
A
B

13. Waveform features of earthquake swarm (3)

Swarm earthquakes occurring in a short-time interval share similar waveforms called the "earthquake family" (TSUJIURA, 1979).

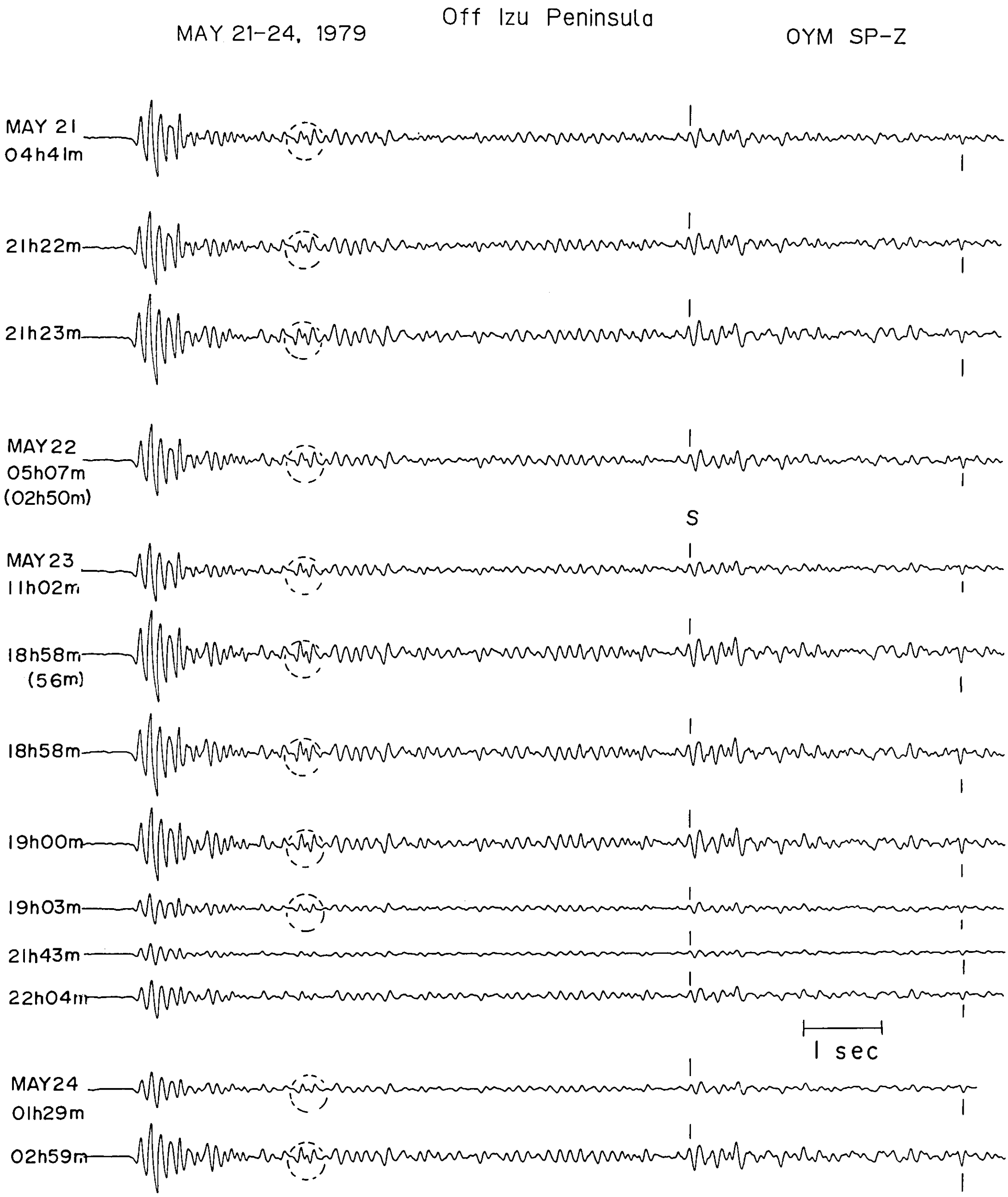
This figure shows the seismograms belonging to one family obtained by SP-Z seismograph at OYM for the 1979 earthquake swarm off the East Coast of Izu Peninsula. Magnitudes of these events lie between 1.4 and 2.4, and their epicentral distances to OYM are about 50 km.

The peaks to troughs of each wavelet coincided well from *P* wave onset until coda waves even in high frequencies ($f > 10$ Hz). The *S*-*P* times of these events also agreed within a few ten miliseconds.

Similar behavior, but with different waveforms are seen in other groups of this swarm sequence.

Spectral features of swarm earthquakes are shown in later figures (Figs. 92, 93).

Fig. 13


MAY 21-24, 1979
Off Izu Peninsula
OYM SP-Z
MAY 21
04h41m
21h22m
21h23m
MAY 22
05h07m
(02h50m)
S
MAY 23
11h02m
18h58m
(56m)
18h58m
19h00m
19h03m
21h43m
22h04m
1 sec
MAY 24
01h29m
02h59m

14. *P* waveforms of large near-earthquakes

P waveforms of large near-earthquakes obtained by two kinds of seismographs at DDR. Two seismograms on the left-hand side show the *P* waves obtained by WB-Z and LP-Z seismographs for the 1978 Izu-Oshima-Kinkai earthquake (M7.0), the center two are those of the 1980 off the East Coast of Izu Peninsula (Izu-Hanto-Oki) M6.7 and the right two are the seismograms obtained by MP-Z and LP-Z seismographs for the 1983 Central Japan Sea earthquake (M7.7).

The focal parameters by JMA are as follows:

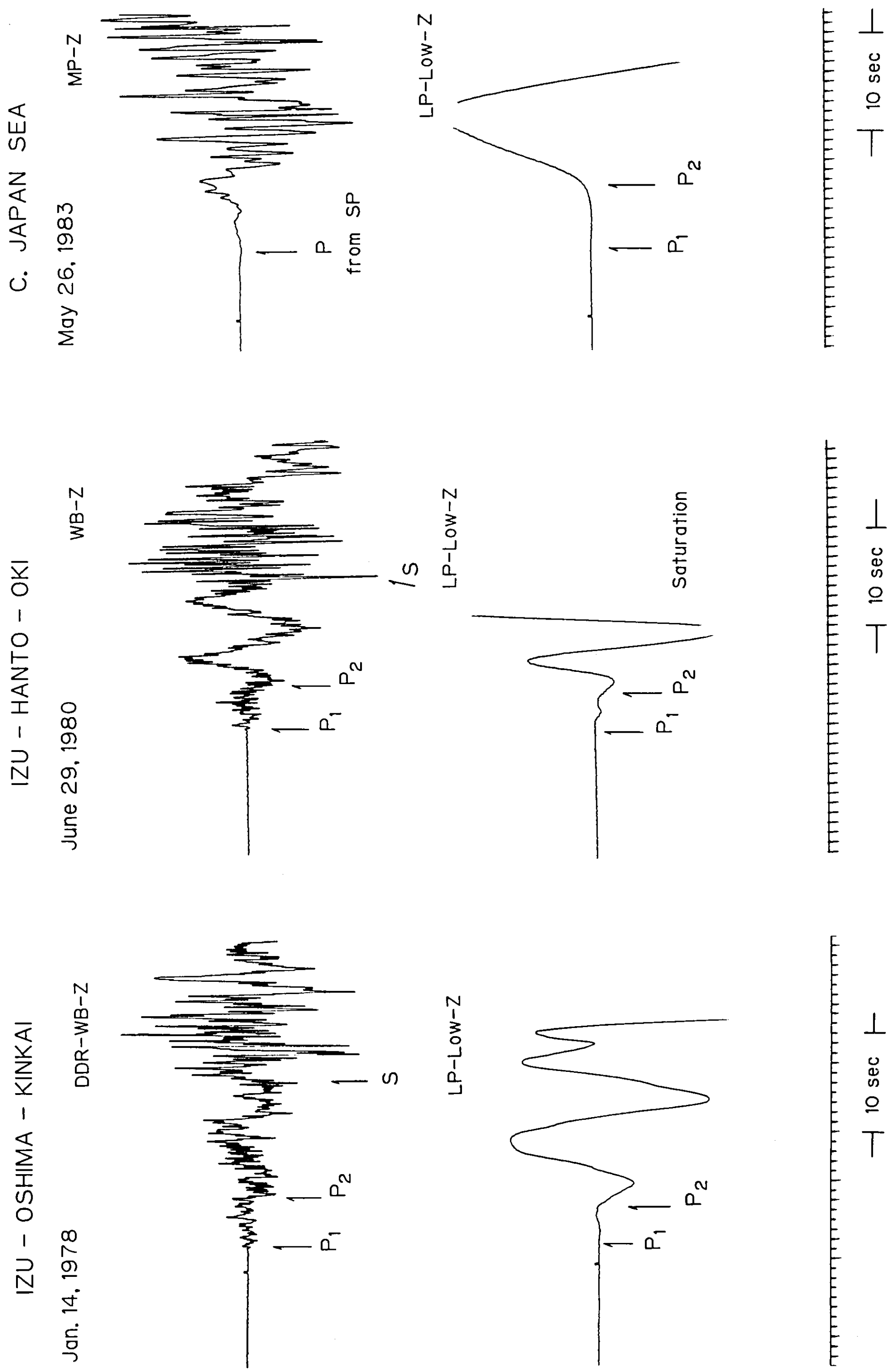
Origin Time	Epicenter		h	M	Δ
d h m s	N	E	km		km
Jan. 14, 12 24 38.6	34°77	139°25	0	7.0	140
Jun. 29, 16 20 07.5	34.92	139.23	10	6.7	120
May 26, 11 59 57.5	40.36	139.08	14	7.7	480

Comments

1) The *P* wave is separated, at least, into two phases indicated by P_1 and P_2, and an initial amplitude is very small compared with that of P_2 phase. This feature is more clearly seen on the LP seismogram. Similar waveform features are seen for the 1982 off Ibaraki Prefecture earthquake (M7.0) and the others (see Figs. 15, 96, 97).
2) The amplitude of P_1 phase is almost the same for small events in each region (see Figs. 96, 97).

These features suggest that the beginning of rupture is small even in large earthquakes.

Fig. 14


C. JAPAN SEA
May 26, 1983
MP-Z
P
from SP
LP-Low-Z
P1
P2
10 sec
IZU - HANTO - OKI
June 29, 1980
WB-Z
S
P1
P2
LP-Low-Z
Saturation
P1
P2
10 sec
IZU - OSHIMA - KINKAI
Jan. 14, 1978
DDR-WB-Z
S
P1
P2
LP-Low-Z
P1
P2
10 sec

15. *P* waveform of large near-earthquake (2)

P waveforms of the 1982 off Ibaraki Prefecture earthquake ($M7.0$) obtained by MP and LP seismographs at DDR.

The focal parameters by JMA are as follows:

Origin Time	Epicenter		h	M	Δ
h m s	N	E	km		km
23 23 50.9*	36°.18	141°.95	30	7.0	200

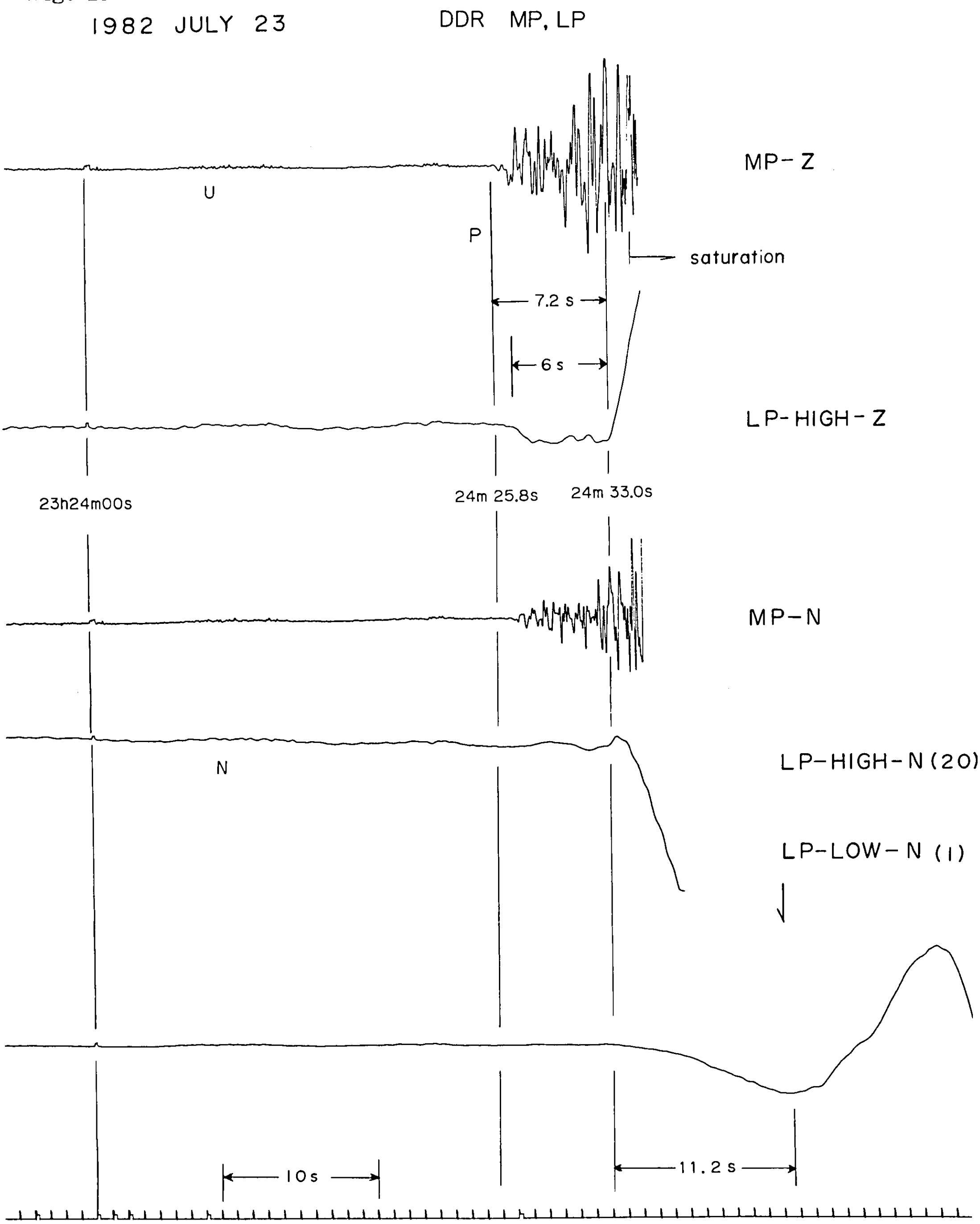
*: JST (UT+9h).

Comments

1) *P* waveforms consist of two phases (events) separated by about 7 seconds.
2) High gain LP-Z seismogram shows large amplitude for the 2nd event.
3) The polarity of the 1st and 2nd events is changed from up to down.
4) This earthquake was preceded by many foreshocks; their seismograms are shown in a later figure (Fig. 95).

As shown in the previous figure, large shallow-earthquakes show double or multiple type occurrence, and the initial event is very small compared with the 2nd one.

Fig. 15


1982 JULY 23
DDR MP, LP
MP- Z
U
P
saturation
7.2 s
6 s
LP-HIGH-Z
23h24m00s
24m 25.8s
24m 33.0s
MP-N
N
LP-HIGH-N (20)
LP-LOW-N (1)
10s
11.2 s

16. Spectral features of tsunami earthquake (1)

Seismograms show the spectral features of tsunami earthquakes in the Kurile Islands region. These seismograms were obtained by MP-N seismograph at DDR with the same magnification and frequency characteristics. Numerals from 1 to 5 on the seismograms correspond to the epicenter number on the map.

The focal parameters by JMA are as follows:

No.	Origin Time*	Epicenter		h	M	T
	h m s	N	E	km		cm
1	10 57 34.1	44°67	151°40	50	6.9	—
2	04 47 43.9	44.33	149.82	40	7.3	39
3	12 15 17.6	44.80	149.42	60	7.0	26
4	18 43 55.3	44.39	148.91	40	6.8	14
5	14 35 46.9	43.47	146.82	30	6.5	—

*: JST (UT+9h).

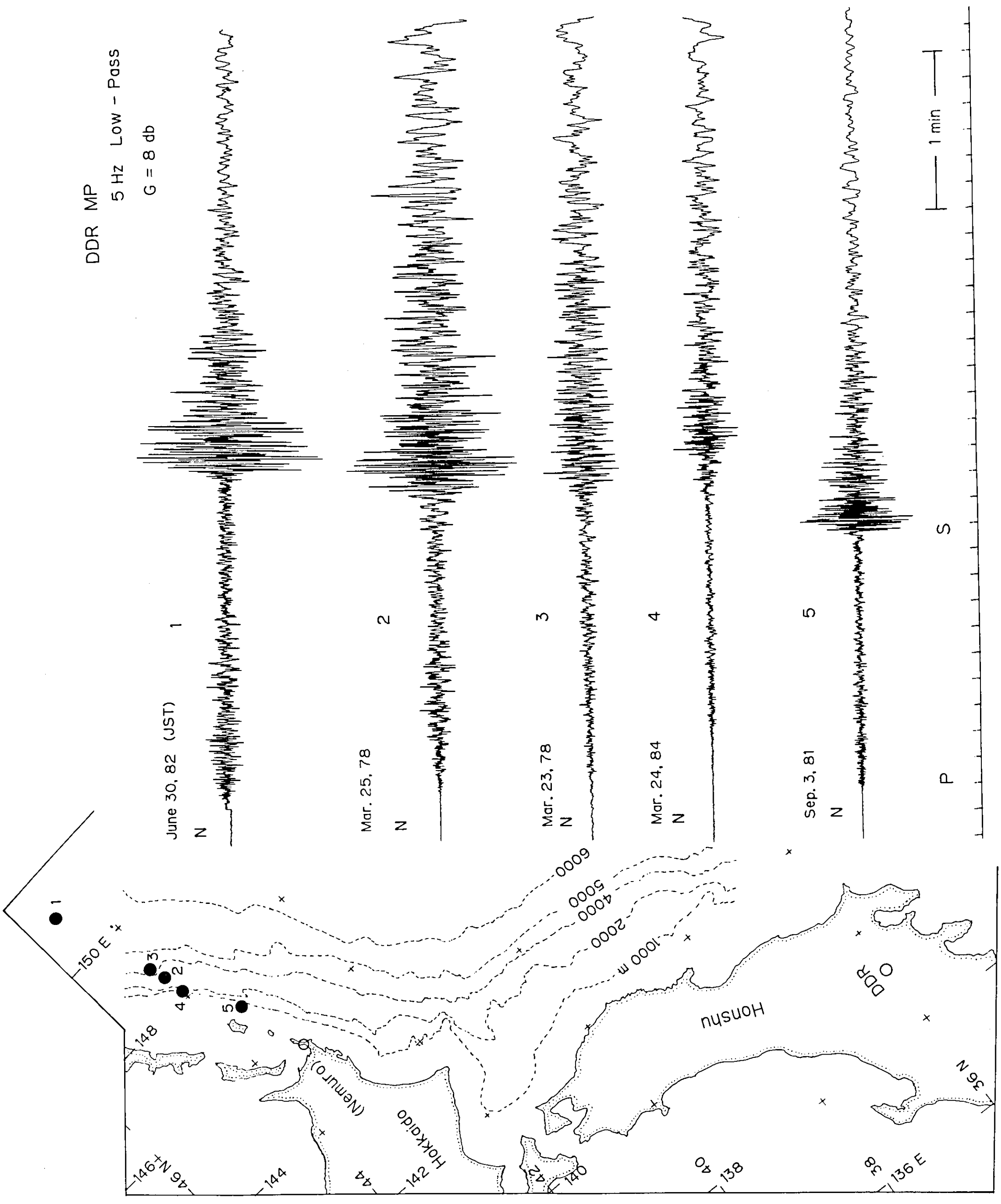
T: peak to peak amplitude of tsunami waves recorded at Hanasaki, Nemuro (open circle in the map).

Comments

The seismograms of No. 2, 3 and 4 predominate in low-frequency components comparing with those of No. 1 and No. 5 events. This feature is more clearly seen on the coda waves after S phase, and there is a correlation between the spectrum and tsunami waves.

(to be continued)

Fig. 16


DDR MP
5 Hz Low - Pass
G = 8 db
June 30, 82 (JST) 1
N
Mar. 25, 78 2
N
Mar. 23, 78 3
N
Mar. 24, 84 4
N
Sep. 3, 81 5
N
P
S
1 min
6000
5000
4000
2000
1000 m
Honshu
Hokkaido
(Nemuro)
DDR
150 E
148
146
46 N
144
44
142
42
140
40
138
38
136 E
36 N

17. Spectral features of tsunami earthquake (2)

Comparison of seismograms obtained by three kinds of seismographs, MP, LP and ULP, at DDR for two earthquakes in the Kurile Islands region.

The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	h^*	Mb	Ms	Δ
d h m s	N	E	km	km			deg
10 13 47 18.5	43°.18	147°.36	24	0	5.6	7.0	9.55
14 18 08 17.8	43.26	147.39	72	0	5.9	6.4	9.62

*: depth by JMA. *Ms*: surface-wave magnitude from NEIS.

The seismograms of each event pair are reproduced by the same magnification as indicated by G.

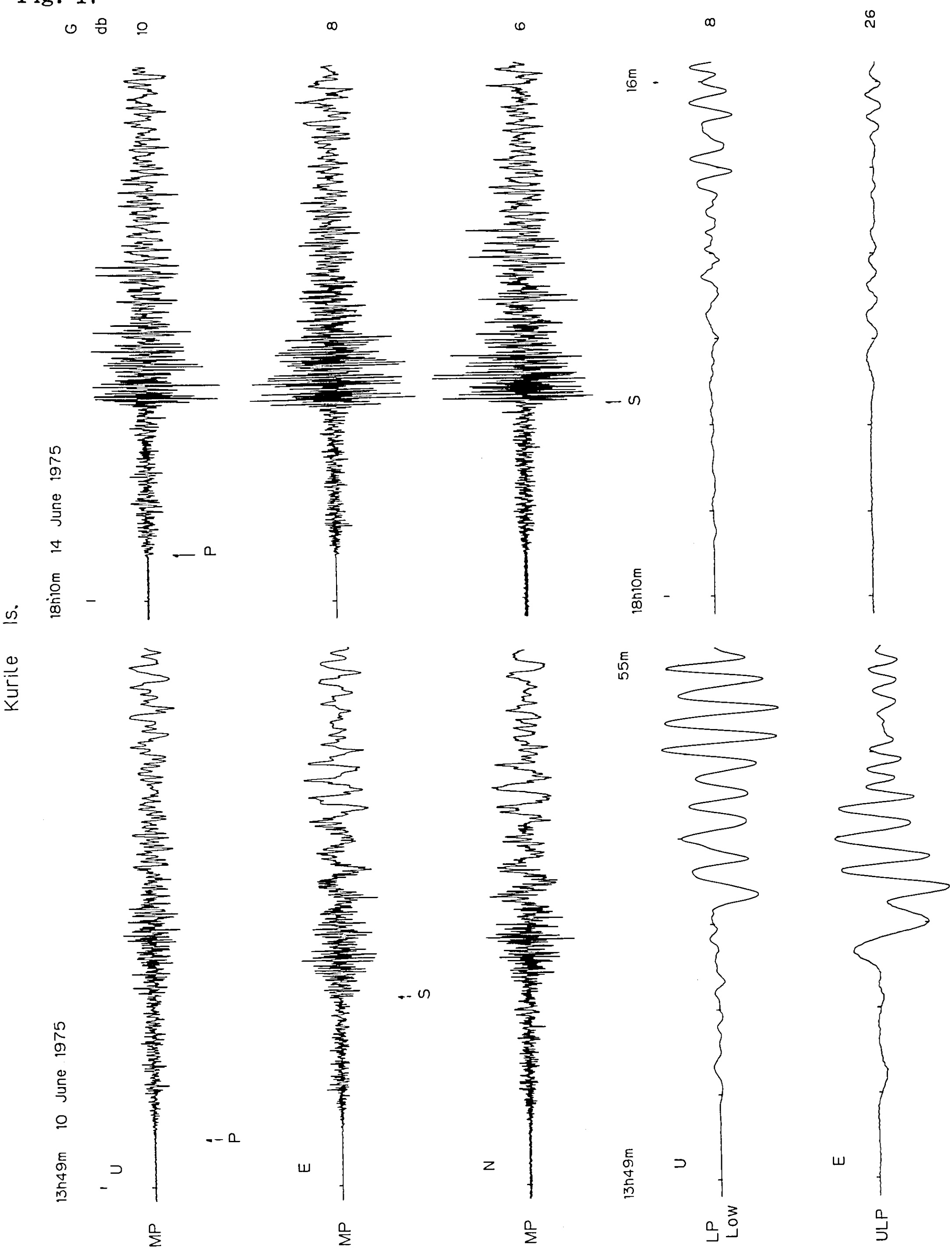
Comments

In spite of small differences of *Mb*, *Ms* and location, clear differences of spectral ratio are seen between the two events. The former event abounds in low-frequency components compared with those of the latter event, and its difference of amplitude ratio arrived at about 100 times between the frequency range of 0.01 Hz and 5 Hz (TSUJIURA, 1975).

Another feature of the difference of two events is tsunami generation. A tsunami wave of 81 cm was recorded at Hanasaki, Nemuro in Hokkaido for the former event, but no tsunami wave was observed for the latter event.

Observed spectra may be affected by the rupture process at the source. Slow rupture may be expected for the former event; such an event is called a tsunami earthquake or slow earthquake (FUKAO, 1979).

Fig. 17


Kurile Is.
13h49m 10 June 1975
18h10m 14 June 1975
G
db
10
8
6
8
26
U
E
N
P
S
16m
55m
13h49m
18h10m
MP
MP
MP
LP
Low
ULP

18. *ScS* wave from near earthquakes

Three sets of seismograms from near earthquakes obtained by WB and MP seismographs at DDR. The upper trace of each set shows the seismogram from vertical and the lower trace is that from horizontal component.

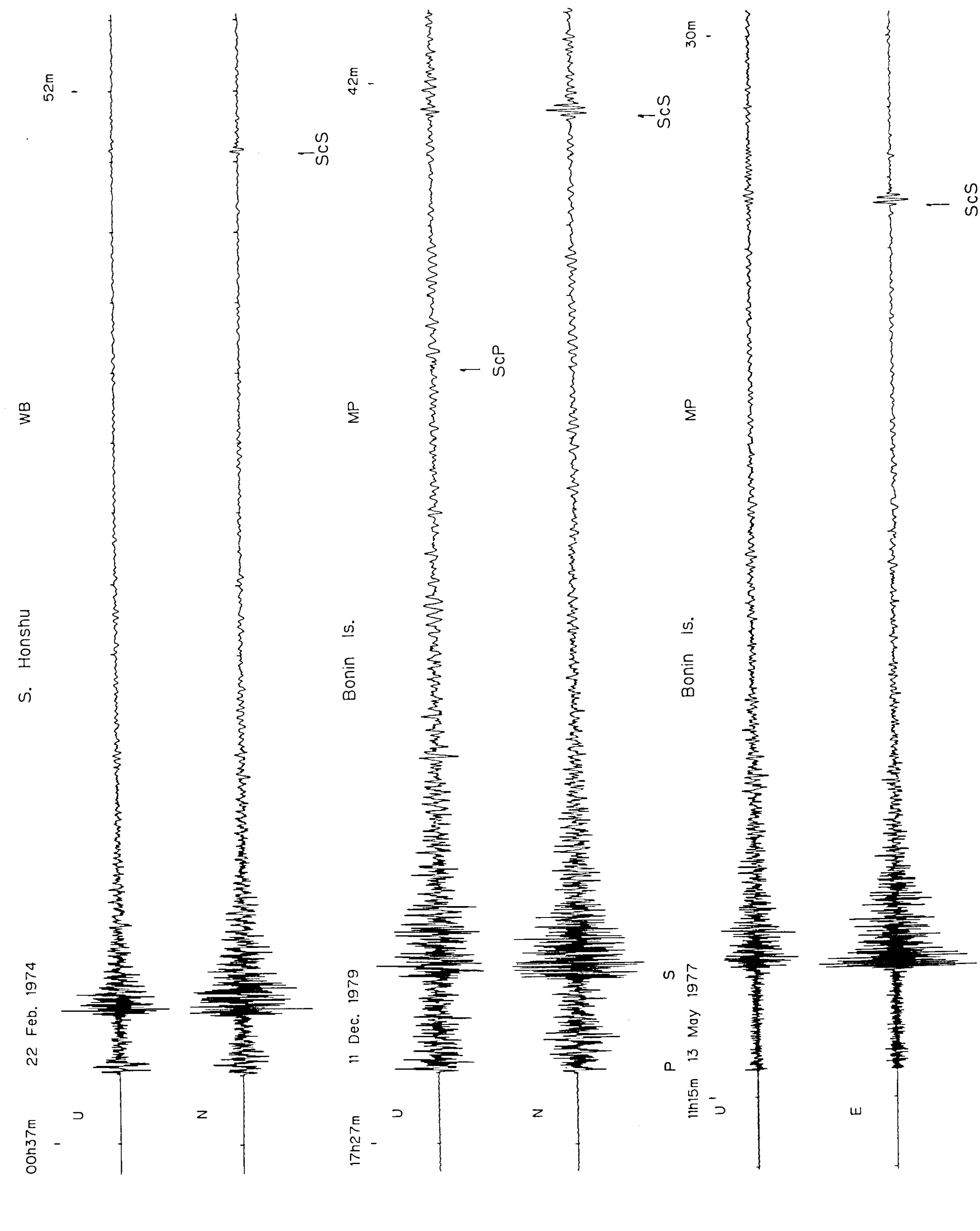
The focal parameters of three events by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
00 36 54.6	33°.17	136°.98	391	5.9	3.36
17 26 18.5	28.95	140.94	126	6.2	7.18
11 13 32.9	28.42	139.59	448	5.7	7.57

Comments

1) Clear *ScS* wave appears on the seismogram of each horizontal seismogram, and the event with distance of 3.36° is the nearest event for the appearance of the *ScS* wave.
2) Small and complicated *ScS* wave appears on the vertical seismogram.
3) The amplitude ratio of *ScS*/*S* for the same frequency band is less than 0.2.
4) No *PcP* phase is observed, except for poor *ScP* phase on the 1979 seismogram.

Fig. 18


00h37m
22 Feb. 1974
S. Honshu
WB
52m
U
N
ScS
17h27m
11 Dec. 1979
Bonin Is.
MP
42m
ScP
U
N
ScS
11h15m
13 May 1977
P
S
Bonin Is.
MP
30m
U
E
ScS

19. *ScP* wave from regional earthquakes

Seismograms show converted waves at the mantle-core boundary from *S* to *P* (*ScP*) obtained by MP-Z seismograph at DDR. These events were located at the shortest epicentral distance for the appearance of *ScP* phase. The upper four traces show seismograms from the Okhotsk Sea region, and the bottom seismogram is from the Marianas region. The magnification of each seismogram is arbitrary.

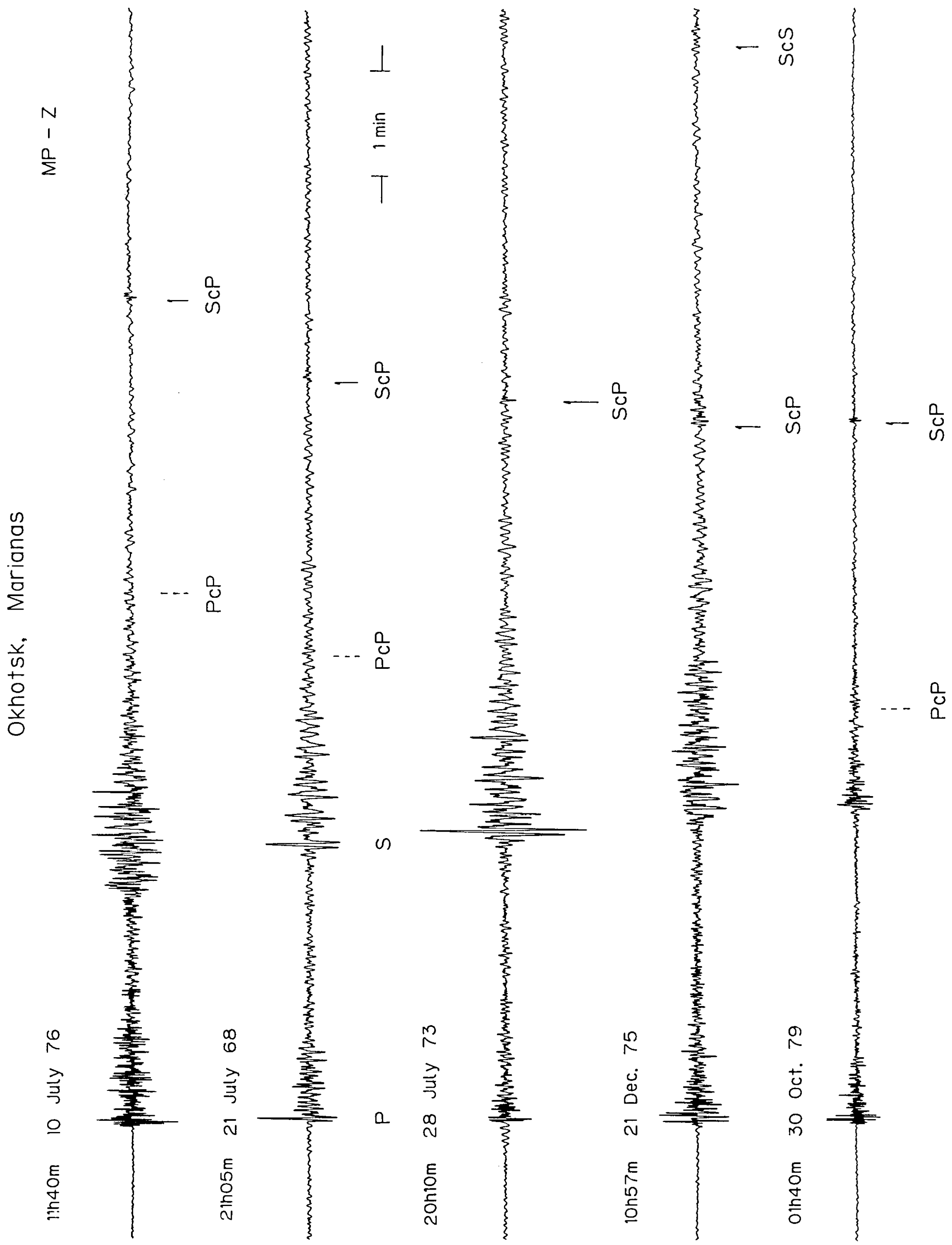
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
11 37 14.0	47°31	145°75	402	5.8	12.31
21 02 31.4	49.56	147.95	576	4.8	14.98
20 06 35.4	50.45	148.92	585	5.5	16.07
10 54 17.2	51.93	151.57	546	6.0	17.7
01 37 06.0	18.77	145.16	585	5.6	17.96

Comments

1) The *ScP* phase appears on deep-earthquake for this epicentral range.
2) The *ScP* phase from regional earthquakes contains high frequency components, above 3 Hz.
3) Clear *ScS* waves appear on the horizontal component seismograms, though not shown here.
4) The *PcP* phase is not clear for this epicentral range.

Fig. 19


Okhotsk, Marianas
MP - Z
11h40m 10 July 76
21h05m 21 July 68
20h10m 28 July 73
10h57m 21 Dec. 75
01h40m 30 Oct. 79
P
S
PcP
ScP
ScS
1 min

20. Multi-reflections of *ScS* waves

Seismograms obtained by LP-E component seismograph at DDR for the event in the North Korea region. Seismograms of initial 9 minutes including *P*- and *S* waves are excluded, and no data are available on magnetic tape after 01h 47m. Note the time of beginning of each trace. LP(L): LP-Low gain seismograph.

The focal parameters by ISC are as follows:

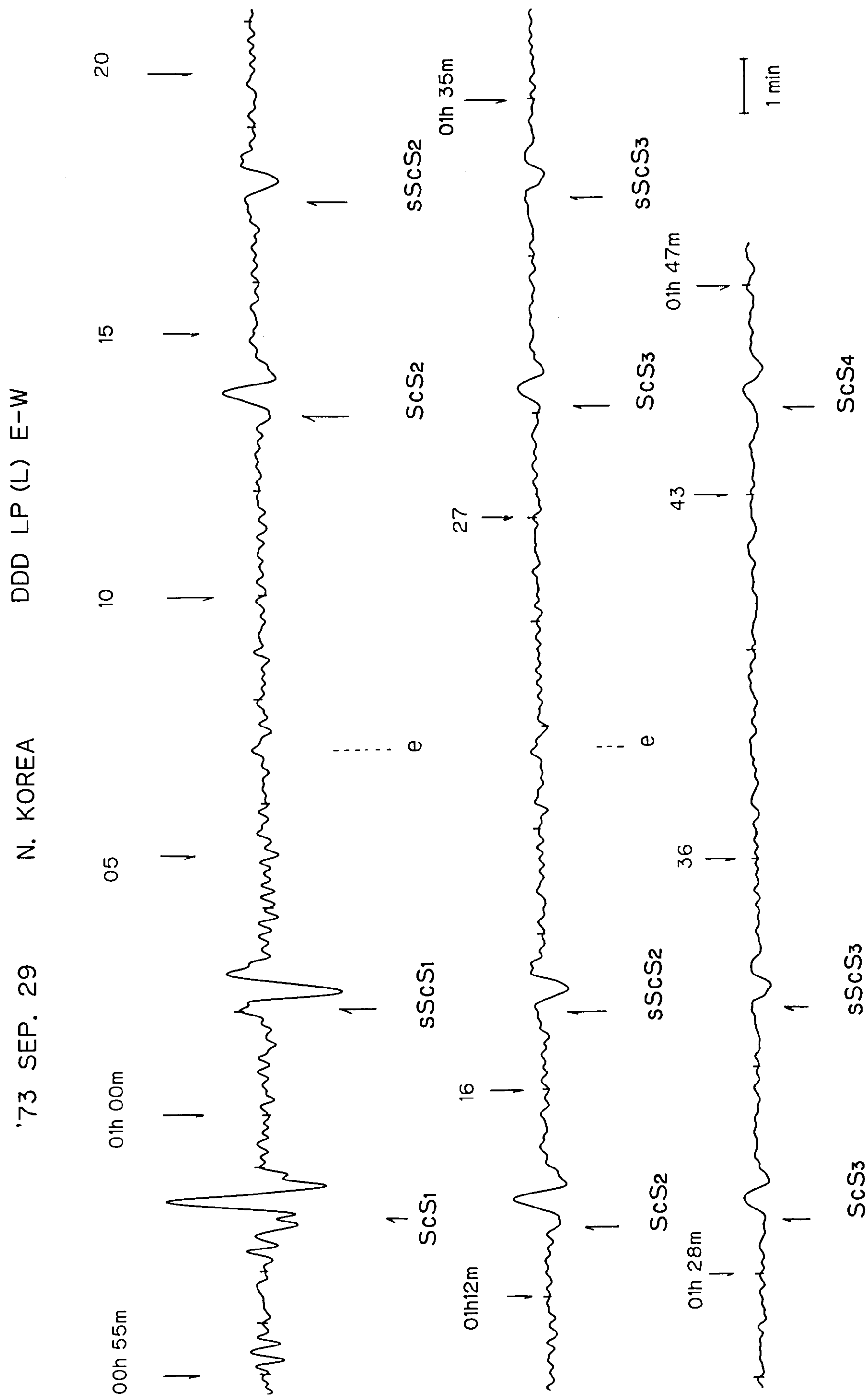
Origin Time	Epicenter		*h*	*Mb*	*Δ*
h m s	N	E	km		deg
00 44 00.3	41°.93	130°.99	567	6.3	8.71

Comments

1) Four times reflected waves at the free surface and the core boundary (*ScS*, *sScS*) are seen on the seismograms of three traces.
2) Reverse polarities are seen between *ScS* and *sScS* waves.
3) A detailed comparison of three traces shows that an artificial phase indicated by "*e*" seems to exist at the middle part of each trace.

Combined data of ScS_1 and $sScS_1$ through ScS_4 and $sScS_3$ make it possible to determine the *Q* structure of the earth.

Fig. 20


'73 SEP. 29
N. KOREA
DDD LP (L) E-W
00h 55m
01h 00m
05
10
15
20
ScS1
sScS1
e
ScS2
sScS2
01h12m
16
27
01h 35m
ScS2
sScS2
e
ScS3
sScS3
01h 28m
36
43
01h 47m
ScS3
sScS3
ScS4
1 min

21. *P* waveform of large deep-focus earthquake (1)

This earthquake was one of the largest deep-focus earthquakes in and near Honshu in the past two decades. The top trace shows the seismogram obtained by WB-Z seismograph at DDR, and the middle trace shows the seismogram passed through a band-pass filter. The bottom trace shows the seismogram obtained by LP-Z.

The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	M	Δ
h m s	N	E	km			deg
02 17 21.0	29°35	138°92	454	6.1	7.9*	6.63

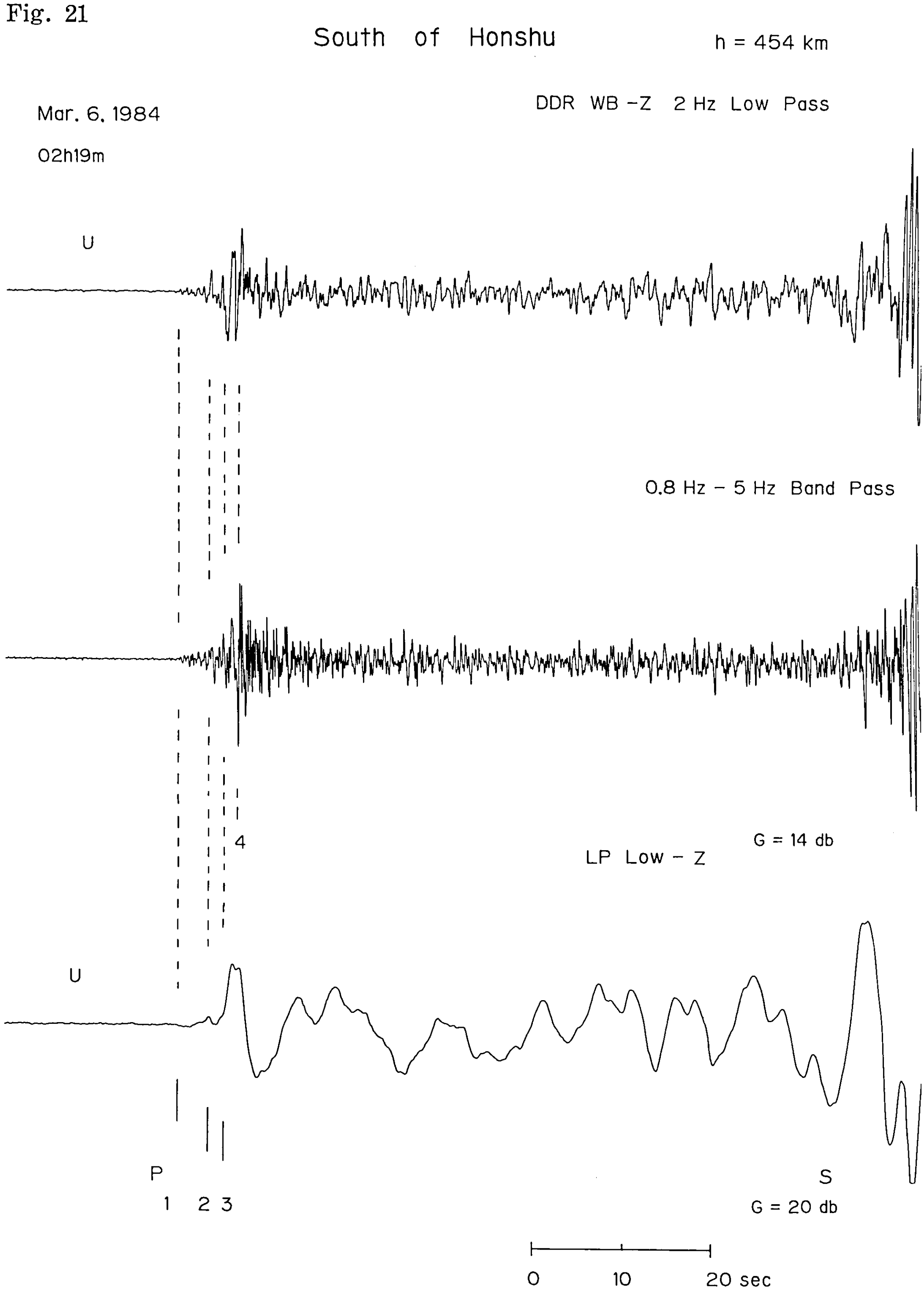
*: *M* by JMA.

Comments

1) Initial motion of *P* waves is very small compared with the phases of later arrivals, and the maximum amplitude of *P* waves appears about 7 seconds after the initial motion.
2) The *P* waveforms consist of three or four phases as indicated by dotted lines.

Similar features of waveforms are seen in the events of other seismic regions as shown below.

Fig. 21


South of Honshu
h = 454 km
Mar. 6, 1984
02h19m
DDR WB -Z 2 Hz Low Pass
U
0.8 Hz - 5 Hz Band Pass
4
G = 14 db
LP Low - Z
U
P
1 2 3
S
G = 20 db
0 10 20 sec

22. *P* waveform of large deep-focus earthquake (2)

P waveform of large deep-focus earthquake in the Kurile Islands region. The top trace shows the seismogram obtained by MP-Z seismograph at DDR, and the 2nd trace shows the seismogram passed through a band-pass filter. The third trace shows the seismogram obtained by LP-Z, and the bottom trace shows the seismogram of a small event in the same region. The sizes of bars show relative differences of magnification.

The focal parameters by ISC are as follows:

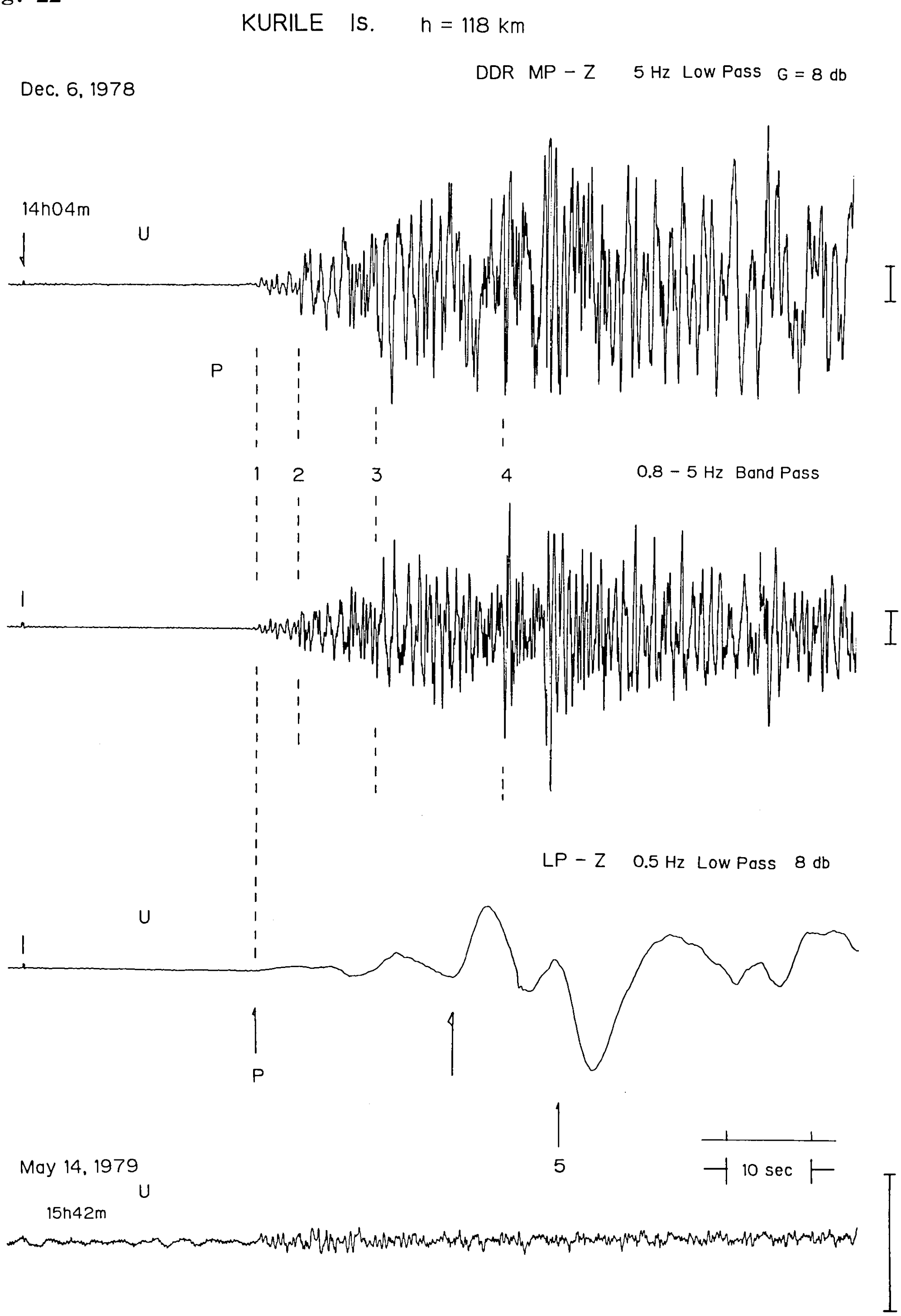
Origin Time	Epicenter		*h*	*Mb*	*Δ*
h m s	N	E	km		deg
14 02 04.5	44°.55	146°.67	118	6.3	10.27
15 39 52.1	44.67	147.57	103	5.5	10.76

Comments

1) At least five phases can be recognized on the *P* wave group of MP seismogram, especially, phase No. 4 is very sharp and impulsive.
2) The LP seismogram also shows a complicated pattern consisting of several phases, but the beginning of each phase does not agree with the MP seismogram.
3) Phase No. 5 after about 32 sec from the initial motion is possibly stopping phase.
4) No noticeable phase appears on the seismogram of a small event in the same region (bottom).

Complexities of the waveform of a large event are related to rupture irregularities at the source; such behavior of seismograms suggests the existence of asperity and a fracture-barrier along the fault plane (KANAMORI, 1981; DAS and AKI, 1977).

Fig. 22


KURILE Is. h = 118 km
Dec. 6, 1978
DDR MP − Z 5 Hz Low Pass G = 8 db
14h04m
U
P
1 2 3 4
0.8 − 5 Hz Band Pass
LP − Z 0.5 Hz Low Pass 8 db
U
P
5
10 sec
May 14, 1979
U
15h42m

23. *P* waveform of regional deep-focus earthquakes —dependence on earthquake size—

Comparison of *P* waveforms from deep-focus earthquakes in the region of southern Honshu, including Volcano and Marianas. The upper two traces show seismograms obtained by MP-Z and LP-Z seismographs at DDR for the event in the Volcano Islands region, and the lower two seismograms are for the event in the Marianas region. All seismograms are reproduced by 8 db gain from magnetic tape.

The focal parameters of two events by ISC are as follows:

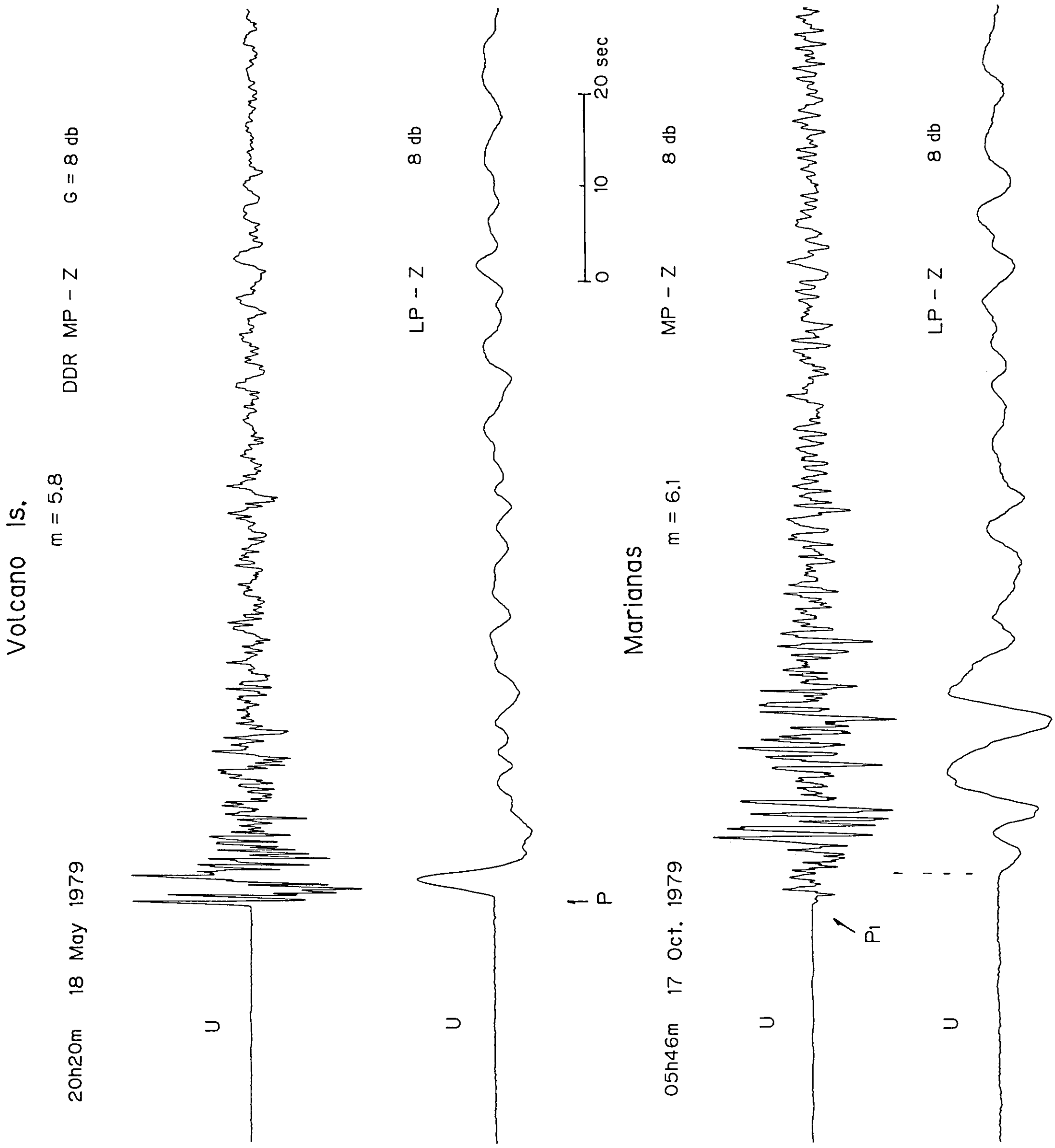
Origin Time	Epicenter		*h*	*Mb*	*Δ*
h m s	N	E	km		deg
20 18 03.5	24°.13	142°.41	598	5.8	12.15
05 43 03.1	18.49	145.39	601	6.1	18.28

Different waveforms are seen between the two events, although they have similar source depths:

1) An impulsive *P* waveform is seen for the event of Volcano region (upper two seismograms).
2) Complicated waveforms consisting of two or three rupturing events are seen for the event of Marianas region (lower two seismograms).

From the analysis of seismograms in this region, it is found that the *P* waveform is different between large and small earthquakes. When the *Mb* exceeds a valve of 6 their earthquakes show double or multiple-shock type waveforms. Similar tendencies of *P* waveforms are seen in the other seismic region as shown later.

Fig. 23


Volcano Is.
m = 5.8
DDR MP - Z
G = 8 db
20h20m 18 May 1979
U
LP - Z
8 db
U
P
0
10
20 sec
Marianas
m = 6.1
MP - Z
8 db
05h46m 17 Oct. 1979
U
P_1
LP - Z
8 db
U

24. Regional variation of P waveform from deep earthquakes

Comparison of seismograms with deep source in different seismic regions. The upper three traces are seismograms obtained by LP-Z seismograph at DDR for events south of Honshu, including the Bonin, Volcano and Marianas regions, and the lower three seismograms show events in the Sea of Japan, including the E. Russia and N. Korea regions. Bars show relative differences of magnification. The polarity of initial motion is arranged by change of the sense of play-back amplifier.

The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Δ
	d h m s	N	E	km		deg
Feb. 14,	10 50 24.0	24°.54	140°.32	572	5.4	9.48
May 18,	20 18 03.5	24.13	142.41	598	5.8	12.15
Oct. 17,	05 43 03.1	18.49	145.39	601	6.1	18.28
Sep. 10,	07 43 32.3	42.48	131.05	552	5.8	9.04
Aug. 16,	21 31 24.9	41.85	130.86	566	5.8	8.73
Sep. 29,	00 44 00.3	41.93	130.99	567	6.3	8.71

In spite of small differences of depth, magnitude and epicentral distance, clear differences of waveforms are seen between the two regions:

A. South of Honshu

1) Short-period and impulsive waveforms are seen for the P waves of small events ($Mb \leqq 5.8$).

2) Complicated waveforms consisting of P_1, P_2 and P_3 phases are seen for the largest event with Mb6.1.

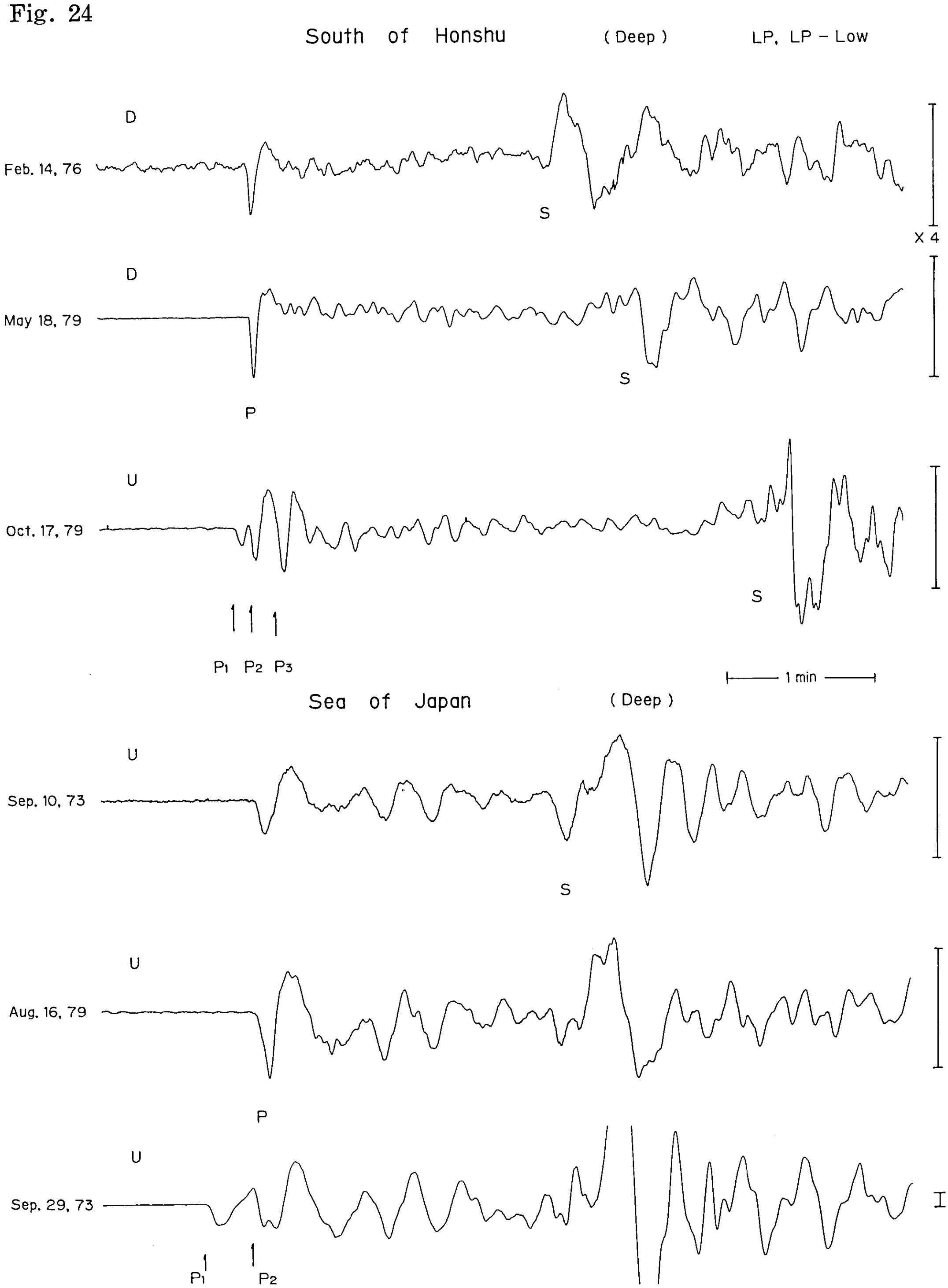
B. Sea of Japan

1) Sharp initial motion, but with longer period than those of A is seen for the small events (Mb5.8); this tendency is the same for P-coda waves.

2) Complicated waveforms consisting of P_1 and P_2 phases are seen for the largest event with Mb6.3.

From the comparison of seismograms of two regions, it is confirmed that events in the Sea of Japan region consist of low-frequency waves, and such a difference will be due to the difference of the asperity size or the barrier interval between the two regions.

Fig. 24


South of Honshu
(Deep)
LP, LP - Low
D
Feb. 14, 76
S
X 4
D
May 18, 79
S
P
U
Oct. 17, 79
S
P1 P2 P3
1 min
Sea of Japan
(Deep)
U
Sep. 10, 73
S
U
Aug. 16, 79
P
U
Sep. 29, 73
P1
P2

25. Low-frequency waves from deep-focus earthquakes

Seismograms from regional deep-focus earthquakes obtained by LP-Z seismograph at DDR. The upper two traces show seismograms from the Marianas region, and the lower two seismograms are from the Okhotsk region. The sizes of bars show relative differences of magnification.

The focal parameters by ISC are as follows:

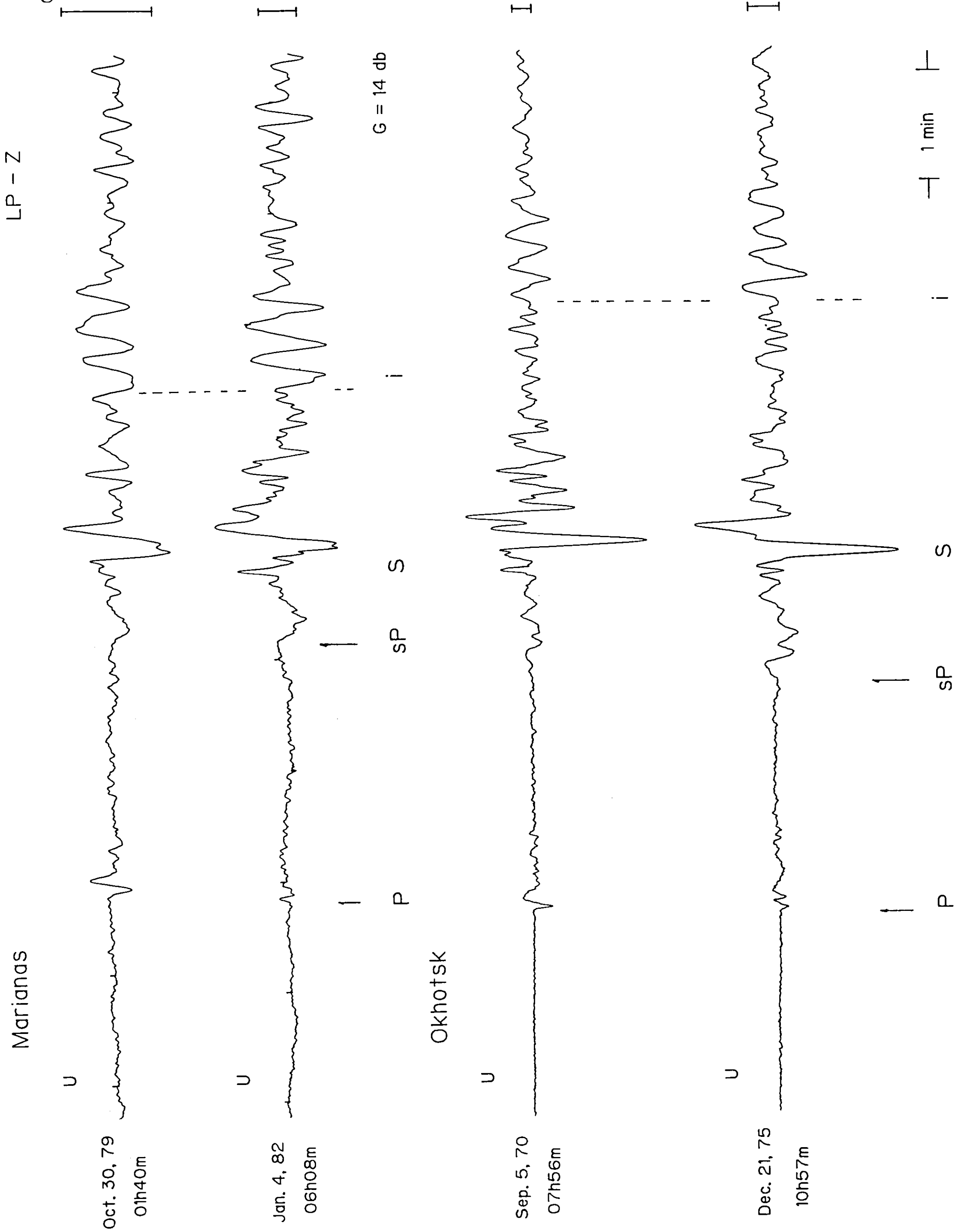
Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
01 37 06.6	18°77	145°16	585	5.6	17.96
06 05 02.6	18.00	145.67	607	6.1	18.83
07 52 27.2	52.28	151.49	560	5.7	18.47
10 54 17.2	51.93	151.57	546	6.0	18.19

Comments

1) Two clear phases indicated by sP and "i" appear, although they were located in different regions.
2) The arrival times of i phases are different between the Marianas and Okhotsk regions, but their times are almost constant within the regions.
3) The i phase consists of low-frequency waves, and continued for a few circles with identical frequency, like the channel waves.
4) The i phase appears only for events with narrow epicentral range and source depth.

The physical meaning of i phase is unknown. Collection of similar seismograms in different regions will be needed.

Fig. 25


LP - Z
G = 14 db
1 min
Marianas
Oct. 30, 79
01h40m
Jan. 4, 82
06h08m
Okhotsk
Sep. 5, 70
07h56m
Dec. 21, 75
10h57m
U
P
sP
S
i

26. X phases from regional deep-focus earthquake (1)

Seismograms obtained by MP-Z and MP-E seismographs at DDR for the deep-focus earthquake in the Sea of Okhotsk region. The upper three traces are seismograms of vertical component (Z), and the lower three traces are those of horizontal component (E-W).

The focal parameters by ISC are as follows:

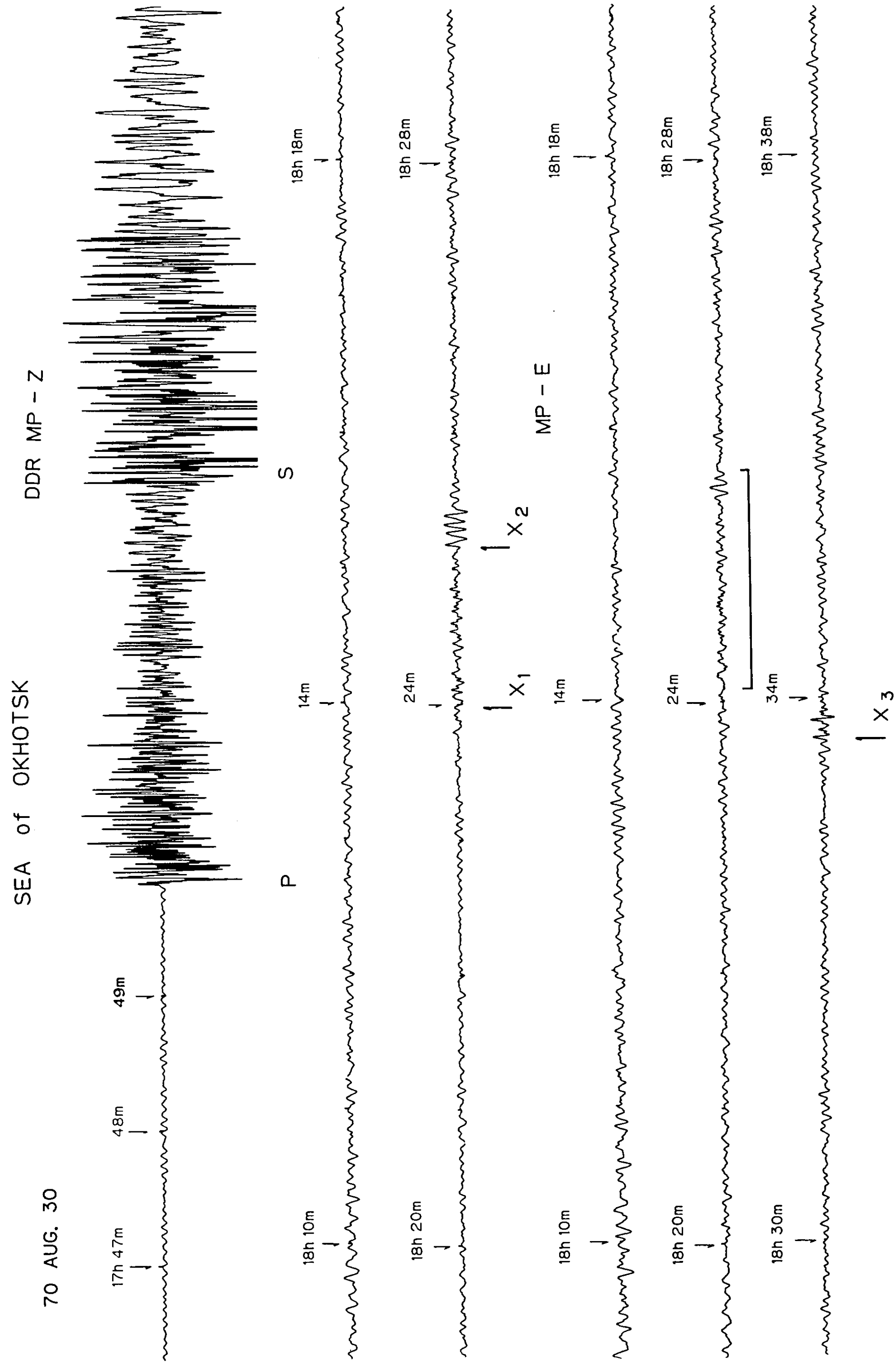
Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
17 46 08.9	52°.36	151°.64	643	6.5	18.59

In spite of short distance (18°), some later phases are followed:

1) Three X phases indicated by X_1, X_2 and X_3 appear, and among these phases, X_3 phase appears only on the horizontal component seismogram.
2) The arrival time of X_1 phase measured from the origin time is about 37m 54s and that of X_3 phase is about 47m 36s.
3) The time interval of X_1 and X_2 phases is about 01m 06s, though the onset of X_1 phase is not clear.

Considering the arrival time of X_2 phase, this phase is probably reflected wave (*PKPPKP*), and X_1 phase is the similar reflected wave from the discontinuity about 100 km beneath the free surface. The X_3 phase on the E-W seismogram is converted wave from *PKPPKP* to *PKPPKPcS* as discussed later.

Fig. 26


70 AUG. 30
SEA of OKHOTSK
DDR MP - Z
17h 47m
48m
49m
P
S
18h 10m
14m
18h 18m
18h 20m
24m
18h 28m
X_1
X_2
MP - E
18h 10m
14m
18h 18m
18h 20m
24m
18h 28m
18h 30m
34m
18h 38m
X_3

27. *X* phase from regional deep-focus earthquakes (2) —*PKPPKPcS* ?—

Seismograms obtained by MP-Z and MP-E seismographs at DDR for deep-focus earthquakes in the Sea of Okhotsk region. The top pair trace shows seismograms of vertical (Z) and horizontal (E-W) components, and similar pair seismograms are continued to the 2nd and 3rd traces. Note the time at the beginning of each set. The bottom trace shows the latter part of the MP-E seismogram of another event in the same region. G: gain of play-back amplifier.

The focal parameters by ISC are as follows:

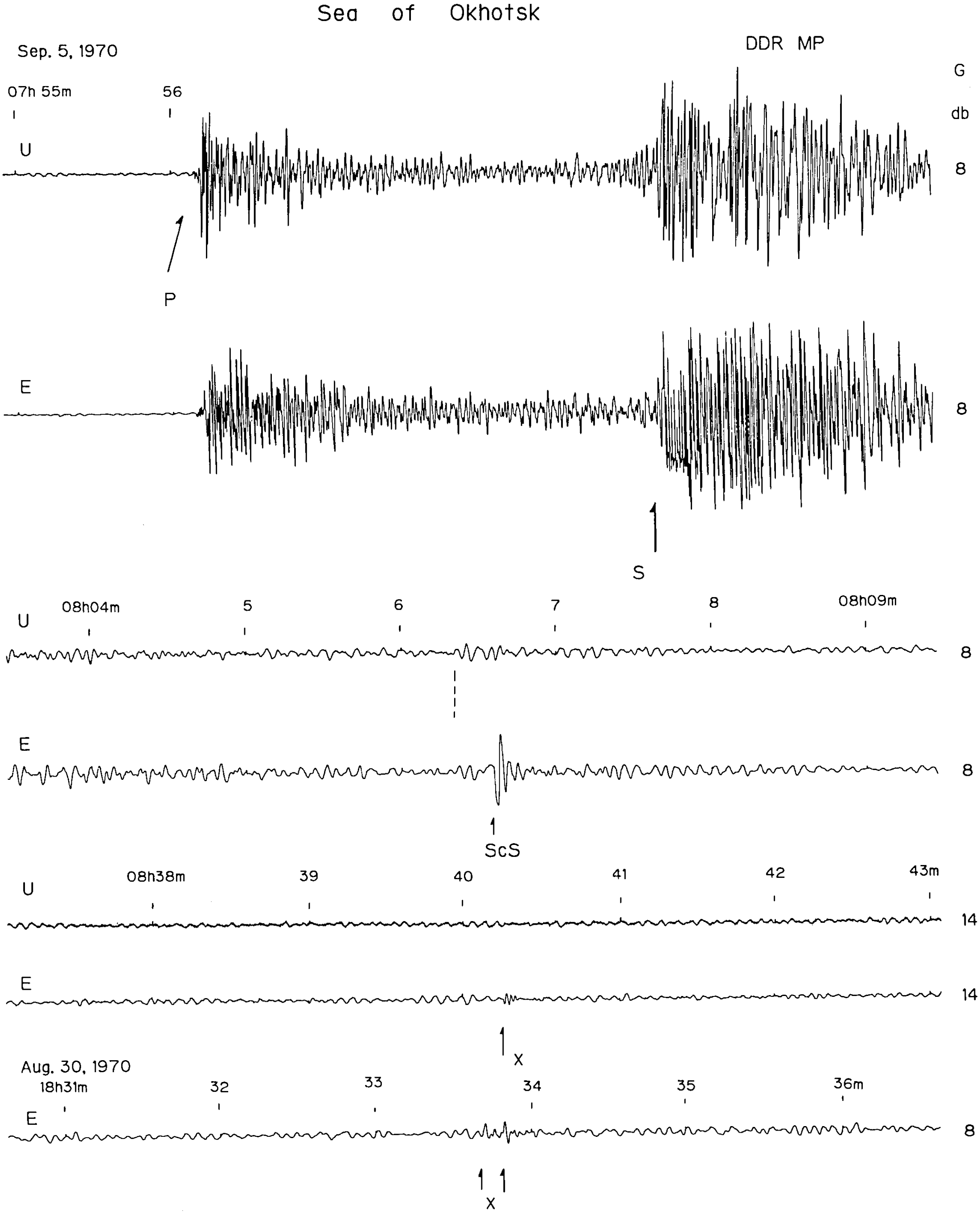
Origin Time	Epicenter		h	Mb	Δ
d h m s	N	E	km		deg
Sep. 05, 07 52 07.2	52°28	151°49	560	5.7	18.47
Aug. 30, 17 46 08.9	52.36	151.64	643	6.5	18.59

Comments

1) Clear *ScS* phase is seen on the horizontal component of the 2nd trace.
2) Small, but clear phase indicated by "*X*" appears on the E-W component seismogram for both events. Note that *X* phase does not appear on the Z component seismogram.

The arrival time of *X* phase is about 48m 08s for the former event and about 47m 36s for the latter event. Considering the arrival time and source depth for both events, the *X* phase is probably converted wave at the core boundary from *PKPPKP* to *PKPPKPcS*, though such a phase does not appear on the *J-B* Table. It is also noticed that the *X* phase is a shorter period ($T \cong 1.5$s) than *ScS*.

Fig. 27


Sea of Okhotsk
Sep. 5, 1970
DDR MP
G
db
07h 55m
56
U
8
P
E
8
S
08h04m
5
6
7
8
08h09m
U
8
E
8
ScS
08h38m
39
40
41
42
43m
U
14
E
14
X
Aug. 30, 1970
18h31m
32
33
34
35
36m
E
8
X

28. Reflected waves at the 20° discontinuity (1)

Reflected waves (*PxP, SxS*) from the Volcano Islands region observed by MP and LP seismographs at DDR. The upper two traces show seismograms obtained by vertical and horizontal (N-S) components of MP seismograph, and the lower three traces show those of three components of LP seismograph. The sizes of bars show relative differences of magnification.

The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
d h m s	N	E	km		deg
Feb. 21, 16 16 52.3	22°.33	143°.59	117	6.0	14.15

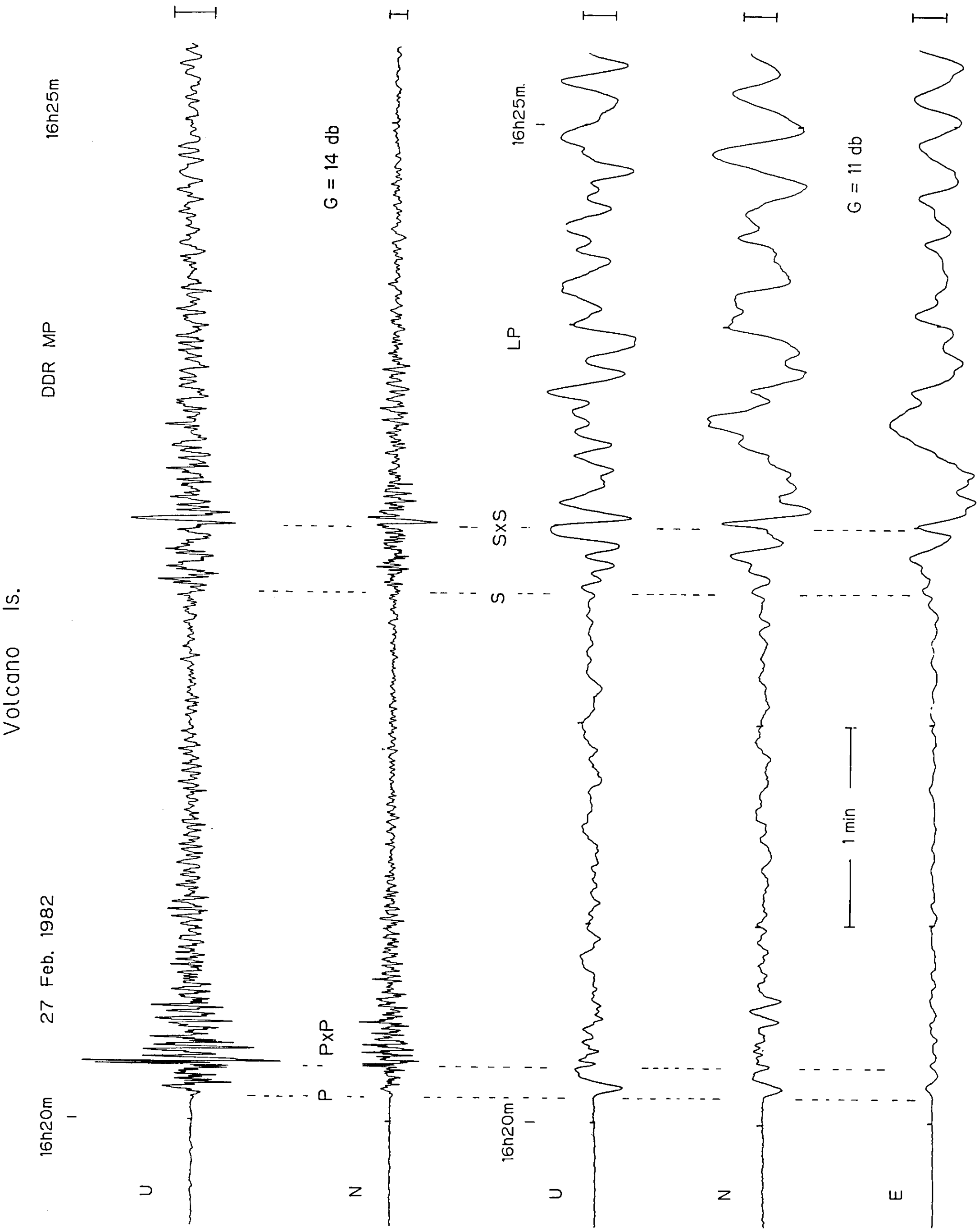
Comments

1) Clear and large two phases indicated by *PxP* and *SxS* are seen on the MP seismograms.
2) Small, but clear *PxP* phase also appears on the LP seismogram, and a large *SxS* phase follows the *S* waves.

Considering the source depth (117 km), the *PxP* and *SxS* phases are not reflected waves at the surface (*pP, sS*). They are probably the reflected waves from *P* to *P* or from *S* to *S* at the discontinuity of 400 km depth which is called the "20° discontinuity".

(to be continued)

Fig. 28


Volcano Is.
27 Feb. 1982
DDR MP
16h20m
16h25m
G = 14 db
P
PxP
S
SxS
LP
G = 11 db
1 min
U
N
U
N
E

29. Reflected waves at the 20° discontinuity (2)

The reflected waves similar to that shown in the previous figure appeared on the seismograms from different regions.

This figure shows typical examples of reflected waves (*PXP*) phase obtained by SP-Z seismograph at DDR and their epicentral locations (closed circles).

The focal parameters by ISC are as follows:

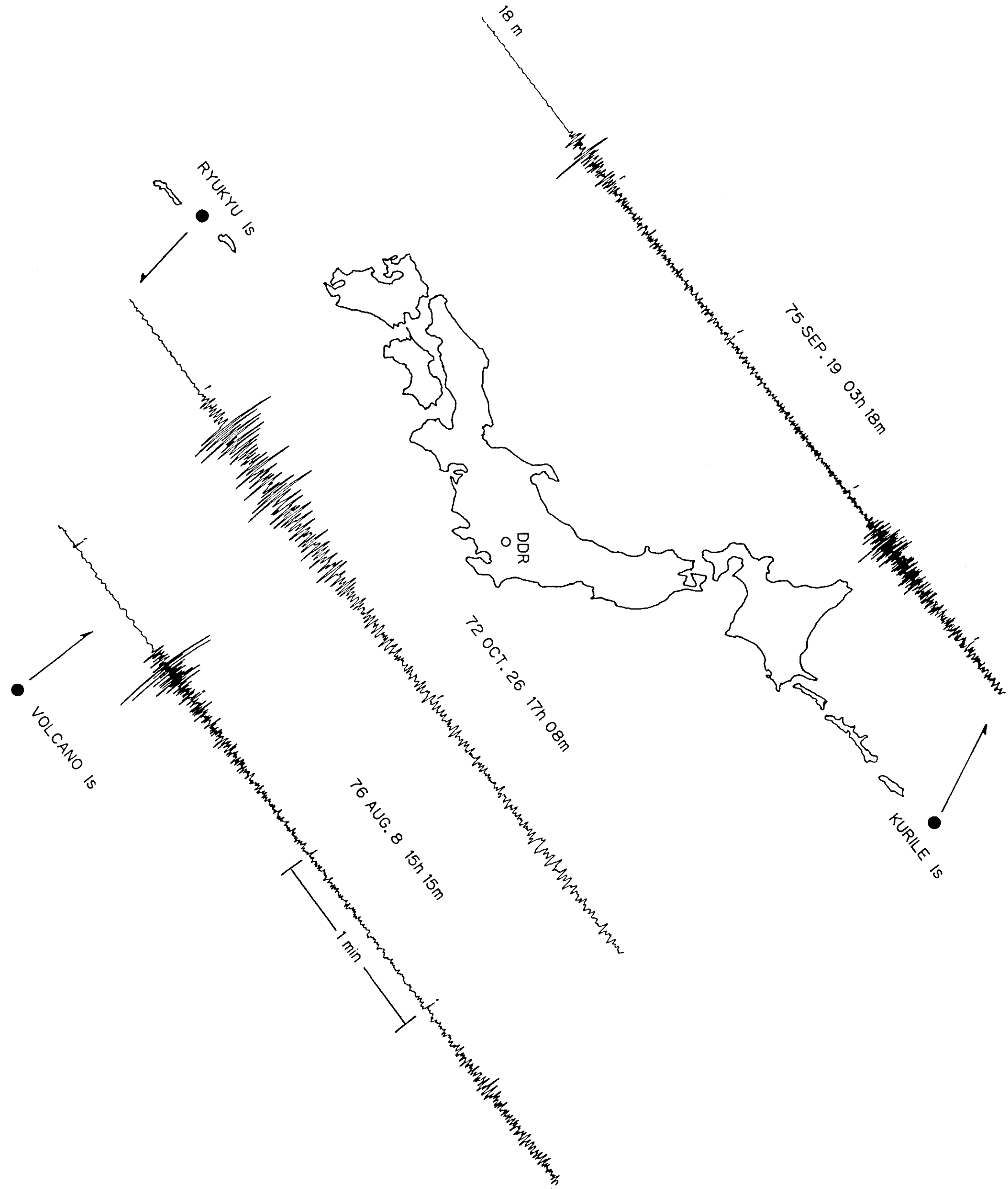
Origin Time	Epicenter		*h*	*Mb*	*Δ*
d h m s	N	E	km		deg
Sep. 19, 03 15 20.9	46°.96	151°.86	118	5.5	14.47
Oct. 26, 17 05 05.6	27.48	128.57	63	6.0	12.40
Aug. 08, 15 12 29.0	22.22	143.25	184	4.6	14.18

Comments

Although they are located at different azimuth angles from DDR, a clear *PXP* phase is commonly observed after about 7–12 sec from the *P* wave onset.

Note that the source depth and the epicentral distance for the appearance of *PXP* phase differ from region to region. The appearance of reflected waves along the epicentral distance for each region is as follows.

Fig. 29


18 m
RYUKYU Is
75 SEP. 19 03h 18m
DDR
72 OCT. 26 17h 08m
VOLCANO Is
76 AUG. 8 15h 15m
1 min
KURILE Is

30. Reflected waves from Kurile Islands region

An arrangement of seismograms observed by SP-Z seismograph at DDR for events along the Kurile Islands region. The ordinate on the left-hand side shows the epicentral distance in degrees.

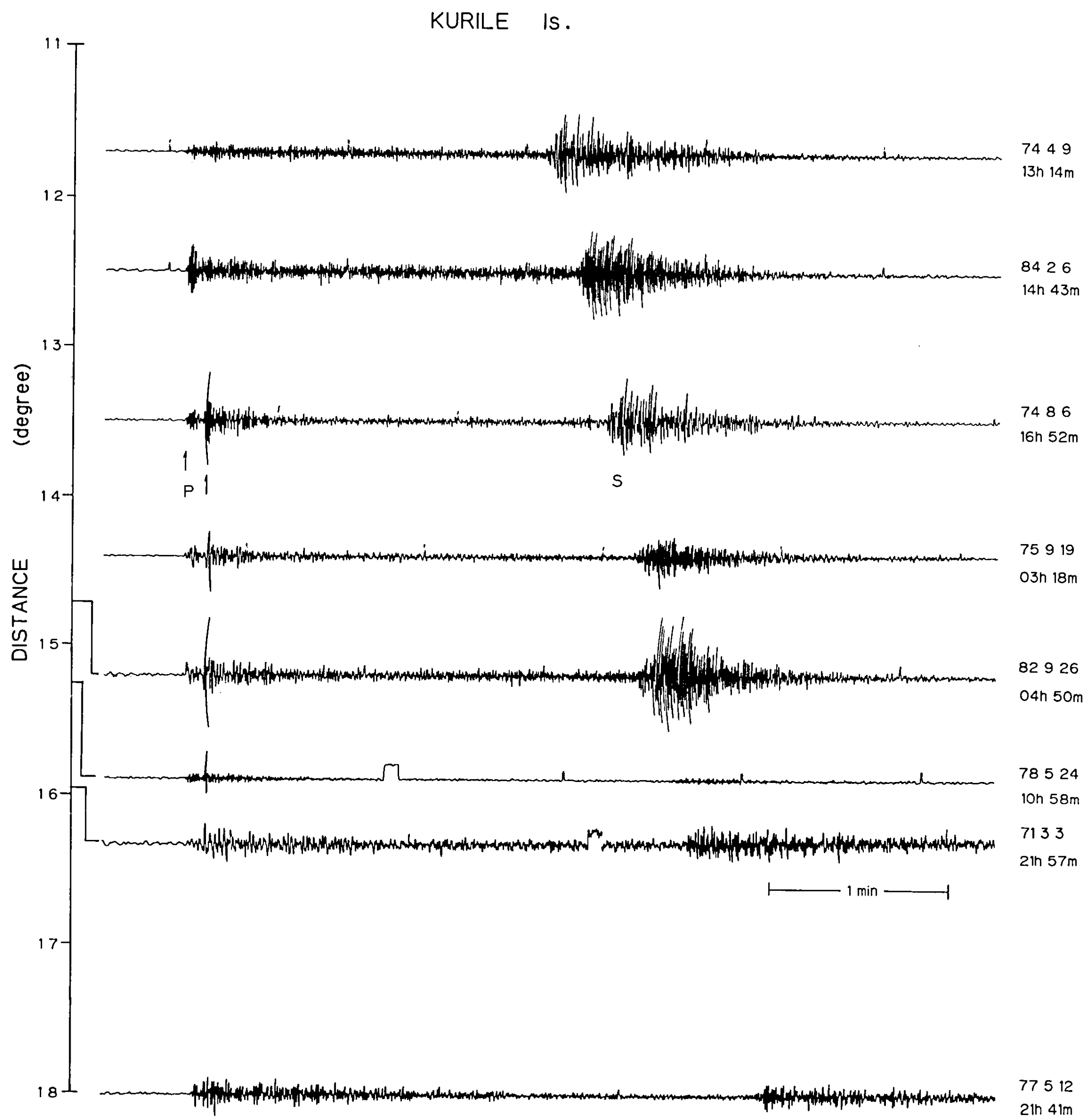
The focal parameters by ISC are as follows:

Origin Time	Epicenter		*h*	*Mb*	*Δ*
d h m s	N	E	km		deg
Apr. 09, 13 11 23.6	45°.38	148°.41	159	5.4	11.69
Feb. 06, 14 40 11.6	45.40	150.20	96	5.5	12.55
Aug. 06, 16 49 22.6	46.65	150.60	170	5.3	13.65
Sep. 19, 03 15 20.9	46.96	151.86	118	5.5	14.47
Sep. 26, 04 46 38.1	47.04	152.21	113	5.6	14.70
May 24, 10 55 24.4	47.35	152.91	115	4.5	15.26
Mar. 03, 21 54 09.7	48.23	153.07	127	5.7	15.95
May 12, 21 37 32.6	50.12	155.03	129	5.2	18.15

Comments

1) Clear reflected waves (*PXP*) are observed at the distance of 13.6°-16°.
2) The time intervals of *P* and *PXP* waves are almost constant having a value of 6-7 sec.
3) Seismograms accompanied with a later phase are from earthquakes with intermediate source depths.
4) Travel time residuals (*O-JB*) of *P* and *S* waves are negative having values of 1-3 sec and 7-10 sec, respectively (see ISC Bulletin).

Fig. 30


KURILE Is.
11
12
13
14
15
16
17
18
DISTANCE (degree)
P
S
74 4 9
13h 14m
84 2 6
14h 43m
74 8 6
16h 52m
75 9 19
03h 18m
82 9 26
04h 50m
78 5 24
10h 58m
71 3 3
21h 57m
1 min
77 5 12
21h 41m

31. Reflected waves from Volcano-Mariana region

An arrangement of seismograms observed by SP-Z seismograph at DDR for events along the Volcano-Mariana Islands region. The ordinate shows the epicentral distance in degrees.

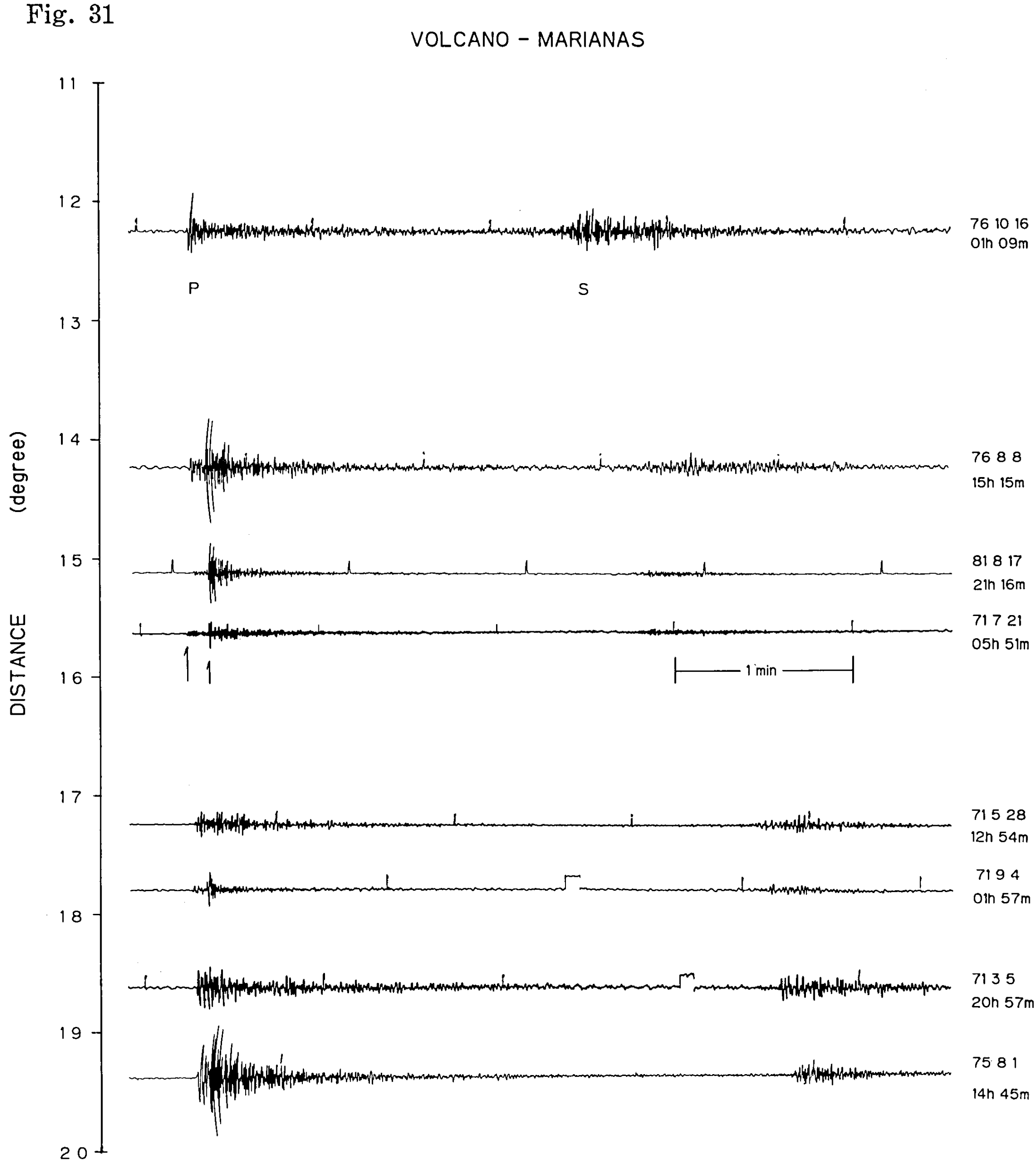
The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Δ
	d h m s	N	E	km		deg
Oct.	16, 01 06 26.0	23°.92	141°.70	81	5.0	12.23
Aug.	08, 15 12 29.0	22.22	143.25	184	4.6	14.18
Aug.	17, 21 12 53.0	22.13	143.49	176	4.5	14.31
Jul.	21, 05 47 55.1	22.07	143.62	79	4.4	14.41
May	28, 12 50 40.8	19.22	145.38	163	5.2	17.58
Sep.	04, 01 54 00.3	18.96	145.37	235	4.6	17.82
Mar.	05, 20 53 18.1	18.49	145.54	224	5.1	18.32
Aug.	01, 14 41 29.5	18.41	145.55	199	5.2	18.40

Comments

1) Predominant reflected waves (*PXP*) appear at the distance of 14°-17° arriving 5-7 sec after the initial motion.
2) Seismograms accompanied by reflected waves are from earthquakes with intermediate depths the same as those of the Kurile Islands region.
3) *S* waves in this region are not clear compared with those of the Kurile Islands region.

Fig. 31


VOLCANO - MARIANAS
DISTANCE (degree)
11
12
13
14
15
16
17
18
19
20
P
S
1 min
76 10 16
01h 09m
76 8 8
15h 15m
81 8 17
21h 16m
71 7 21
05h 51m
71 5 28
12h 54m
71 9 4
01h 57m
71 3 5
20h 57m
75 8 1
14h 45m

32. Reflected waves from Ryukyu-Taiwan region

An arrangement of seismograms observed by SP-Z seismograph at DDR for events along the Ryukyu-S.E. of Taiwan region. The ordinate shows the epicentral distance in degrees.

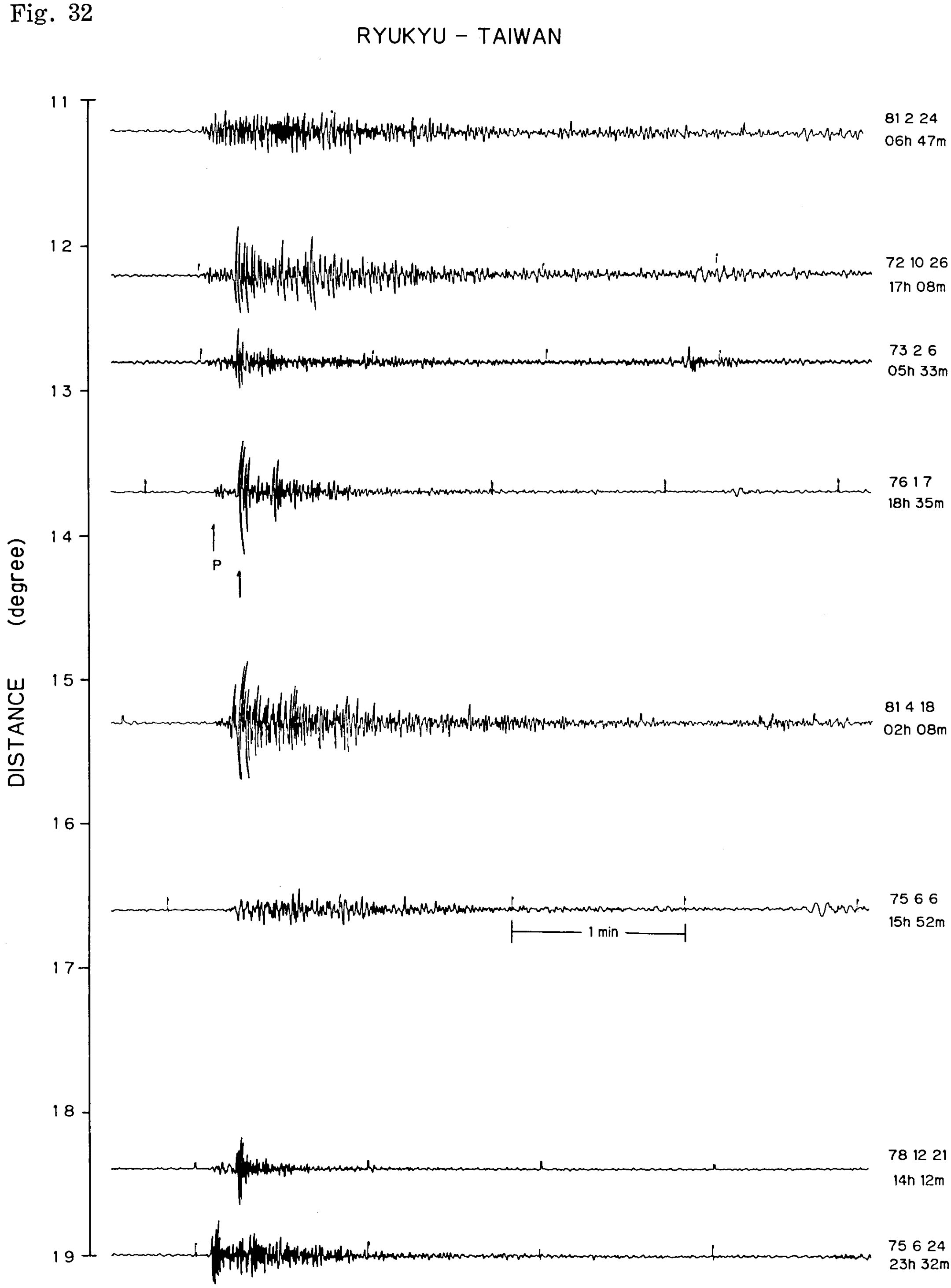
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
d h m s	N	E	km		deg
Feb. 24, 06 45 11.2	28°31	129°48	56	5.7	11.24
Oct. 26, 17 05 05.6	27.48	128.57	63	6.0	12.40
Feb. 06, 05 30 04.8	27.82	127.80	107	5.4	12.65
Jan. 07, 18 32 08.7	26.40	127.69	43	5.2	13.72
Apr. 18, 02 05 00.8	25.79	125.82	84	5.6	15.32
Jun. 06, 15 49 31.2	23.45	126.61	67	5.4	16.59
Dec. 21, 14 07 46	21.95	125.40	2	5.0	18.45
Jun. 24, 23 28 41.0	22.96	123.10	25	5.4	19.08

Comments

1) Predominant reflected waves (PxP) appear at the distance of 12°-18°.
2) The time intervals of P and PxP waves lie between 7 and 11 sec, and these values are larger than those of the Kurile and Volcano Islands regions.
3) The source depths accompaning with reflected waves in this region are shallower than those of the Kurile and Volcano Islands regions.
4) S waves do not appear at this distance (see also the following figures).

Fig. 32


RYUKYU - TAIWAN
DISTANCE (degree)
11
12
13
14
15
16
17
18
19
P
81 2 24
06h 47m
72 10 26
17h 08m
73 2 6
05h 33m
76 1 7
18h 35m
81 4 18
02h 08m
75 6 6
15h 52m
1 min
78 12 21
14h 12m
75 6 24
23h 32m

33. Regional variation of 20° discontinuity

Comparison of seismograms from two regions. The upper three traces show seismograms obtained by SP-Z seismograph at DDR for the events of Kurile Islands region, and the lower three traces are those of China Sea-Ryukyu Islands regions.

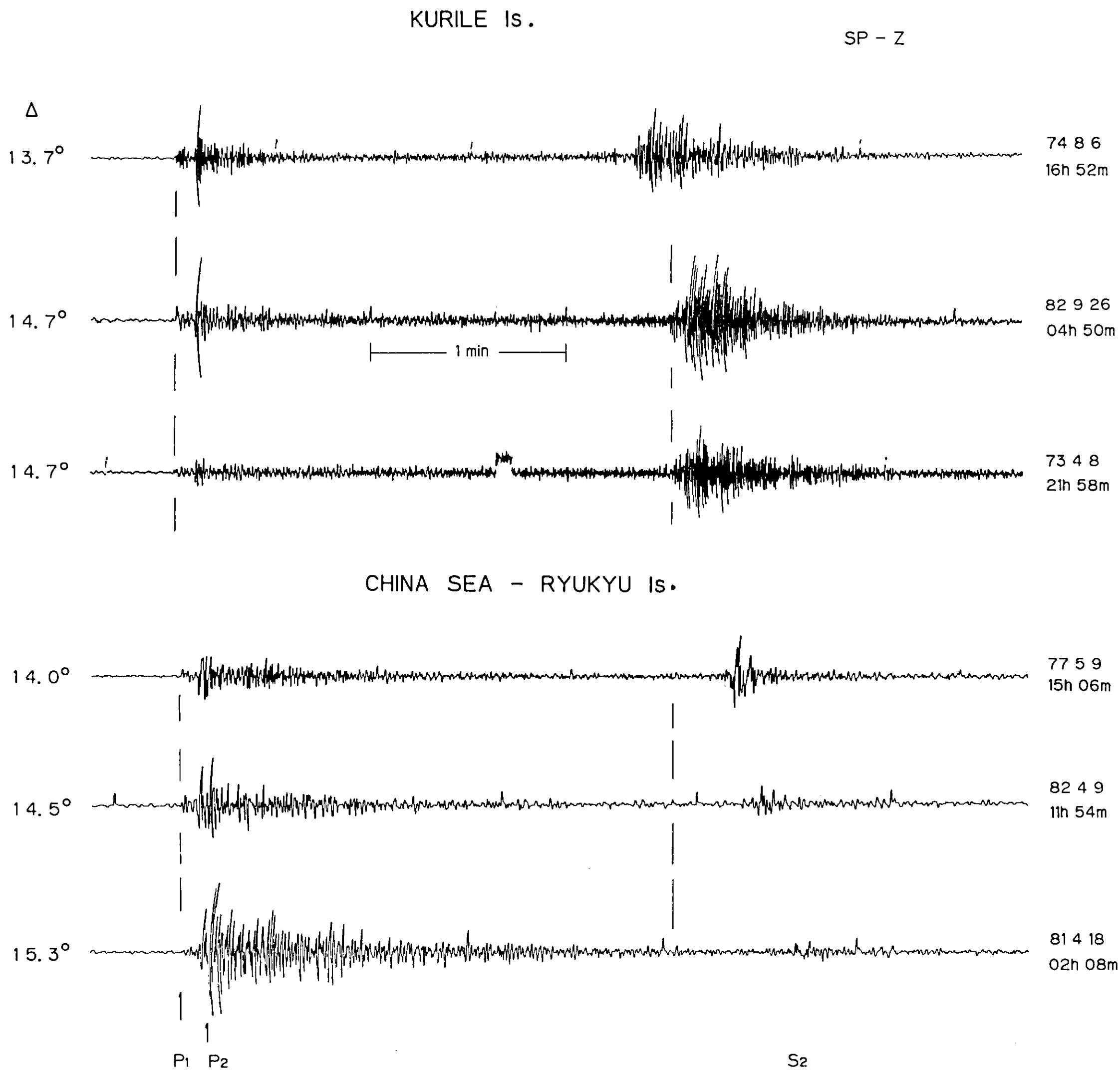
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
16 49 22.6	46°.65	150°.60	170	5.3	13.65
04 46 38.1	47.04	152.21	113	5.6	14.70
21 55 00.3	46.95	152.28	115	5.7	14.67
15 02 48.2	27.15	126.71	141	5.2	14.0
11 50 59.8	26.54	126.31	118	5.5	14.49
02 05 00.8	25.79	125.82	84	5.6	15.32

Although the earthquakes in both regions have similar source depths and epicentral distances, clear differences of waveforms and arrival times of S waves are seen between the two regions:

1) Two phases indicated by P_1 and P_2 (PXP in previous figure) appear for both regions.
2) The seismograms from the Kurile Islands region contained larger high-frequency components than those of the Ryukyu Islands region.
3) Travel time residuals of S waves (O-JB) are clearly different between the two regions. The residuals of S waves are negative ($-7\sim-10$s) for the Kurile region and positive (+16s in Δ14.5°) for the Ryukyu region. The S waves (S_2) which arrived later from the Ryukyu region are not direct S waves, as shown later.

Fig. 33


KURILE Is.
SP - Z
Δ
13.7°
74 8 6
16h 52m
14.7°
82 9 26
04h 50m
1 min
14.7°
73 4 8
21h 58m
CHINA SEA - RYUKYU Is.
14.0°
77 5 9
15h 06m
14.5°
82 4 9
11h 54m
15.3°
81 4 18
02h 08m
P1 P2
S2

34. S waves from S.W. Ryukyu Is. region

An appearance of S waves for events in the South-western Ryukyu Islands region obtained by MP seismographs at DDR.

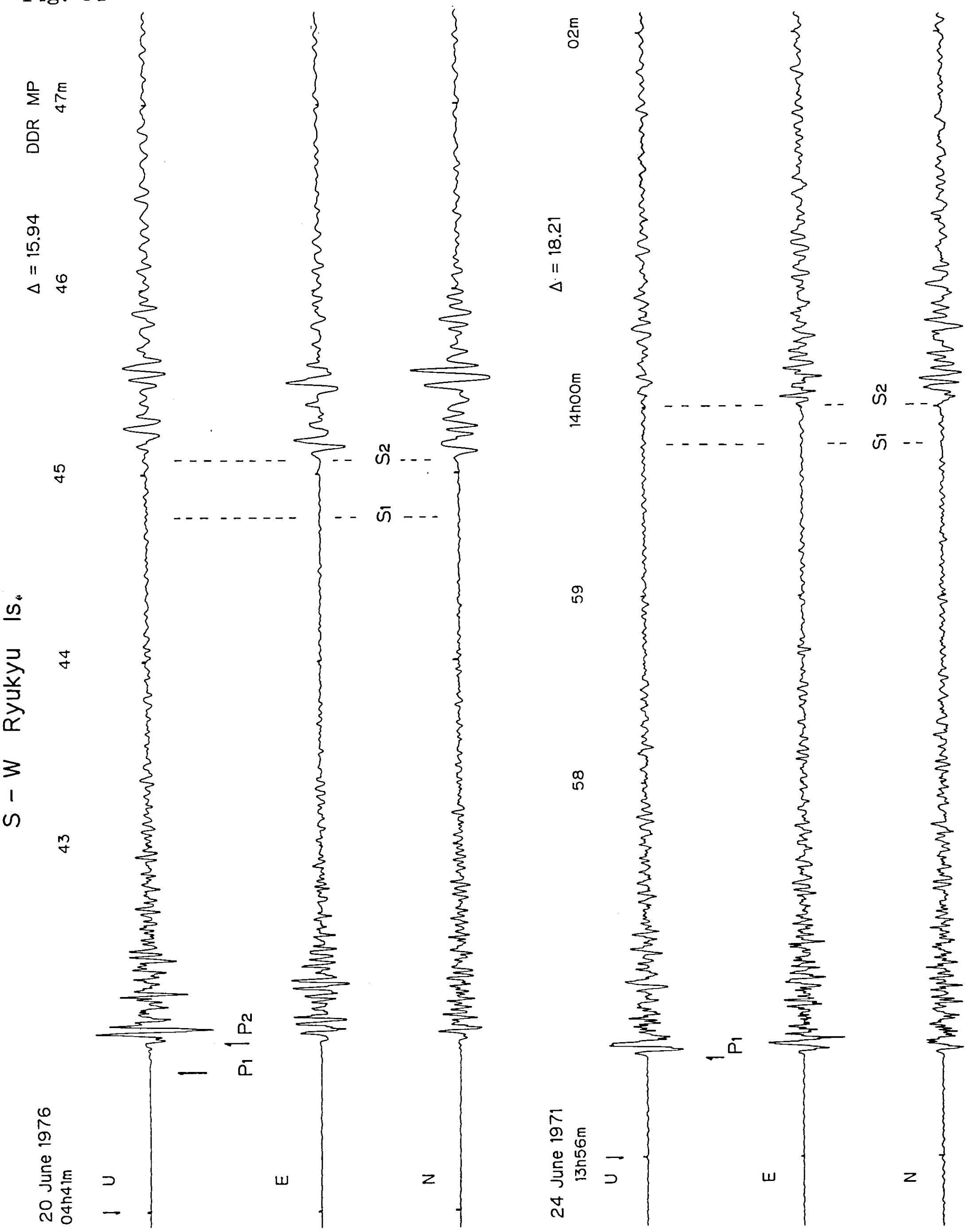
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
d h m s	N	E	km		deg
Jun. 20, 04 38 06.1	24°.79	125°.99	21	5.8	15.94
Jun. 24, 13 52 17.1	23.57	123.78	21	5.6	18.21

Comments

1) Dotted lines labeled by S_1 show the J-B travel times of S waves. There is no appearance of direct S wave.
2) Clear S_2 waves appear after S_1 waves. The time interval between S_1 and S_2 waves depends on the epicentral distance, and their values are about 18 sec for the upper event (15.94°) and about 12 sec for the lower event (18.21°).

Fig. 34


S – W Ryukyu Is.
20 June 1976
04h41m
U
E
N
P1
P2
43
44
45
46
47m
Δ = 15.94
DDR MP
S1
S2
24 June 1971
13h56m
U
E
N
P1
58
59
14h00m
Δ = 18.21
02m
S1
S2

35. *S* waves from Ryukyu-Taiwan region —$\Delta=10°$-$20°$—

An arrangement of seismograms obtained by MP-E, MP-N seismographs at DDR for the events along the Ryukyu-Taiwan regions. The ordinate shows the epicentral distance in degrees.

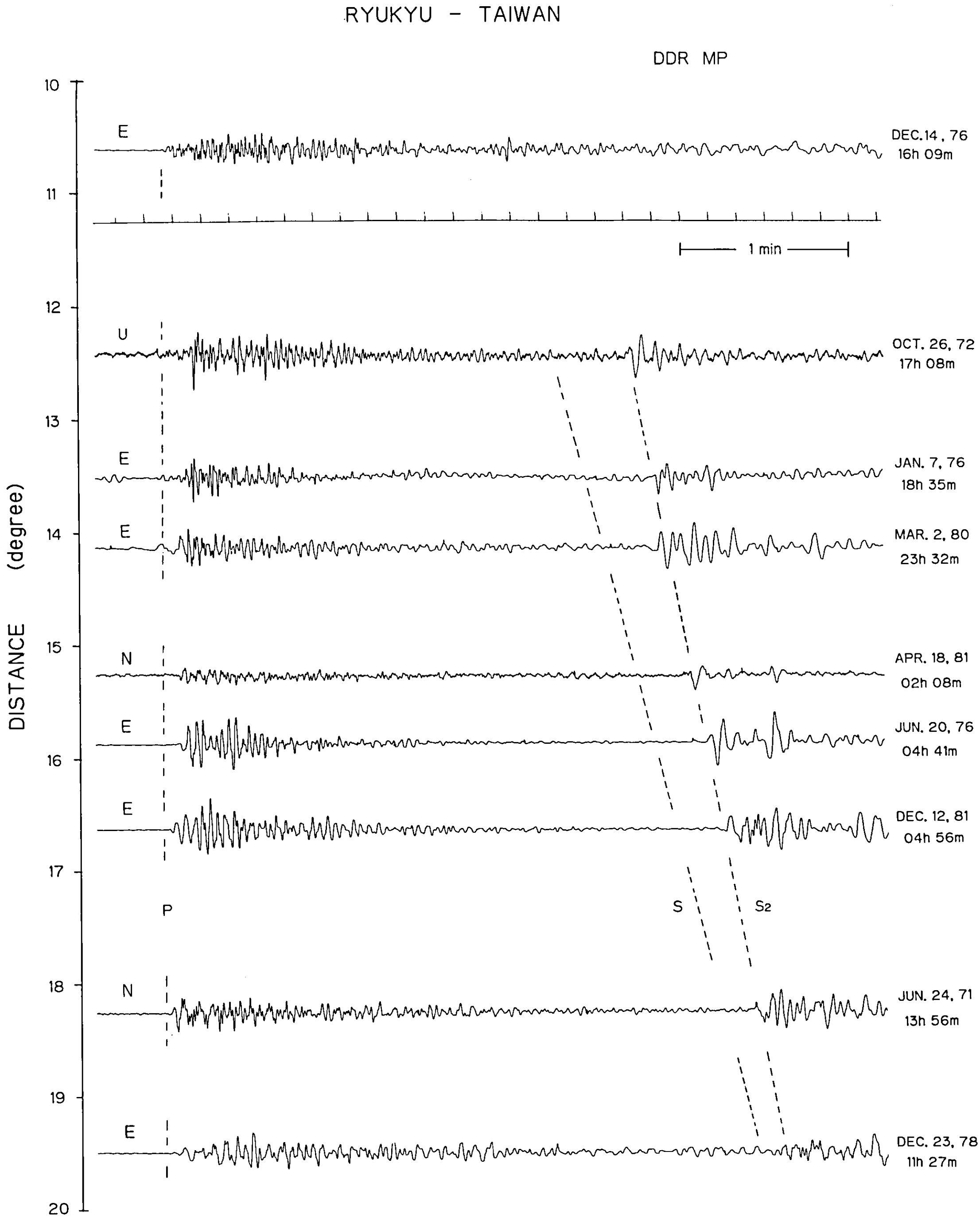
The focal parameters by ISC are as follows:

Origin Time	Epicenter		*h*	*Mb*	Δ
h m s	N	E	km		deg
16 06 40.4	28°27	130°67	11	6.3	10.56
17 05 05.6	27.48	128.57	63	6.0	12.40
18 32 08.7	26.40	127.69	43	5.2	13.72
23 28 58.7	26.99	126.73	41	5.4	13.90
02 05 00.8	25.79	125.82	84	5.6	15.32
04 38 06.1	24.79	125.99	21	5.8	15.94
04 52 37.3	23.96	125.92	10	6.1	16.60
13 52 17.1	23.57	123.78	21	5.6	18.21
11 23 13.7	23.17	122.00	47	6.5	19.64

Comments

1) The dotted line labeled by *S* shows the *J-B* travel times of *S* waves. Note that direct *S* waves do not appear at this epicentral distance.
2) Clear S_2 phases appear after direct *S* waves. The time intervals of *S* and S_2 phases are decreasing with the increase of epicentral distance. The time interval of two phases is about 31 sec for $\Delta=12.4°$ and about 5 sec for $\Delta=19.64°$, respectively.

Fig. 35


RYUKYU - TAIWAN
DDR MP
10
11
12
13
14
15
16
17
18
19
20
DISTANCE (degree)
1 min
E
DEC. 14, 76
16h 09m
U
OCT. 26, 72
17h 08m
E
JAN. 7, 76
18h 35m
E
MAR. 2, 80
23h 32m
N
APR. 18, 81
02h 08m
E
JUN. 20, 76
04h 41m
E
DEC. 12, 81
04h 56m
P
S
S2
N
JUN. 24, 71
13h 56m
E
DEC. 23, 78
11h 27m

36. S waveforms in the Marianas region —dependence on source depth—

An arrangement of seismograms obtained by MP-E seismograph at DDR for events in the Marianas region. The ordinate shows the source depth in kilometers. G: gain of play-back amplifier.

The focal parameters by ISC are as follows:

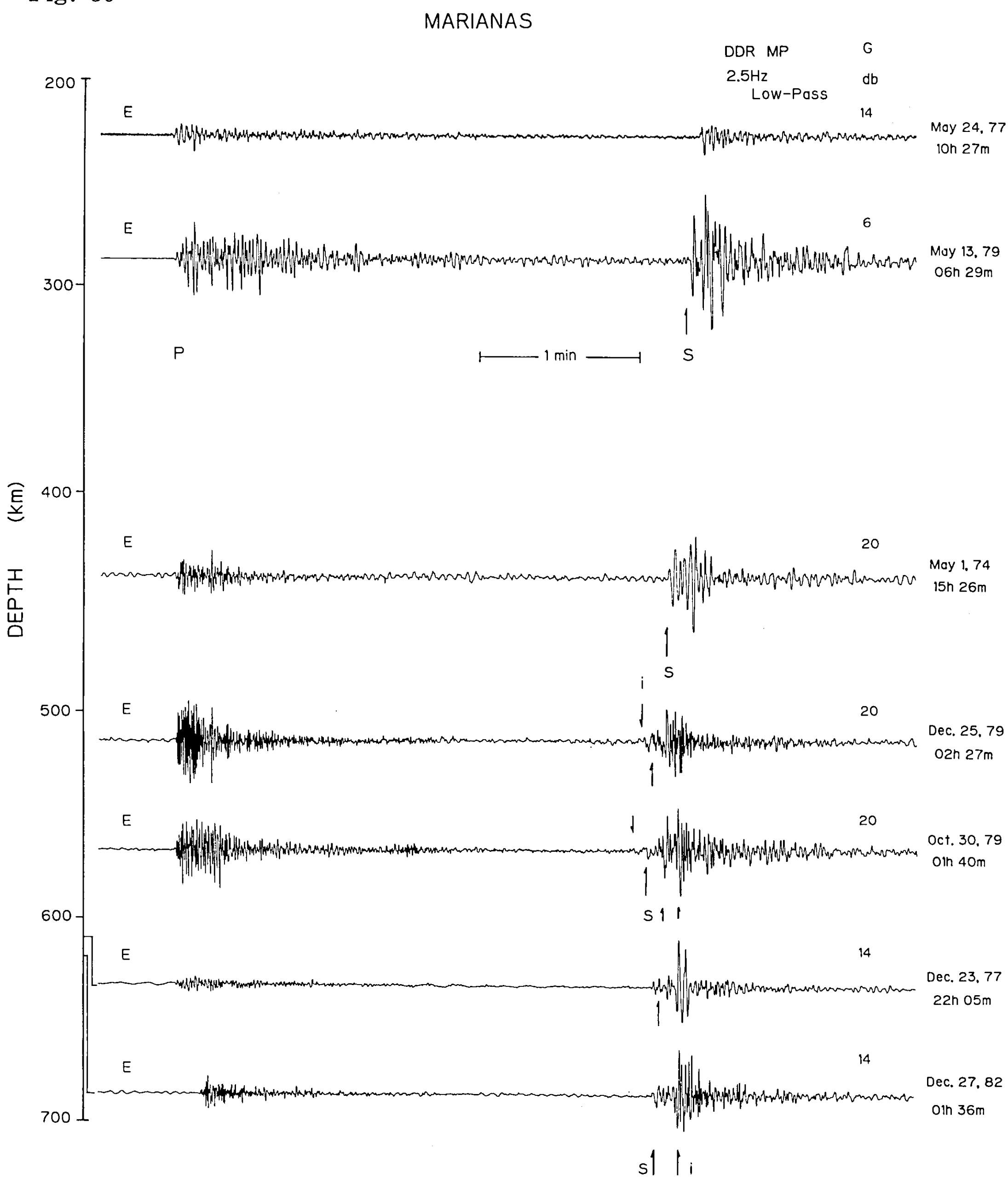
Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
10 23 26.2	18°.78	145°.49	231	5.6	18.04
06 26 08.4	19.00	145.42	256	5.9	17.80
15 22 25.1	18.25	145.26	455	5.4	18.48
02 23 35.5	18.71	145.30	578	5.4	18.04
01 37 06.6	18.77	145.16	585	5.6	17.96
22 02 06.2	18.18	145.60	605	5.3	18.64
01 32 58.9	18.99	145.03	615	5.3	17.71

Although they are located at almost the same epicentral distances, clear differences of S waveforms are seen among the seismograms:

1) The arrows labeled by S show the J-B travel times of S waves.
2) S waveforms of the events with deeper source ($h>500$ km) show a complicated pattern consisting of two or three phases.
3) The amplitude of the S-later phase indicated by i is large compared with that of S waves, and it contains high-frequency components.

A detailed study of multi-S phases has not yet been given, however, the later phase is probably the waves passing through the seismic zone with high Q.

Fig. 36


MARIANAS
DDR MP
2.5Hz
Low-Pass
G
db
DEPTH (km)
200
300
400
500
600
700
E
14
May 24, 77
10h 27m
6
May 13, 79
06h 29m
P
1 min
S
20
May 1, 74
15h 26m
i
20
Dec. 25, 79
02h 27m
20
Oct. 30, 79
01h 40m
S
14
Dec. 23, 77
22h 05m
14
Dec. 27, 82
01h 36m

37. Reflected waves from Marianas region

Seismograms from intermediate-focus earthquake in the Marianas region. The upper three seismograms are obtained from three components (Z, E, N) of MP seismograph, and the lower three seismograms are those of LP seismograph. G: gain of play-back amplifier.

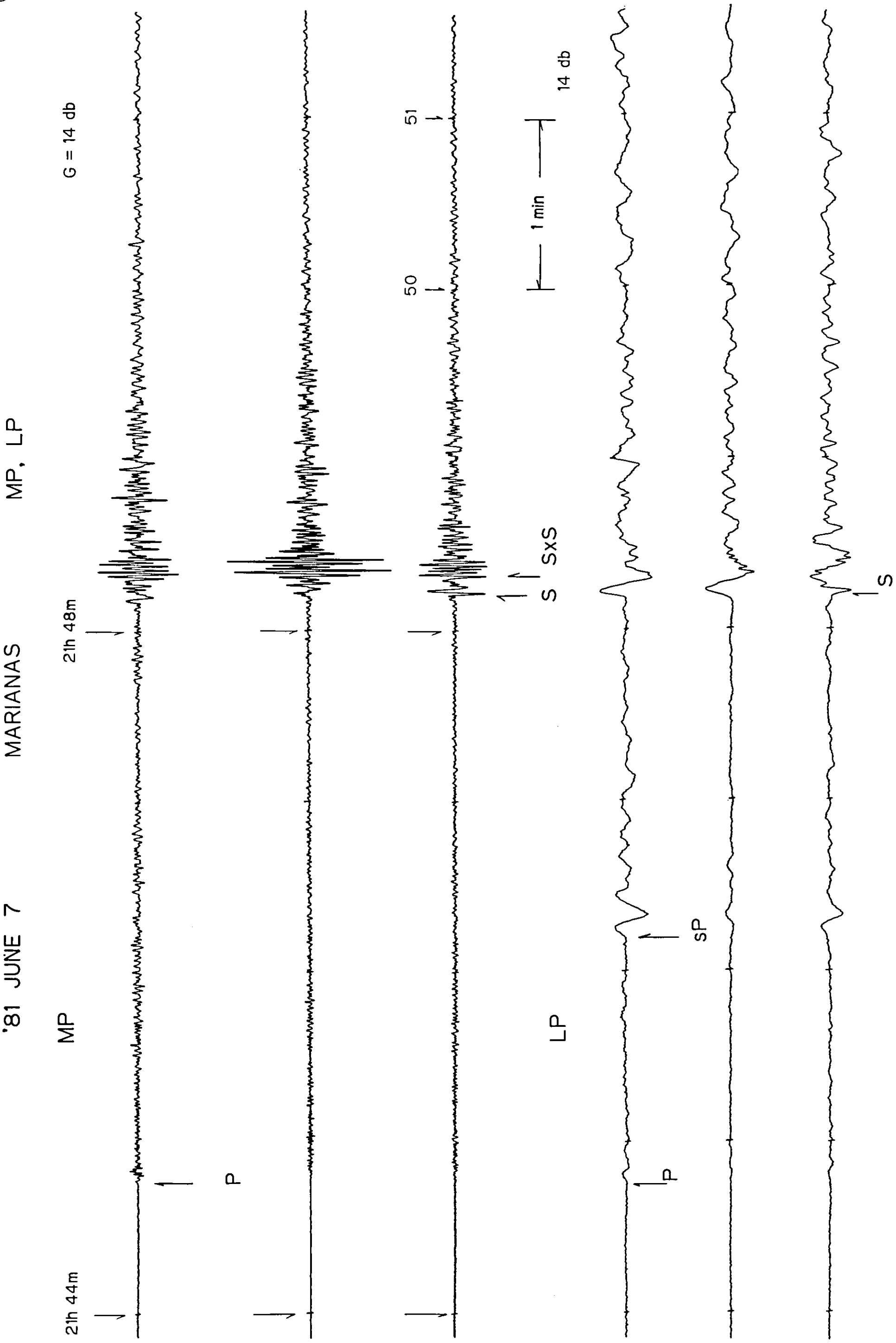
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
21 40 36.0	16°.57	145°.48	316	5.8	20.14

Comments

1) Reflected wave at the surface from S to P (sP) is clearly seen on LP seismograms, but not clear on MP seismograms. Note also for the difference of spectrum between sP and S waves.
2) SxS phase appears on MP seismograms at about 7 seconds after the S wave onset.

Fig. 37


'81 JUNE 7
MARIANAS
MP, LP
MP
G = 14 db
21h 44m
21h 48m
P
50
51
1 min
14 db
S
SxS
LP
P
sP
S

38. Seismograms from Taiwan-Philippine region

Seismograms obtained by SP-Z seismograph at DDR for the events along the Taiwan-Philippine region. This figure is continued from the previous figure (Fig. 35). The ordinate shows the epicentral distance in degrees.

The focal parameters by ISC are as follows:

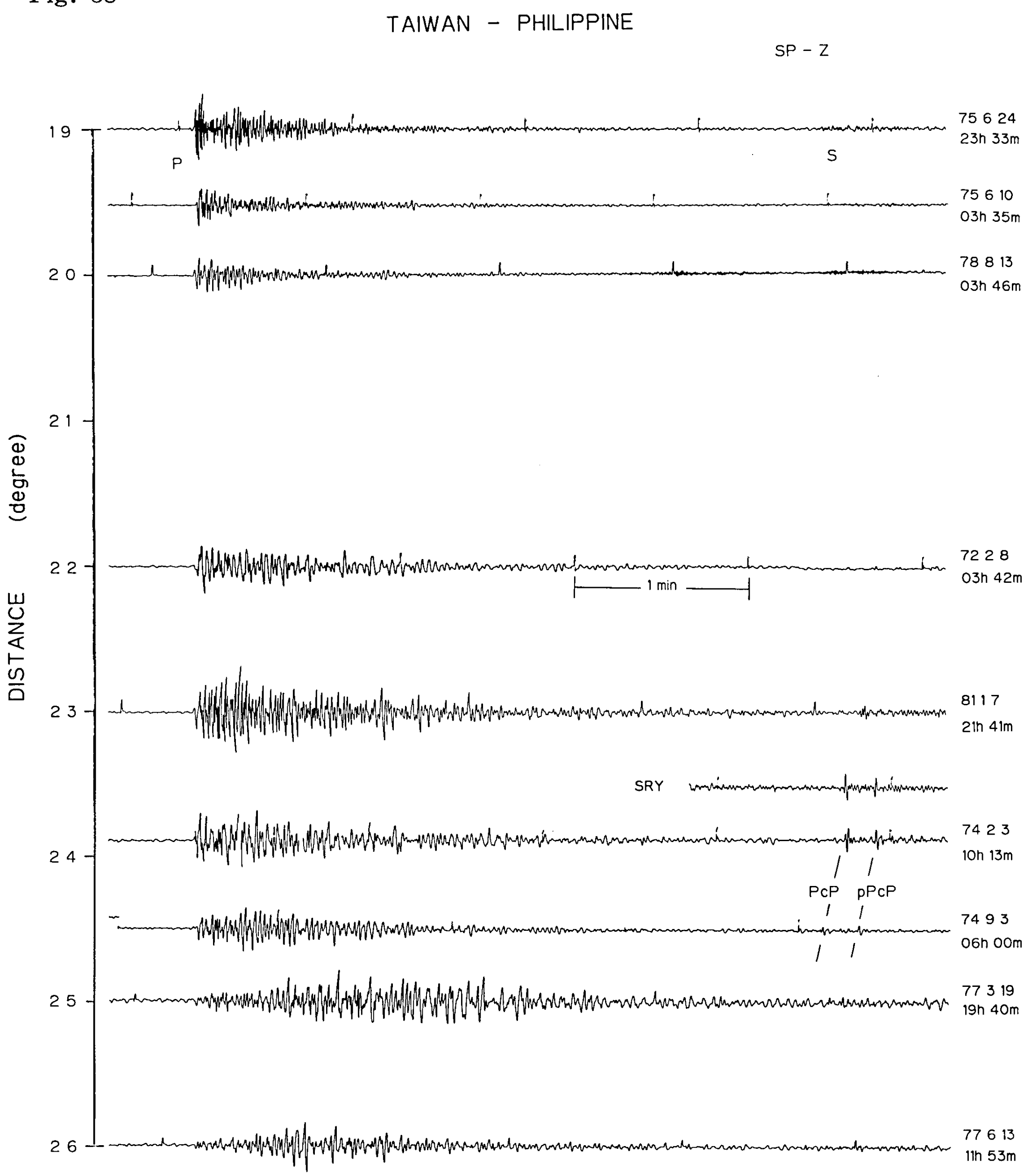
Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
23 28 41.0	22°.96	123°.10	25	5.4	19.08
03 30 53.6	22.69	122.72	26	5.1	19.51
03 41 34.9	22.25	121.48	39	5.3	20.54
03 37 52.0	19.36	122.06	45	5.8	22.42
21 36 23.1	19.11	121.17	42	5.6	23.14
10 08 47.4	18.93	120.13	21	5.8	23.91
05 55 09.7	18.26	119.20	34	5.9	24.90
19 35 09.9	16.80	122.34	53	5.6	24.29
11 47 42.4	13.33	124.69	41	5.6	26.07

Although the earthquakes presented here have similar source depths (21-53 km), some differences of waveforms are seen along the epicentral distance increase:

1) The sharp P wave onset is seen for events with short epicentral distance ($\Delta < 24°$). After that, P wave onset is small and increases gradually with time.
2) Clear PcP phase is seen for three events dated on Jan. 7, 1981, Feb. 3, 1974 and Sep. 3, 1974, and this is the shortest epicentral distance for the appearance of PcP phase.

(to be continued)

Fig. 38


TAIWAN - PHILIPPINE
SP - Z
DISTANCE (degree)
19
20
21
22
23
24
25
26
P
S
75 6 24
23h 33m
75 6 10
03h 35m
78 8 13
03h 46m
72 2 8
03h 42m
1 min
81 1 7
21h 41m
SRY
74 2 3
10h 13m
PcP
pPcP
74 9 3
06h 00m
77 3 19
19h 40m
77 6 13
11h 53m

39. Seismograms from Philippine-Celebes region

An arrangement of seismograms obtained by MP-Z component seismograph at DDR for the events along the Philippine-Celebes region and New Ireland region (bottom two seismograms). The magnification of each trace is arbitrary. The ordinate shows the epicentral distance in degrees.

The focal parameters by ISC are as follows:

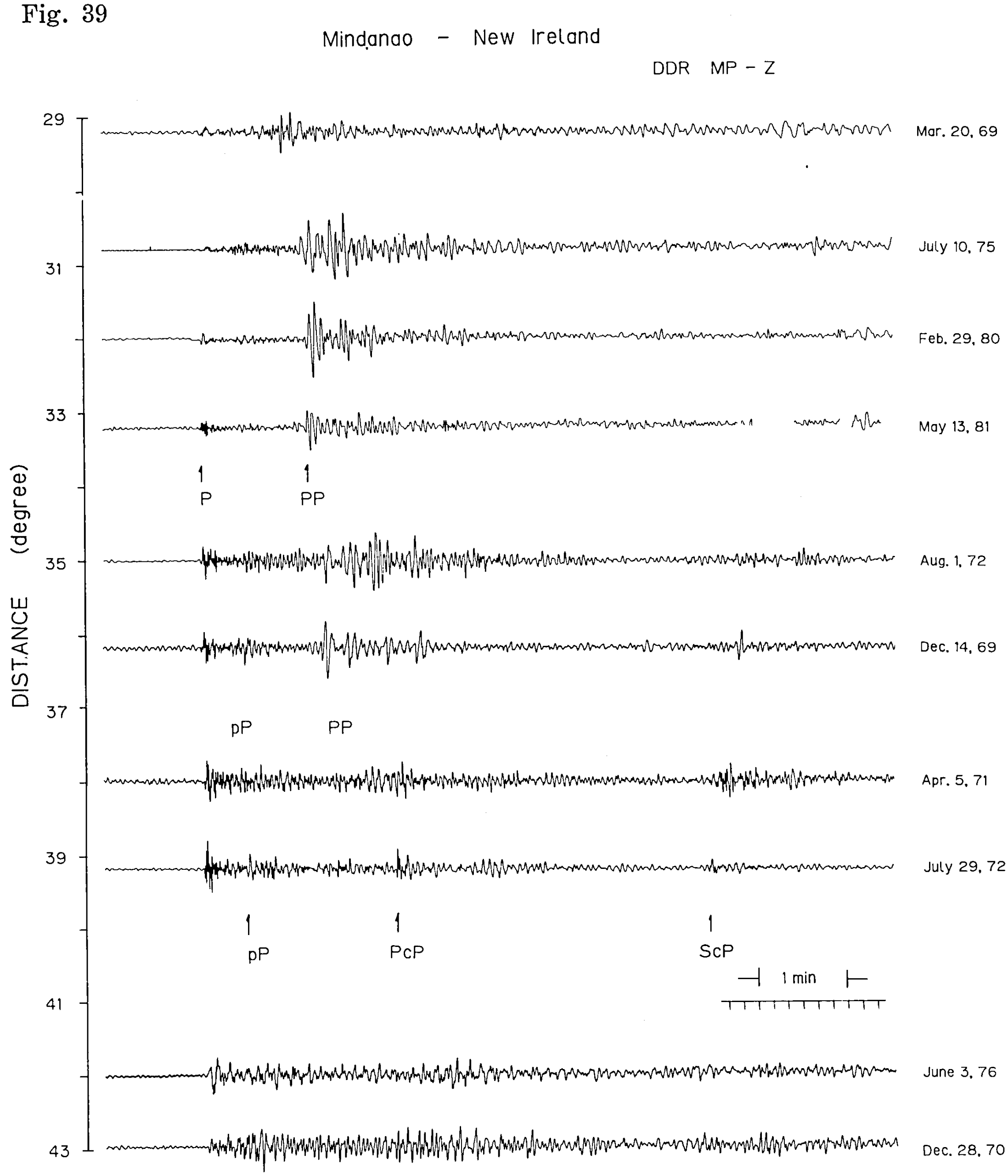
Origin Time		Epicenter		h	Mb	Δ
d	h m s			km		deg
Mar. 20,	16 18 57.5	08°69N	127°35E	43	6.1	29.25
Jul. 10,	18 29 15.5	08.51N	126.65E	81	5.9	31.52
Feb. 29,	11 13 27.5	06.33N	126.90E	112	6.0	31.61
May 13,	01 39 54.0	05.82N	126.98E	140	5.9	32.06
Aug. 01,	19 06 33.8	02.35N	127.56E	91	5.8	35.17
Dec. 14,	02 42 10.4	01.99N	126.94E	51	6.0	35.70
Apr. 05,	05 02 15.9	00.36S	124.73E	67	6.0	38.60
Jul. 29,	05 04 21.7	00.06N	123.44E	151	5.7	38.64
Jun. 03,	16 44 40.3	05.13S	153.55E	95	6.1	43.07
Dec. 28,	20 03 25.5	05.23S	153.59E	63	6.2	43.18

Comments

1) Small P and large PP amplitudes are seen for the events of short distance ($\Delta < 33°$), and such a waveform feature is continued from the epicentral distance of 25° (see previous figure).
2) For distances above 35°, the amplitude of initial motion increases with increasing distance.

Small P and large PP amplitudes are also seen for events in the China region as shown elsewhere (Fig. 52).

Fig. 39


Mindanao - New Ireland
DDR MP - Z
DISTANCE (degree)
29
31
33
35
37
39
41
43
Mar. 20, 69
July 10, 75
Feb. 29, 80
May 13, 81
P
PP
Aug. 1, 72
Dec. 14, 69
pP
PP
Apr. 5, 71
July 29, 72
pP
PcP
ScP
1 min
June 3, 76
Dec. 28, 70

40. Seismograms from Aleutian-Alaska region

An arrangement of seismograms obtained by MP-Z component seismograph at DDR for the events along from the Andreanof Islands (Aleutian Is.) to Alaska Peninsula. The magnification of each trace is arbitrary. The ordinate shows the epicentral distance in degrees.

The focal parameters by ISC are as follows:

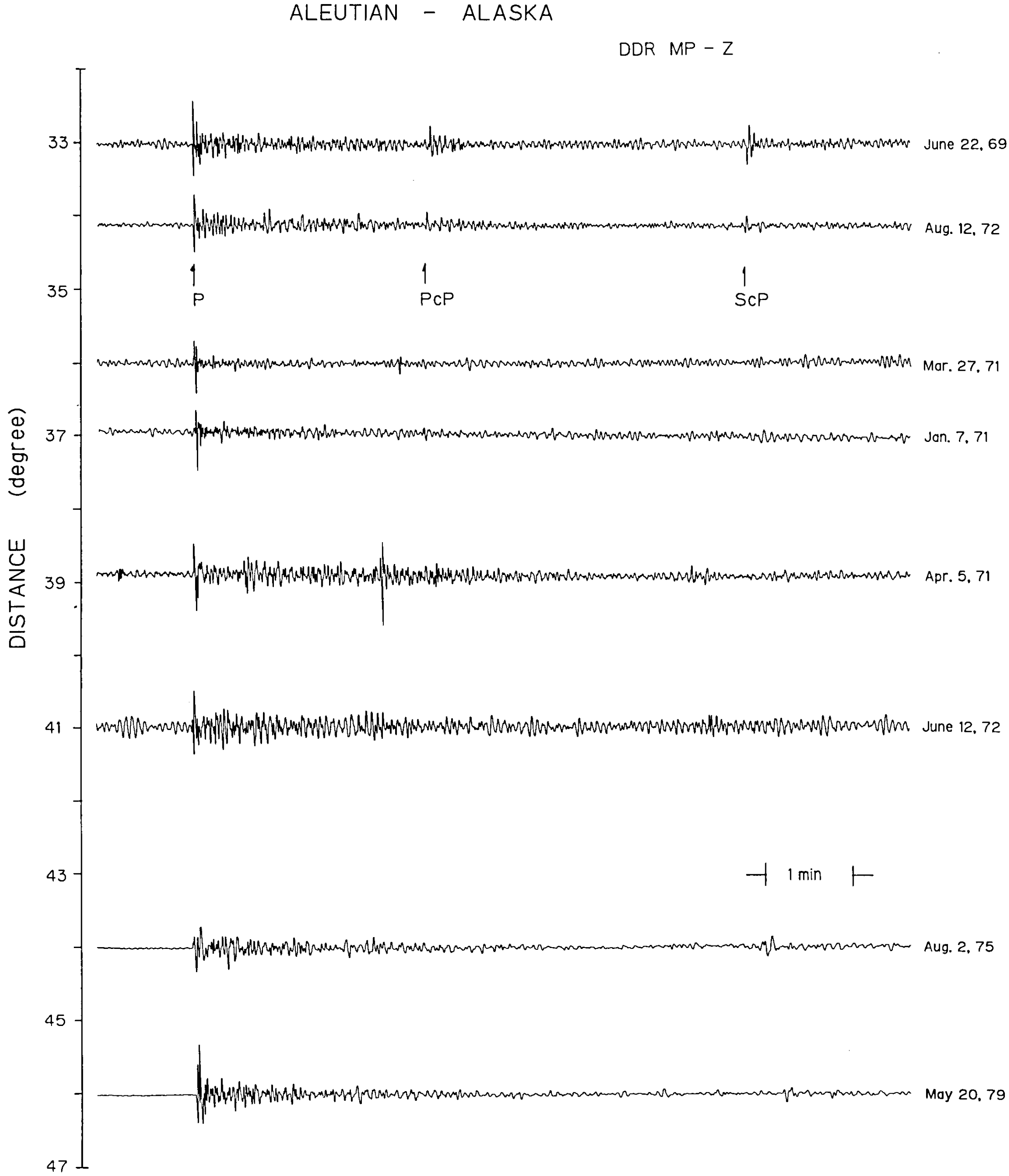
Origin Time	Epicenter		h	Mb	Δ
d h m s	N	W	km		deg
Jun. 22, 10 45 24.8	51°.46	179°.95	56	6.1	32.84
Aug. 12, 09 42 07.3	51.34	179.29	45	5.8	33.22
Mar. 27, 17 09 51.8	52.52	174.55	133	5.6	36.31
Jan. 07, 02 49 56.7	52.31	173.27	80	5.7	37.06
Apr. 05, 09 04 42.3	53.26	170.53	150	5.8	38.82
Jun. 12, 19 47 35.5	53.25	166.78	27	5.8	41.06
Aug. 02, 10 18 19.7	53.48	161.39	46	6.0	44.32
May 20, 08 13 58.4	56.65	156.72	55	6.4	46.88

Comments

1) Sharp and large P waves, contrasting with the events in the Philippine region with similar distances, are seen on the seismograms through the whole epicentral distances.
2) Clear PcP phase is seen, especially for the events with deeper source ($h > 133$ km).
3) No appearance of PP phase.

The difference of waveform features between the Aleutian and Philippine regions may be due to the difference of the tectonic nature of propagation path, or the source mechanism.

Fig. 40


ALEUTIAN - ALASKA
DDR MP - Z
DISTANCE (degree)
33
35
37
39
41
43
45
47
June 22, 69
Aug. 12, 72
P
PcP
ScP
Mar. 27, 71
Jan. 7, 71
Apr. 5, 71
June 12, 72
1 min
Aug. 2, 75
May 20, 79

41. Seismograms in the Andreanof Is. region —dependence on source depth—

An arrangement of seismograms obtained by MP-Z component seismograph at DDR for the events in the Andreanof Islands (Aleutian) region. The ordinate shows the source depth in kilometers. Note that the top trace is the seismogram from the underground explosion "MILROW" in the Rat Islands, Aleutian Islands. Two events with deep source in the Fox Islands region ($h>133$ km) are added for comparison.

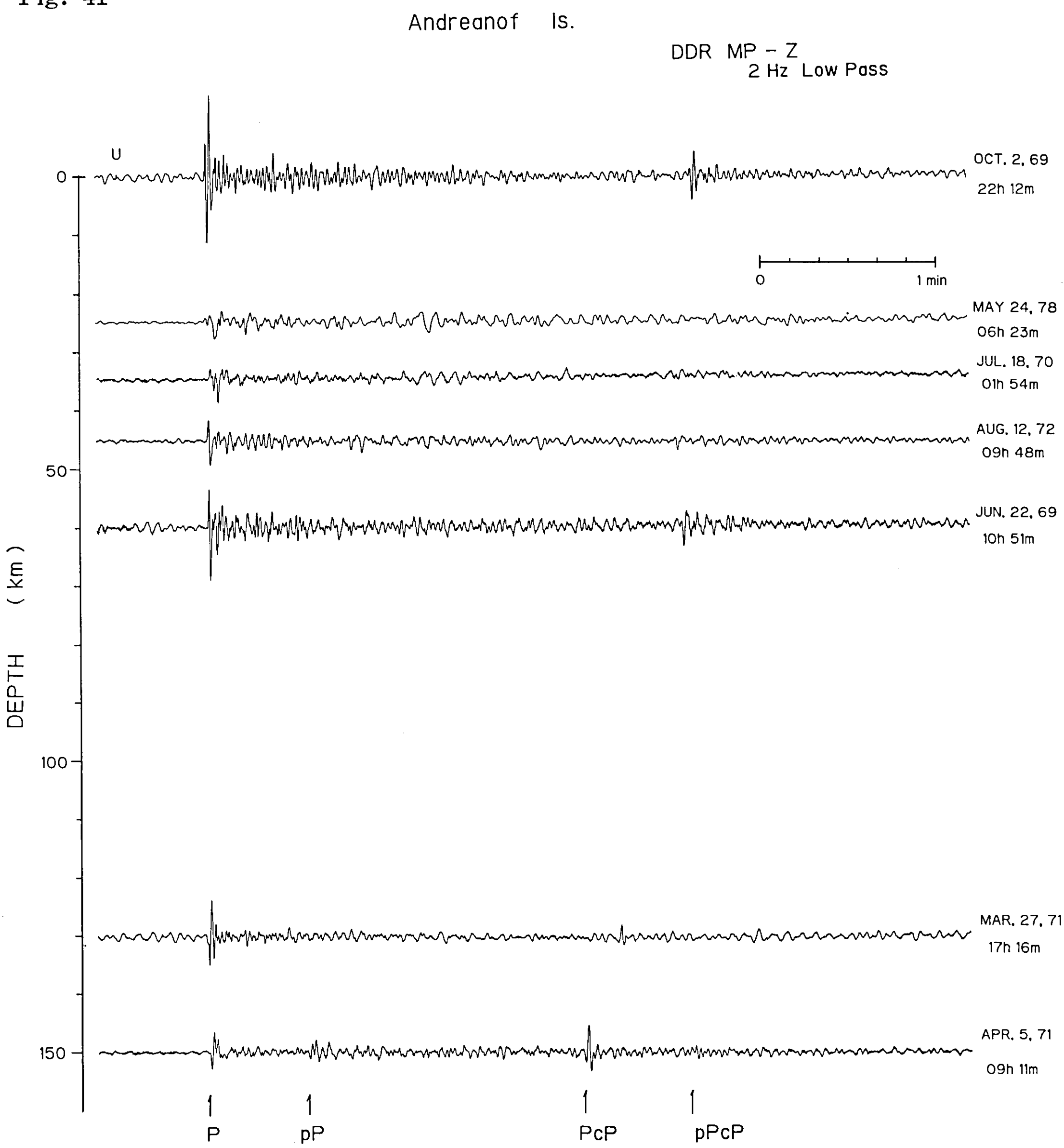
The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Δ
	d h m s			km		deg
Oct.	02, 22 06 01.9	51°.59N	179°.19E	34	6.4	32.30
May	24, 06 16 56	51.24N	179.24W	28	5.9	33.23
Jul.	18, 01 48 38.9	51.35N	178.51W	44	5.8	33.70
Aug.	12, 09 42 07.3	51.34N	179.29W	45	5.8	33.22
Jun.	22, 10 45 24.8	51.46N	179.95W	56	6.1	32.84
Mar.	27, 17 09 51.8	52.52N	174.55W	133	5.6	36.31
Apr.	05, 09 04 42.3	53.26N	170.53W	150	5.8	38.82

Comments

1) High-frequency components in the seismograms are increasing with increase of source depth, and no clear differences are seen in the seismograms between the explosion and the Jun. 22 event with the source depth of 56 km.
2) The amplitude ratio of PcP/P increases with increase of source depth. Note that the PcP/P ratio of deep event (150 km) is larger than that of the explosion.

Fig. 41



Andreanof Is.
DDR MP – Z
2 Hz Low Pass
U
OCT. 2, 69
22h 12m
0
1 min
MAY 24, 78
06h 23m
JUL. 18, 70
01h 54m
AUG. 12, 72
09h 48m
JUN. 22, 69
10h 51m
MAR. 27, 71
17h 16m
APR. 5, 71
09h 11m
0
50
100
150
DEPTH (km)
P
pP
PcP
pPcP

42. Seismograms of explosion in the Rat Islands

Seismograms obtained by MP seismographs at DDR for the underground explosion "MILROW" in the Rat Islands, Aleutian Islands region. The upper three traces show seismograms of three components of MP seismograph, and the bottom trace shows the seismogram at double the paper speed of the top seismogram (60 mm/min). G: gain of play-back amplifier.

The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	h	Mb	Δ
h m s	N	E	km			deg
22 06 01.9	51°.59	179°.19	34	0*	6.4	32.30

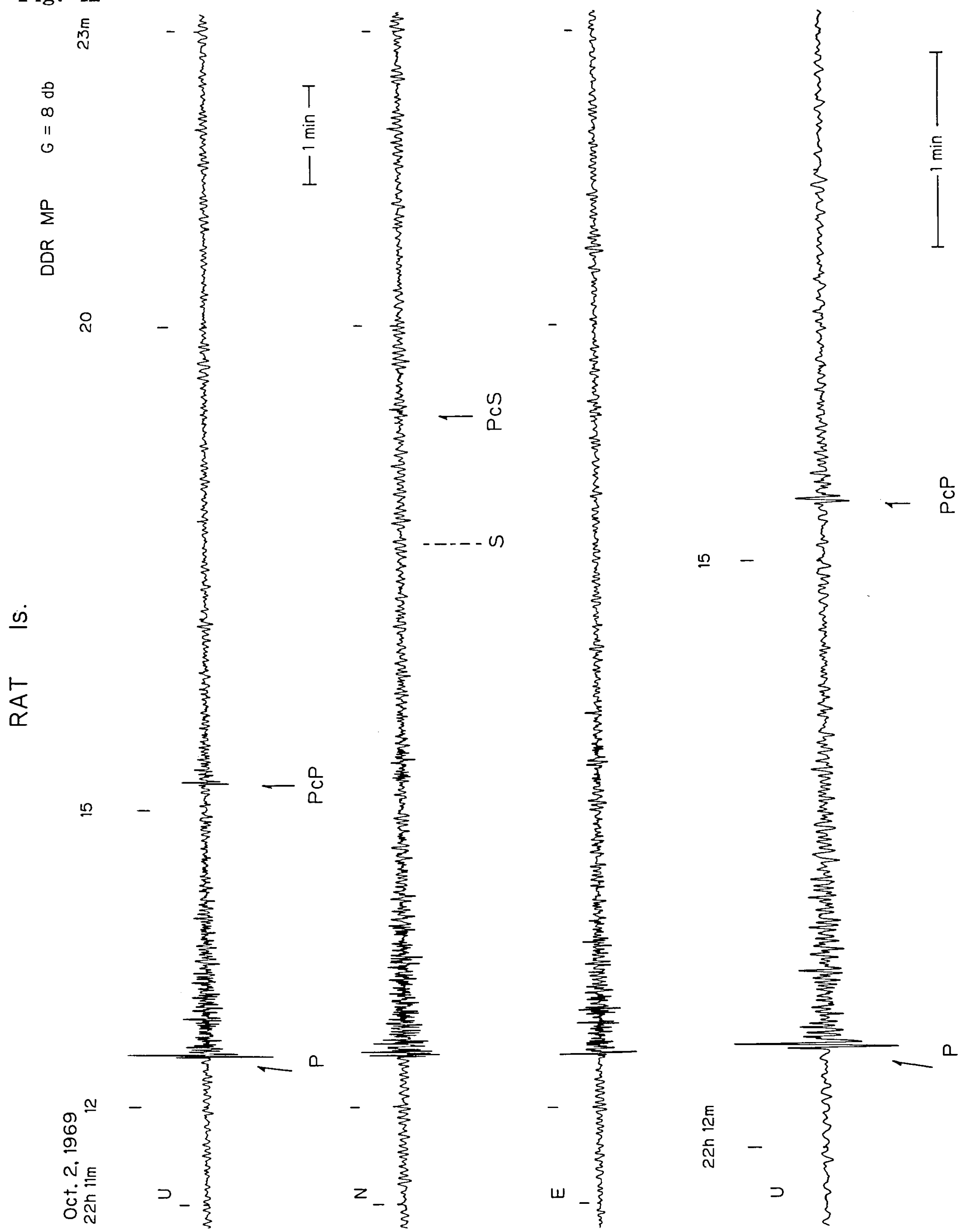
*: depth by USAEC.

Comments

1) Sharp and impulsive P and PcP waves are seen on the vertical component seismogram.
2) Small, but clear PcS wave is seen on the N-S component seismogram.
3) No S wave appears on both horizontal seismograms.

These waveform features are quite different from those of shallow-focus earthquakes ($h<45$ km) in the same region as shown previously (Fig. 41).

Fig. 42


RAT Is.
DDR MP
G = 8 db
Oct. 2, 1969
22h 11m
12
15
20
23m
U
N
E
P
PcP
S
PcS
1 min
22h 12m
15
U
P
PcP
1 min

43. Seismograms from Mindanao, Philippine region (1) —dependence on source depth—

An arrangement of seismograms obtained by SP-Z seismograph at DDR for events in the Mindanao, Philippine region. The ordinate shows the source depth in kilometers.

The focal parameters by ISC are as follows:

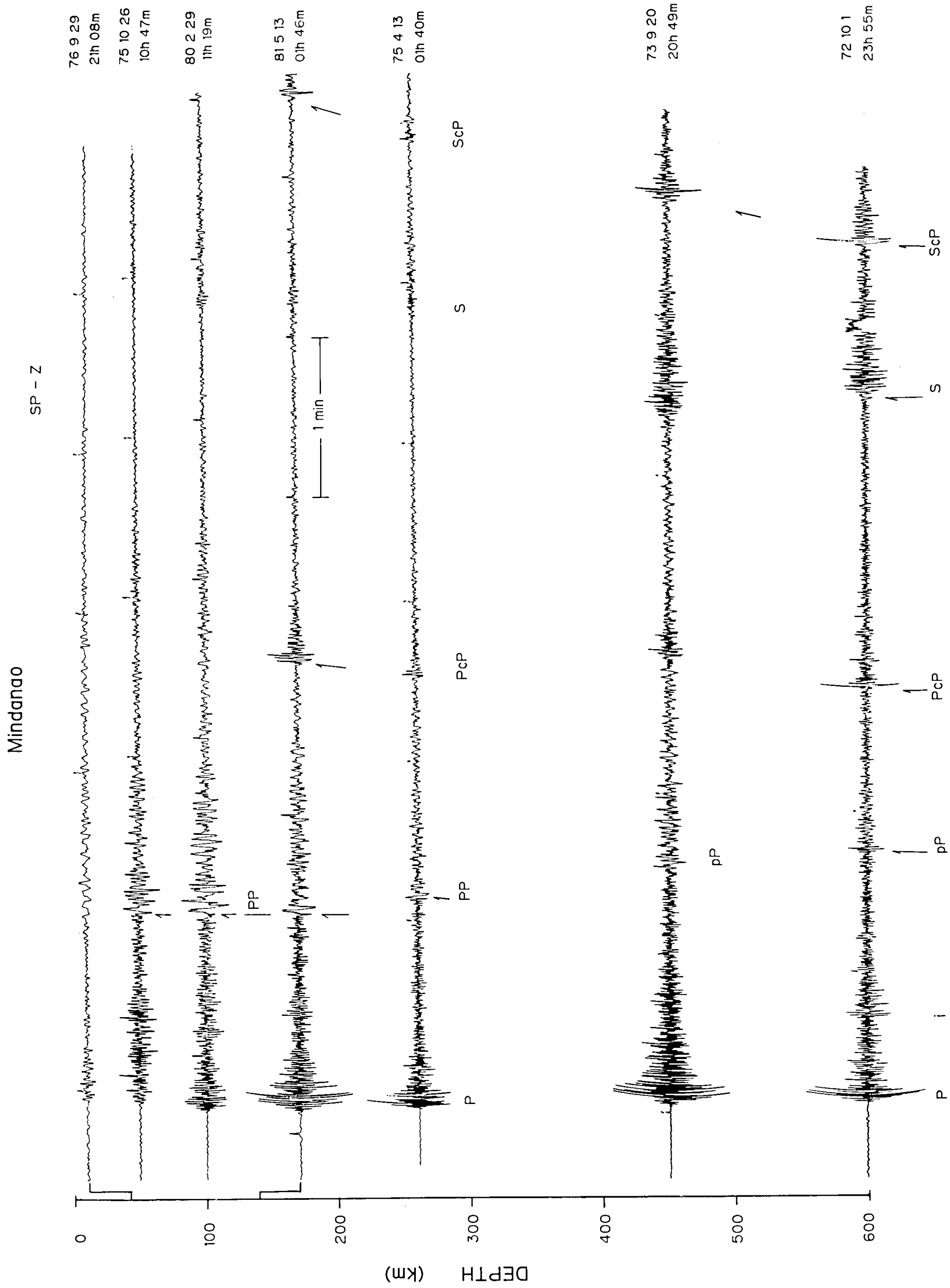
Origin Time		Epicenter		*h*	*Mb*	*Δ*
	d h m s	N	E	km		deg
Sep.	29, 21 02 32.9	06°93	124°04	40	5.9	32.09
Oct.	26, 10 41 33.2	06.54	126.81	61	5.9	31.44
Feb.	29, 11 13 27.5	06.33	126.90	112	6.0	31.61
May	13, 01 39 54.0	05.82	126.98	140	5.9	32.06
Apr.	13, 01 34 37.4	05.66	125.38	235	5.5	32.75
Sep.	20, 20 43 38.5	09.23	123.92	542	5.9	30.05
Oct.	01, 23 49 37.5	07.46	123.77	632	6.0	31.71

Comments

1) The amplitude of initial *P* wave increases with increase of source depth.
2) The appearance of phases is different between shallow and deep-focus earthquakes. For shallow events, the *PP* phase dominates, and for deeper events, sharp core-phases such as *PcP* and *ScP* predominate, especially for the event with 632 km depth.
3) The *pP* phase and another phase indicated by *i* appear on the deep source seismogram.

(to be continued)

Fig. 43


Mindanao
SP - Z
76 9 29
21h 08m
75 10 26
10h 47m
80 2 29
11h 19m
81 5 13
01h 46m
75 4 13
01h 40m
73 9 20
20h 49m
72 10 1
23h 55m
1 min
P
PP
PcP
S
ScP
pP
i
DEPTH (km)
0
100
200
300
400
500
600

44. Seismograms from Mindanao, Philippine region (2)
—*ScSp*—

The later seismograms of two events shown in the previous figure. The *ScP* phase overlaps. The ordinate shows the source depth in kilometers.

The focal parameters by ISC are as follows:

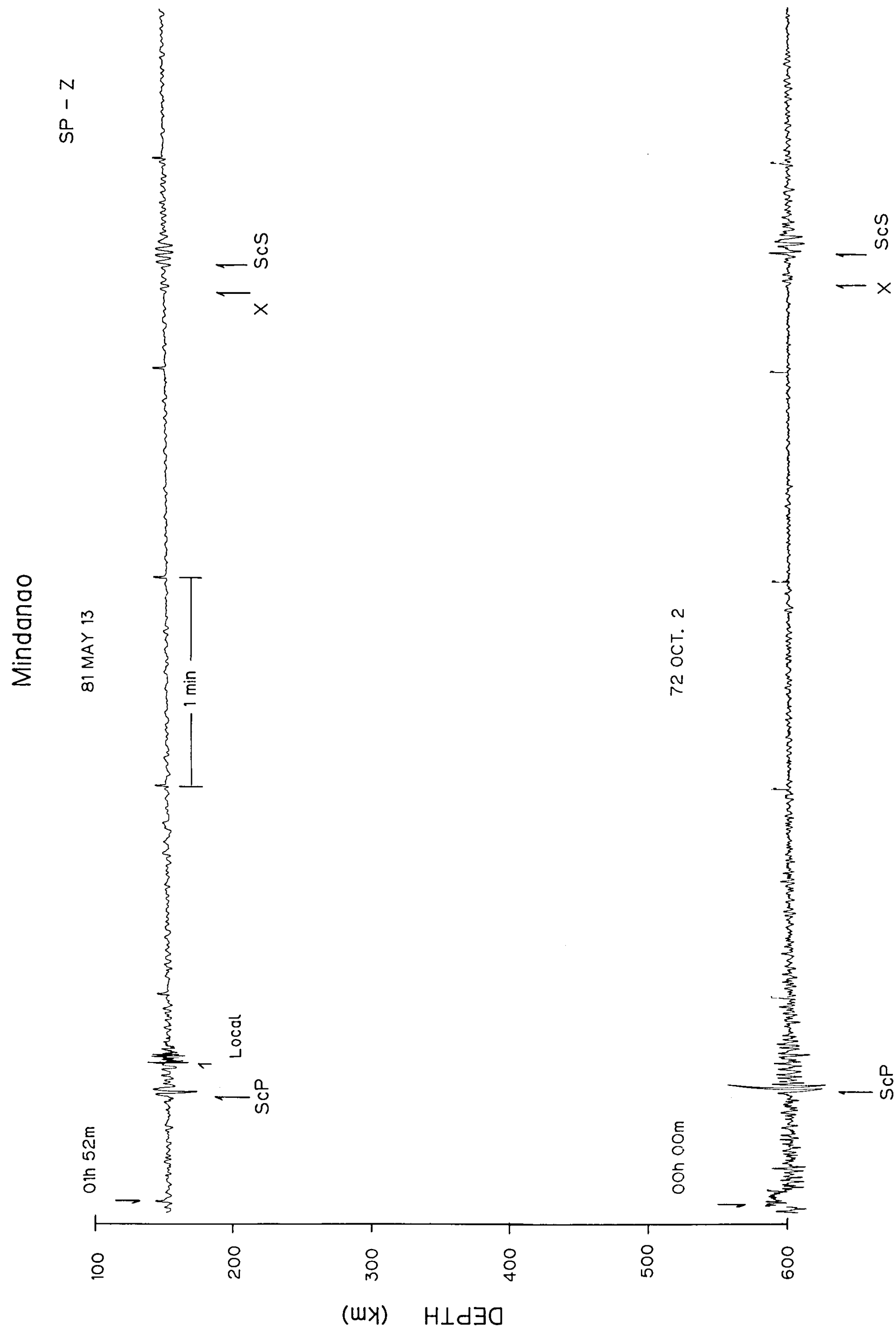
Origin Time	Epicenter		h	Mb	Δ
d h m s	N	E	km		deg
May 13, 01 39 54.0	05°.82	126°.98	140	5.9	32.06
Oct. 01, 23 49 37.5	07.46	123.77	632	6.0	31.71

Comments

1) The *ScS* phase is separated into two phases as indicated by X and *ScS*, and such phases are commonly observed for both shallow (140 km) and deep (632 km) sources.
2) The time interval between X and *ScS* phases is about 10 seconds for both events.

Combined seismograms of this and previous figures show that the X phase is probably converted waves at the plate boundary from *ScS* to P (*ScSp*) as suggested by OKADA (1971).

Fig. 44


Mindanao
SP - Z
81 MAY 13
01h 52m
1 min
ScP
Local
X
ScS
72 OCT. 2
00h 00m
ScP
X
ScS
DEPTH (Km)
100
200
300
400
500
600

45. Seismograms from Celebes region (1) —dependence on source depth—

An arrangement of seismograms obtained by SP-Z seismograph at DDR for events in the Celebes region. The ordinate shows the source depth in kilometers.

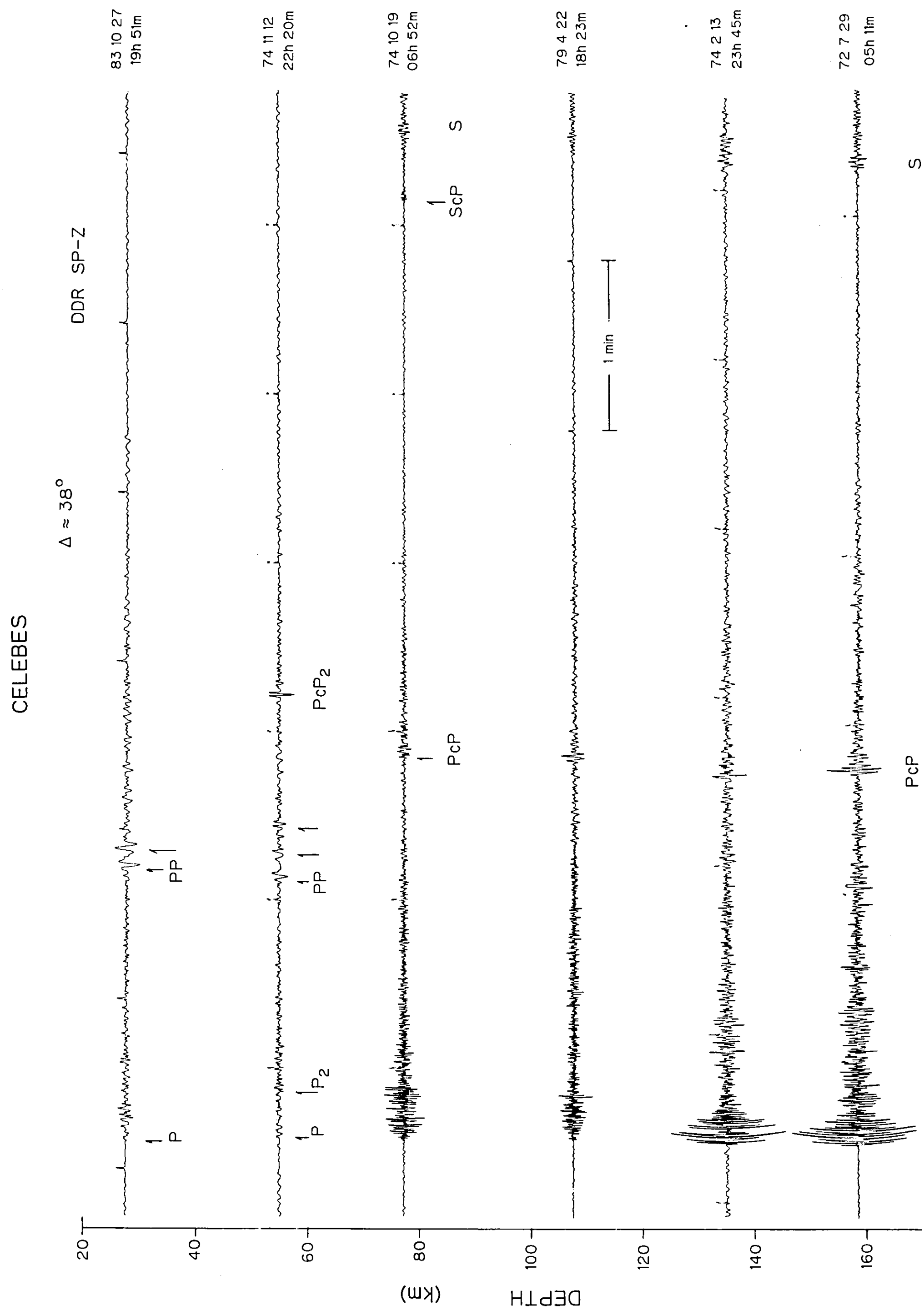
The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Δ
	d h m s			km		deg
Oct. 27,	19 43 48.9	01°12N	120°89E	28	5.7	38.64
Nov. 12,	22 13 26.9	02.27N	121.06E	58	5.8	37.53
Oct. 19,	06 45 18.9	00.11S	123.89E	77	5.4	38.65
Apr. 22,	18 16 33.7	00.05S	123.03E	108	5.8	38.89
Feb. 13,	23 38 08.5	00.11S	122.90E	143	5.5	38.99
Jul. 29,	05 04 21.7	00.06N	123.44E	151	5.7	38.64

Comments

General trends of waveform and phase appearance are similar to those of the Mindanao region, but the spindle-shaped P waveforms of shallow events ($h<108$ km) are quite different from those of the Aleutian region where the epicentral distances are nearly the same (see Fig. 41).

Fig. 45


CELEBES
Δ ≈ 38°
DDR SP-Z
83 10 27 19h 51m
74 11 12 22h 20m
74 10 19 06h 52m
79 4 22 18h 23m
74 2 13 23h 45m
72 7 29 05h 11m
P
PP
P
P2
PP
PcP2
PcP
ScP
S
S
PcP
1 min
DEPTH (KM)
20
40
60
80
100
120
140
160

46. Seismograms from Celebes region (2)
—*ScSp*—

Seismograms obtained by three components of MP seismograph at DDR for the event in the Celebes Sea region.

Note the difference of time scale between the upper three and lower two seismograms.

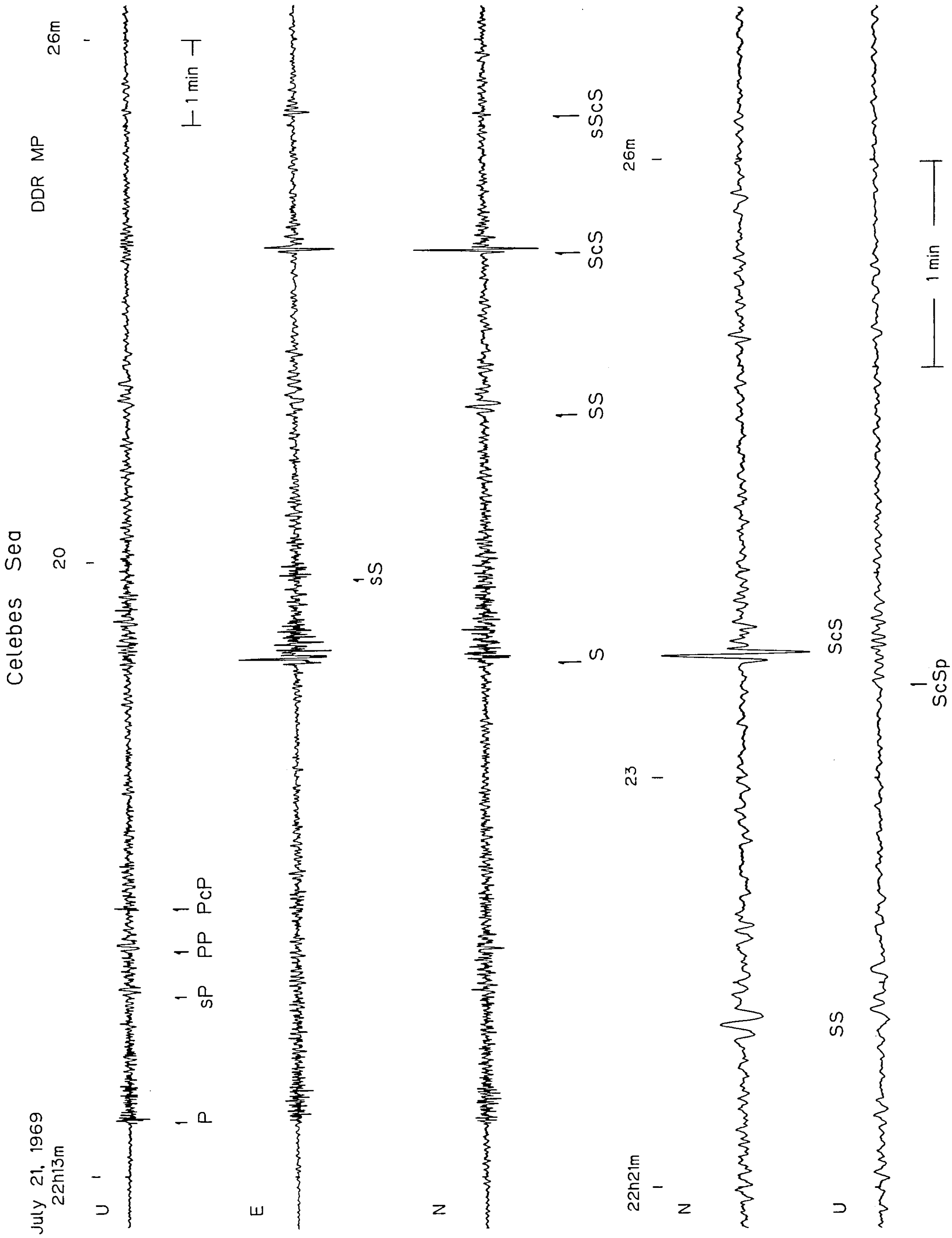
The focal parameters by ISC are as follows:

Origin Time	Epicenter		*h*	*Mb*	*Δ*
h m s	N	E	km		deg
22 06 57.3	02°.88	124°.76	226	5.4	35.8

Comments

1) Reflected waves at the surface, *sP*, *PP*, *SS* and reflected waves at the core boundary, *PcP*, *ScS*, are clearly identified through the three component seismograms, especially, sharp and impulsive *ScS* wave is seen on the N–S component seismogram.
2) The *ScS* wave on vertical seismogram shows a complicated pattern compared with that of N–S seismogram, and its arrival time is earlier, about 7 seconds, than the N–S component. This phase therefore is the converted wave at the plate boundary (*ScSp*) similar to that shown in the previous figure (Fig. 44).

Fig. 46



July 21, 1969
22h13m
Celebes Sea
DDR MP
20
26m
U
E
N
P
sP
PP
PcP
1 min
sS
S
SS
ScS
sScS
22h21m
23
26m
N
U
ScS
SS
ScSp
1 min

47. Spectral variations of *ScS* waves

An arrangement of *ScS* waves obtained by MP–E or MP–N component seismograph at DDR for events in the Mindanao-Molucca Sea region. The top two seismograms show the *ScS* waves from the Mindanao, and the center two seismograms show those from the Celebes. The bottom two seismograms show the *ScS* waves from the Molucca Sea region.

The ordinate shows the epicentral distance in degrees, and bars show relative differences of magnification.

The focal parameters by ISC are as follows:

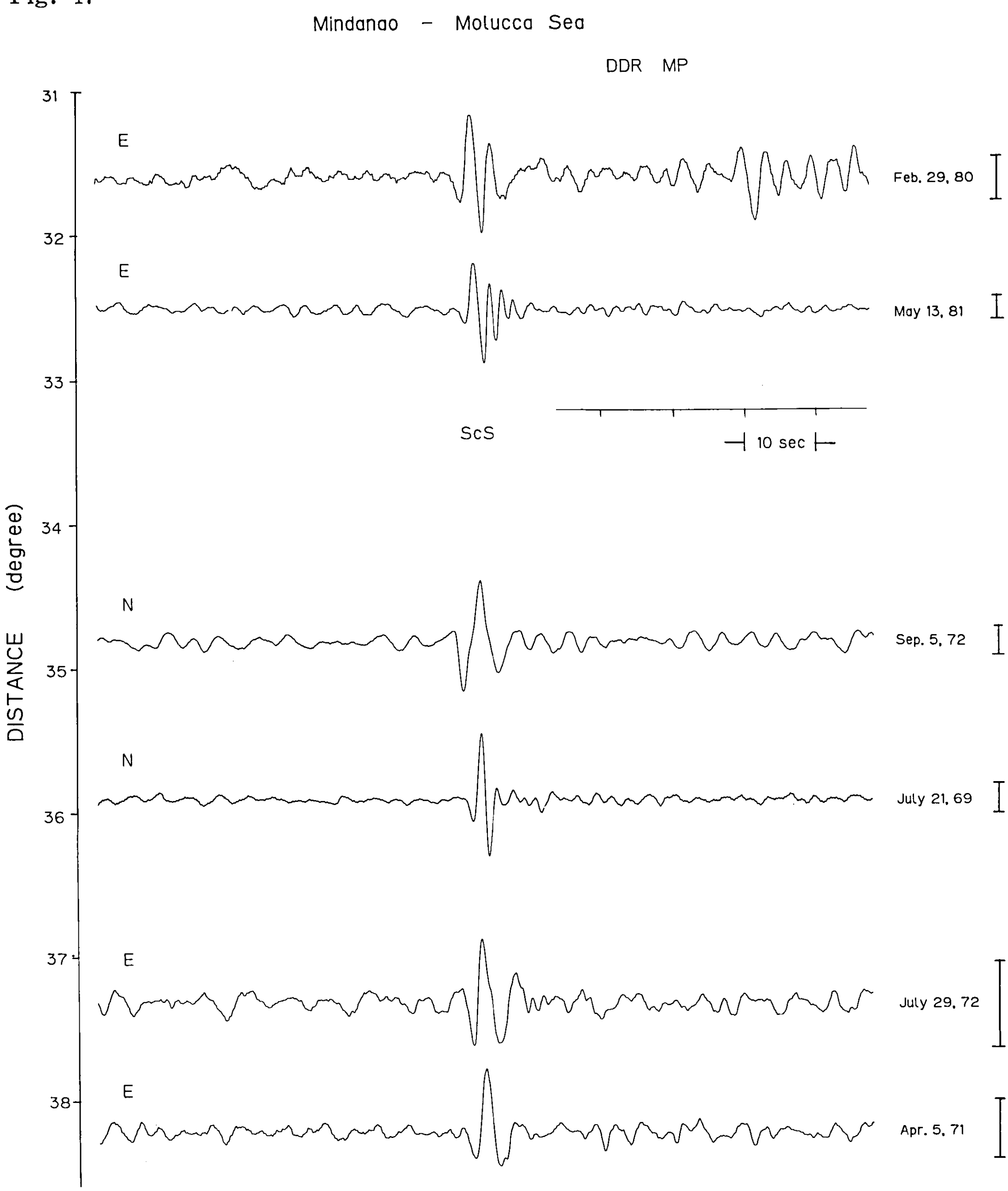
Origin Time		Epicenter		h	Mb	Δ
	d h m s	N	E	km		deg
Feb.	29, 11 13 27.5	06°.33	126°.90	112	6.0	31.61
May	13, 01 39 54.0	05.82	126.98	140	5.9	32.06
Sep.	05, 17 18 29.5	01.90	128.20	154	5.9	35.43
Jul.	21, 22 06 57.3	02.88	124.76	226	5.4	35.5
Jul.	29, 05 04 21.7	00.06	123.44	151	5.7	38.64
Apr.	05, 05 02 15.9	00.36	124.73	67	6.0	38.6

Although the events in each group are located in the same region, clear differences of waveform and spectrum are seen between the seismograms in each group:

1) The *ScS* wave on the lower seismogram in each group contains higher-frequency components than that of the upper seismogram.
2) The differences of spectrum are neither due to the differences of source depth nor the earthquake size.

Do these differences reflect the difference of source spectrum?

Fig. 47


Mindanao - Molucca Sea
DDR MP
31
32
33
34
35
36
37
38
DISTANCE (degree)
E
E
N
N
E
E
ScS
10 sec
Feb. 29, 80
May 13, 81
Sep. 5, 72
July 21, 69
July 29, 72
Apr. 5, 71

48. Seismograms from Banda Sea region (1) —dependence on source depth—

An arrangement of seismograms obtained by SP-Z seismograph at DDR for events in the Banda Sea region. The ordinate shows the source depth in kilometers.

The focal parameters by ISC are as follows:

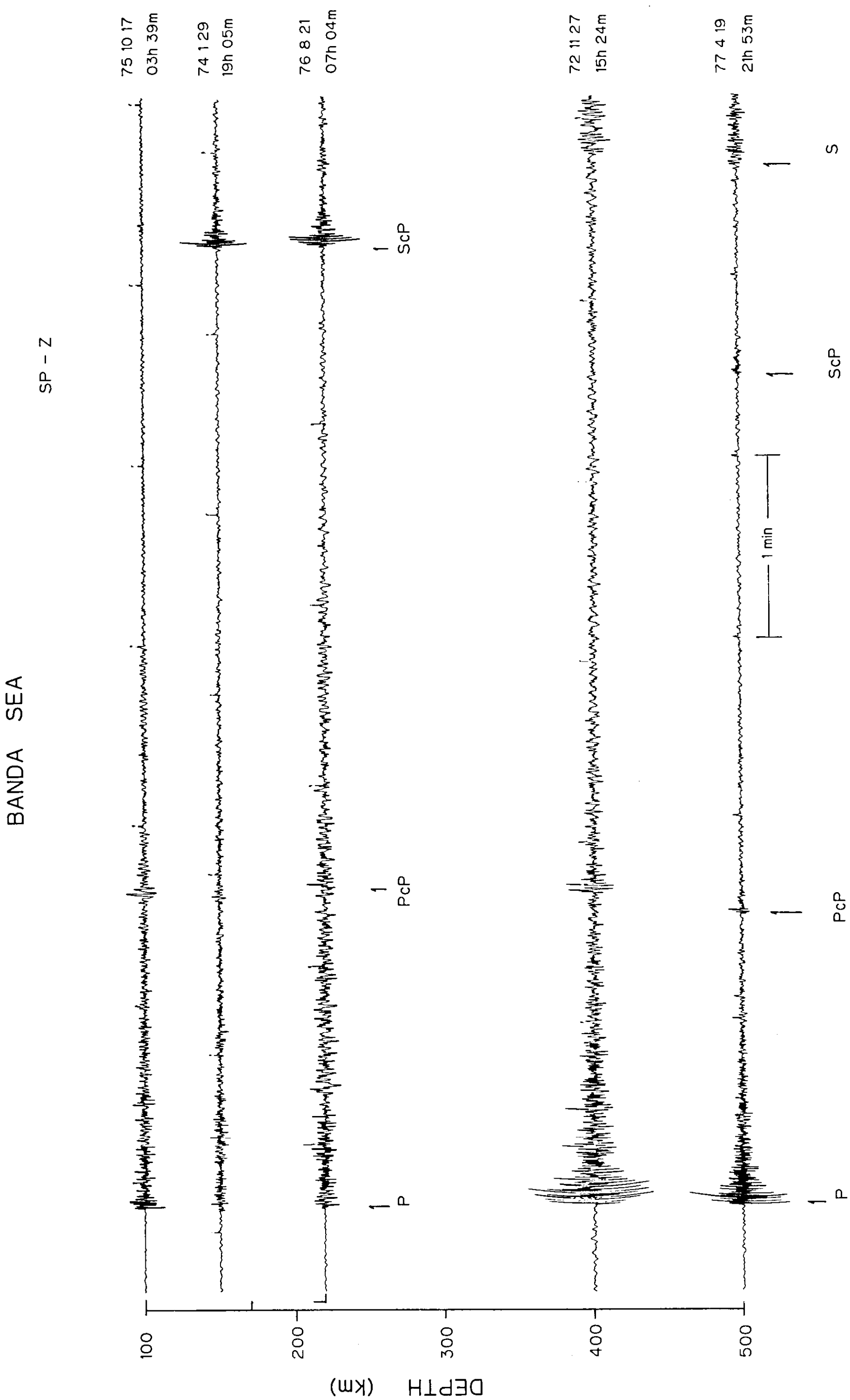
Origin Time						Epicenter		h	Mb	Δ
	d	h	m	s		S	E	km		deg
Oct.	17,	03	31	51.8		07°.54	128°.76	106	6.1	44.40
Jan.	29,	18	57	10.3		07.36	128.45	127	5.7	44.30
Aug.	21,	06	56	52.0		06.77	129.62	165	5.9	43.48
Nov.	27,	15	17	39.8		05.30	126.62	412	5.6	42.8
Apr.	19,	21	46	34.4		05.58	125.35	533	5.6	43.35

Comments

1) The *PcP* phase commonly appears for earthquakes in this depth range.
2) The *ScP* phase predominates for events with intermediate depths (h=127, 165 km).

(to be continued)

Fig. 48


BANDA SEA
SP - Z
75 10 17
03h 39m
74 1 29
19h 05m
76 8 21
07h 04m
72 11 27
15h 24m
77 4 19
21h 53m
P
PcP
ScP
S
1 min
DEPTH (km)
100
200
300
400
500

49. Seismograms from Banda Sea region (2) —dependence on source depth—

An arrangement of seismograms obtained by MP-E or MP-N seismograph at DDR for events in the Banda Sea region. The ordinate shows the source depth in kilometers.

The focal parameters by ISC are as follows:

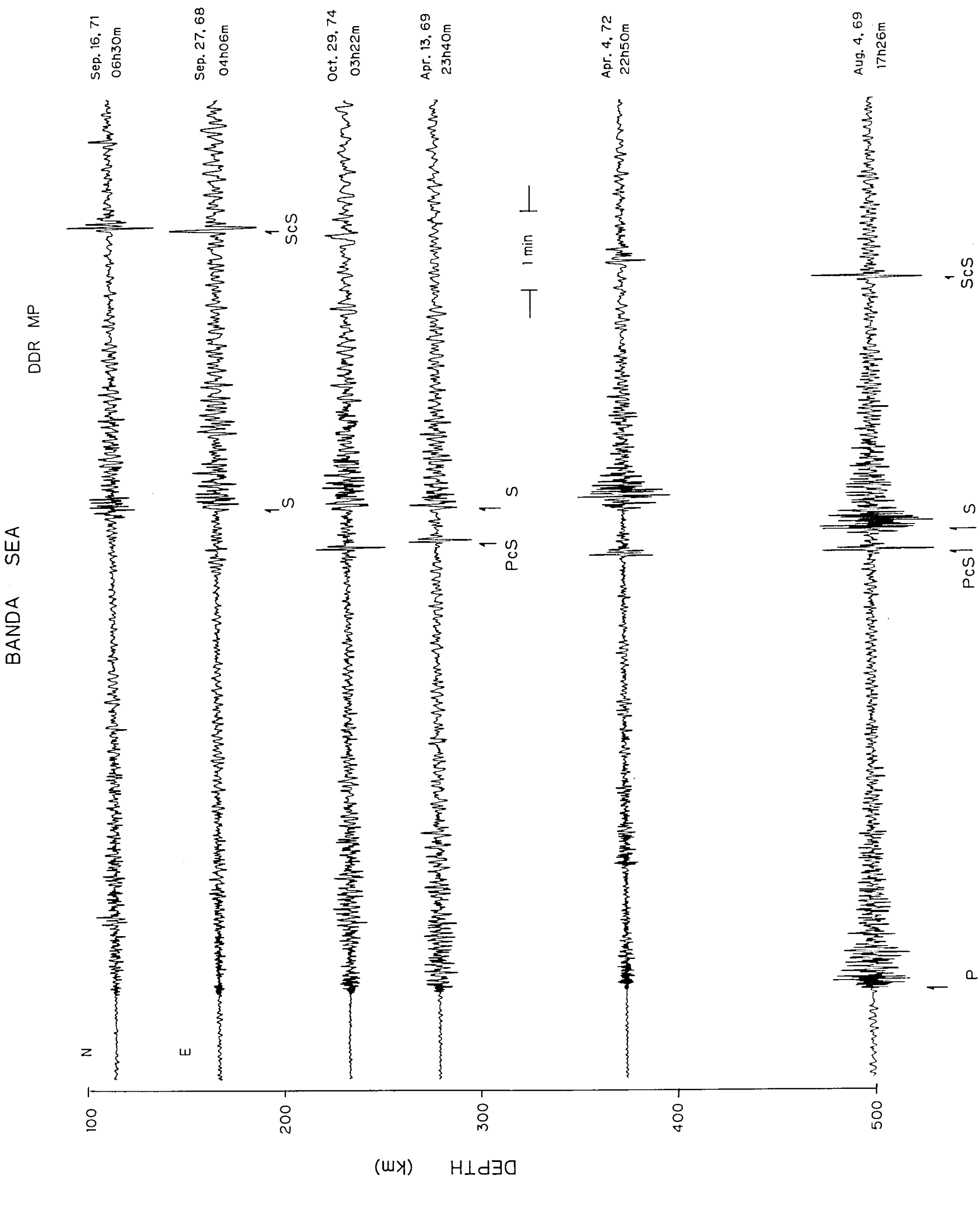
Origin Time					Epicenter		*h*	*Mb*	*Δ*
	d	h	m	s	S	E	km		deg
Sep.	16,	06	22	36.7	05°93	130°68	107	6.4	42.46
Sep.	27,	03	58	58	06.89	129.21	151	5.9	43.68
Oct.	29,	03	14	18.6	06.93	125.52	156	6.3	43.66
Apr.	13,	23	33	17.3	06.11	129.91	170	5.8	42.78
Apr.	04,	22	43	06.7	07.47	125.56	375	6.1	45.06
Aug.	04,	17	19	20.5	05.71	125.42	531	6.3	43.45

Comments

1) Top two seismograms with depths of 107 and 151 km show clear *ScS* waves.
2) Center two seismograms with depths of 156 and 170 km show clear *PcS* waves, but *ScS* waves are hard to identify.
3) Bottom two seismograms with depths of 375 and 531 km show clear *PcS* and *ScS* waves.

Combined seismograms of this and the previous figures show that there exists a systematic difference of phase appearance by source depth, especially for the appearance of *ScS* waves.

Fig. 49


BANDA SEA
DDR MP
Sep. 16, 71 06h30m
Sep. 27, 68 04h06m
Oct. 29, 74 03h22m
Apr. 13, 69 23h40m
Apr. 4, 72 22h50m
Aug. 4, 69 17h26m
N
E
ScS
S
PcS
P
1 min
100
200
300
400
500
DEPTH (KM)

50. Seismograms of deep-focus earthquakes in the Flores Sea —comparison of *PcP* and *PcS* waves—

Seismograms of two deep-focus earthquakes in the Flores Sea region obtained by MP seismographs at DDR. The top two traces show MP-Z seismograms, and the center two are those of MP-E. The bottom two traces show seismograms of *PcP* and *PcS* waves for the same events.

Note the difference of time scale between the upper four and bottom two seismograms.

The focal parameters by ISC are as follows:

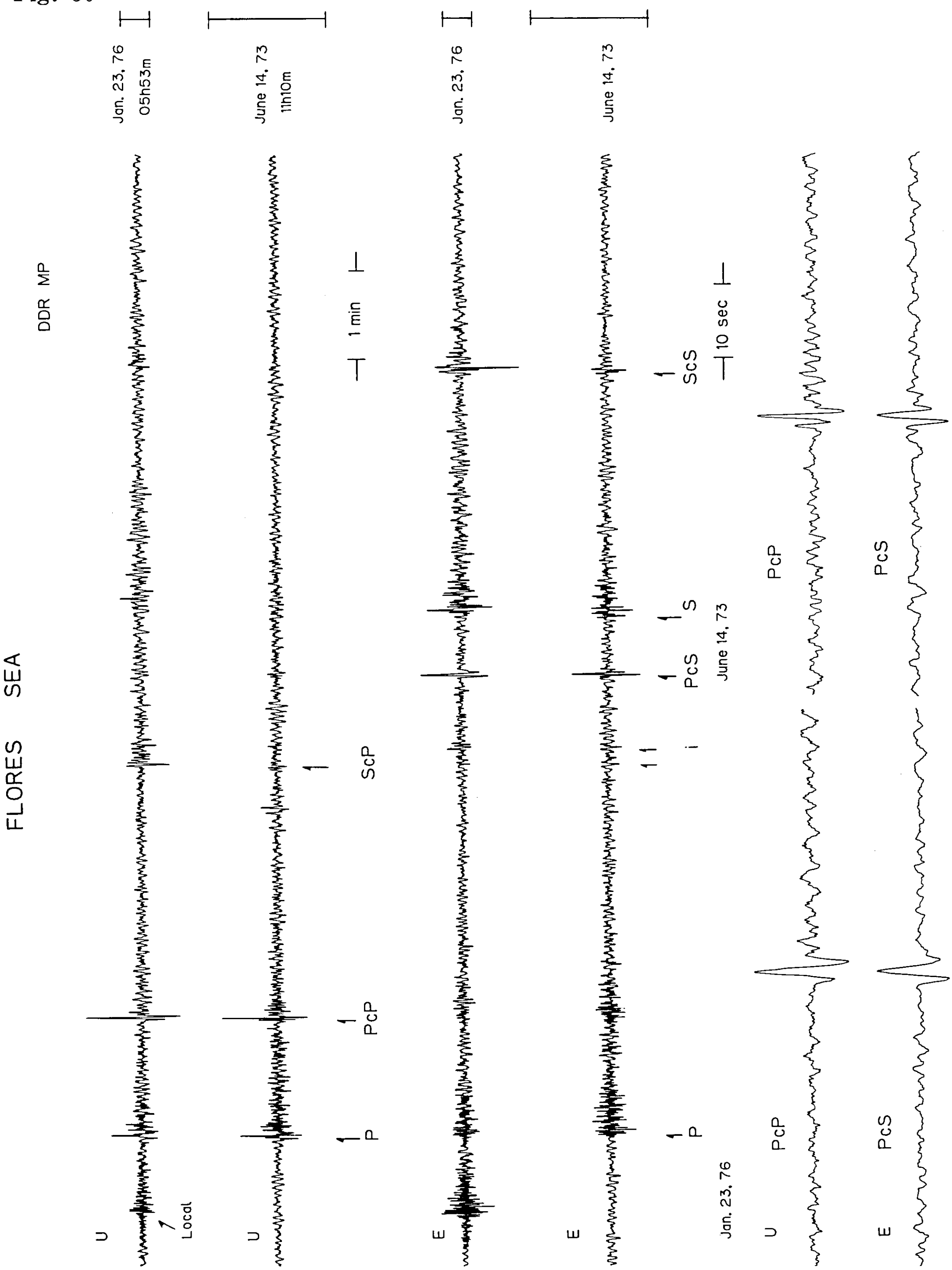
Origin Time	Epicenter		h	Mb	Δ
d h m s	S	E	km		deg
Jan. 23, 05 45 30.5	7°46	119°89	615	6.2	46.88
Jun. 14, 11 02 46.9	7.34	120.32	628	5.7	46.62

Comments

Core-reflections of *PcP* and *ScP* waves are clearly demonstrated on the Z component, and similar reflections of *PcS* and *ScS* waves appear on the E-W component, especially, the *PcP* and *PcS* waves are remarkable. Deep-focus earthquakes in this region are usually accompanied by similar core-reflections.

Clear *PcP* and *PcS* waves provide the data to obtain the attenuation property of the earth's interior.

Fig. 50


FLORES SEA
DDR MP
Jan. 23, 76
05h53m
June 14, 73
11h10m
Jan. 23, 76
June 14, 73
U
Local
U
E
E
P
PcP
ScP
1 min
P
i
PcS
S
ScS
10 sec
Jan. 23, 76
June 14, 73
U
PcP
PcP
E
PcS
PcS

51. Surface waves from West Irian region

Seismograms obtained by three components of LP seismograph at DDR for the event in the West Irian region. Note the difference of time scale between the upper three and lower two seismograms.

The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ	Ms
h m s	S	E	km		deg	
19 18 57.5	4°.58	140°.14	33	6.3	40.37	7.1*

*: *Ms* in NEIS.

Comments

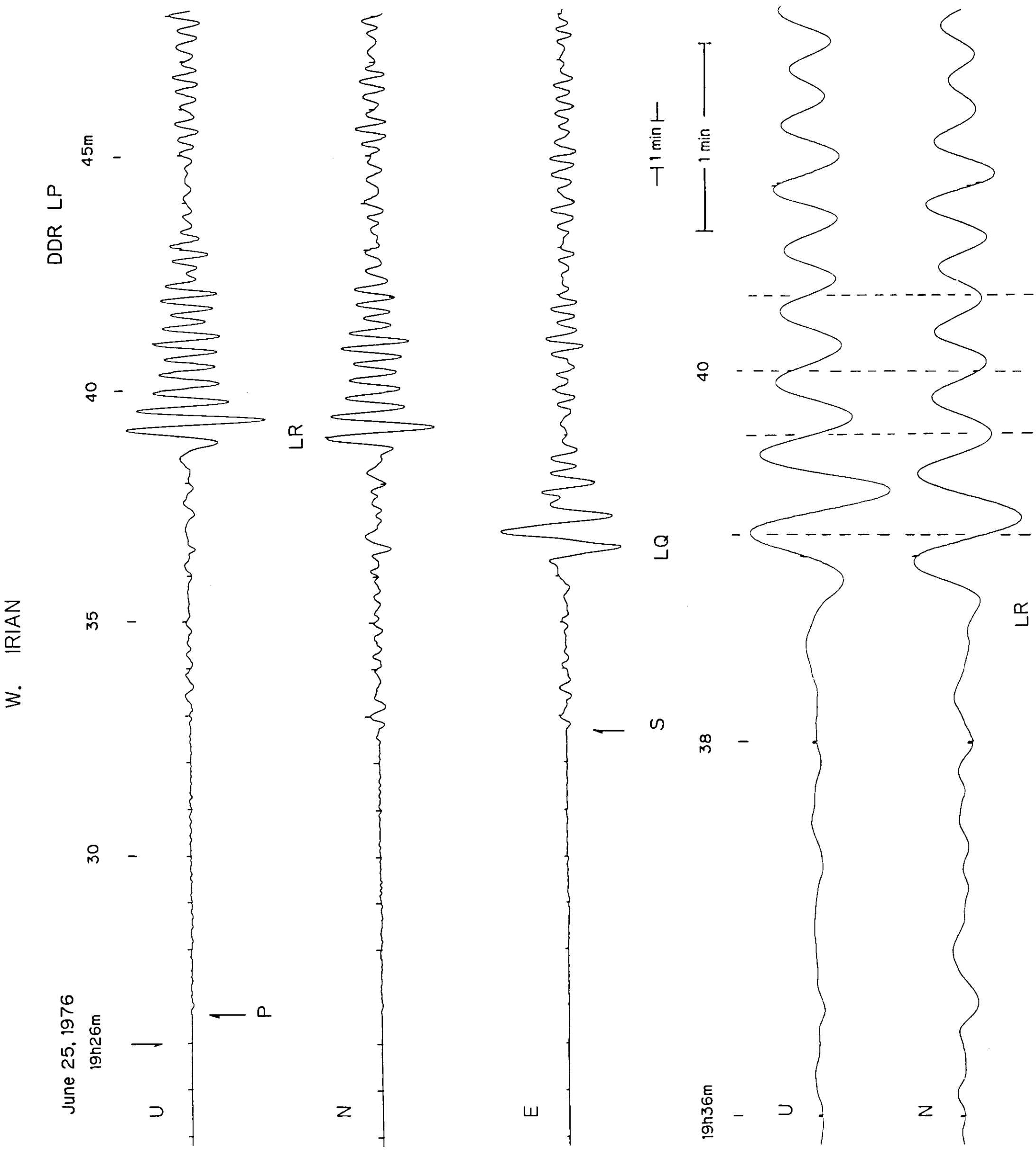
The earthquake was located due south of the station ($\theta=359°$). The *LR* is the Rayleigh wave of longitudinal type. Particle motion is retrograde elliptical traveling (bottom seismograms).

The *LQ*, Love wave, of the transverse or shear type, can be seen only on the E–W component.

The travel path is oceanic.

θ: epicentral azimuth measured from the North to East.

Fig. 51


W. IRIAN
DDR LP
June 25, 1976
19h26m
30
35
40
45m
P
S
LQ
LR
U
N
E
1 min
1 min
19h36m
38
40
U
N
LR

52. Surface waves from Mongolia region

Seismograms obtained by MP and LP-Low gain seismographs at DDR for the event in the Mongolia, China region. The sizes of bars show relative differences of magnification.

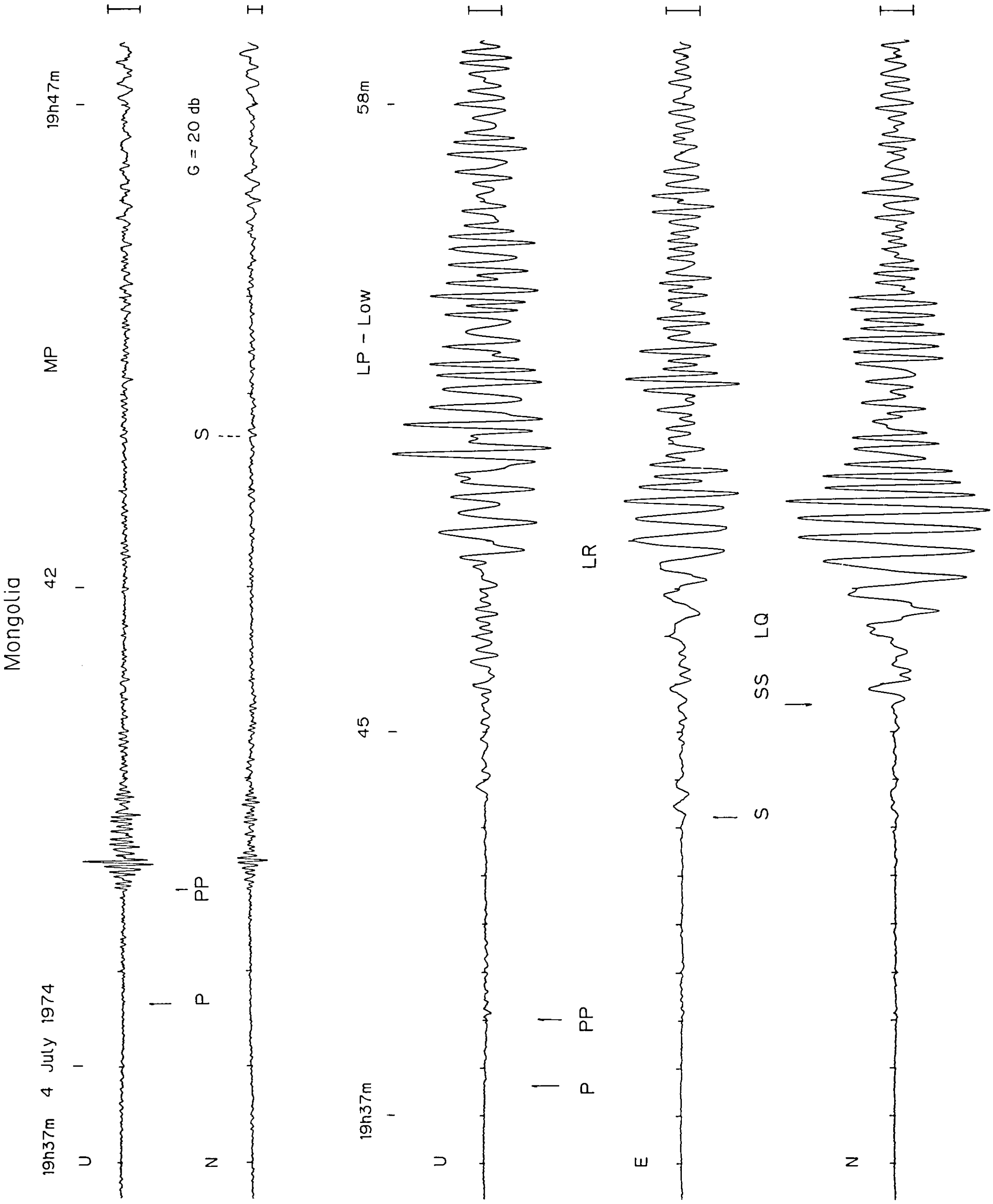
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
19 30 41.1	45°.20	93°.86	16	5.9	35.23

Comments

1) Small P and large PP waves appear on the MP seismograms, and such features of seismograms are commonly seen for events in the China region.
2) Clear dispersion of LQ wave is seen on the N-S component of LP. This is also a common feature for events in the China region.
   The travel path is continental.

Fig. 52


Mongolia
19h37m 4 July 1974
42
MP
19h47m
U
N
P
PP
S
G = 20 db
19h37m
45
LP - Low
58m
U
E
N
P
PP
LR
S
SS
LQ

53. Surface waves from Burma-India Border

Seismograms obtained by three components of MP and LP seismographs at DDR for the event in the Burma-India Border region. G: gain of play-back amplifier.

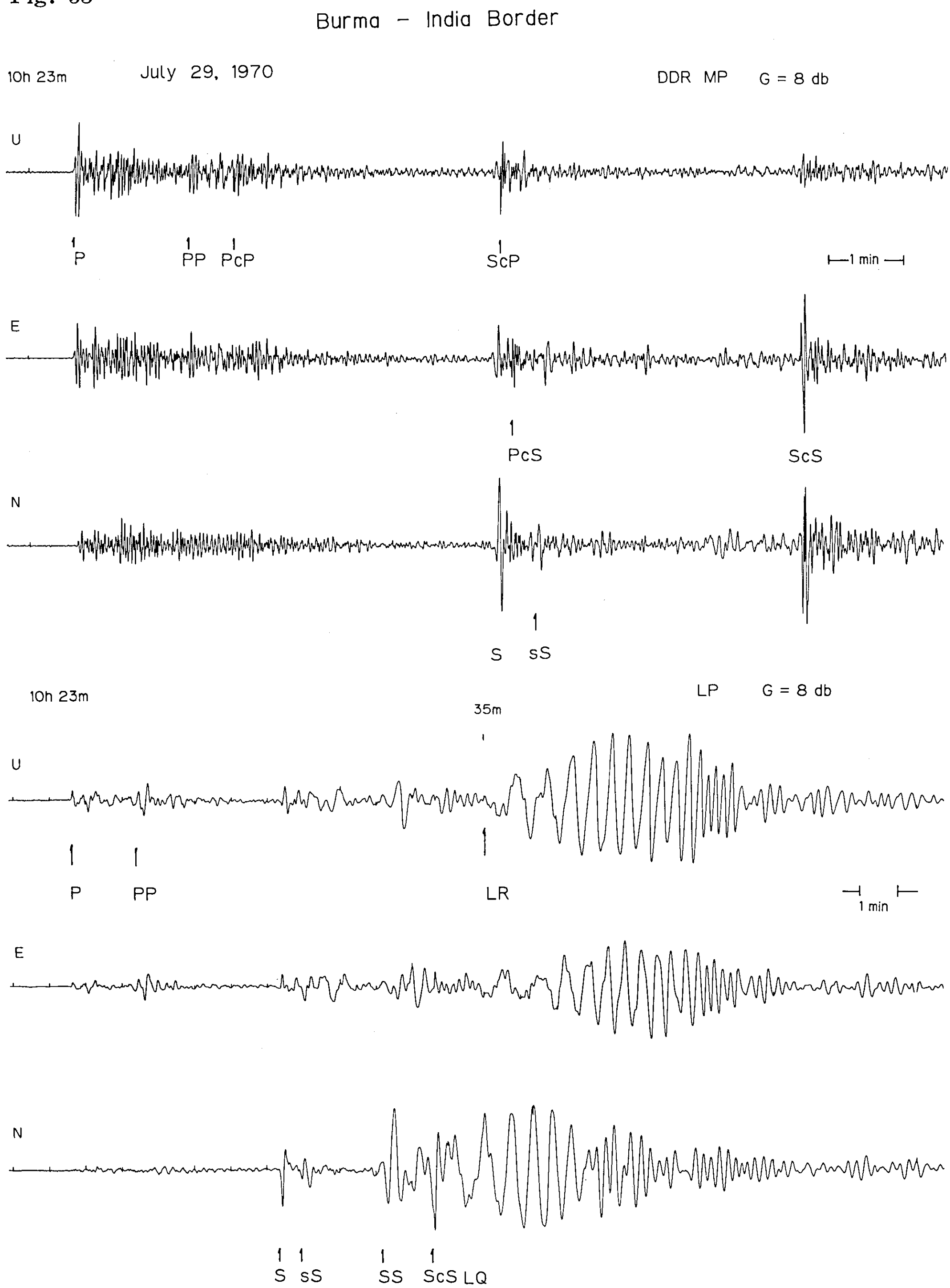
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
10 16 20.4	26°.02	95°.37	68	6.4	38.58

Comments

1) The arrival times of *S*, *ScP* and *PcS* waves are similar in this distance range, but the discrimination of these phases is possible using spectral differences.
2) Clear dispersions of surface waves are seen on the LP seismograms.
   Most of the travel path is continental.

Fig. 53


Burma – India Border
10h 23m
July 29, 1970
DDR MP
G = 8 db
U
P
PP
PcP
ScP
1 min
E
PcS
ScS
N
S
sS
10h 23m
LP
G = 8 db
35m
U
P
PP
LR
1 min
E
N
S
sS
SS
ScS
LQ

54. Comparison of surface waves —continental and oceanic—

Comparison of surface waves for different paths. The upper three traces show seismograms obtained three components of LP seismograph at DDR for the event in the Burma-India Border region, and lower three traces are from the West Irian region. G: gain of play-back amplifier.

The focal parameters by ISC are as follows:

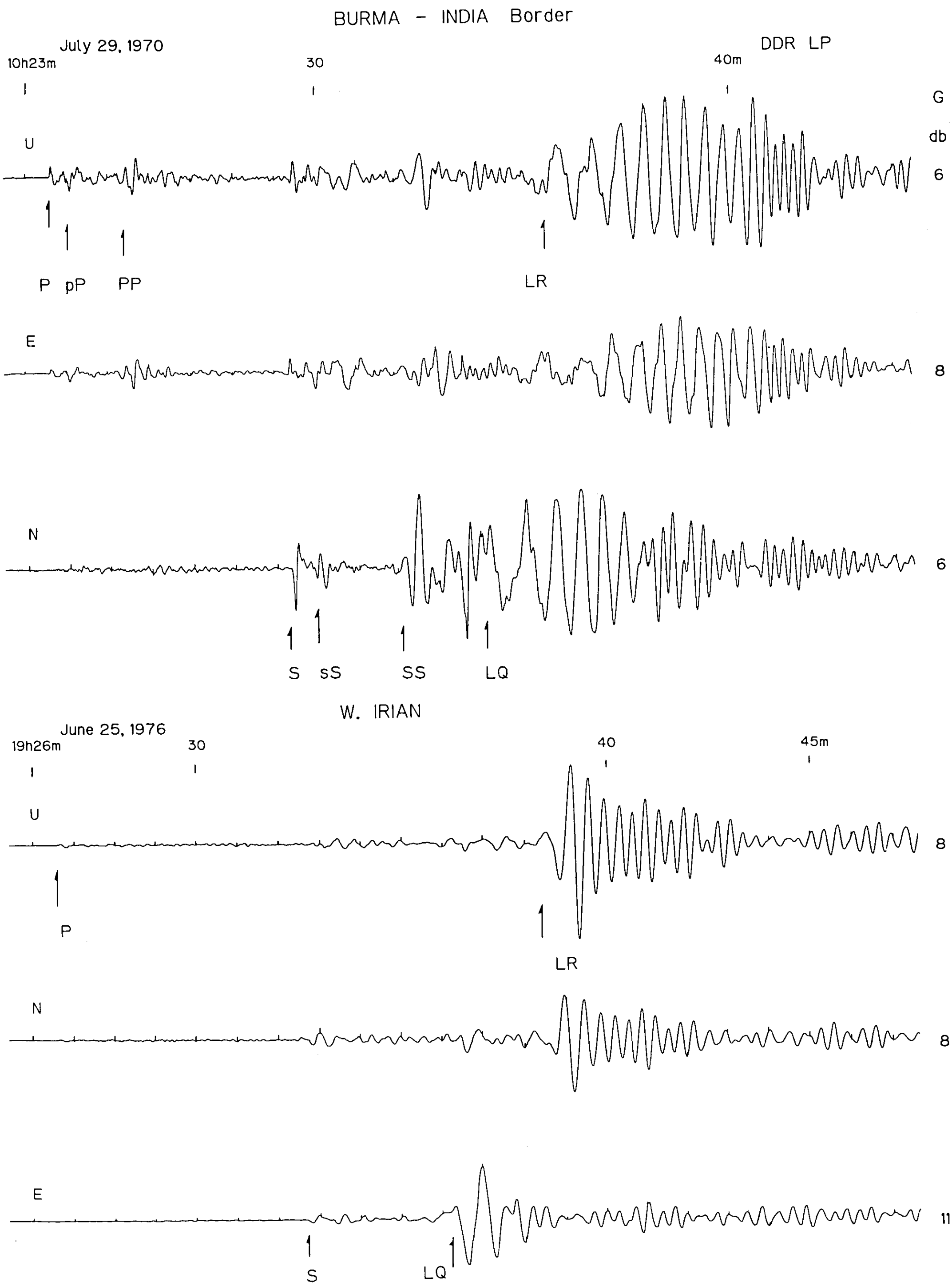
Origin Time	Epicenter		h	Mb	Δ
d h m s			km		deg
Jul. 29, 10 16 20.4	26°.02N	95°.37E	68	6.4	38.58
Jun. 25, 19 18 57.5	04.58S	140.14E	33	6.3	40.37

The travel path from Burma to DDR consists mainly of continent, except for the Japan Sea, and that of W. Irian is purely oceanic.

Comments

1) Remarkable *LQ* and *LR* waves with dispersion are seen for the Burma event comparing with those of Irian event.
2) Higher mode surface wave, or *SS* wave, can be seen on the N-S seismogram of the Burma event.
3) The arrival time of the *LQ* wave in the Irian event is earlier than that for the Burma event.

Fig. 54


BURMA - INDIA Border
July 29, 1970
10h23m
30
40m
DDR LP
G
db
U
6
P pP PP
LR
E
8
N
6
S sS SS LQ
W. IRIAN
June 25, 1976
19h26m
30
40
45m
U
8
P
LR
N
8
E
11
S
LQ

55. Surface waves from New Guinea region

Seismograms obtained by MP and LP-Low gain seismographs at DDR for the event in the New Guinea region. G: gain of play-back amplifier.

The focal parameters by ISC are as follows:

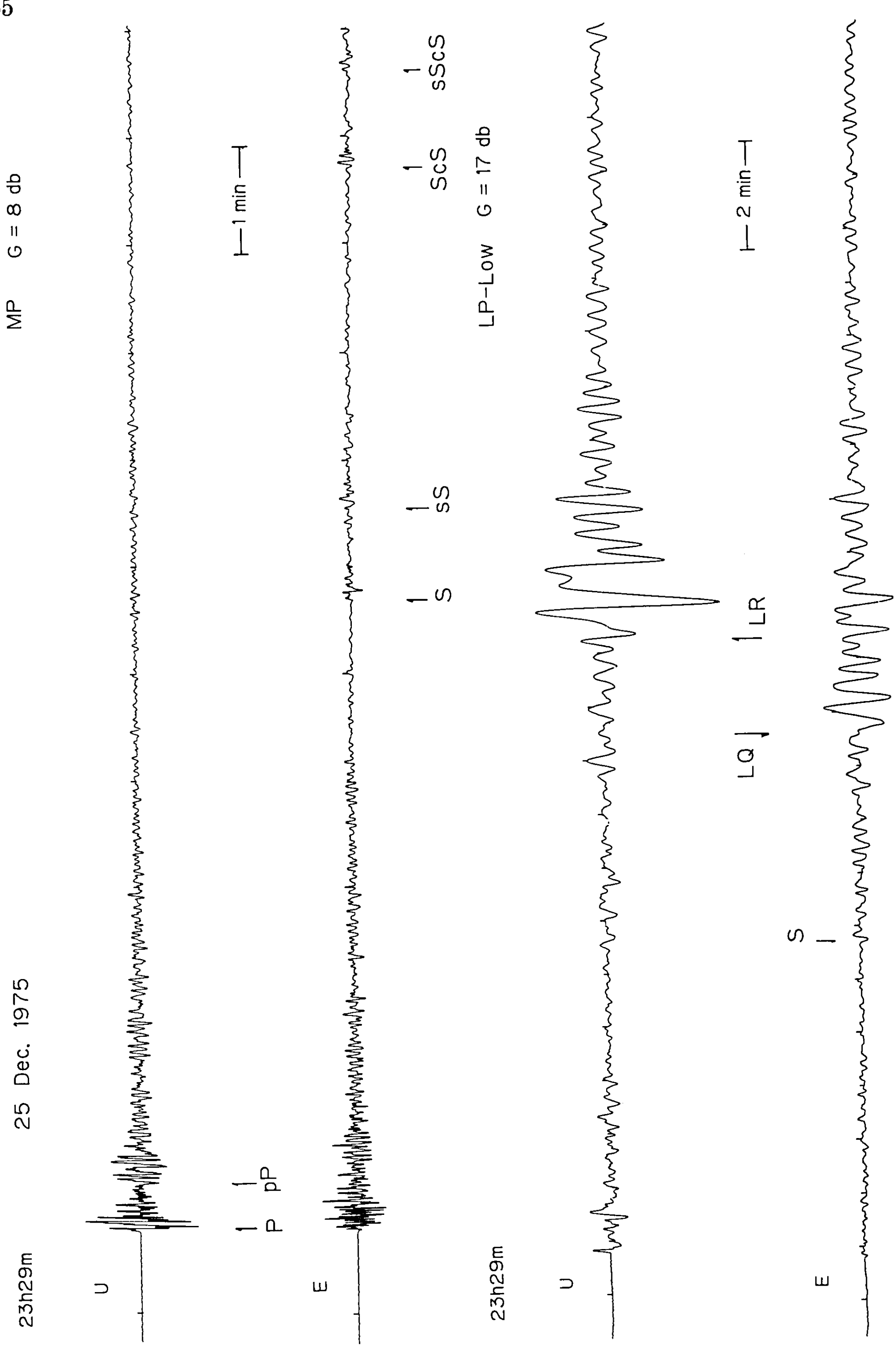
Origin Time	Epicenter		h	Mb	Δ
h m s	S	E	km		deg
23 22 20.3	04°07	142°11	102	6.4	39.96

Comments

1) Reflected waves of *pP*, *sS* and *sScS* are seen on the MP seismograms.
2) Pulse-like *LR* wave is seen on the LP-Z seismogram.

An intermediate-depth earthquake usually shows *LR* waves with pulse-like character.

Fig. 55


New Guinea
25 Dec. 1975
MP G = 8 db
23h29m
U
E
P
pP
1 min
S
sS
ScS
sScS
LP-Low G = 17 db
23h29m
U
E
2 min
S
LQ
LR

56. Surface waves from Aleutian Islands region

Comparison of seismograms from the Andreanof Islands, Aleutian Islands region. The upper three traces show seismograms obtained by MP and LP seismographs at DDR, the middle two are similar seismograms for a different event, and the bottom trace is that of a deep source in the same region. Bars at the ends of seismograms show relative differences of magnification.

The focal parameters by ISC are as follows

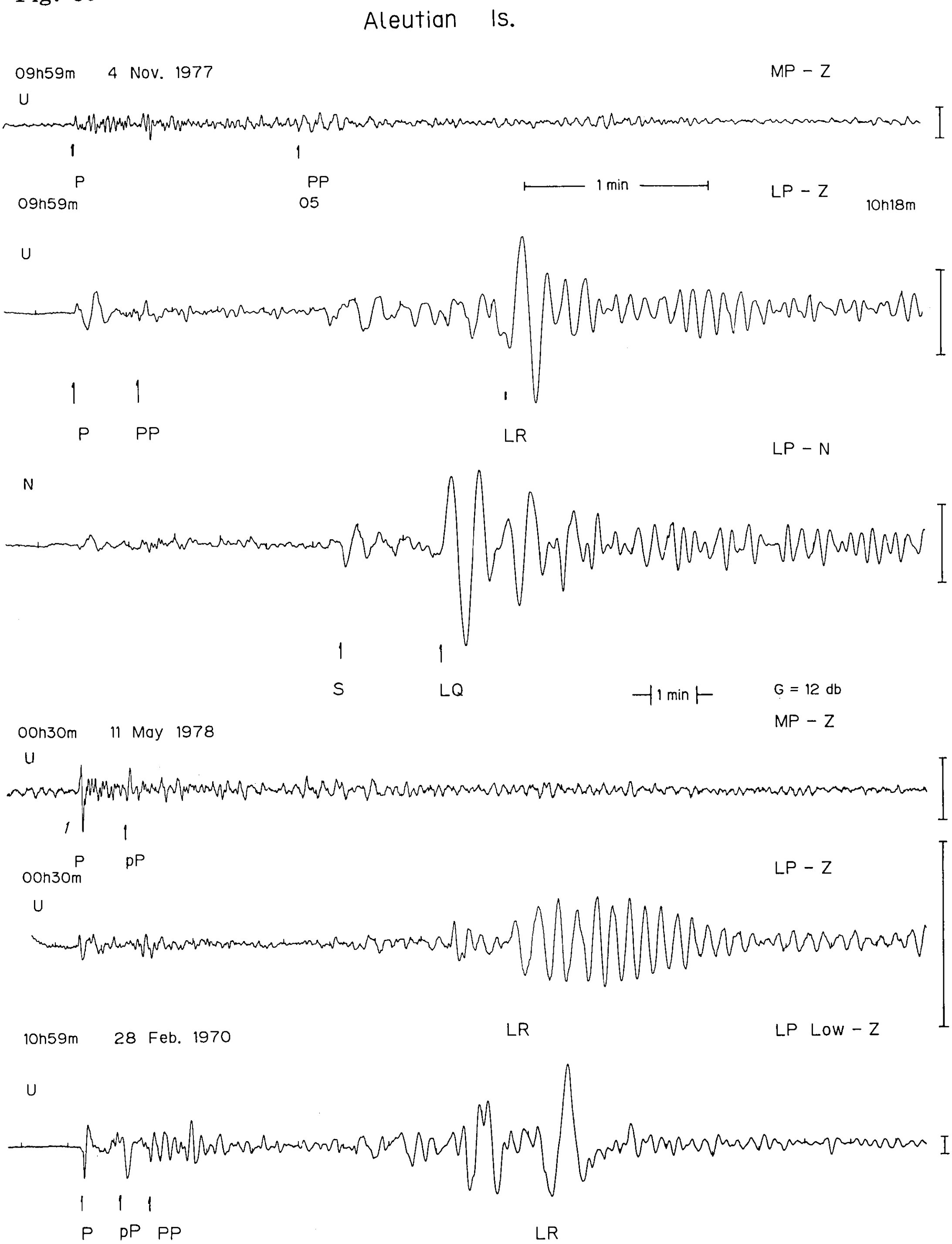
Origin Time		Epicenter		h	Mb	Δ
	d h m s	N	W	km		deg
Nov.	04, 09 52 58.0	51°.63	175°.97	51	5.6	35.31
May	11, 00 23 37.4	51.65	176.08	56	5.6	35.25
Feb.	28, 10 52 31.1	52.59	175.04	161	6.0	36.03

Although the upper two events have similar depths and magnitudes, clear differences of surface waves are seen:

1) The surface waves in the Nov. 4 event show impulsive waveforms, like the deep source event (bottom seismogram).
2) The seismograms of the Nov. 4 event predominate in low-frequency components compared with those of the May 11 event.
3) The seismograms in this region with depth less than 60 km usually show wave trains of the May 11 event type.

Through the waveform analysis of events in this region, it is confirmed that the Nov. 4 event shows unusual waveform features.

Fig. 56


Aleutian Is.
09h59m 4 Nov. 1977
MP – Z
U
P
PP
1 min
09h59m
05
LP – Z
10h18m
U
P
PP
LR
LP – N
N
S
LQ
1 min
G = 12 db
MP – Z
00h30m 11 May 1978
U
P
pP
00h30m
LP – Z
U
LR
LP Low – Z
10h59m 28 Feb. 1970
U
P
pP
PP
LR

57. Seismograms from Aleutian Islands region
—dependence on source size—

Comparison of seismograms of two events in the Andreanof Islands, Aleutian Islands region. The upper two traces show seismograms obtained by MP-Z seismograph at DDR, and the center two and bottom two traces are those of LP-Z, LP-N seismographs, respectively. The sizes of bars show relative differences of magnification.

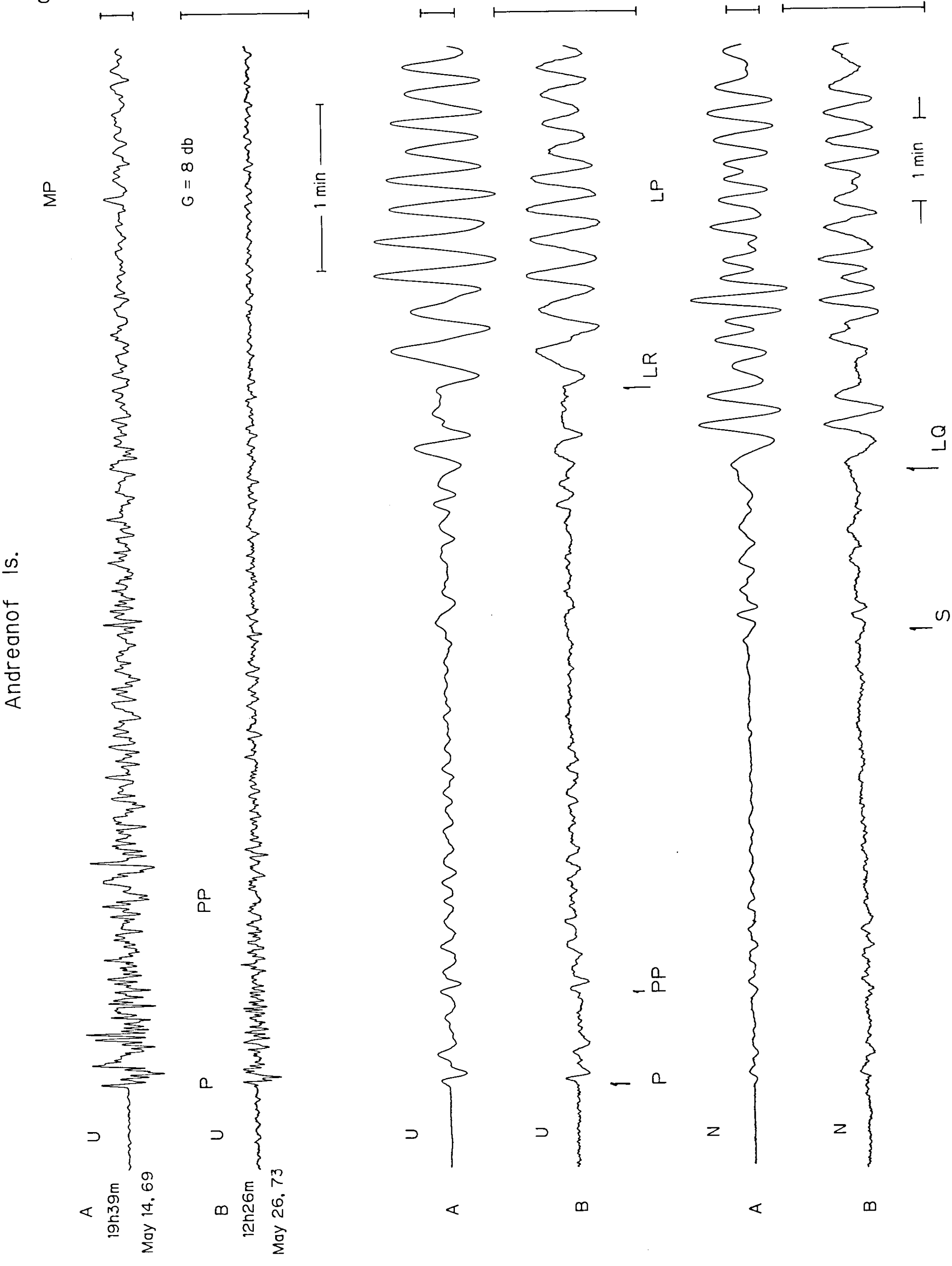
The focal parameters by ISC are as follows:

Origin Time	Epicenter		*h*	*Mb*	*Ms*	*Δ*
d h m s	N	E	km			deg
May 14, 19 32 55	51°.29	179°.85	22	6.2	7.0	32.86
May 26, 12 19 34.2	51.29	179.71	35	5.7	5.7	32.95

Comments

1) Similar waveform features are seen between the seismograms of two events, especially for LP seismograms.
2) Spectral ratios for *P* and surface waves of these events are almost constant, though their *Ms* values are different by a factor of 1.3 (TSUJIURA, 1973b).

Fig. 57


Andreanof Is.
MP
G = 8 db
1 min
LP
LR
LQ
S
PP
P
PP
P
U
U
U
U
N
N
A
19h39m
May 14, 69
B
12h26m
May 26, 73
A
B
A
B

58. Seismograms from Novaya Zemlya explosions

Seismograms of two underground nuclear explosions from the Novaya Zemlya region. The upper three traces show seismograms obtained by three components of MP seismograph at DDR for the 1973 event, and the center two are similar seismograms for the 1974 event. The bottom three traces are LP seismograms for the same event in the center. G: gain of play-back amplifier.

The focal parameters by ISC are as follows:

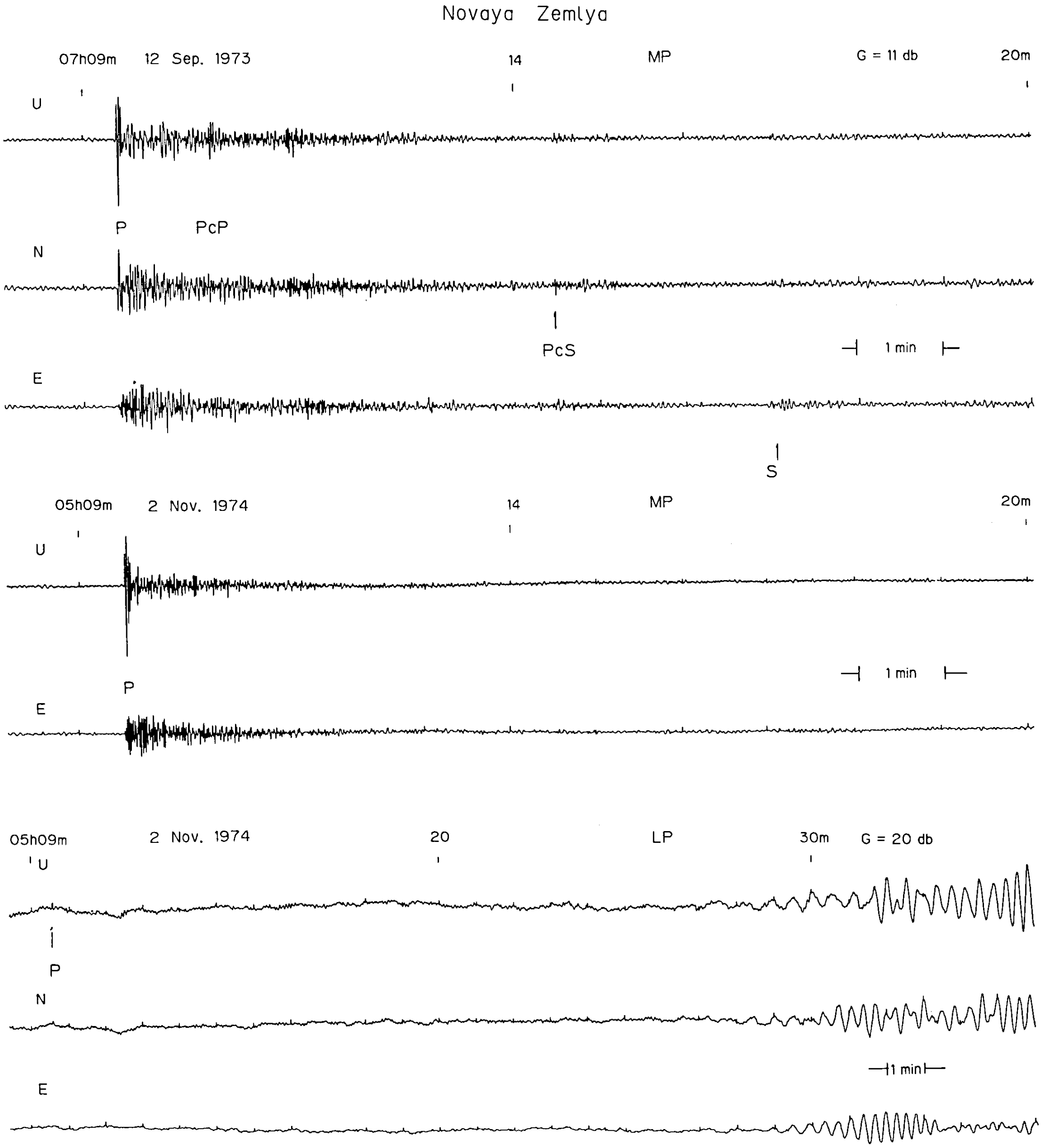
Origin Time	Epicenter		h	Mb	Δ
d h m s	N	E	km		deg
Sep. 12, 06 59 54.6	73°.32	54°.97	0	6.8	54.28
Nov. 02, 04 59 56.9	70.81	53.91	0	6.4	54.95

Although they are located in the same region, some differences of waveform are seen:

1) The seismograms in the 1973 event contain larger low-frequency components than those of the 1974 event.
2) Core reflections of *PcP* and *PcS* waves are seen in the 1973 event, but no appreciable later phases appear in the 1974 event.
3) Small amplitudes (Ms=5.3), and no notable phases, appear on the LP seismograms.

(to be continued)

Fig. 58



Novaya Zemlya
07h09m 12 Sep. 1973
14
MP
G = 11 db
20m
U
P
PcP
N
PcS
1 min
E
S
05h09m 2 Nov. 1974
14
MP
20m
U
1 min
P
E
05h09m 2 Nov. 1974
20
LP
30m
G = 20 db
U
P
N
1 min
E

59. Regional variation of seismograms from Novaya Zemlya

A chronological arrangement of the seismograms obtained by MP-Z seismograph at DDR for the nuclear explosions from the Novaya Zemlya region. The sizes of bars show relative differences of magnification.

The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
d h m s	N	E	km		deg
Oct. 14, 05 59 57.3	73°.31	54°.89	0	6.6	54.23
Aug. 28, 05 59 56.8	73.39	54.65	0	6.3	54.36
Sep. 12, 06 59 54.6	73.32	54.97	0	6.8	54.28
Nov. 02, 04 59 56.9	70.81	53.91	0	6.4	54.95
Oct. 18, 08 59 56.5	70.84	53.53	0	6.7	55.07

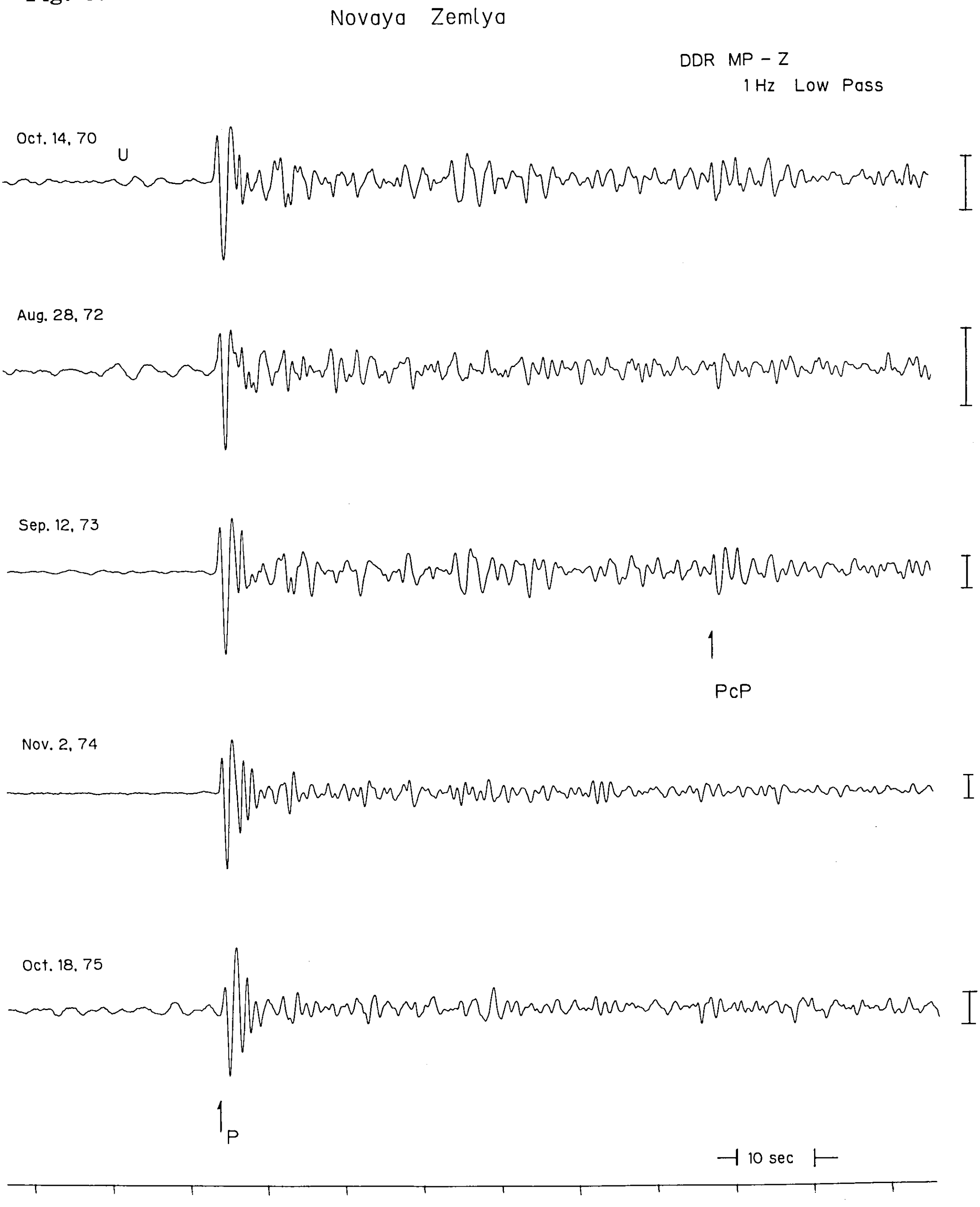
The waveforms are different between the upper three seismograms and the lower two:

1) Bottom two seismograms predominate in higher-frequency components than those of the upper three, and such differences are independent of the explosion size.
2) The explosion test site is separated into two regions, about 73°N and 70°N, and the difference of seismograms depends on the test site.

The difference of the spectrum therefore may be due to the difference of geological setting at the test site.

(to be continued)

Fig. 59


Novaya Zemlya
DDR MP - Z
1 Hz Low Pass
Oct. 14, 70
U
Aug. 28, 72
Sep. 12, 73
PcP
Nov. 2, 74
Oct. 18, 75
P
10 sec

60. Similarity of waveforms from Novaya Zemlya explosions

Comparison of seismograms from two Novaya Zemlya explosions obtained by MP–Z seismograph at DDR. The top two traces show seismograms passed through the low-pass filter with cut-off frequency of 1 Hz, the middle two are those by the band-pass filter with 0.8 Hz–5 Hz for the same events, and the bottom two are those by the band-pass filter with 1.6 Hz–5 Hz. G: gain of play-back amplifier.

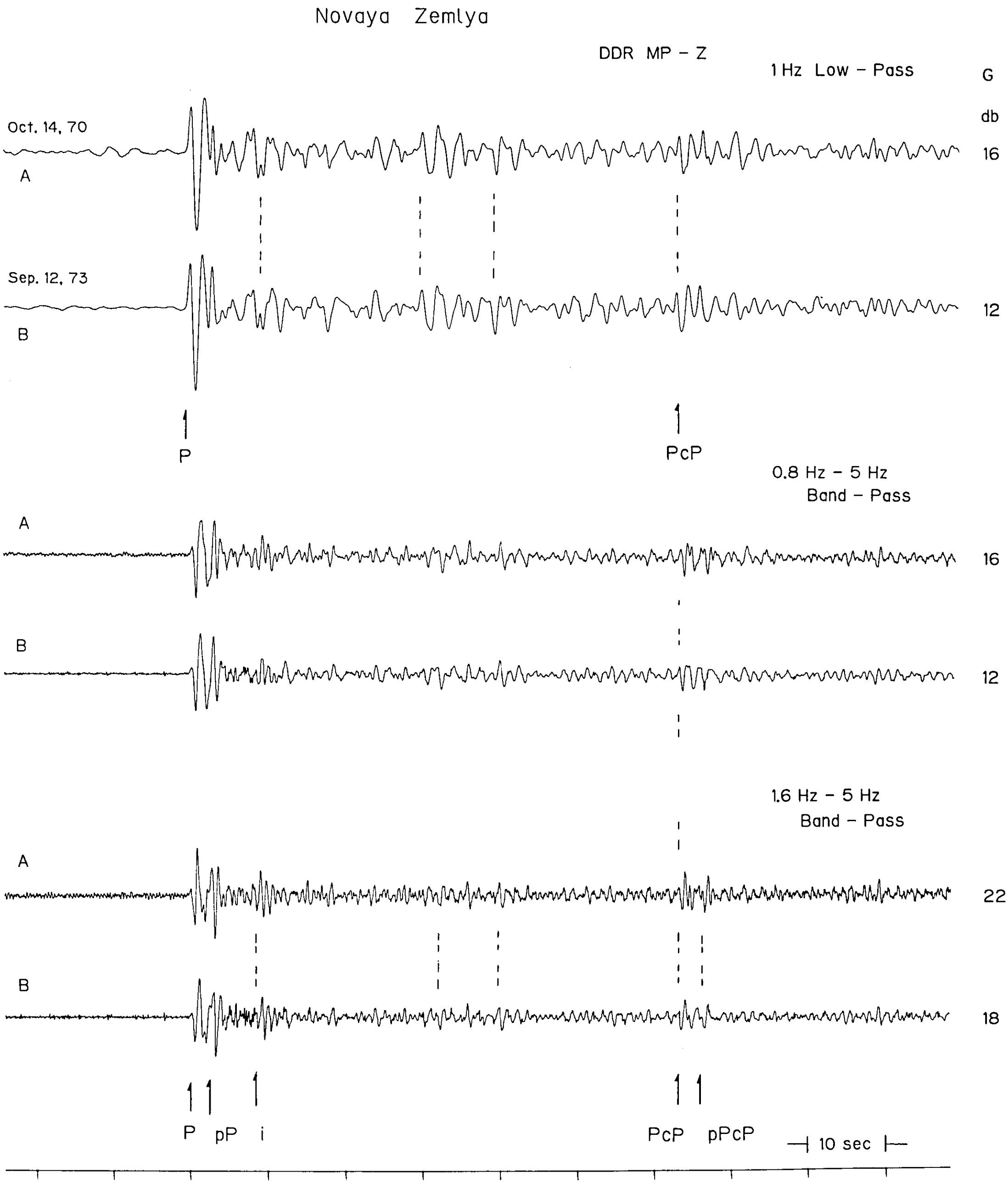
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
d h m s	N	E	km		deg
Oct. 14, 05 59 57.3	73°.31	54°.89	0	6.6	54.23
Sep. 12, 06 59 54.6	73.32	54.97	0	6.8	54.28

Comments

1) The waveforms of two events coincide well with each other from *P* wave onset until coda waves, especially isolated wavelets indicated by dotted lines agree even in the frequency up to 2 Hz; such a similarity of waveforms cannot be expected for natural earthquakes of comparable magnitude.
2) The *P* and *PcP* waves seem to be separated into two wavelets such as *P*, *pP* and *PcP*, *pPcP*.
3) Isolated wavelets indicated by *i* are clearly seen on the high-frequency seismograms (bottom). The interpretation of this phase is left for future study.

Fig. 60


Novaya Zemlya
DDR MP - Z
1 Hz Low - Pass
G
db
Oct. 14, 70
A
16
Sep. 12, 73
B
12
P
PcP
0.8 Hz - 5 Hz
Band - Pass
A
16
B
12
1.6 Hz - 5 Hz
Band - Pass
A
22
B
18
P
pP
i
PcP
pPcP
10 sec

61. *pP* phase from Afghanistan-USSR Border

An arrangement of seismograms from the Afghanistan-USSR Border region obtained by SP-Z seismographs at TSK and SRY. The ordinate shows the source depth in kilometers.

The focal parameters by ISC are as follows:

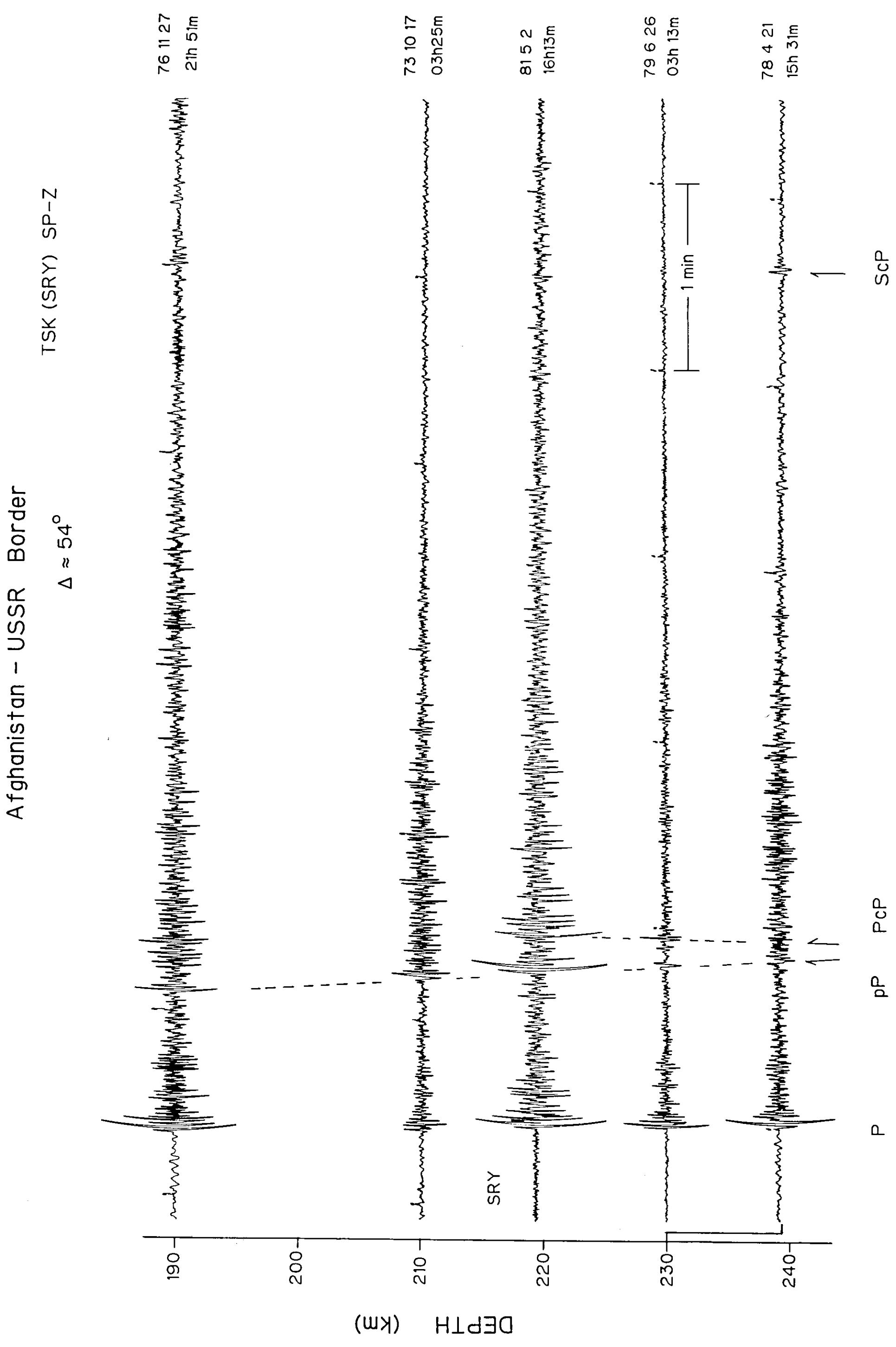
Origin Time		Epicenter		h	Mb	Δ
	d h m s	N	E	km		deg
Nov.	27, 21 42 12.1	36°52	71°05	190	6.2	54.46
Oct.	17, 03 16 17.6	36.38	71.11	211	5.4	54.46
May	02, 16 04 54.6	36.40	71.15	217	5.9	54.02
Jun.	26, 03 04 51.9	36.47	71.24	229	5.7	54.33
Apr.	21, 15 22 57.9	36.64	71.26	230	5.8	54.25

The seismic activity with intermediate depth is very active in this region.

Comments

1) Sharp *P* and clear *pP* phases appear on the most of the seismograms in this region.
2) The waveform of *pP* phase is impulsive and contains higher-frequency compared with those of other seismic regions, as shown later.

Fig. 61


Afghanistan - USSR Border
Δ ≈ 54°
TSK (SRY) SP-Z
76 11 27
21h 51m
73 10 17
03h25m
81 5 2
16h13m
79 6 26
03h 13m
78 4 21
15h 31m
1 min
SRY
P
pP
PcP
ScP
DEPTH (km)
190
200
210
220
230
240

62. *pP* phase along the source depth

An arrangement of the *pP* phases obtained by MP-Z seismograph at DDR. These seismograms are taken from various regions. The amplitude of each trace is arbitrary. *h*: source depth in kilometers.

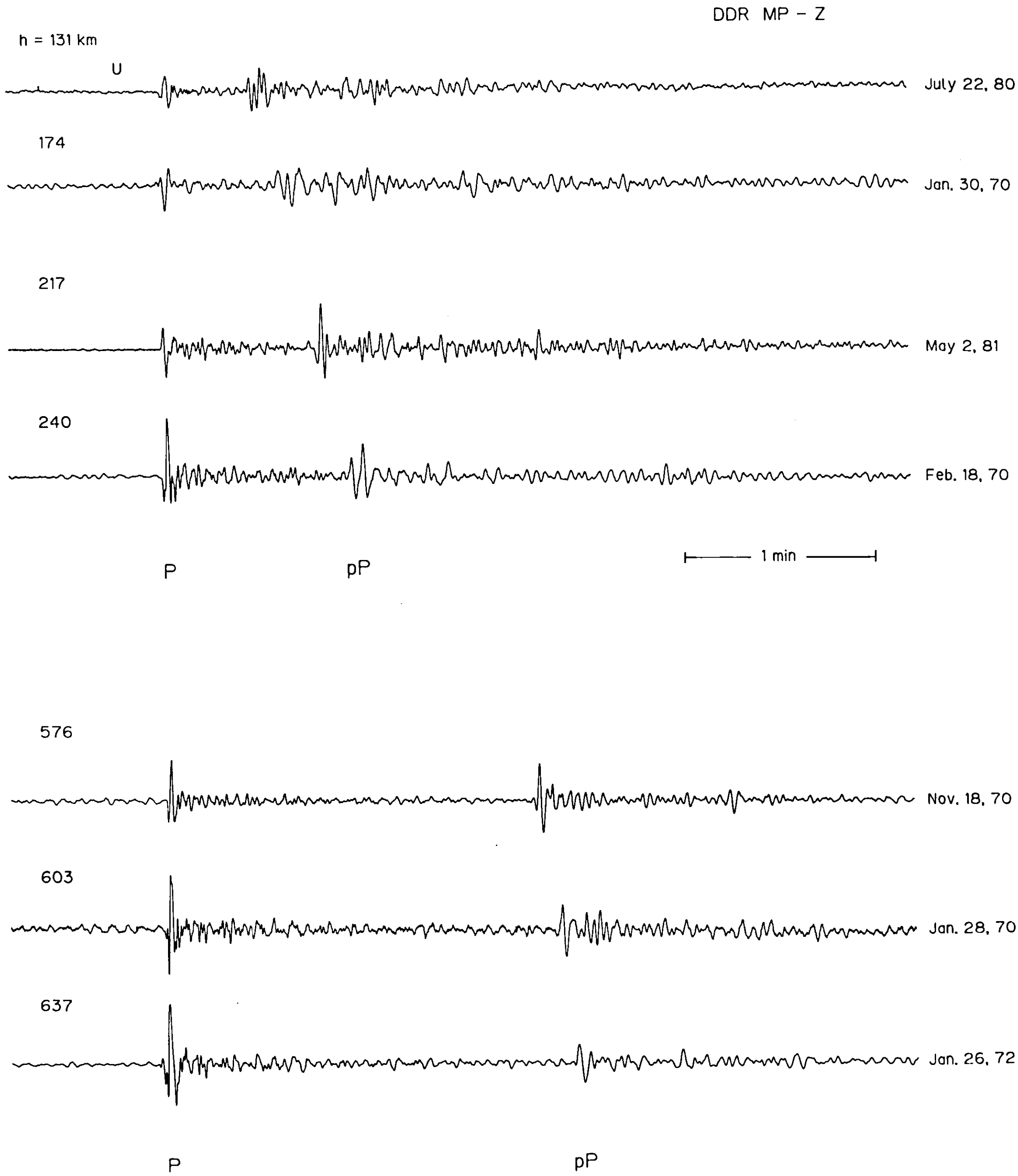
The focal parameters by ISC are as follows:

Origin Time		Epicenter		*h*	*Mb*	*Δ*
	d h m s			km		deg
Jul.	22, 07 06 24.0	20°.30S	169°.61E	131	6.1	62.96
Jan.	30, 08 28 22.9	14.61S	167.31E	174	5.6	56.93
May	02, 16 04 54.6	36.40N	71.15E	217	5.9	54.02
Feb.	18, 15 23 31.5	20.83S	176.71W	240	5.7	70.25
Nov.	18, 16 43 14.8	21.81S	175.23E	576	5.5	66.84
Jan.	28, 23 06 01.4	20.68S	178.79W	603	5.6	68.99
Jan.	26, 23 00 22.1	20.19S	178.89W	637	5.7	68.53

Comments

1) The waveform and spectrum of *pP* phase depend on the seismic region and source depth. The *pP* phase in the Afghanistan-USSR Border region (third trace) is rather simple and contains higher-frequency components than the others with similar depths.
2) The *pP* phase with deep source ($h>500$ km) is very simple, and there is no special phase between *P* and *pP* waves.

Fig. 62


DDR MP - Z
h = 131 km
U
July 22, 80
174
Jan. 30, 70
217
May 2, 81
240
Feb. 18, 70
1 min
P
pP
576
Nov. 18, 70
603
Jan. 28, 70
637
Jan. 26, 72
P
pP

63. Double phases in the P waves (1)

Seismograms of large earthquakes in the three regions, Loyalty Is., New Hebrides and Santa Cruz Is., obtained by SP-Z seismographs at OYM, SRY, DDR and TSK.

The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Δ	
	d h m s	S	E	km		deg	
Jul.	06, 03 08 34.1	22°.29	171°.64	114	6.3	65.10	(OYM)
Aug.	02, 10 55 25.2	20.59	169.31	43	6.0	62.58	(OYM)
Nov.	21, 05 57 12.0	11.87	166.55	119	6.5	54.17	(DDR)

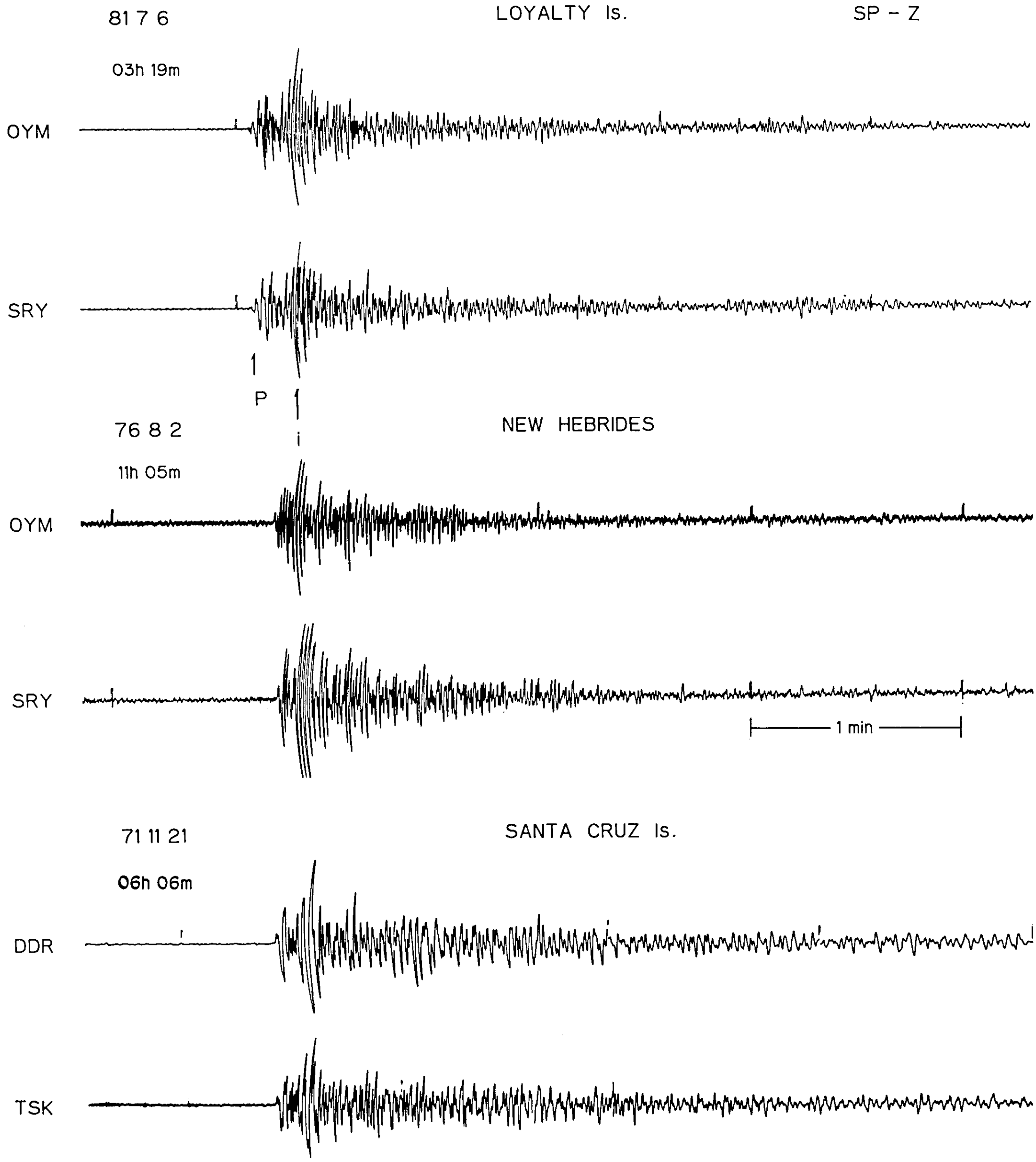
Comments

1) Clear phase indicated by i appears on the pair seismograms in each event.
2) The time interval between P and i phases is less than 10 sec.
3) The source depth of these events lies between 43 km and 119 km.

Considering the source depth of these events, the i phase is probably the P wave of the 2nd shock which occurred a few seconds after the 1st shock on the same fault plane.

(to be continued)

Fig. 63


81 7 6
LOYALTY Is.
SP - Z
03h 19m
OYM
SRY
P
i
76 8 2
NEW HEBRIDES
11h 05m
OYM
SRY
1 min
71 11 21
SANTA CRUZ Is.
06h 06m
DDR
TSK

64. Double phases in the *P* waves (2)

Seismograms of large earthquakes in the three regions, New Hebrides, Santa Cruz Is. and Loyalty Is., obtained by MP-Z seismograph at DDR. Seismograms of small events in the same regions are also shown for comparison. The sizes of bars show relative differences of magnification.

The focal parameters by ISC are as follows:

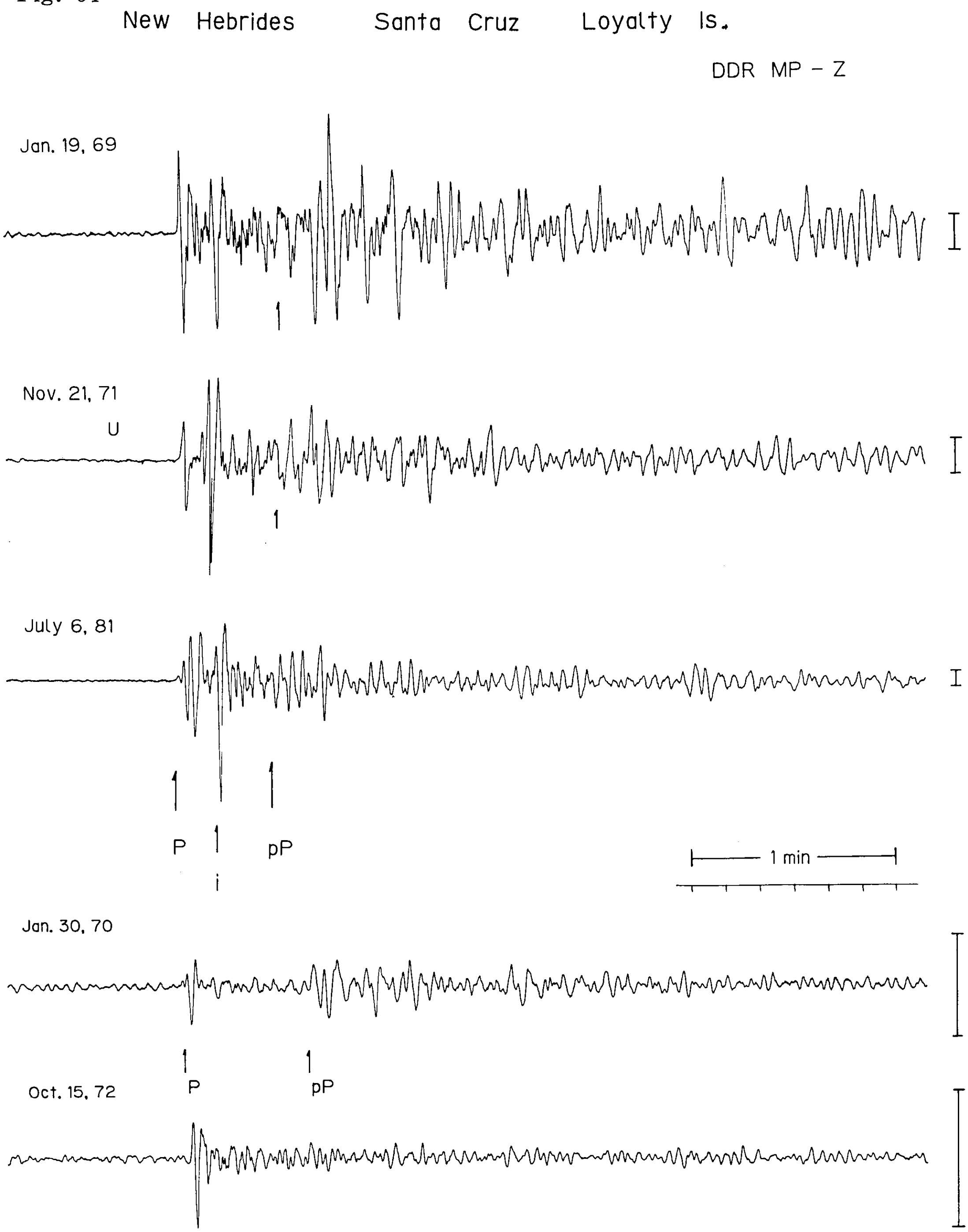
Origin Time					Epicenter		h	Mb	Δ
	d	h	m	s	S	E	km		deg
Jan.	19,	18	50	52.4	14°.89	167°.22	114	6.2	57.13
Nov.	21,	05	57	12.0	11.87	166.55	119	6.5	54.17
Jul.	06,	03	08	34.1	22.29	171.64	114	6.3	65.60
Jan.	30,	08	28	22.9	14.61	167.31	174	5.6	56.93
Oct.	15,	10	28	12.8	22.18	171.25	144	5.6	65.33

Comments

1) Clear and impulsive phase indicated by *i* appears on the upper three seismograms.
2) The *pP* phase is shown by arrows.
3) No *i* phase appears in the small events as shown in the lower two seismograms.

As shown previously (Figs. 22, 23, 24), when the earthquake size exceeds magnitude 6 the *P* waves show double or multiple type waveforms. Similar tendencies are seen in these regions. This suggests that there is some limitation of earthquake size for the occurrence as a single event.

Fig. 64


New Hebrides Santa Cruz Loyalty Is.
DDR MP – Z
Jan. 19, 69
Nov. 21, 71
U
July 6, 81
P
i
pP
1 min
Jan. 30, 70
P
pP
Oct. 15, 72

65. Seismograms from New Hebrides (1)

Seismograms of the three components of MP and LP seismographs at DDR for the event in the New Hebrides region. G: gain of playback amplifier.

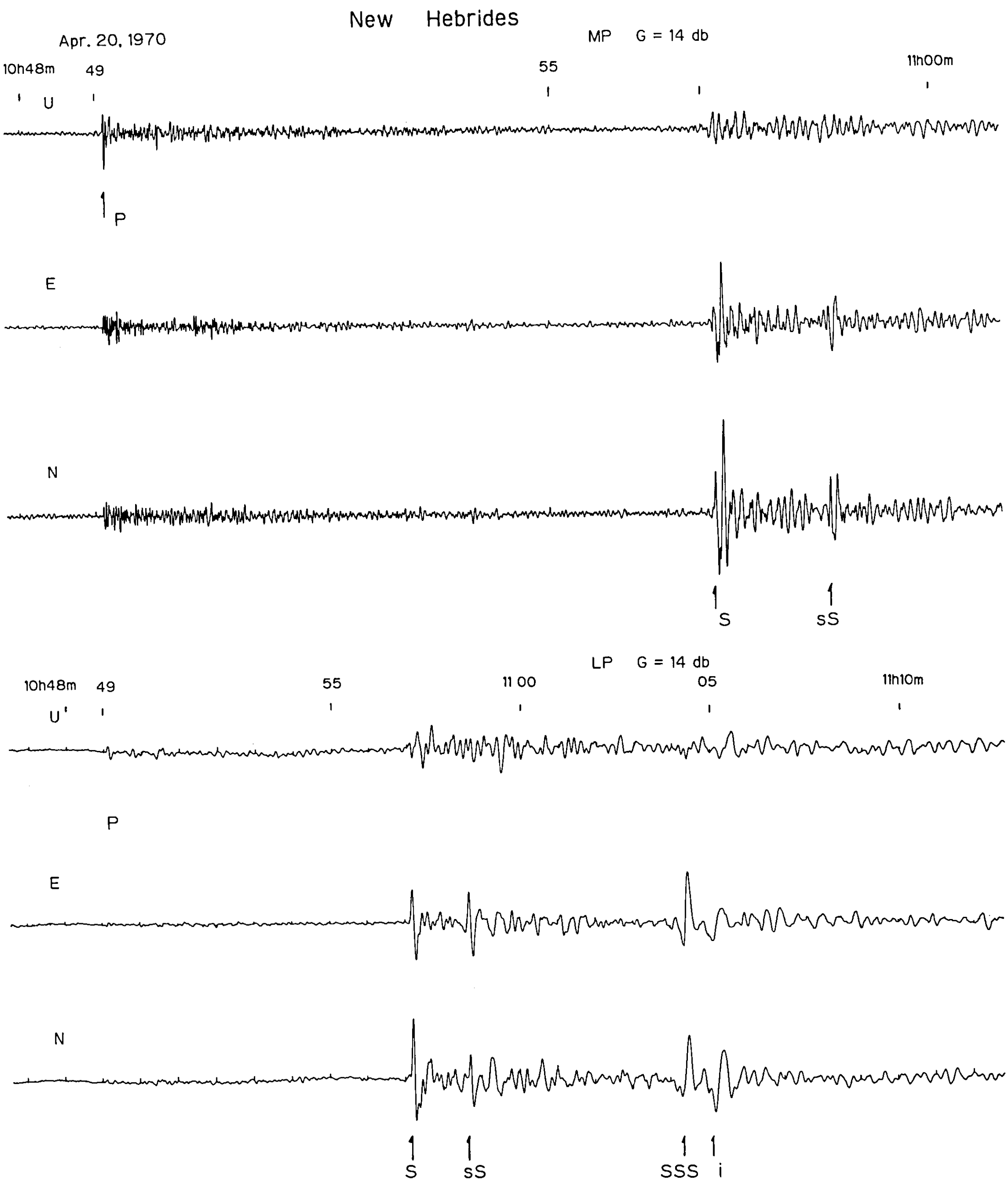
The focal parameters by ISC are as follows:

Origin Time	Epicenter		*h*	*Mb*	*Δ*
h m s	S	E	km		deg
10 39 12.8	18°.79	169°.29	243	6.2	61.49

Comments

1) Unusual short-period *P* and *S* waves are seen on the MP and LP seismograms despite of large earthquake.
2) Multi-reflections of *S* waves are seen on the LP seismograms.
3) Deep earthquake does not accompany surface waves.
4) The *i* phase is unexplained here.

Fig. 65


New Hebrides
Apr. 20, 1970
MP G = 14 db
10h48m
49
55
11h00m
U
P
E
N
S
sS
LP G = 14 db
10h48m
49
55
11 00
05
11h10m
U'
P
E
N
S
sS
SSS
i

66. Seismograms from New Hebrides (2)

Comparison of seismograms of two events from the New Hebrides region obtained by LP-Z, LP-N seismographs at DDR. LP-Low: low magnification LP seismograph (1/10 of ordinary one).

The focal parameters by ISC are as follows:

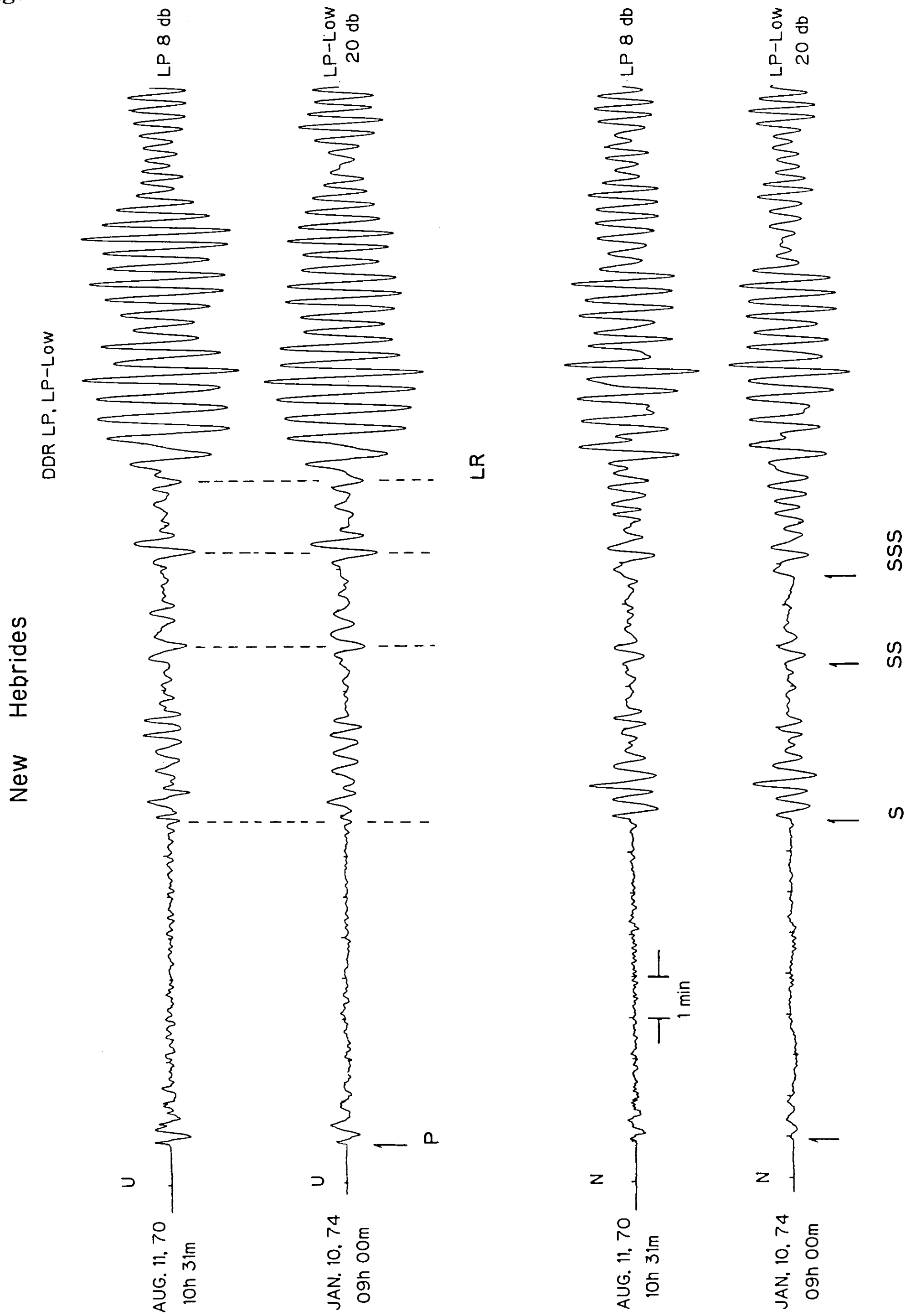
Origin Time	Epicenter		h	Mb	Δ
d h m s	S	E	km		deg
Aug. 11, 10 22 20	14°.13	166°.56	20	6.1	56.17
Jan. 10, 08 51 13.8	14.45	166.87	36	6.3	56.59

Comments

1) Similar waveforms are seen for pair seismograms.
2) The shallow and distant earthquakes ($\Delta>50°$) usually show multi-reflections of S waves.

It is interesting to examine whether the earthquakes occurring at close locations show similar waveforms or not.

Fig. 66


New Hebrides
DDR LP, LP-Low
AUG. 11, 70
10h 31m
U
LP 8 db
JAN. 10, 74
09h 00m
U
LP-Low
20 db
P
LR
AUG. 11, 70
10h 31m
N
LP 8 db
1 min
JAN. 10, 74
09h 00m
N
LP-Low
20 db
S
SS
SSS

67. Seismograms of deep-focus earthquake, South of Fiji

Seismograms of the three components of MP and LP seismographs at DDR for the deep-focus earthquake in the South of Fiji region. This earthquake is one of the deepest earthquakes in this region.

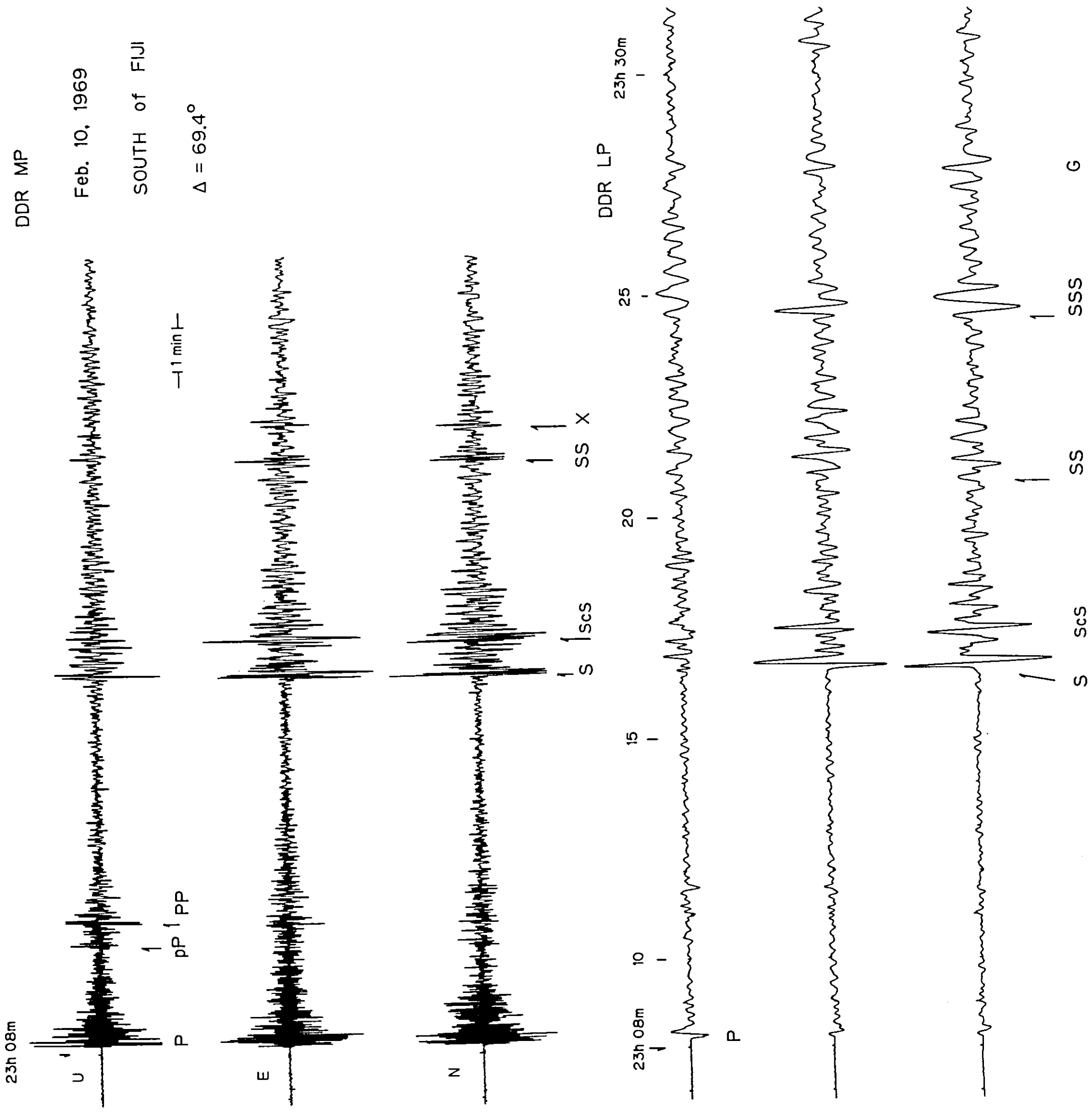
The focal parameters by ISC are as follows:

Origin Time	Epicenter		*h*	*Mb*	*Δ*
h m s	S	E	km		deg
22 58 03.3	22°.75	178°.76	635	6.0	69.38

Comments

1) Deep earthquakes usually show sharp *P* and *S* waves.
2) Multi-reflections of *S* waves are seen the same as those of shallow events (see Fig. 66).
3) The *X* phase after *SS* wave on MP seismograms is unexplained here.
4) The polarities of LP seismograms are somewhat uncertain.

Fig. 67


DDR MP
Feb. 10, 1969
SOUTH of FIJI
Δ = 69.4°
1 min
23h 08m
U
E
N
P
pP
PP
S
ScS
SS
X
DDR LP
23h 08m
10
15
20
25
23h 30m
P
S
ScS
SS
SSS
G

68. Seismograms of deep-focus earthquakes, South of Fiji

Seismograms of two deep-focus earthquakes in the South of Fiji region obtained by LP seismographs at DDR.

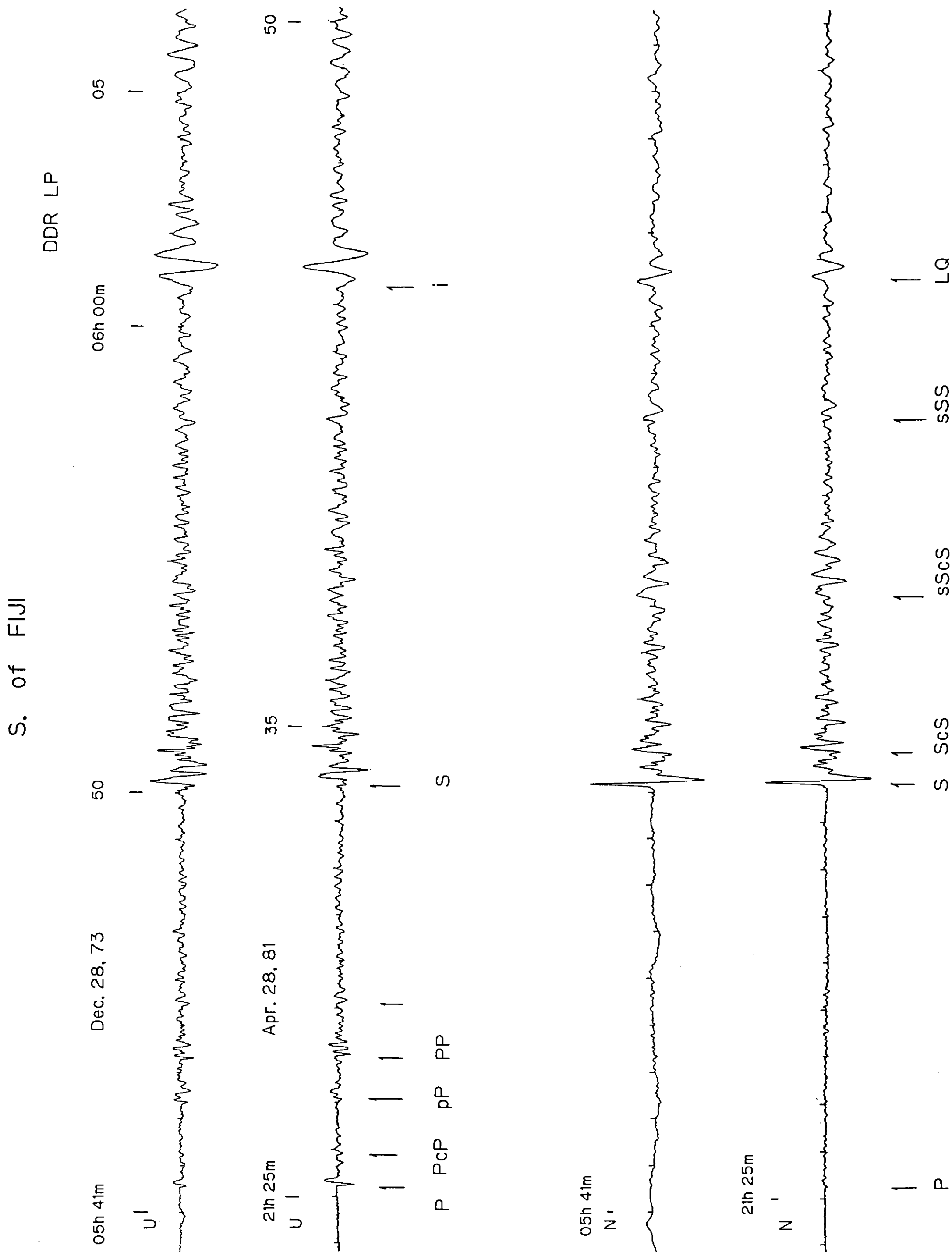
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
d h m s	S	E	km		deg
Dec. 28, 05 31 03.8	23°.88	180°.00	517	6.2	70.96
Apr. 28, 21 14 47.1	23.70	179.99	522	6.0	70.80

Comments

1) Earthquakes in almost the same locations show similar waveforms and reflected waves (see also Fig. 66).
2) Small *LQ* wave appears on the N-S component seismograms.
3) The *i* phase with large amplitude on the vertical component seismograms is unexplained here.

Fig. 68


S. of FIJI
DDR LP
05h 41m
Dec. 28, 73
50
06h 00m
05
U
21h 25m
Apr. 28, 81
35
50
U
P
PcP
pP
PP
S
i
05h 41m
N
21h 25m
N
P
S
ScS
sScS
sSS
LQ

69. Seismograms from Tonga-Fiji region —dependence on source depth—

An arrangement of seismograms obtained by MP-Z seismograph at DDR for events in the Tonga-Fiji region. The ordinate shows the source depth in kilometers, and bars on the right-hand side show relative differences of magnification.

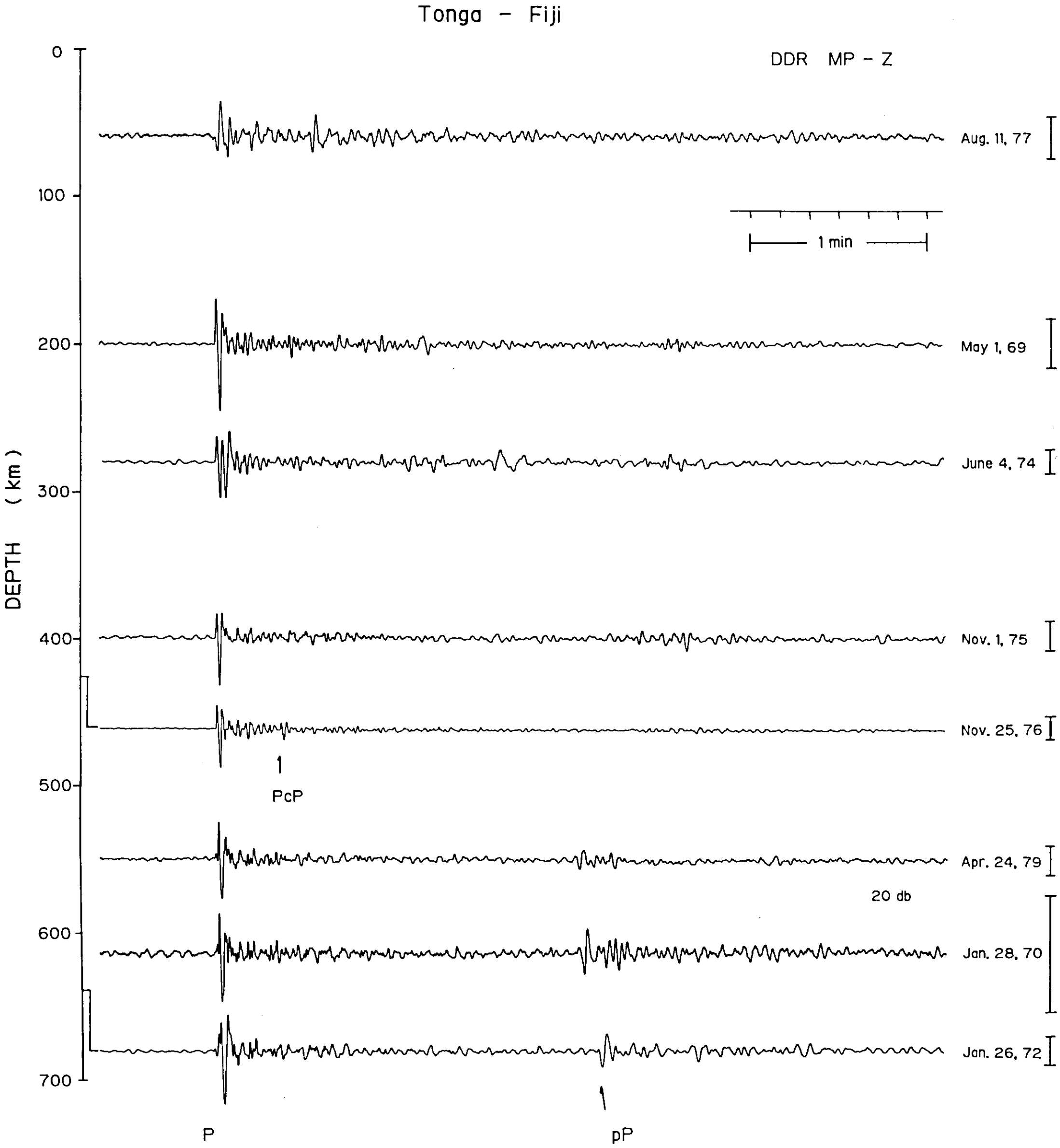
The focal parameters by ISC are as follows:

Origin Time d h m s	Epicenter S	W	h km	Mb	Δ deg
Aug. 11, 01 42 47.1	17°.58	174°.39	53	6.2	69.04
May 01, 19 05 24.5	16.71	174.66	200	5.9	68.21
Jun. 04, 04 14 13.8	15.89	175.04	256	6.1	67.35
Nov. 01, 06 14 54.0	18.39	177.88	405	5.8	67.65
Nov. 25, 14 06 34.1	19.50	177.70	424	6.0	68.63
Apr. 24, 01 45 08.7	20.82	178.67	596	5.9	69.16
Jan. 28, 23 06 01.4	20.69	178.79	603	5.6	68.99
Jan. 26, 23 00 22.1	20.19	178.89	637	5.7	68.53

Comments

1) Sharp and impulsive P waves are seen for deep events ($h>200$ km).
2) The P waves of deep events ($h>500$ km) contain ripple components with high-frequency ($f\approx 3$ Hz).
3) Clear pP phase appears on the seismograms from deep sources ($h>500$ km).

Fig. 69



Tonga - Fiji
DDR MP - Z
0
100
200
300
400
500
600
700
DEPTH (km)
Aug. 11, 77
1 min
May 1, 69
June 4, 74
Nov. 1, 75
Nov. 25, 76
PcP
Apr. 24, 79
20 db
Jan. 28, 70
Jan. 26, 72
P
pP

70. *PKPPKP* wave (*P'P'*)

The *P'P'* wave is frequently observed for large earthquakes with epicentral distance of about 70 degrees. This figure shows a typical example of *P'P'* wave obtained by MP seismographs (Z, E, N) at DDR for the earthquake in the North of New Zealand region.

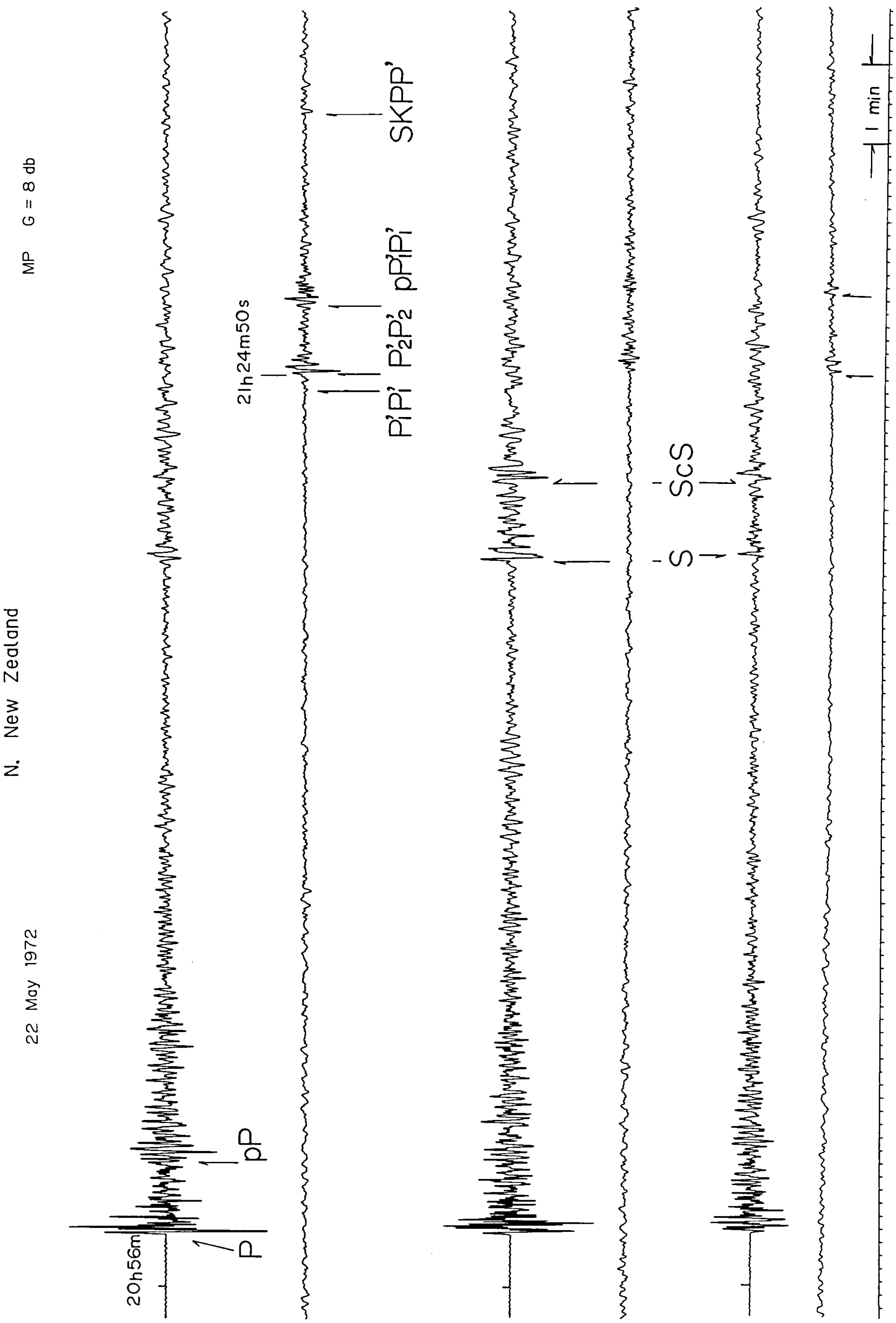
The focal parameters by ISC are as follows:

Origin Time	Epicenter		*h*	*Mb*	*Δ*
h m s	S	W	km		deg
20 45 55.1	17°.76	175°.05	208	6.1	68.79

Comments

The *P'P'* wave consisting of the branch of $P_1'P_1'$ and $P_2'P_2'$ is clearly identified after about 28 minutes of the *P* wave onset.

Fig. 70


22 May 1972
N. New Zealand
MP G = 8 db
20h56m
P
pP
21h24m50s
$P'_1P'_1$
$P'_2P'_2$
$pP'_1P'_1$
SKPP'
S
ScS
1 min

71. *P′P′* waves along the epicentral distance

An arrangement of seismograms obtained by SP-Z seismograph at DDR for events in the Solomon-Fiji region. The ordinate shows the epicentral distance in degrees, and the abscissa shows the lapse time measured from the origin time.

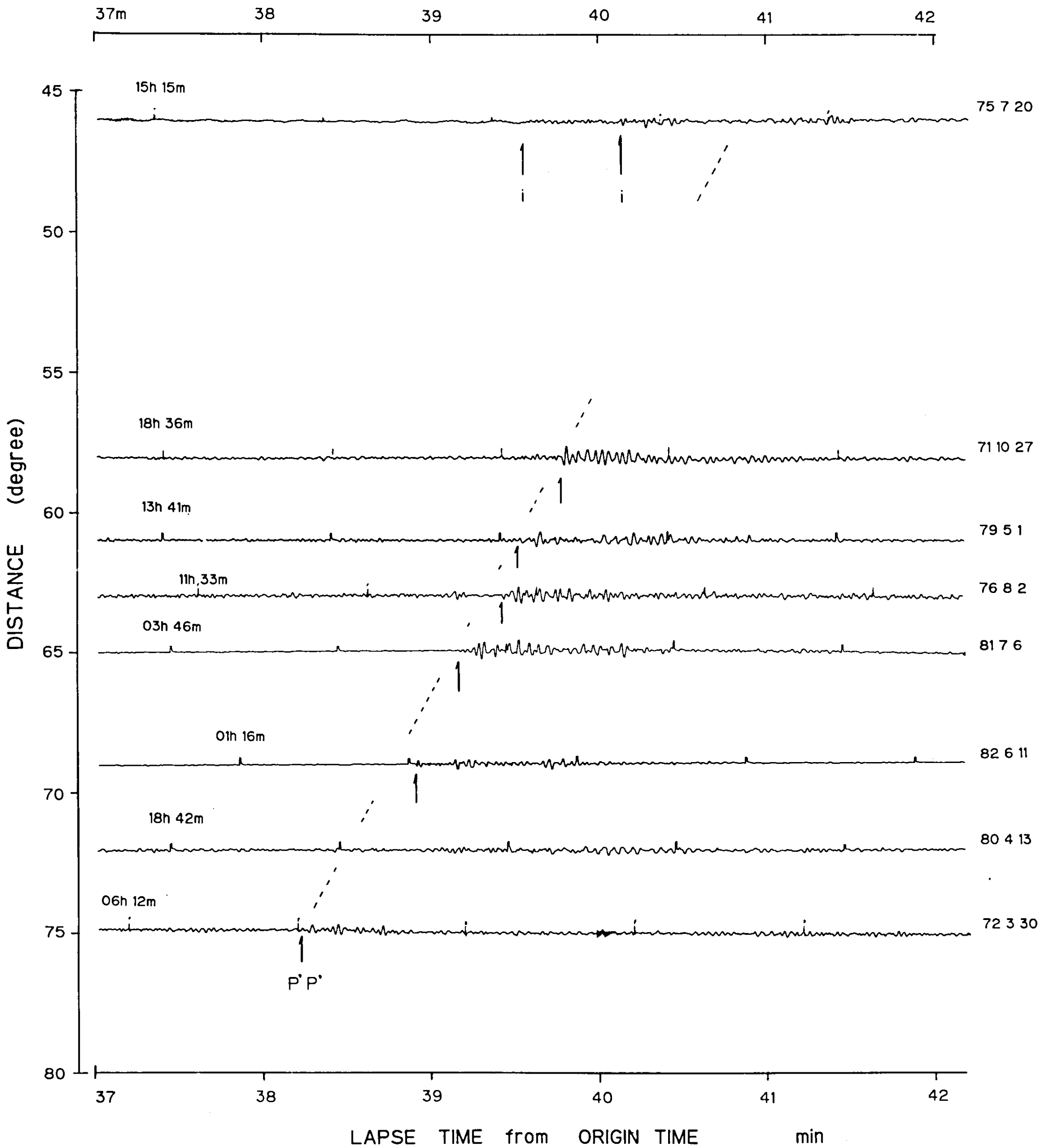
The focal parameters by ISC are as follows:

Origin Time (d h m s)	Epicenter		h (km)	Mb	Δ (deg)
Jul. 20, 14 37 40.6	06°64S	155°09E	54	6.5	44.96
Oct. 27, 17 58 37.9	15.57S	166.24E	49	6.3	57.74
May 01, 13 03 37.6	21.22S	169.72E	77	6.2	63.82
Aug. 02, 10 55 25.2	20.59S	169.31E	43	6.0	63.09
Jul. 06, 03 08 34.1	22.29S	171.64E	114	6.3	65.60
Jun. 11, 00 38 10.0	17.61S	174.45W	125	6.3	69.03
Apr. 13, 18 04 34.5	23.53S	177.27W	102	6.6	72.11
Mar. 30, 05 34 50.4	25.69S	179.58E	479	6.1	72.24

Comments

1) The *P′P′* phase appears after about 38-40 minutes depending on the epicentral distance.
2) The arrival time of the *P′P′* phase in the event with 45 degrees (top seismogram) is earlier, by about one minute, than the others.
3) Precursors preceding the *P′P′* wave, such as the reflected waves from the mantle discontinuity, cannot be found in these seismograms.

Fig. 71


37m
38
39
40
41
42
45
50
55
60
65
70
75
80
DISTANCE (degree)
15h 15m
75 7 20
i
i
18h 36m
71 10 27
13h 41m
79 5 1
11h,33m
76 8 2
03h 46m
81 7 6
01h 16m
82 6 11
18h 42m
80 4 13
06h 12m
72 3 30
P'P'
37
38
39
40
41
42
LAPSE TIME from ORIGIN TIME min

72. Double phases of P waves from Tonga-Macquarie region

An arrangement of seismograms obtained by SP-Z seismograph at DDR for events in the Tonga-Kermadec-Macquarie Islands region. h: source depth. Δ: epicentral distance.

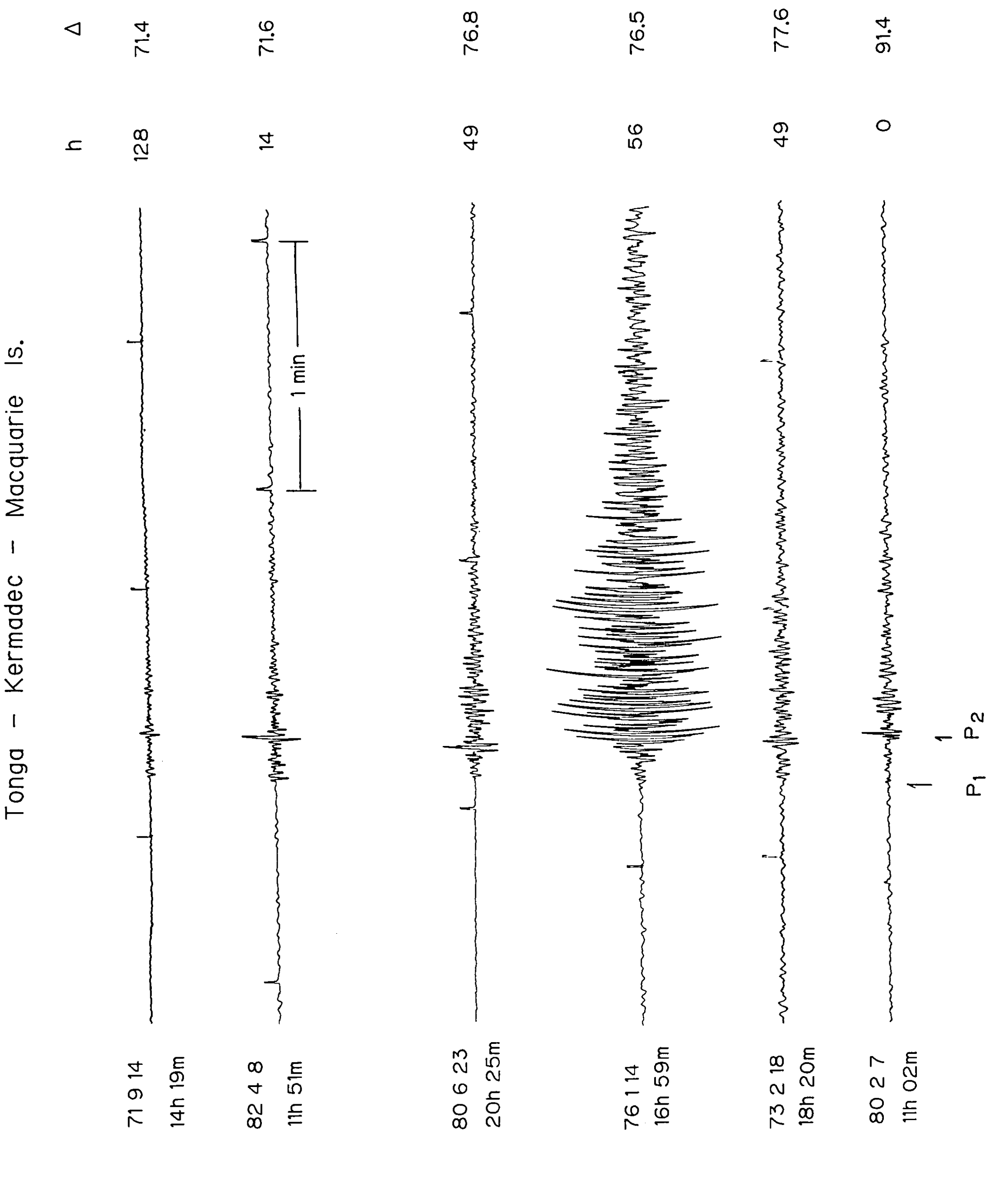
The focal parameters by ISC are as follows:

Origin Time					Epicenter		h	Mb	Δ
	d	h	m	s			km		deg
Sep.	14,	14	08	05.9	20°57S	174°39W	128	4.9	71.37
Apr.	08,	11	40	26.9	20.63S	174.13W	14	5.4	71.57
Jun.	23,	20	13	21.0	28.96S	176.64W	49	5.6	76.83
Jan.	14,	16	47	37.0	29.02S	177.42W	56	6.5	76.48
Feb.	18,	18	09	26.4	30.46S	177.44W	49	5.4	77.65
Feb.	07,	10	49	16.3	54.02S	158.08E	0	6.0	91.42

In spite of these earthquakes, which have wide ranges of magnitude and source depth, similar later phases indicated by P_2 appear after about 6-11 sec from the P wave onset.

The interpretation of the P_2 phase is unknown, it probably includes the pP or PcP phase for some events. Further collection of seismograms at other stations will be needed.

Fig. 72


Tonga - Kermadec - Macquarie Is.
h
Δ
71 9 14
14h 19m
128
71.4
82 4 8
11h 51m
14
71.6
1 min
80 6 23
20h 25m
49
76.8
76 1 14
16h 59m
56
76.5
73 2 18
18h 20m
49
77.6
80 2 7
11h 02m
0
91.4
P_1
P_2

73. Seismograms from Chagos Archipelago region

Seismograms from the Chagos Archipelago (Indian Ocean) region obtained by MP and LP seismographs at DDR.

The top trace shows the seismogram of MP-Z, the middle two are seismograms of LP (low gain) Z and N-S, and the bottom two traces are seismograms after *S* waves of the same instruments. Note the difference of time scale of MP and LP seismograms. G: gain of playback amplifier.

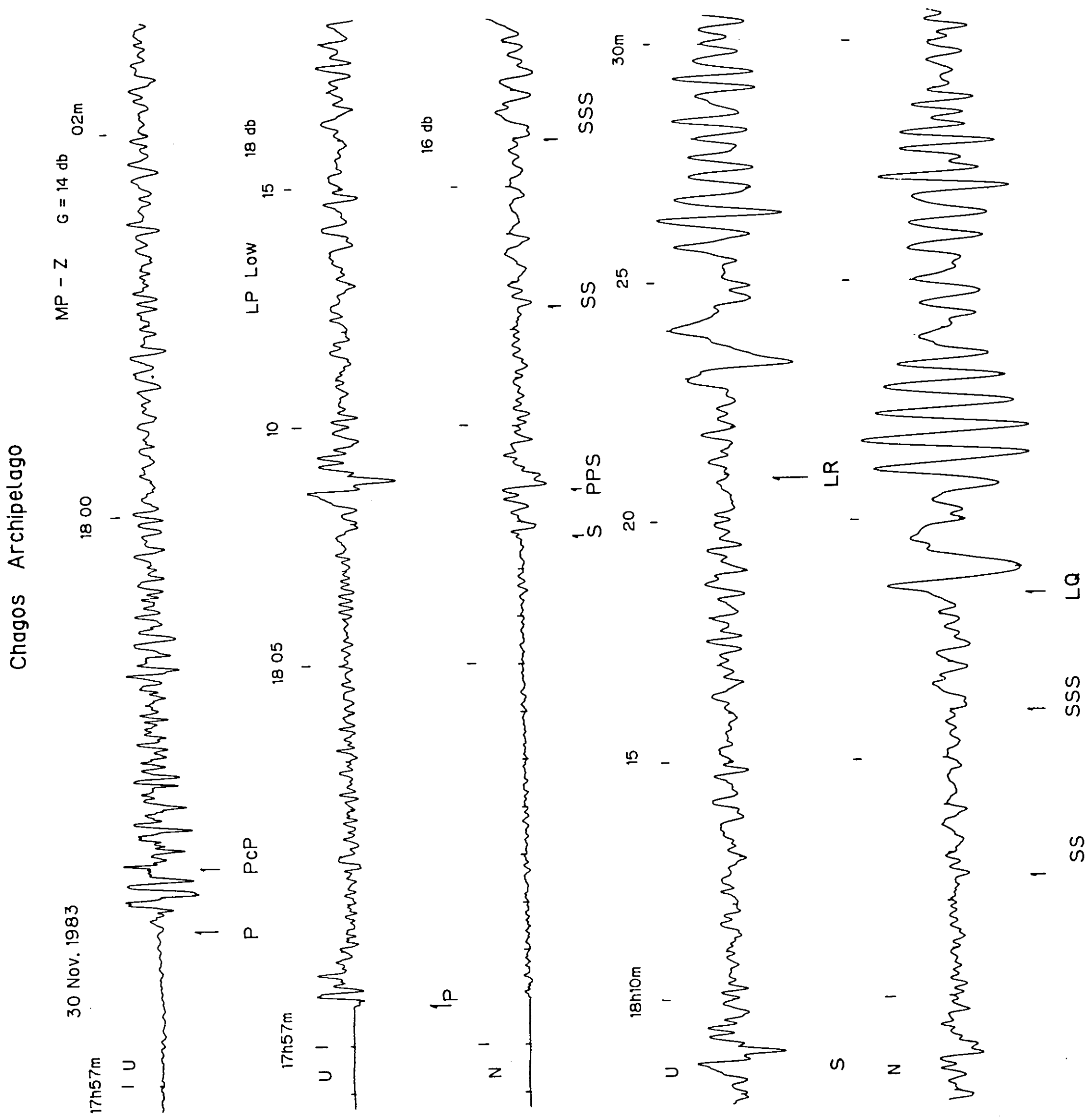
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	S	E	km		deg
17 46 00.8	06°.85	72°.04	10	6.5	75.92

Comments

1) The *LQ* wave is separated into two wave groups. Inverse dispersion?
2) Later arrival of *LR* wave. The path is partly oceanic and partly continental.

Fig. 73


Chagos Archipelago
30 Nov. 1983
MP - Z G = 14 db
LP Low 18 db
16 db
17h57m
18 00
02m
18 05
10
15
18h10m
20
25
30m
U
N
S
P PcP
P
S PPS SS SSS
LR
SS SSS LQ

74. Seismograms from North Atlantic Ridge

Seismograms from the North Atlantic Ridge region obtained by three components of LP seismograph at DDR.

The focal parameters by ISC are as follows:

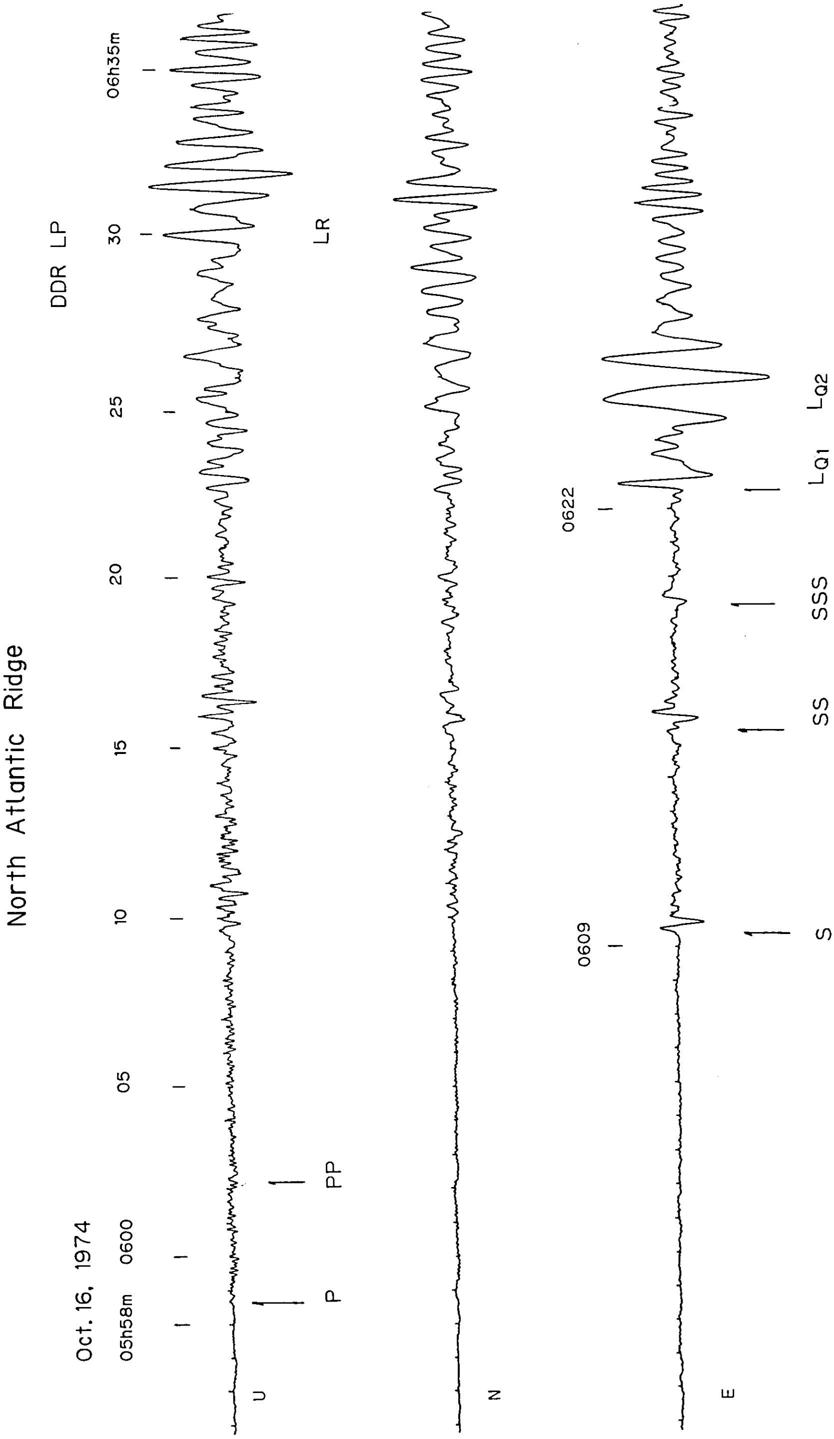
Origin Time	Epicenter		h	Mb	Δ
h m s	N	W	km		deg
05 45 11.2	52°.71	32°.00	41	5.7	91

Comments

1) Clear S and multi-reflections of S waves are seen.
2) The LQ wave seems to be separated into two wave groups of LQ_1 and LQ_2. Is LQ_1 the $SKKS$ wave or a higher mode?

A detailed study of this phase is needed.

Fig. 74


North Atlantic Ridge
Oct. 16, 1974
DDR LP
05h58m
0600
05
10
15
20
25
30
06h35m
LR
P
PP
U
N
E
0609
0622
S
SS
SSS
LQ1
LQ2

75. Seismograms from Macquarie Island region —in comparison with N. Atlantic Ridge—

Seismograms from the Macquarie Island region obtained by LP-Low gain seismographs at DDR. The LP-E seismogram from the North Atlantic Ridge region is also shown for comparison.

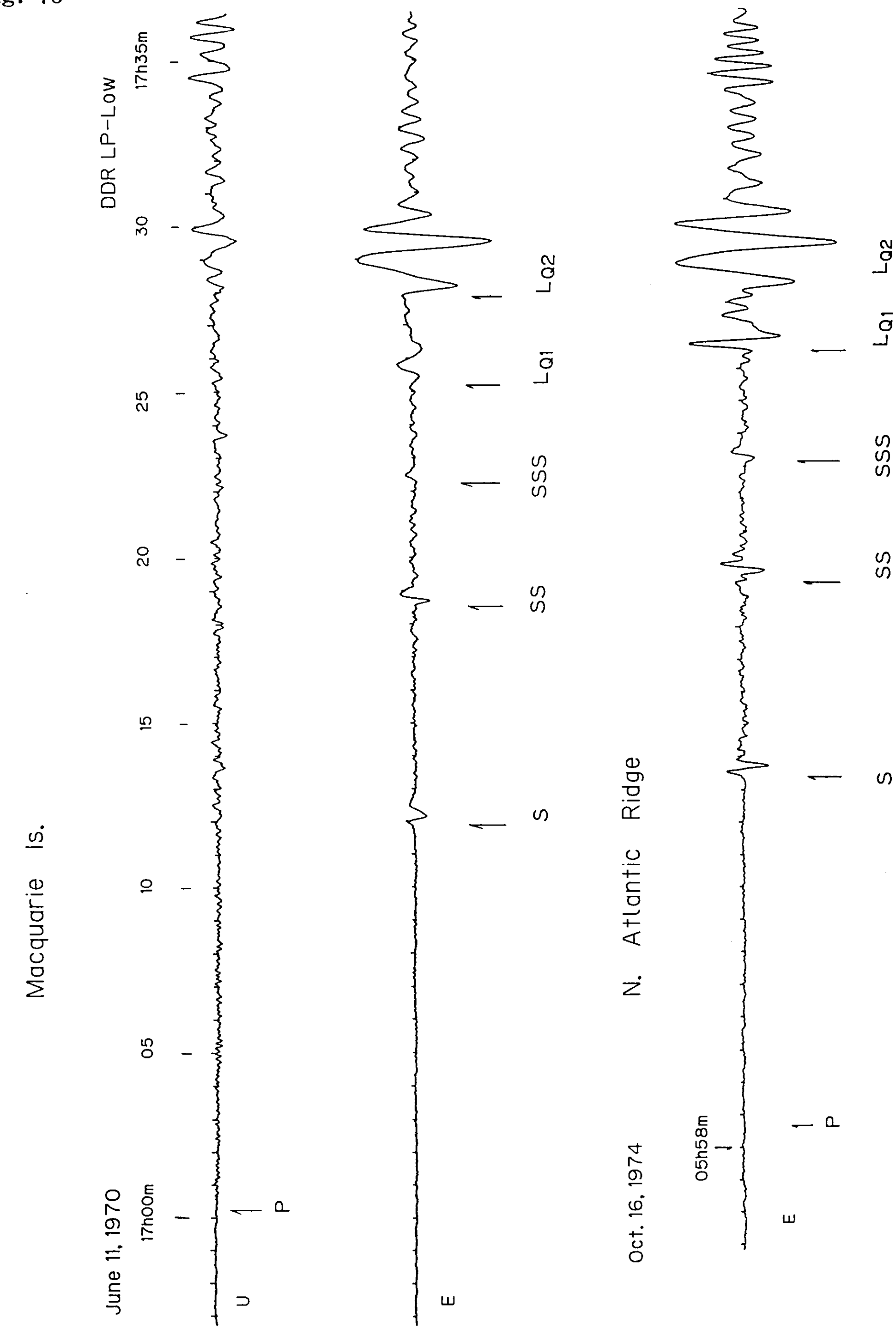
The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Δ
	d h m s			km		deg
Jun.	11, 16 46 43.7	58°.86S	157°.6 E	64	6.0	95.75
Oct.	16, 05 45 11.2	52.71N	32.00W	41	5.7	91

Comments

1) Clear S wave and multi-reflections of S wave are seen.
2) The LQ wave seems to be separated into two wave groups, LQ_1 and LQ_2.
3) Similar waveform features are seen on seismograms of the North Atlantic Ridge, though their epicenters are located far from each other ($\theta=345°$, $8°$).

Fig. 75


Macquarie Is.
June 11, 1970
17h00m
05
10
15
20
25
30
17h35m
DDR LP-Low
U
P
E
S
SS
SSS
LQ1
LQ2
N. Atlantic Ridge
Oct. 16, 1974
05h58m
E
P
S
SS
SSS
LQ1
LQ2

76. Mantle surface wave from Tonga region

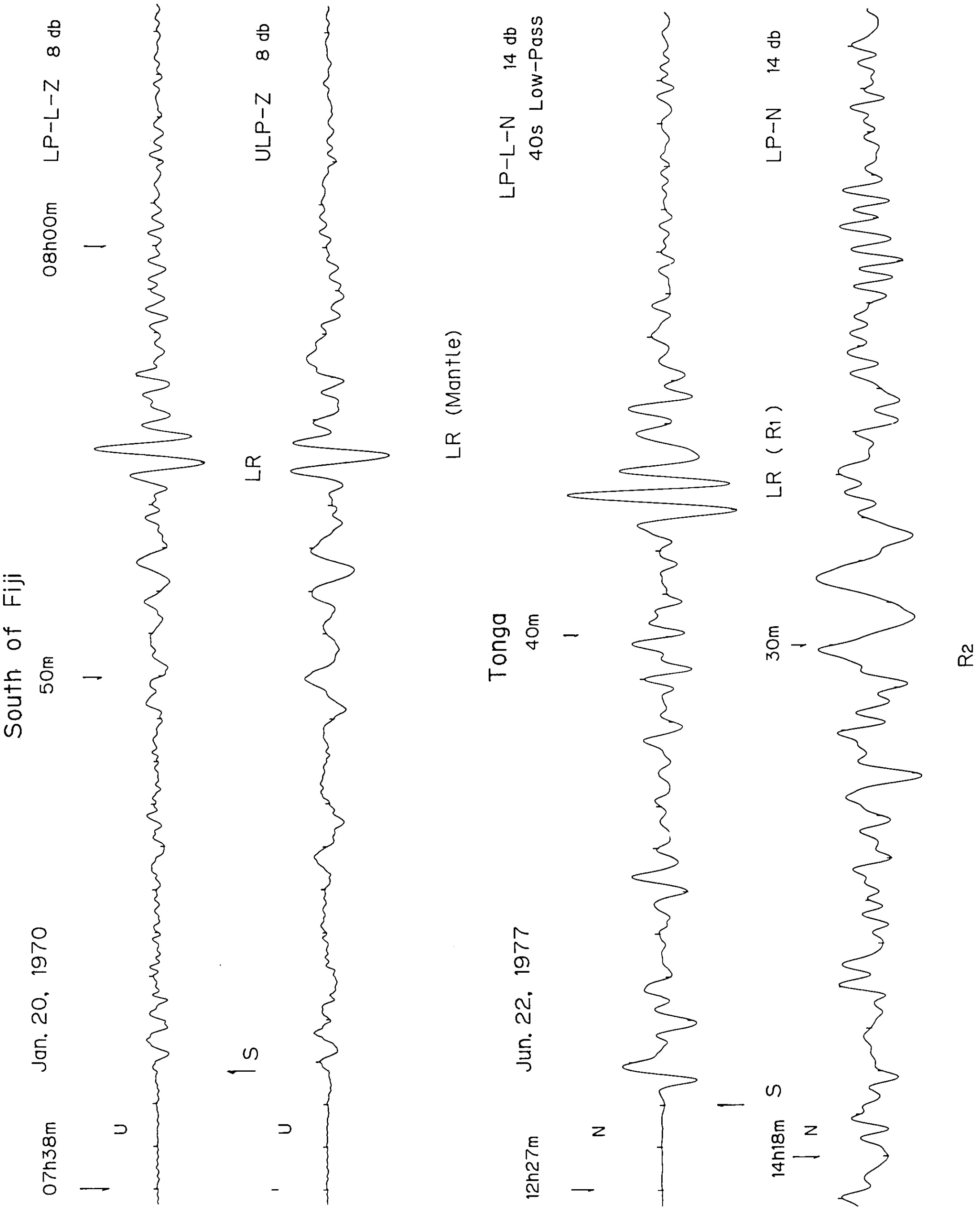
Seismograms of mantle Rayleigh wave (*LR*) obtained by LP and ULP seismographs at DDR for events in the South of Fiji and Tonga regions.

The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
d h m s	S	W	km		deg
Jan. 20, 07 19 51.4	25°.85	177°.29	82	6.2	73.97
Jun. 22, 12 08 33.7	22.91	175.74	69	6.3	72.44

The response of ULP seismograph is flat over the period from a few seconds to 100 seconds (Fig. B). Long-period mantle Rayleigh waves (*LR*) are seen on the ULP seismogram. Short-period normal dispersion is superimposed on the long-period inverse dispersion.

Fig. 76


South of Fiji
Jan. 20, 1970
07h38m
50m
08h00m
LP-L-Z 8 db
ULP-Z 8 db
U
S
LR
LR (Mantle)
Tonga
Jun. 22, 1977
12h27m
40m
LP-L-N 14 db
40s Low-Pass
N
LP-N 14 db
14h18m
30m
S
LR (R1)
R2

77. Surface wave along the great circle (1)

Seismograms of the Love wave (G) propagating along the great circle obtained by ULP-E seismograph at DDR for the event in the Macquarie Island region. Time marks on the seismograms are minutes. Body waves of this earthquake have already been shown (see Fig. 75).

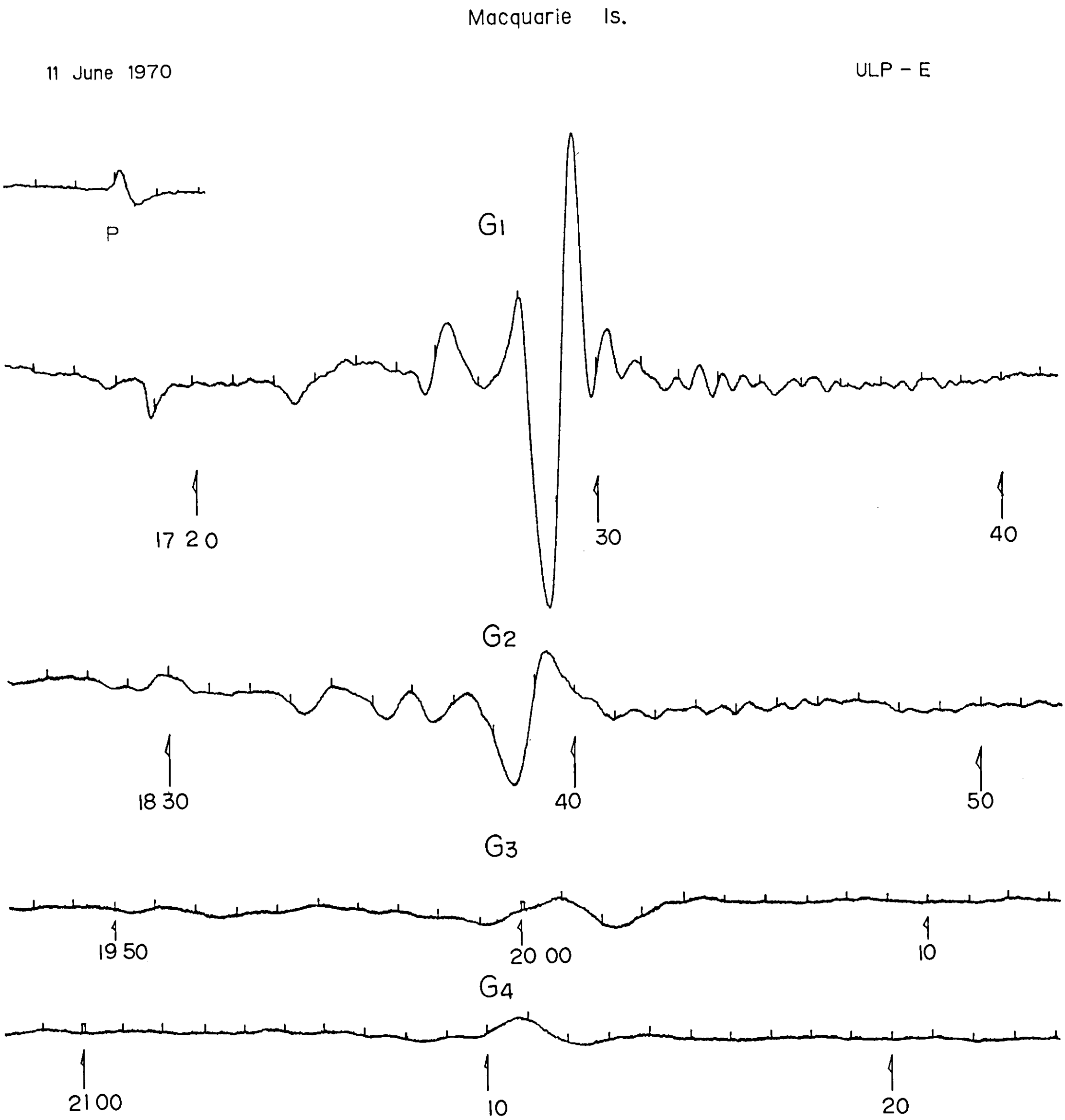
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	S	E	km		deg
16 46 43.7	58°86	157°6	64	6.0	95.75

Comments

1) Clear Love waves of G_1, G_2, G_3 and G_4 are seen.
2) These seismograms provide data to determine the velocity and Q values along the great circle.

Fig. 77


Macquarie Is.
11 June 1970
ULP - E
P
G1
17 20
30
40
G2
18 30
40
50
G3
19 50
20 00
10
G4
21 00
10
20

78. Surface wave along the great circle (2)

Seismograms of Love wave (G) propagating along the great circle obtained by LP-E and LP-L-E seismographs at DDR for the event in the Talaud Islands region. LP-L: LP-Low magnification seismograph (1/10 of LP).

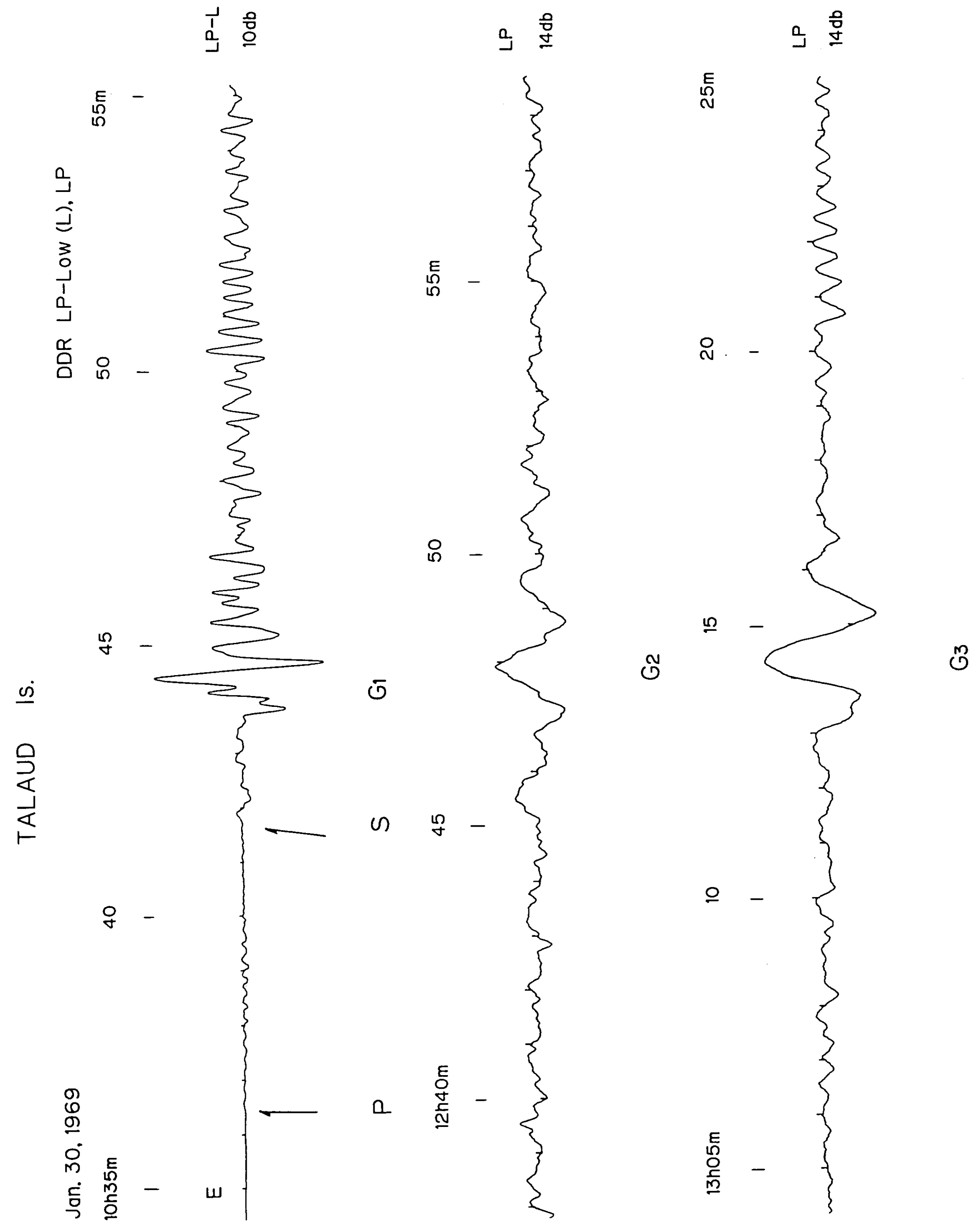
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	N	E	km		deg
10 29 40.3	4°77	127°50	72	5.9	32.89

Comments

1) Clear and impulsive Love waves of G_1, G_2 and G_3 are seen.
2) The differences of the spectrum of G_1 and G_3 waves are clear. These seismograms provide the data to determine the velocity and Q values along the great circle.
3) The amplitude of G_3 wave is greater than the G_2 wave. This is probably due to the effect of the source mechanism.

Fig. 78


TALAUD Is.
Jan. 30, 1969
DDR LP-Low (L), LP
10h35m
40
45
50
55m
LP-L
10db
E
P
S
G1
12h40m
45
50
55m
LP
14db
G2
13h05m
10
15
20
25m
LP
14db
G3

79. Seismograms from North Atlantic Ocean (1)

Seismograms from the North Atlantic Ocean region obtained by MP-Z, LP-Z and three components of LP-Low gain seismographs at DDR. The bottom two seismograms are continuations of the middle two traces.

Note the difference of time scale between the upper two and lower seismograms.

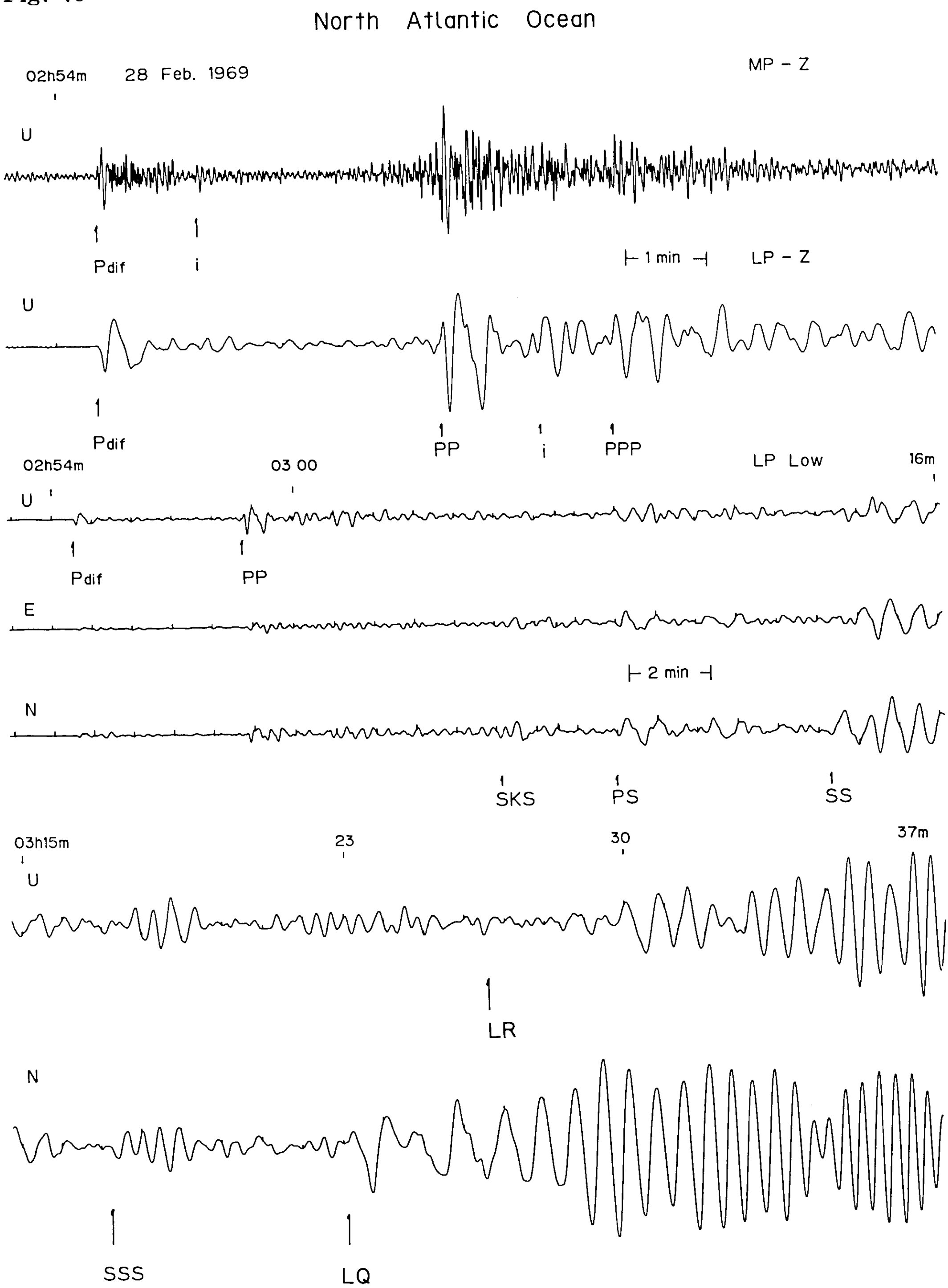
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	N	W	km		deg
02 40 31.2	35°.97	10°.58	14	6.5	103.07

Comments

1) First arrival at this epicentral distance is P(diffracted) wave. Clear P(dif) wave is seen on both MP-Z and LP-Z seismograms.
2) A shallow event at this distance produces many reflected waves at the surface.
3) Later arrival of Rayleigh wave (LR), similar to that shown in Fig. 73.

Fig. 79


North Atlantic Ocean
02h54m
28 Feb. 1969
MP - Z
U
Pdif
i
1 min
LP - Z
U
Pdif
PP
i
PPP
02h54m
03 00
LP Low
16m
U
Pdif
PP
E
2 min
N
SKS
PS
SS
03h15m
23
30
37m
U
LR
N
SSS
LQ

80. Seismograms from North Atlantic Ocean (2)

Seismograms from the North Atlantic Ocean region obtained by three components of LP-Low gain seismograph at DDR.

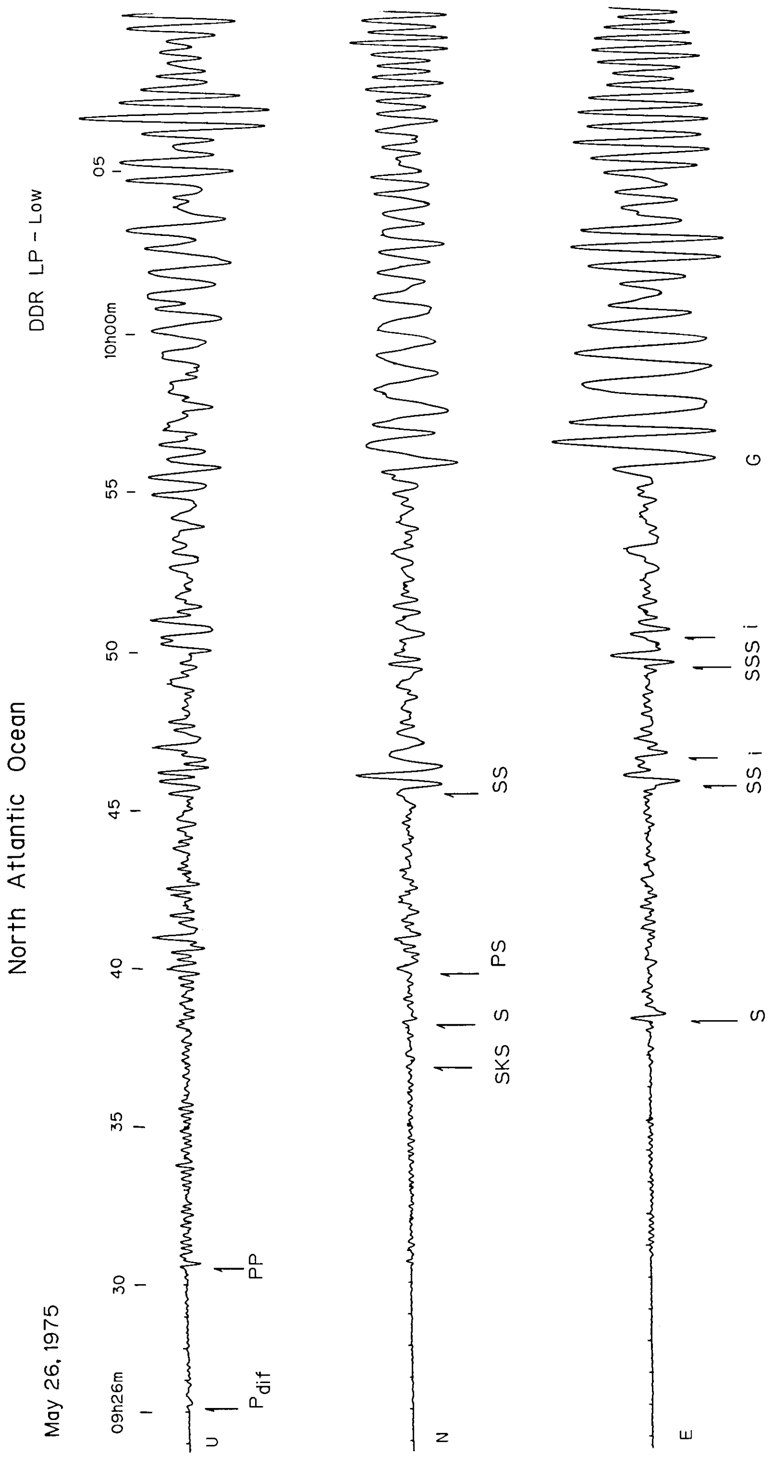
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	N	W	km		deg
09 11 51.6	35°.98	17°.56	34	6.5	105.19

Comments

1) First arrival is *Pdif* wave.
2) Clear S wave is seen on the E-W component seismogram.
3) The i phase after SS and SSS waves remains to be interpreted.

Fig. 80


May 26, 1975
North Atlantic Ocean
DDR LP - Low
09h26m
30
35
40
45
50
55
10h00m
05
U
N
E
Pdif
PP
SKS
S
PS
SS
S
SS i
SSS i
G

81. Seismograms from Guatemala and Mexico

Seismograms of two events from the Guatemala and Near Coast of Chiapas, Mexico regions obtained by LP seismographs at DDR. The middle two traces are continuation of the top two traces. G: gain of play-back amplifier.

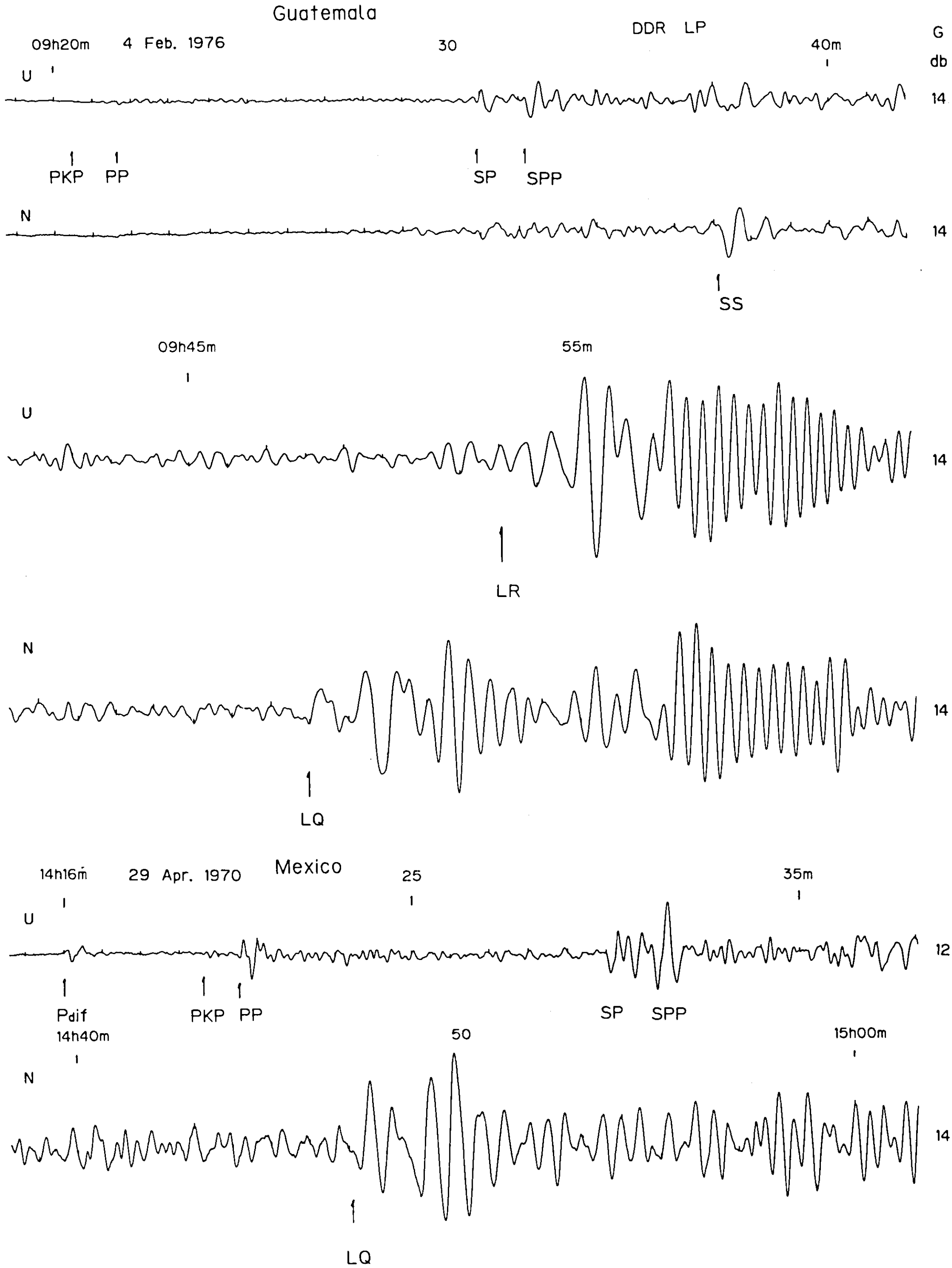
The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
d h m s	N	W	km		deg
Feb. 04, 09 01 43.9	15°28	89°19	5	6.0	111.50
Apr. 29, 14 01 37	14.65	92.59	56	5.8	110

Comments

1) *PKP* wave is first arrival for the Guatemala event; *S* wave did not appear.
2) Long-period mantle Love (*LQ*) and Rayleigh (*LR*) waves are superimposed on the short-period crustal surface waves.

Fig. 81


Guatemala
09h20m 4 Feb. 1976
30
DDR LP
40m
G
db
U
14
PKP PP
SP SPP
N
14
SS
09h45m
55m
U
14
LR
N
14
LQ
Mexico
14h16m 29 Apr. 1970
25
35m
U
12
Pdif
PKP PP
SP SPP
14h40m
50
15h00m
N
14
LQ

82. Seismograms from Peru-Ecuador Border

Seismograms from the Peru-Ecuador Border region obtained by MP and LP-Low gain seismographs at DDR. The top two traces are seismograms of MP, and the other traces are those of LP. The bottom two traces are continuations of the center two.

The focal parameters by ISC are as follows:

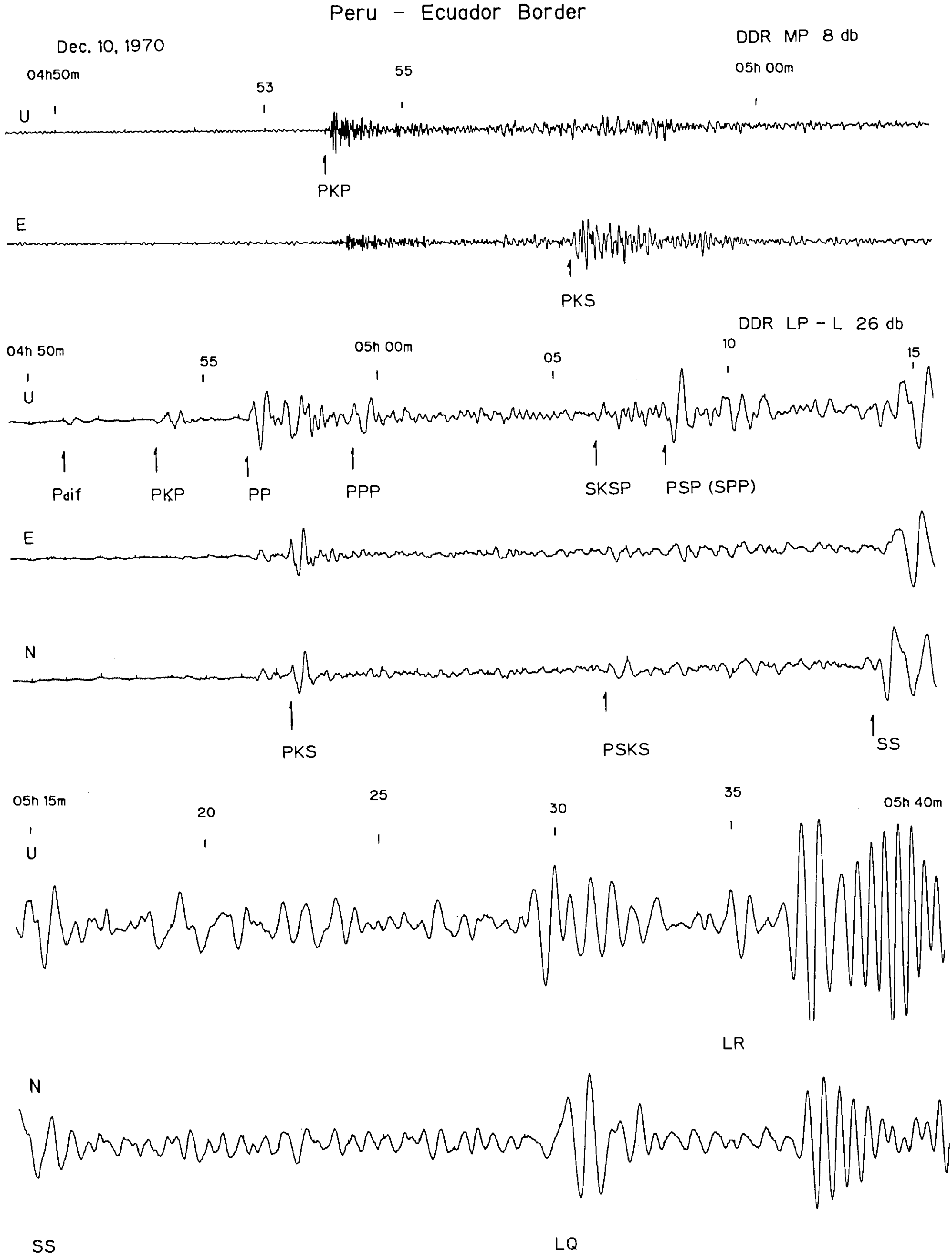
Origin Time	Epicenter		h	Mb	Ms	Δ
h m s	S	W	km			deg
04 34 38	3°.97	80°.66	15	6.3	7.6*	131.40

*: *Ms* by USCGS.

Comments

1) *Pdif* wave is not seen on MP seismogram, but small *Pdif* wave appears on LP seismogram.
2) Distant event produces long-period body waves.
3) Surface wave on Z-component corresponding to *LQ* wave on N-S component remains to be explained.

Fig. 82


Peru - Ecuador Border
Dec. 10, 1970
DDR MP 8 db
04h50m
53
55
05h 00m
U
PKP
E
PKS
DDR LP - L 26 db
04h 50m
55
05h 00m
05
10
15
U
Pdif
PKP
PP
PPP
SKSP
PSP (SPP)
E
N
PKS
PSKS
SS
05h 15m
20
25
30
35
05h 40m
U
LR
N
SS
LQ

83. *P* (diffracted) waves

—Δ=100°-135°—

An arrangement of *P* (diffracted) waves along the epicentral distance obtained by LP-Z seismograph at DDR.

The ordinate shows the epicentral distance in degrees, and the abscissa shows the arrival time measured from the origin time.

The focal parameters by ISC are as follows:

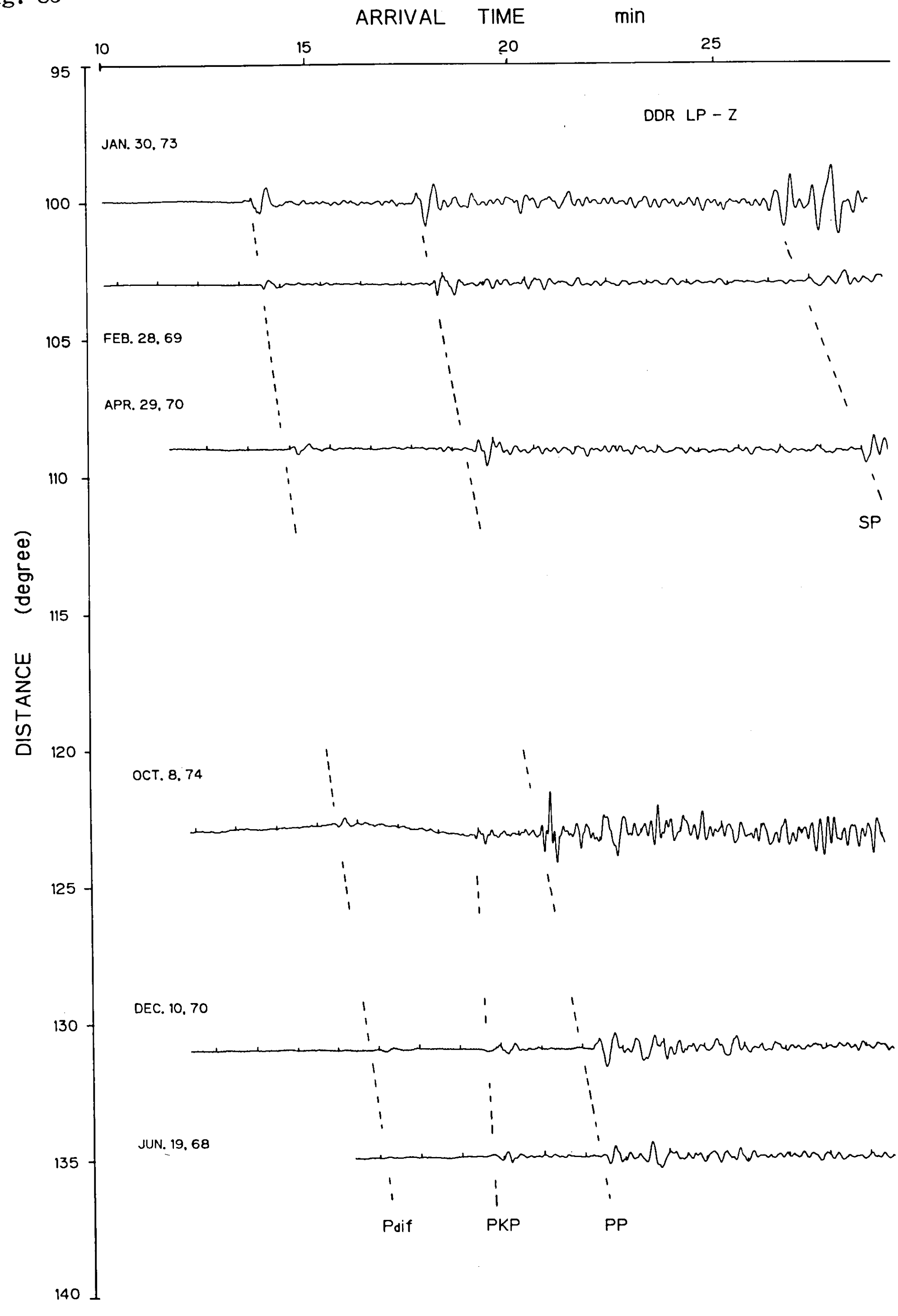
Origin Time	Epicenter		*h*	*Mb*	Δ
d h m s			km		deg
Jan. 30, 21 01 13.8	18°.53N	102°.93W	48	6.1	100.08
Feb. 28, 02 40 31.2	35.97N	10.58W	18	6.5	103.07
Apr. 29, 14 01 37	14.65N	92.59W	56	5.8	110
Oct. 08, 09 50 58.0	17.37N	61.99W	41	6.4	123.26
Dec. 10, 04 34 38	03.97S	80.66W	15	6.3	131.40
Jun. 19, 08 13 35.6	05.55S	77.20W	33	6.1	134.91

These events are located over a wide area, including Mexico, N. Atlantic Ocean, Leeward Is. and Peru regions.

Comments

1) Clear *Pdif* wave is seen for the range from 105 to 135 degrees. Large amplitude in 100 degrees may be direct *P* wave.
2) Small *PKP* wave is seen beyond 110 degrees.
3) The *PP* wave is a common for this epicentral range. Horizontal component seismograms are as follows.

Fig. 83


ARRIVAL TIME min
10
15
20
25
DDR LP - Z
JAN. 30, 73
FEB. 28, 69
APR. 29, 70
SP
OCT. 8, 74
DEC. 10, 70
JUN. 19, 68
Pdif
PKP
PP
DISTANCE (degree)
95
100
105
110
115
120
125
130
135
140

84. Appearance of S wave
—Δ=90°-130°—

An arrangement of seismograms for the events with epicentral distance from 90° to 130°. These seismograms are obtained by horizontal component of LP or LP-Low gain seismograph at DDR. The ordinate shows the epicentral distance in degrees. *Pd*: *P*(diffracted) wave.

The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Δ
	d h m s			km		deg
Oct.	16, 05 45 11.2	52°71N	32°00W	41	5.7	90.71
Jun.	11, 16 46 43.7	58.86S	157.6 E	64	6.0	95.75
Jan.	30, 21 01 13.8	18.53N	102.93W	48	6.1	100.08
May	26, 09 11 51.6	35.98N	17.56W	34	6.5	105.19
Apr.	29, 14 01 37	14.65N	92.59W	56	5.8	110
Oct.	08, 09 50 58.0	17.37N	61.99W	41	6.4	123.26
Dec.	10, 04 34 38	03.97S	80.66W	15	6.3	131.40

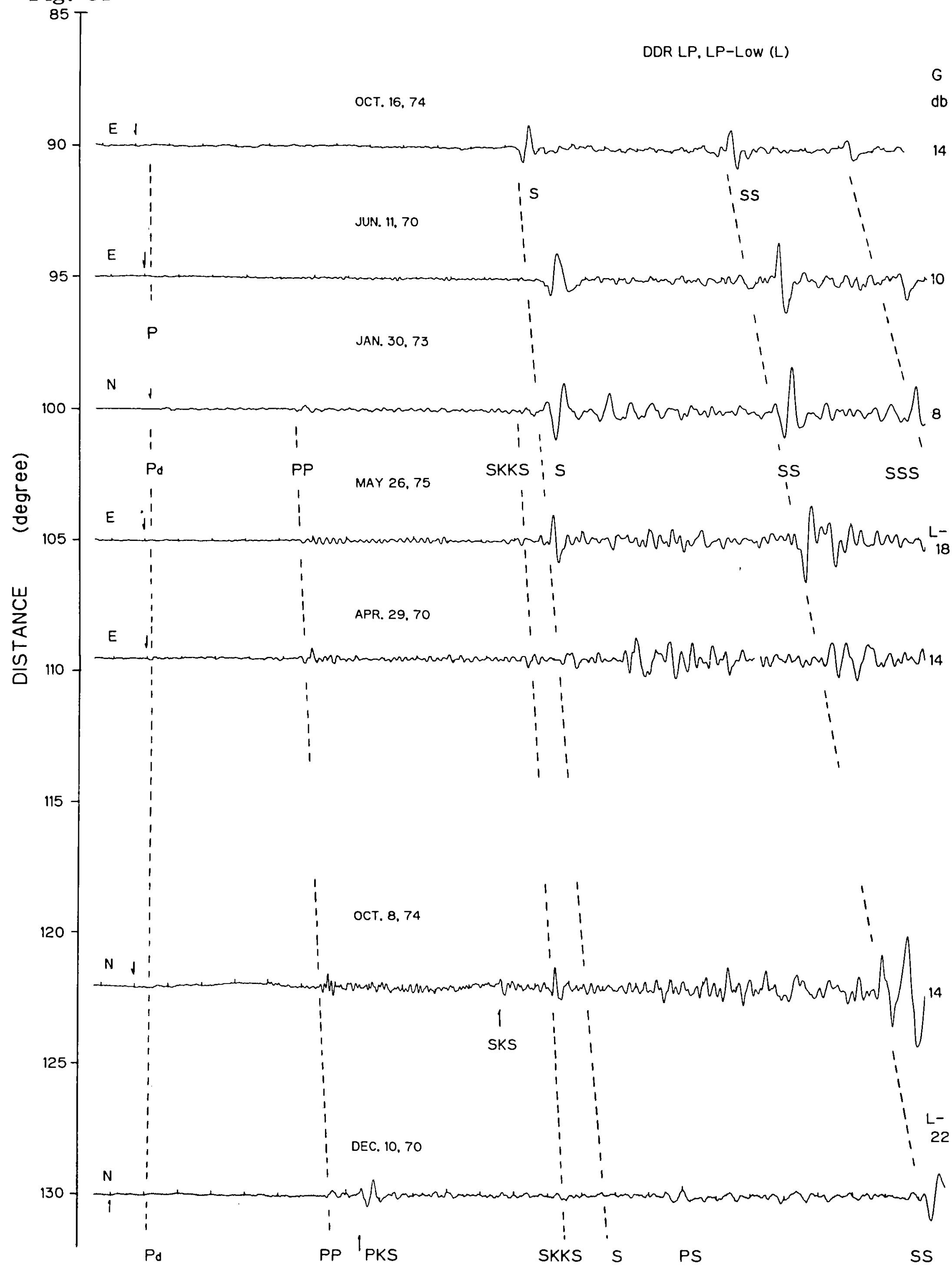
These events are located over a wide region, including the N. Atlantic Ridge, Macquarie Is., Mexico, Leeward Is. and Peru.

The arrival times of *P* and *Pd* waves are arranged as indicated by dotted line.

Comments

1) Clear *S* wave is seen until 110 degrees, and their arrival times seem to be different by region.
2) The *SS* wave is a common phase for this epicentral range.

Fig. 84

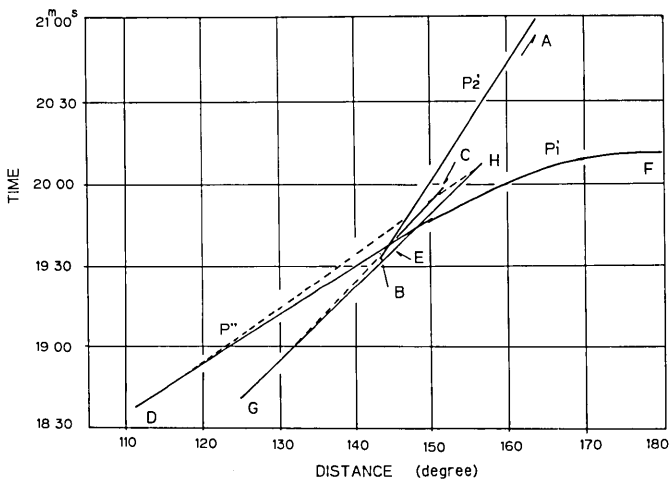


DDR LP, LP-Low (L)
G
db
OCT. 16, 74
JUN. 11, 70
JAN. 30, 73
MAY 26, 75
APR. 29, 70
OCT. 8, 74
DEC. 10, 70
E
E
N
E
E
N
N
14
10
8
L-
18
14
14
L-
22
P
Pd
PP
SKKS
S
SS
SSS
SKS
Pd
PP
PKS
SKKS
S
PS
SS
DISTANCE (degree)
85
90
95
100
105
110
115
120
125
130

85. *PKP* wave
—Δ=153°—

Typical example of *PKP* wave (P') obtained by three components of MP seismograph at DDR.

The travel time curve of *PKP* wave by BOLT (1964) is also shown below for comparison.

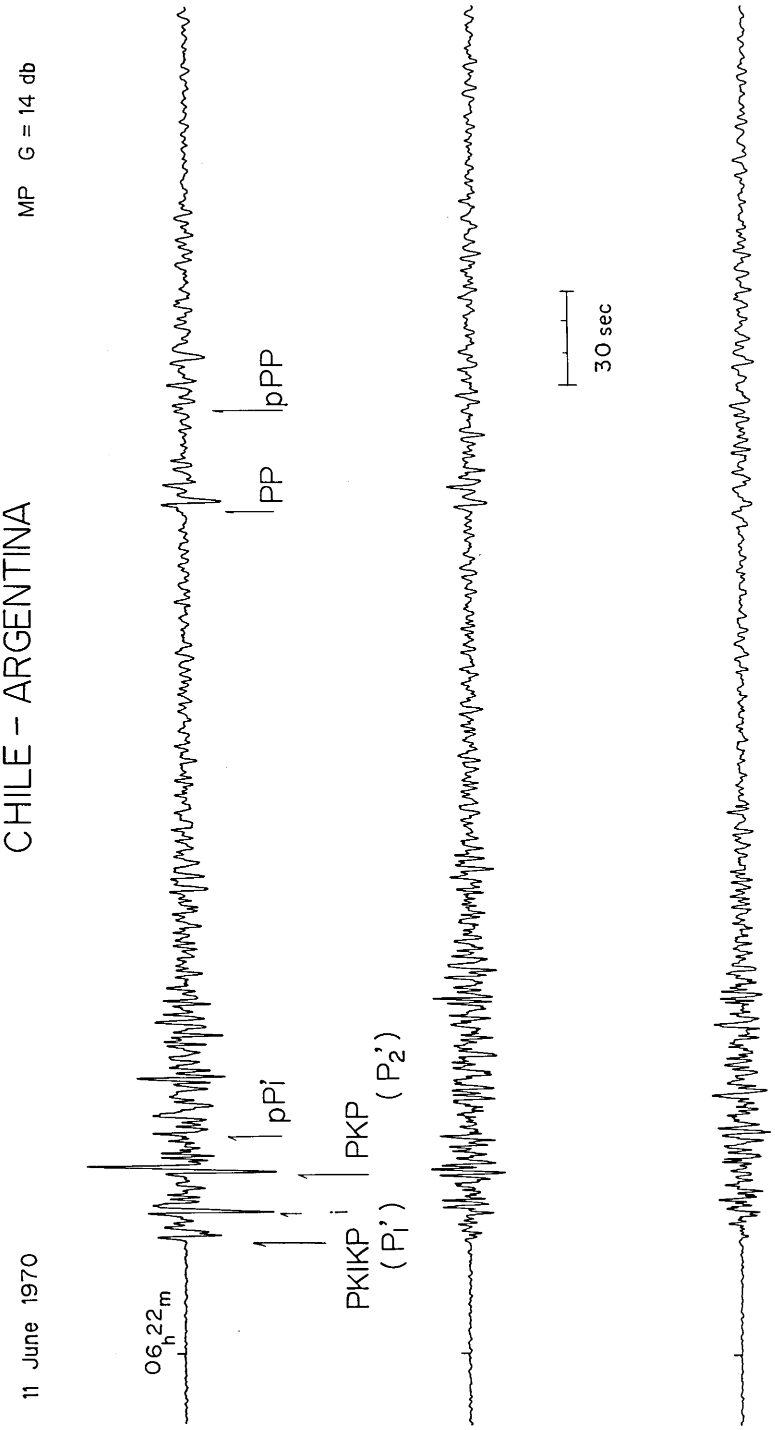


The focal parameters by ISC are as follows:

Origin Time	Epicenter		*h*	*Mb*	Δ
h m s	S	W	km		deg
06 02 52.4	24°.47	68°.46	87	6.3	153.58

Three phases corresponding to the EF, EH and EA branches are clearly demonstrated as indicated by *PKIKP* (P_1'), *i* and *PKP* (P_2') phases in the seismogram.

Fig. 85


11 June 1970
CHILE - ARGENTINA
MP G = 14 db
06h22m
PKIKP
(P1')
PKP
(P2')
pP'i
PP
pPP
30 sec

86. *PKP* waves
—Δ=132°-152°—

An appearance of *PKP* waves for the events with epicentral distance from 132° to 152° obtained by SP-Z seismograph at DDR.

The focal parameters by ISC are as follows:

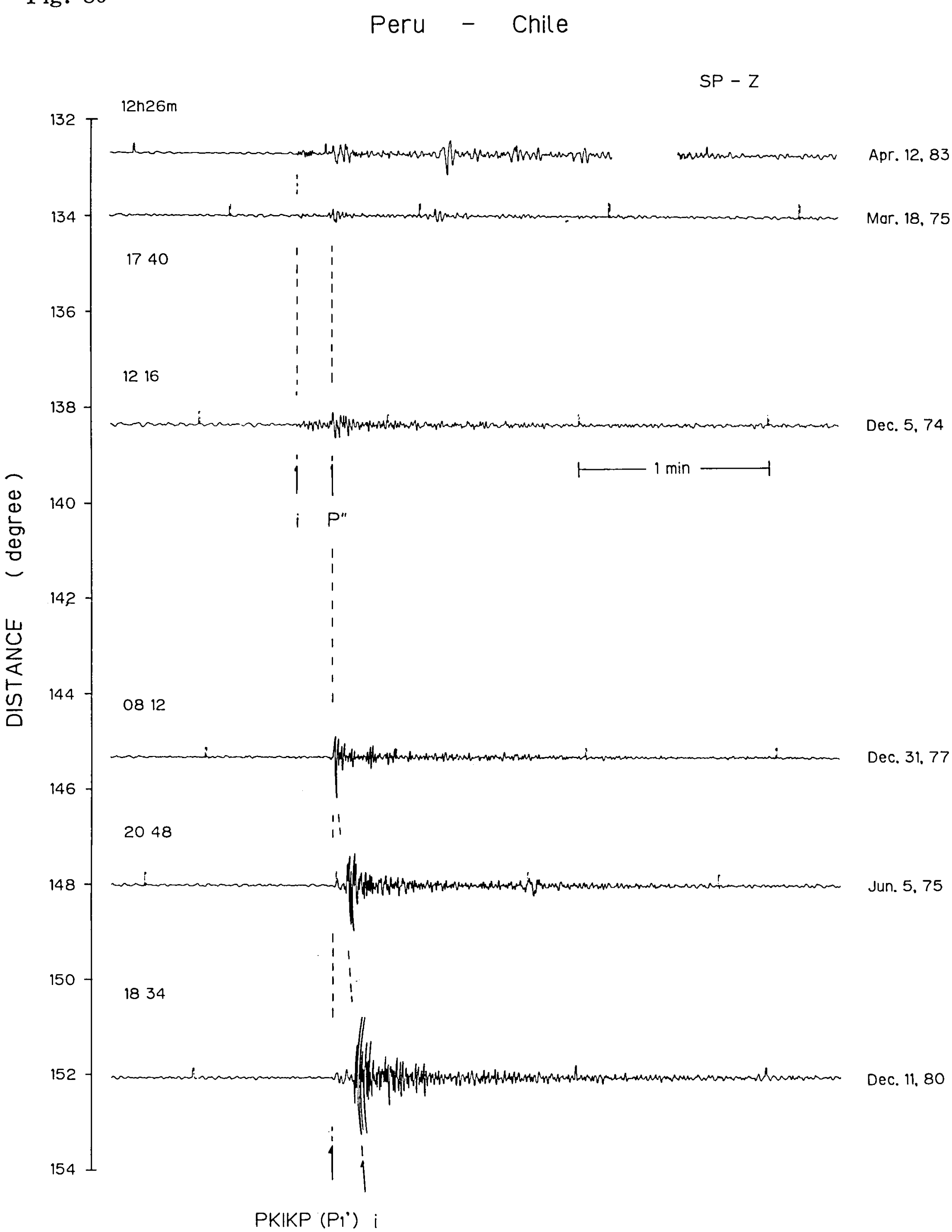
Origin Time	Epicenter		h	Mb	Δ	Δt
d h m s	S	W	km		deg	s
Apr. 12, 12 07 54.4	4°84	78°09	102	6.4	133.78	−8.7
Mar. 18, 17 21 24.7	4.26	77.01	111	6.2	134.09	−8.2
Dec. 05, 11 57 31.1	7.65	74.46	156	6.0	138.29	−7.3
Dec. 31, 07 53 13.9	15.37	71.71	125	6.0	145.63	+1.4
Jun. 05, 20 29 38.3	16.46	69.20	204	5.5	148.13	+3.0
Dec. 11, 18 15 03.0	21.35	68.10	77	5.9	152.08	+1.0

Δt: travel time residual of initial phase taken from the ISC Bulletin.

These events are distributed along the regions from Peru to Chile. An appearance of *PKP* waves is systematically changed between the range of 133°-152°, though the data at 143° are not enough:

1) The *PKP* wave in Δ <145° consists of two phases indicated by i and P'' phases (correspond to EG and ED branches in previous figure). The i phase is called "*PKHKP*" by Bolt (1964).
2) The arrival times of i phase in this range are about 8 sec negative for *J–B* Table.
3) The *PKP* wave in Δ >145° also consists of two or three phases (see previous figure).

Fig. 86


Peru - Chile
SP - Z
12h26m
Apr. 12, 83
Mar. 18, 75
17 40
12 16
Dec. 5, 74
1 min
i P"
08 12
Dec. 31, 77
20 48
Jun. 5, 75
18 34
Dec. 11, 80
PKIKP (P1') i
DISTANCE (degree)
132
134
136
138
140
142
144
146
148
150
152
154

87. *PKP* waves
—Δ=150°-158°—

An appearance of *PKP* waves for the events with epicentral distance from 150° to 158° obtained by SP-Z seismographs at DDR and TSK.

The focal parameters by ISC are as follows:

Origin Time					Epicenter		h	Mb	Δ
	d	h	m	s	S	W	km		deg
Feb.	27,	03	36	10.9	19°.71	69°.12	87	5.5	150.32
Dec.	11,	18	15	03.3	21.35	68.10	77	5.9	151.31
Aug.	10,	10	25	45.4	22.73	66.62	187	6.1	153.23
Jul.	19,	11	52	19.0	29.00	69.69	97	6.0	154.72
May	08,	00	49	45.0	42.29	71.79	146	5.8	155.26
Mar.	25,	06	41	30.0	27.95	66.53	152	5.7	156.79
Jul.	10,	01	42	37	56.17	27.70	120	6.1	157.94
Mar.	10,	21	58	44.5	56.05	27.37	105	5.2	158.40

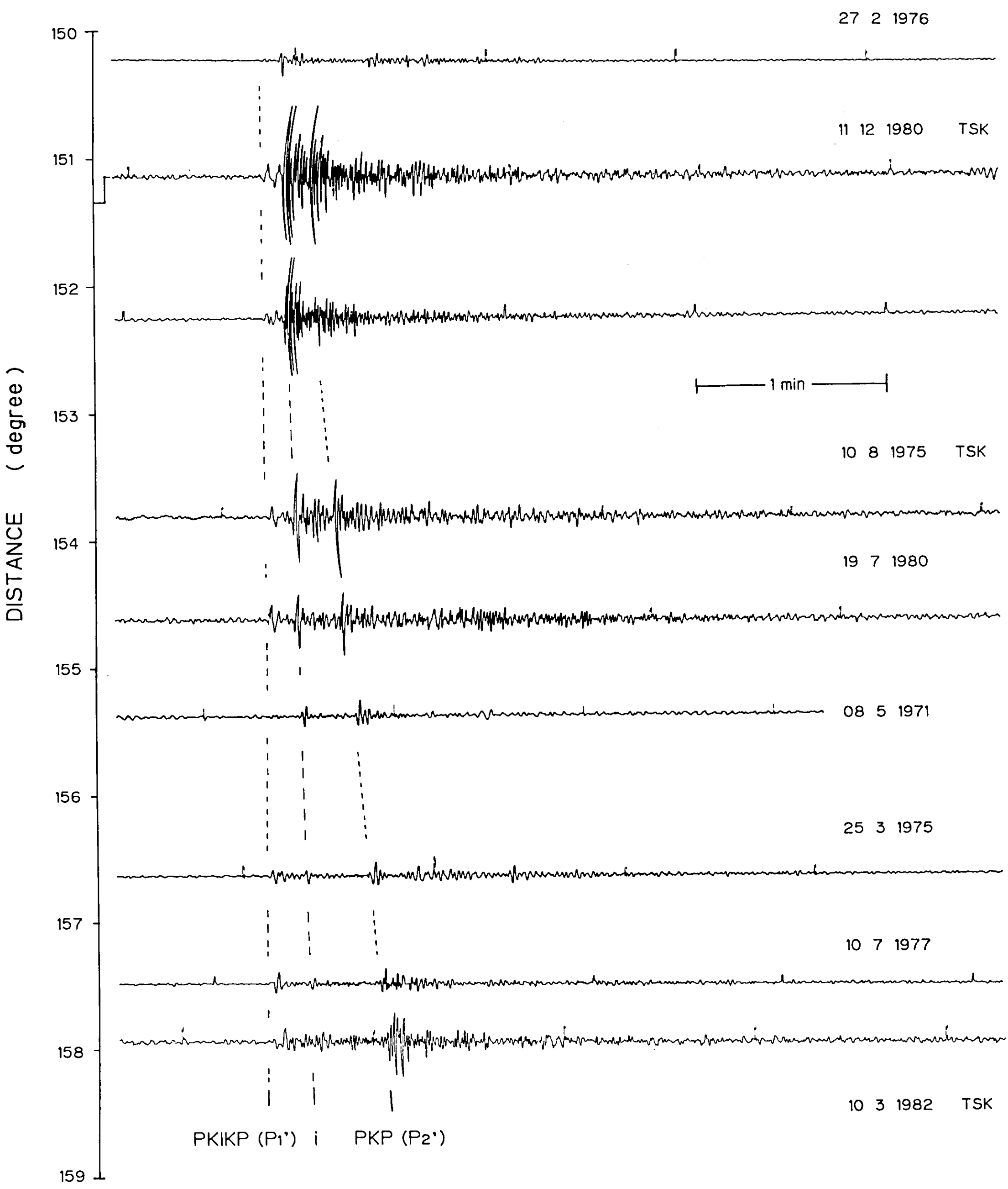
These events are distributed along the Chile, Argentina and South Sandwich Islands regions, and the South Sandwich is located at the most distant region from our station.

Comments

1) The *PKP* waves in this distance range consist of three phases P_1', i and P_2' waves corresponding to EF, EH and EA branches in the previous figure (Fig. 85).
2) The EC branch in previous figure is not clear.
3) The i phase in Δ <155° is very sharp, and its amplitude decreases with increasing distance.

Fig. 87

Chile - Argentina



88. *PKP* wave from deep-focus earthquake (1)

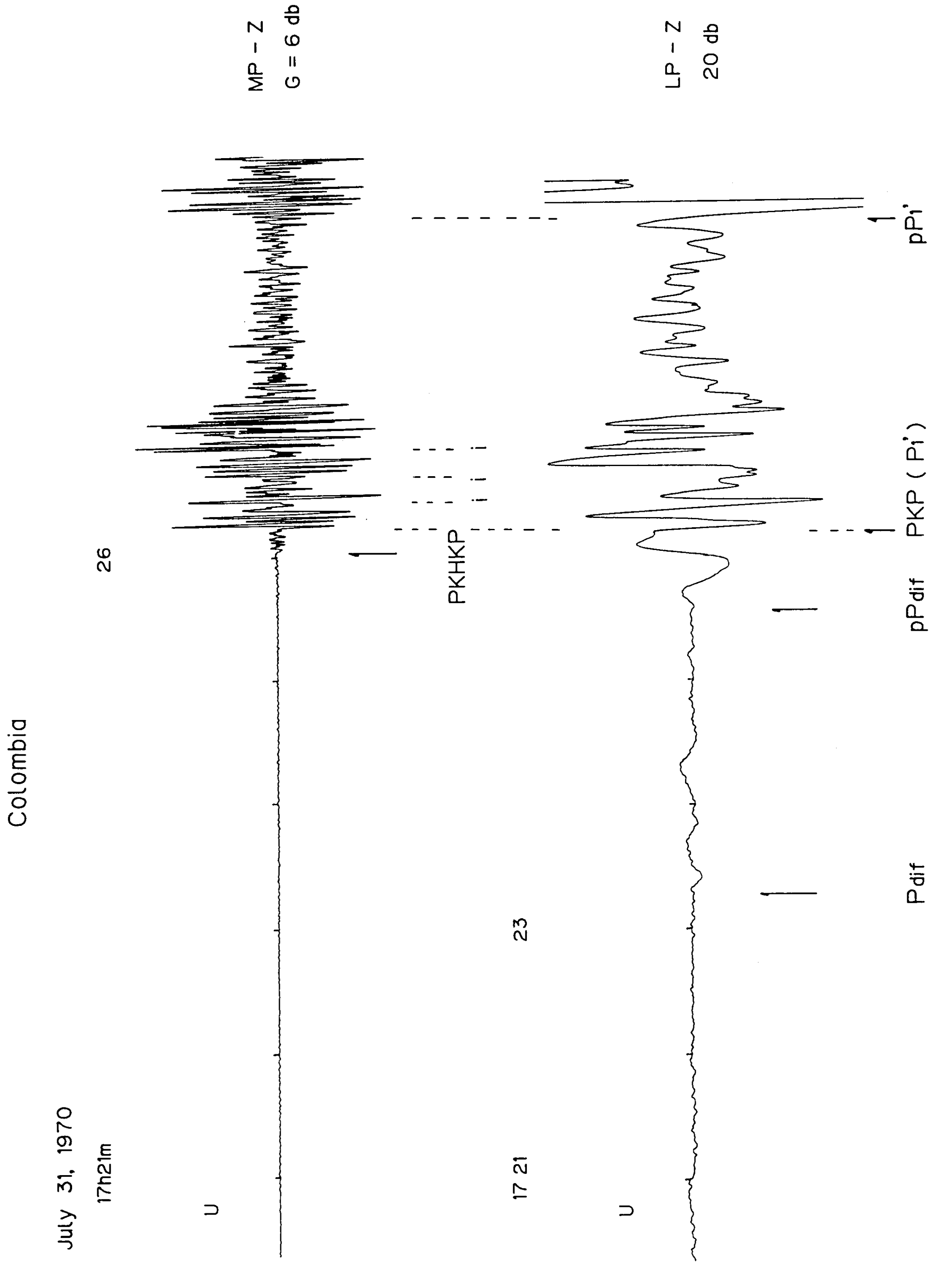
PKP waves from deep-focus earthquake in the Colombia region obtained by the vertical components of MP and LP seismographs at DDR. The focal parameters by ISC are as follows:

Origin Time	Epicenter		h	Mb	Δ
h m s	S	W	km		deg
17 08 05.4	1°.46	72°.56	653	6.5	134.75

Comments

1) Small *P*(diffracted) wave appears on the LP seismograms, and is followed by a large reflected *pPdif* wave.
2) The *pPdif* wave at this depth is superimposed on the *PKP* wave. Note the difference of spectrum between *pPdif* and P_1' waves.
3) The initial phase on the MP seismogram is *PKHKP*, and is followed by a large P_1' phase and others indicated by *i*.

Fig. 88


Colombia
July 31, 1970
17h21m
U
MP - Z
G = 6 db
LP - Z
20 db
26
23
17 21
PKHKP
pPi'
PKP (Pi')
pPdif
Pdif

89. *PKP* waves from deep-focus earthquakes (2)
—Δ=155°-160°—

An arrangement of *PKP* waves from deep-focus earthquakes in the Bolivia-Argentina regions obtained by SP-Z seismograph at DDR. The ordinate shows the epicentral distance in degrees.

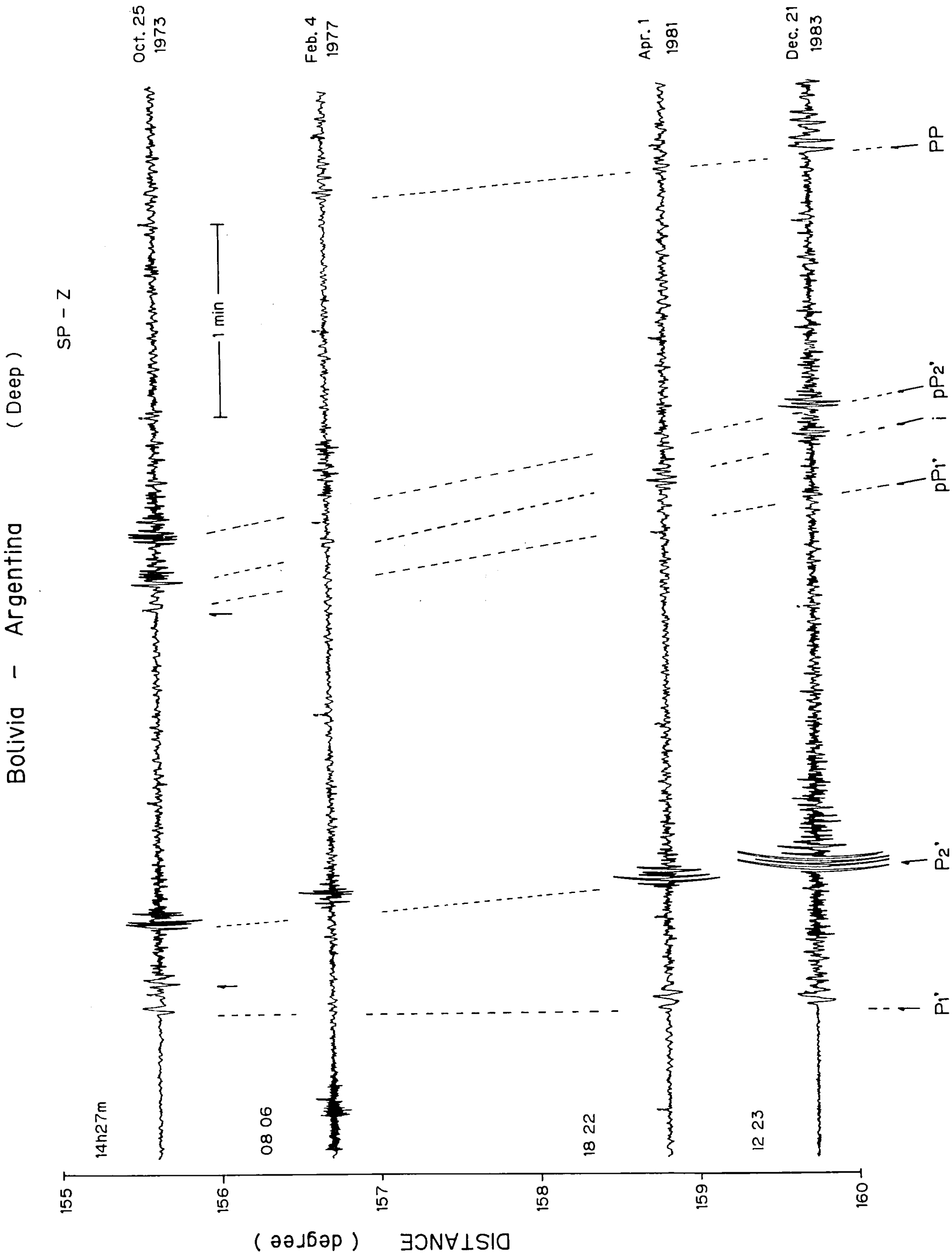
The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Δ
	d h m s	S	W	km		deg
Oct.	25, 14 08 58.5	21°96	63°65	517	6.1	155.68
Feb.	04, 07 46 34.1	24.66	63.39	555	5.9	157.52
Apr.	01, 18 03 36.0	27.28	63.27	544	5.8	159.02
Dec.	21, 12 05 06.0	28.13	63.15	592	6.2	159.53

Comments

1) Appearance of i phase between P_1' and P_2' is limited; it appears only on the seismogram with short distance (Δ<156°).
2) The pair phases of P_1', P_2' and pP_1', pP_2' commonly appear on all seismograms. Note the time intervals between P_1'-P_2' and pP_1'-pP_2'. Note also the difference of spectrum between P_1' and P_2' waves.

Fig. 89


Bolivia - Argentina (Deep)
SP - Z
1 min
Oct. 25 1973
Feb. 4 1977
Apr. 1 1981
Dec. 21 1983
14h27m
08 06
18 22
12 23
PP
pP2'
i
pP1'
P2'
P1'
155
156
157
158
159
160
DISTANCE (degree)

90. Seismograms from Peru-Argentina
—Δ=145°-157°—

An arrangement of seismograms obtained by LP-Z seismograph at DDR for events in the Peru-Chile-Argentina regions. The ordinate shows the epicentral distance in degrees.

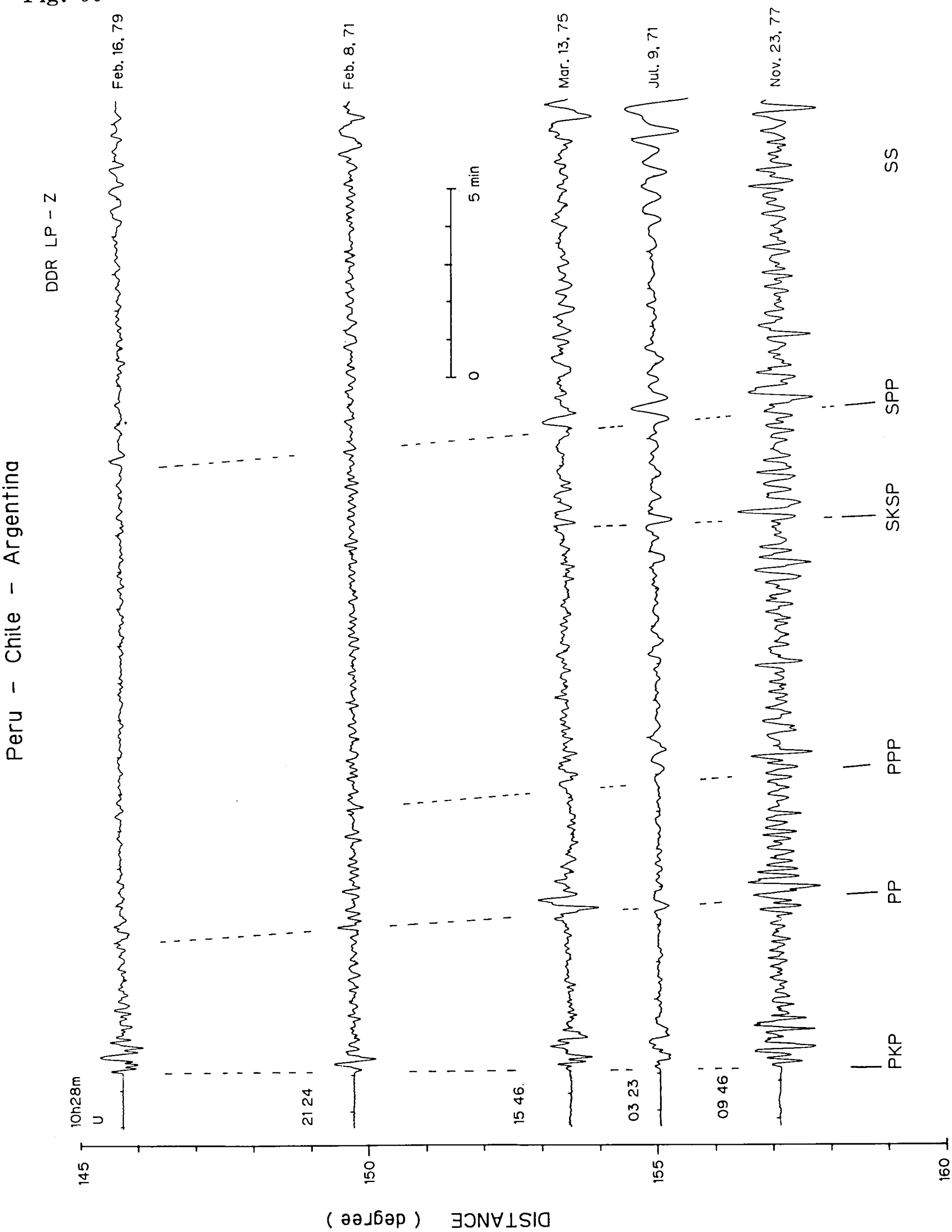
The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Δ
	d h m s	S	W	km		deg
Feb. 16,	10 08 51.9	16°.52	72°.60	42	6.2	145.74
Feb. 08,	21 04 19.1	63.43	61.36	12	6.0	149.78
Mar. 13,	15 26 47	29.86	71.40	28	6.1	153.68
Jul. 09,	03 03 16.9	32.51	71.21	40	6.5	154.68
Nov. 23,	09 26 23.4	31.04	67.76	4	6.4	157.02

Comments

1) Distant earthquake produces long-period body phases, though the onset of each phase is not clear.
2) No separation of *PKP* branch is possible on the LP seismograms. Horizontal component seismograms follow.

Fig. 90


Peru - Chile - Argentina
DDR LP - Z
Feb. 16, 79
Feb. 8, 71
Mar. 13, 75
Jul. 9, 71
Nov. 23, 77
10h28m
U
21 24
15 46
03 23
09 46
0
5 min
PKP
PP
PPP
SKSP
SPP
SS
145
150
155
160
DISTANCE (degree)

91. Seismograms from Chile

—Δ=153°-155°—

An arrangement of seismograms obtained from horizontal components of LP seismograph at DDR for three events in the Chile region. Early parts of seismograms including the *P* wave are omitted. The sizes of bars show relative differences of magnification.

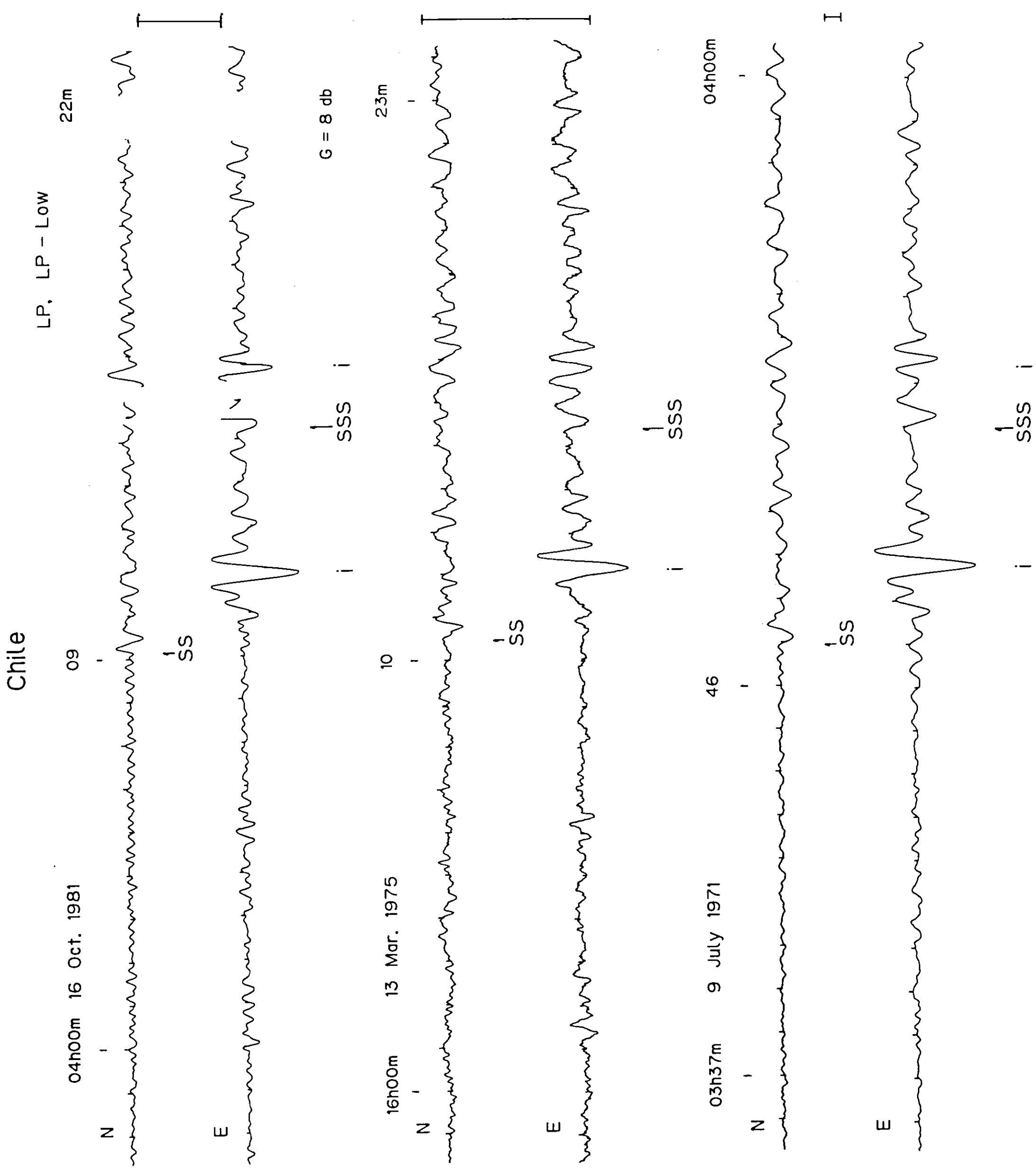
The focal parameters by ISC are as follows:

Origin Time		Epicenter		*h*	*Mb*	Δ
	d h m s	S	W	km		deg
Oct.	16, 03 25 40	33°.15	73°.10	18	6.2	153.32
Mar.	13, 15 26 47	29.89	71.40	28	6.1	153.68
Jul.	09, 03 03 16.9	32.51	71.21	40	6.5	154.68

Comments

1) *SS* and *SSS* waves are commonly observed for all earthquakes.
2) The *i* phases with large amplitude are commonly seen on the E-W component seismograms.

Fig. 91


Chile
LP, LP - Low
04h00m 16 Oct. 1981
09
22m
N
E
SS
SSS
i
G = 8 db
16h00m 13 Mar. 1975
10
23m
03h37m 9 July 1971
46
04h00m

92. Spectral features of earthquake swarm (1)

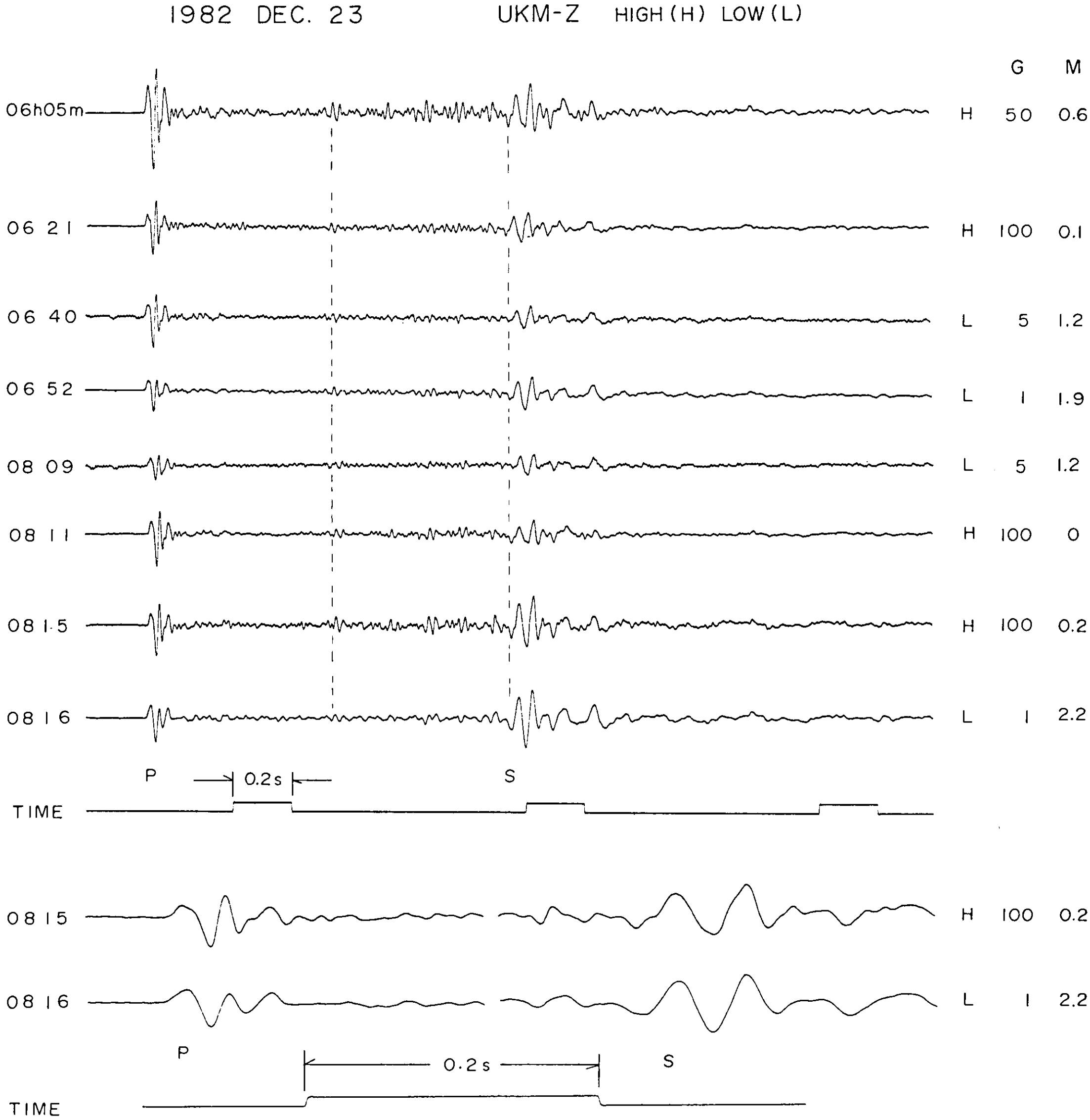
An earthquake swarm occurring in a short-time interval shares similar waveforms called "earthquake family" (see Figs. 11, 12, 13). This figure shows seismograms of an earthquake family including large and small events different by a magnitude unit of 2.2. These seismograms are obtained by SP-Z seismographs at Uchino-komori (UKM) in the Ashio area, Tochigi Prefecture (TSUJIURA, 1983b).

Symbols of H and L at the end of seismograms show high-gain and low-gain seismographs differing by a factor of 50, and G shows relative differences of magnification. The magnitude of these events lies between 0 and 2.2. Seismograms of the smallest and the largest events recorded at a higher paper speed (500 mm/sec) are also shown at the bottom.

Similar waveforms are seen at frequencies of up to 30 Hz, and are independent of the absolute value of amplitude, in a magnitude unit of 2.2.

This tendency of waveform and spectrum, however, becomes somewhat uncertain when an earthquake in the family exceeds a certain size, as shown later.

Fig. 92


1982 DEC. 23
UKM-Z HIGH (H) LOW (L)
G M
06h05m H 50 0.6
06 21 H 100 0.1
06 40 L 5 1.2
06 52 L 1 1.9
08 09 L 5 1.2
08 11 H 100 0
08 15 H 100 0.2
08 16 L 1 2.2
P
0.2s
S
TIME
08 15 H 100 0.2
08 16 L 1 2.2
P
0.2s
S
TIME

93. Spectral features of earthquake swarm (2) —comparison of large and small events—

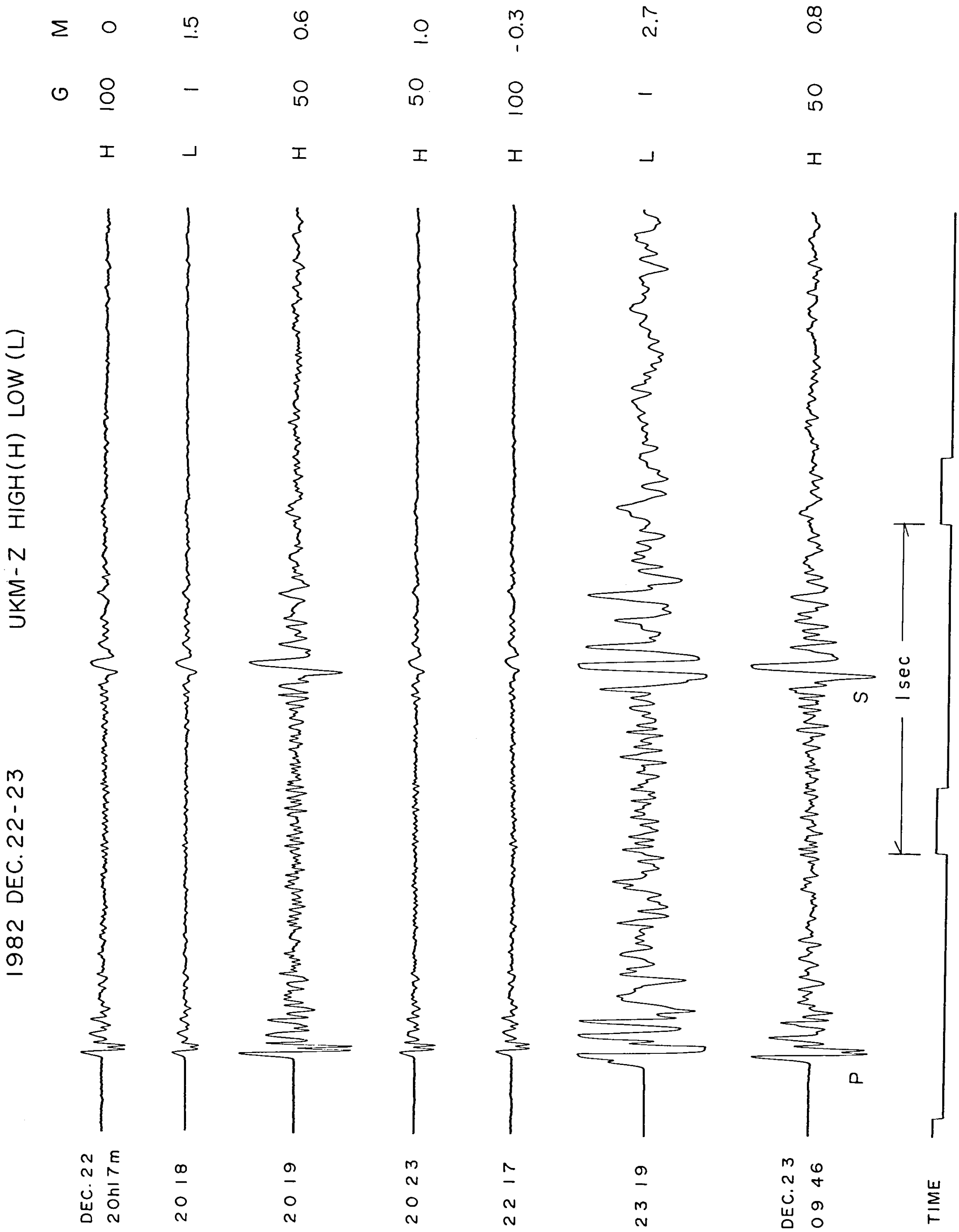
Seismograms of earthquake family including specially large event. These events are obtained from the earthquake swarm in the Ashio area similar to that shown in the previous figure, and the explanation of symbols is also the same for the previous figure. The magnitude of these events lies between -0.3 and 2.7.

Comments

1) The peaks and troughs of wave trains are in good agreement for small events ($M \leqq 1.5$).
2) The waveform of the largest event with $M2.7$ does not agree with small events. An irregular pattern of the P waveform is seen for the $M2.7$ event, and the half-period of the initial motion is about 2 times greater than those of the other events.

These features suggest that the mechanisms of earthquake occurrence are different between large and small events, and the large event with $M2.7$ was probably multiple events. Similar behavior of waveforms was obtained for the earthquake swarm in the Izu Peninsula (TSUJIURA, 1983b).

Fig. 93


1982 DEC. 22-23
UKM-Z HIGH(H) LOW(L)
G M
H 100 0
L 1 1.5
H 50 0.6
H 50 1.0
H 100 -0.3
L 1 2.7
H 50 0.8
DEC. 22 20h17m
2018
2019
2023
2217
2319
DEC. 23 0946
TIME
P
S
1 sec

94. Waveform of foreshocks (1)
—Izu-Oshima-Kinkai earthquake—

The main shock with $M7.0$ occurred at the Izu-Oshima-Kinkai on 12h 24m 38.6s, January 14, 1978 (JST), and active foreshocks were observed preceding the main shock by a few hours. Among these foreshocks, this figure shows seismograms with similar magnitudes from 3.4 to 4.1 obtained by MP-Z seismograph at DDR. G: gain of play-back amplifier.

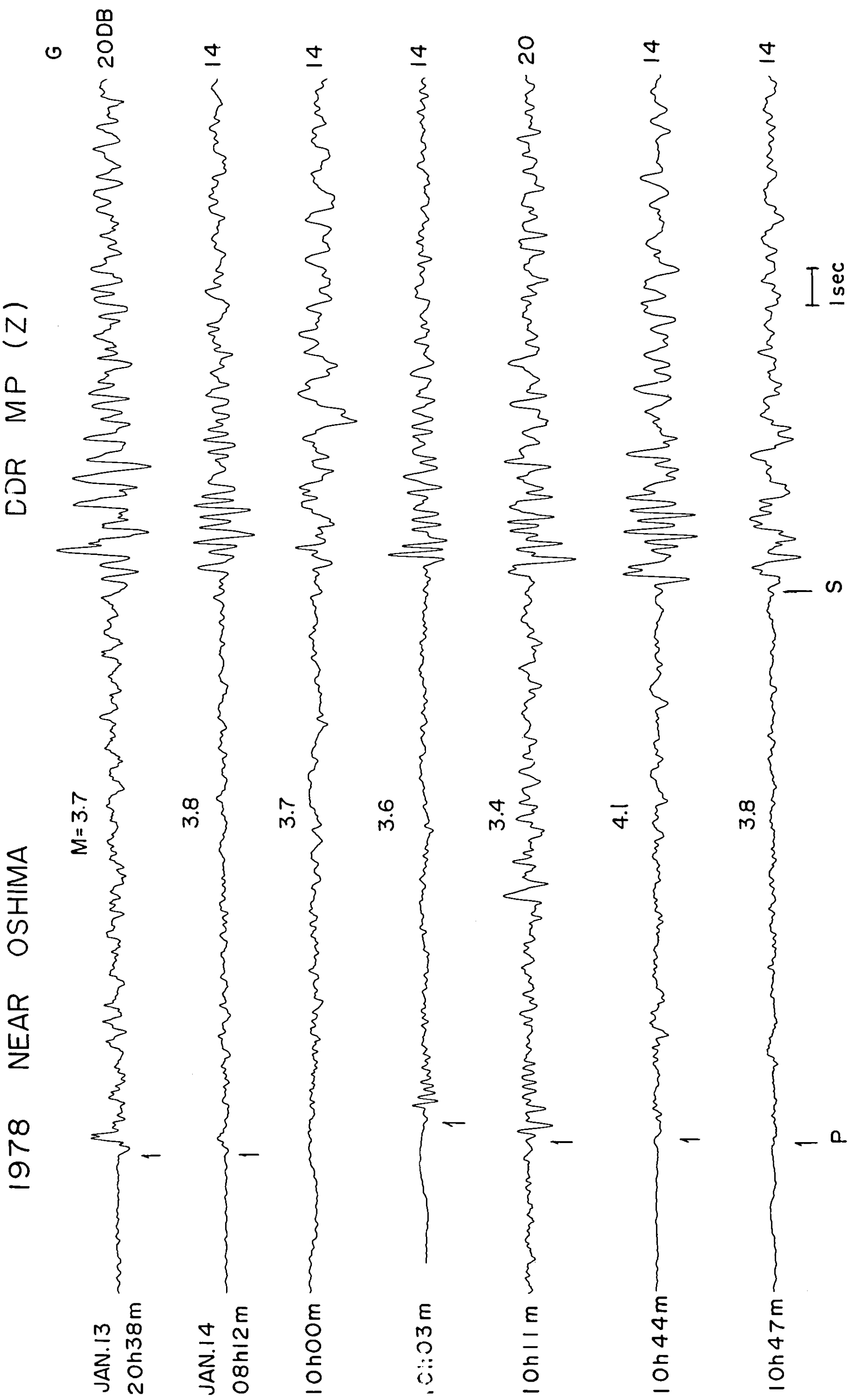
The focal parameters of main shock by JMA are as follows:

Origin Time	Epicenter		h	M	Δ
h m s	N	E	km		km
12 24 38.6	34.°77	139.°25	0	7.0	140

Comments

All seismograms show an individual waveform character having the deviation of S–P times of 1.5 sec, and no family type earthquakes were observed as shown in swarm earthquakes (see Figs. 13, 92, 93). The source spectra of these earthquakes also show large variations differing from those of swarm earthquakes (TSUJIURA, 1978b).

Fig. 94


1978 NEAR OSHIMA
CDR MP (Z)
G
20DB
M=3.7
3.8
3.7
3.6
3.4
4.1
3.8
14
14
14
20
14
14
JAN.13 20h38m
JAN.14 08h12m
10h00m
10h03m
10h11m
10h44m
10h47m
P
S
1sec

95. Waveform of foreshocks (2) —1982 Off Ibaraki Prefecture earthquake—

Seismograms of foreshocks with $M \geqq 4.5$ obtained by MP-Z seismograph at DDR during about 32 hours preceding the Off Ibaraki Prefecture earthquake $M7.0$. The seismogram of main shock is also shown for comparison.

The sizes of bars show relative differences of magnification.

The focal parameters by JMA are as follows:

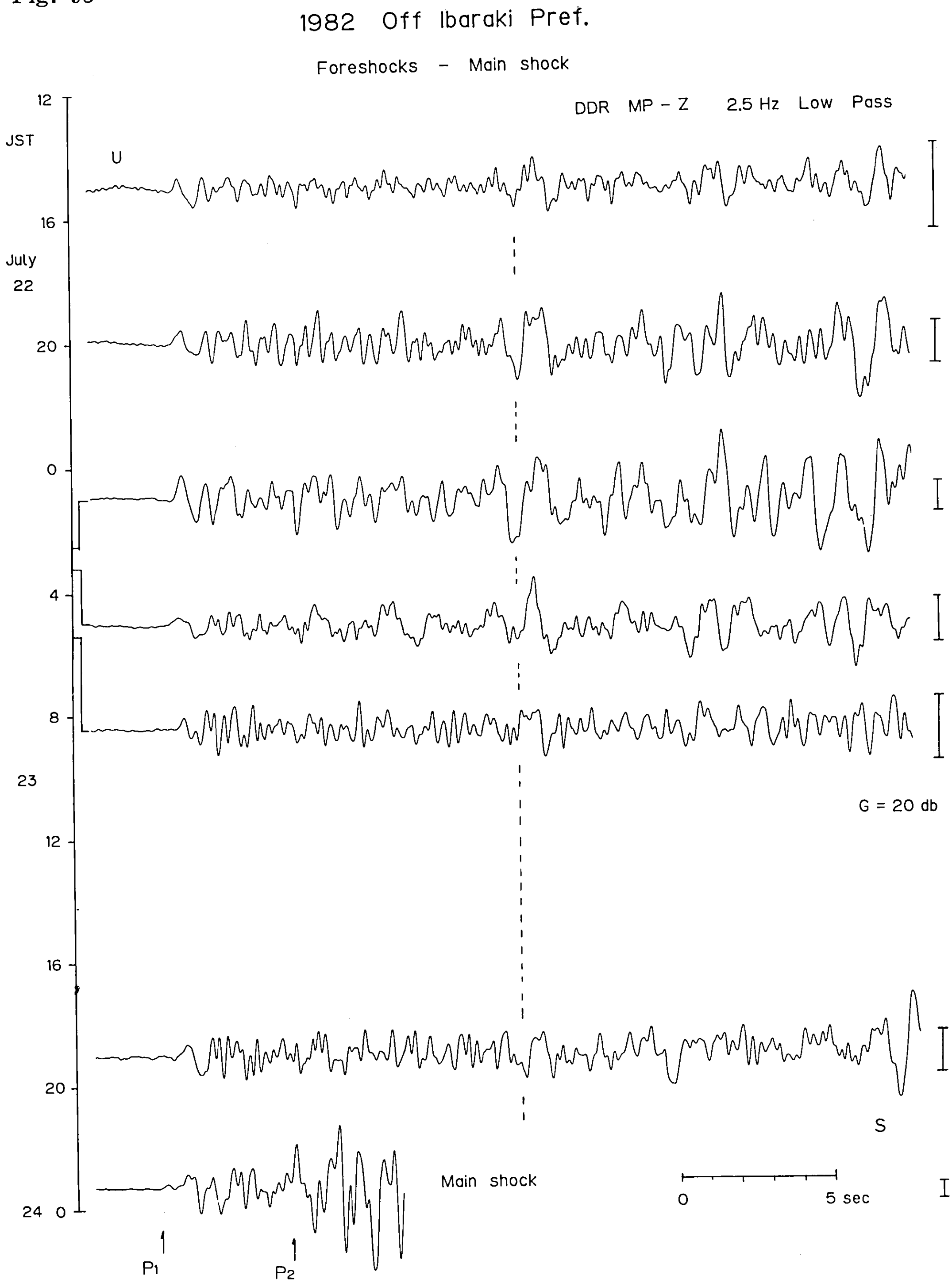
Origin Time	Epicenter		h	M
d h m s	N	E	km	
22 15 22 38.6	36°22	142°03	30	4.5
22 19 57 51.7	36.17	141.98	40	5.0
23 02 32 30.3	36.22	142.05	30	5.4
23 03 17 18.0	36.22	141.87	60	5.0
23 05 24 07.2	36.18	141.98	30	4.7
23 20 25 00.8	36.18	141.92	50	5.0
23 23 23 50.9	36.18	141.95	30	7.0

Comments

1) High-frequency components, about 3 Hz, differ from event to event.
2) The amplitude of high-frequency components increases with time, and the foreshock immediately before the main shock shows a maximum value.
3) Clear phase indicated by dotted line is commonly observed for all foreshocks, and their arrival times measured from P wave onset coincide within a range of 0.3 sec.
4) The main shock shows a multiple-type occurrence (see also Fig. 15).

These features suggest that the foreshocks occurred repeatedly on the same fault plane enclosed by strong barriers, and the strongest barrier is broken, the main shock occurred.

Fig. 95


1982 Off Ibaraki Pref.
Foreshocks - Main shock
DDR MP - Z 2.5 Hz Low Pass
12
JST
U
16
July
22
20
0
4
8
23
12
16
20
24 0
G = 20 db
S
Main shock
0
5 sec
P1
P2

96. Seismograms of foreshock and main shock —1975 Hawaii earthquake—

Comparison of seismograms of the foreshock and the main shock in the Hawaiian Islands region recorded by short-period (SP) and long-period (LP, LP-Low) seismographs at DDR.

Note the different time scale on SP and LP seismograms.

The focal parameters by ISC are as follows:

Origin Time		Epicenter		h	Mb	Ms*
	d h m s	N	W	km		
Nov. 29,	13 35 41.0	19°48	155°17	8	5.7	5.1
Nov. 29,	14 47 41.1	19.46	155.14	11	5.9	7.1

* Ms: from NEIS.

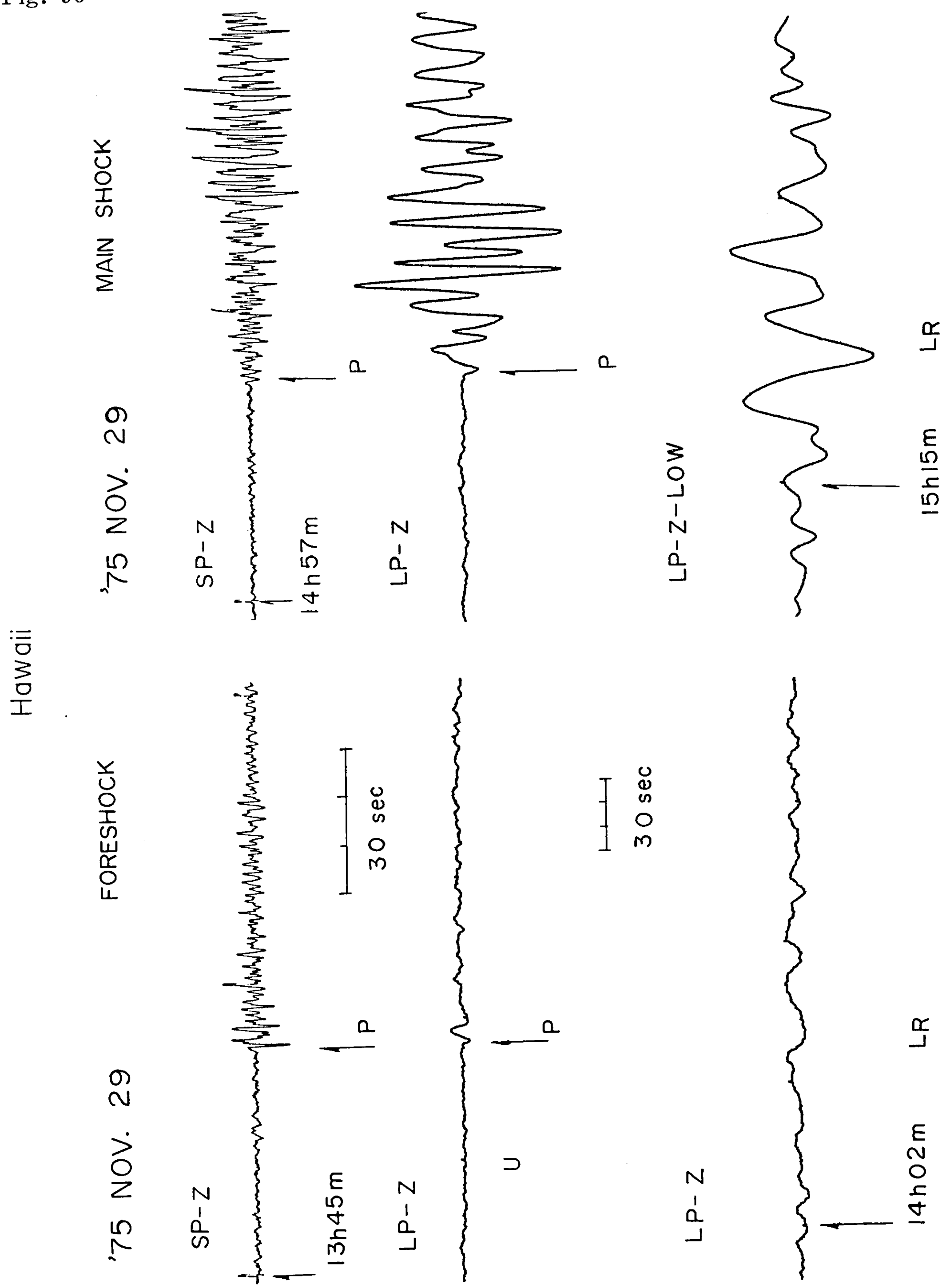
Epicentral distances to DDR are 59.36 and 59.40 degrees, respectively.

Comments

1) Short-period amplitudes pred minate on the P-waves of the foreshock although the Ms is smaller by a factor of 2.0 than that of the main shock.
2) The first motion of P-wave of the main shock is small and increases gradually with time, and the maximum amplitude appears about 40 sec after the initial motion.

This feature may be due to the difference in the source-time function between the two events. The main shock suggests the occurrence of the slower source-time function, apparently common to the multiple shocks or multiple sequence. On the other hand, the foreshock is the event containing high-frequency components which supports the high stress drop.

Fig. 96


Hawaii
'75 NOV. 29
MAIN SHOCK
SP-Z
14h57m
P
LP-Z
P
LP-Z-LOW
15h15m
LR
'75 NOV. 29
FORESHOCK
SP-Z
13h45m
P
30 sec
LP-Z
U
P
30 sec
LP-Z
14h02m
LR

97. Seismograms of foreshock, main shock and aftershock —1986 Aleutian earthquake—

A specially large earthquake with *Ms*7.7 occurred at the Andreanof Islands, Aleutian Is. region.

This figure shows the seismograms of the largest foreshock, main shock and the largest aftershock obtained by MP-Z (left), LP-Z and LP-Low-Z (right) seismographs at DDR. Bars show relative differences of magnification.

The focal parameters by PDE, USGS are as follows:

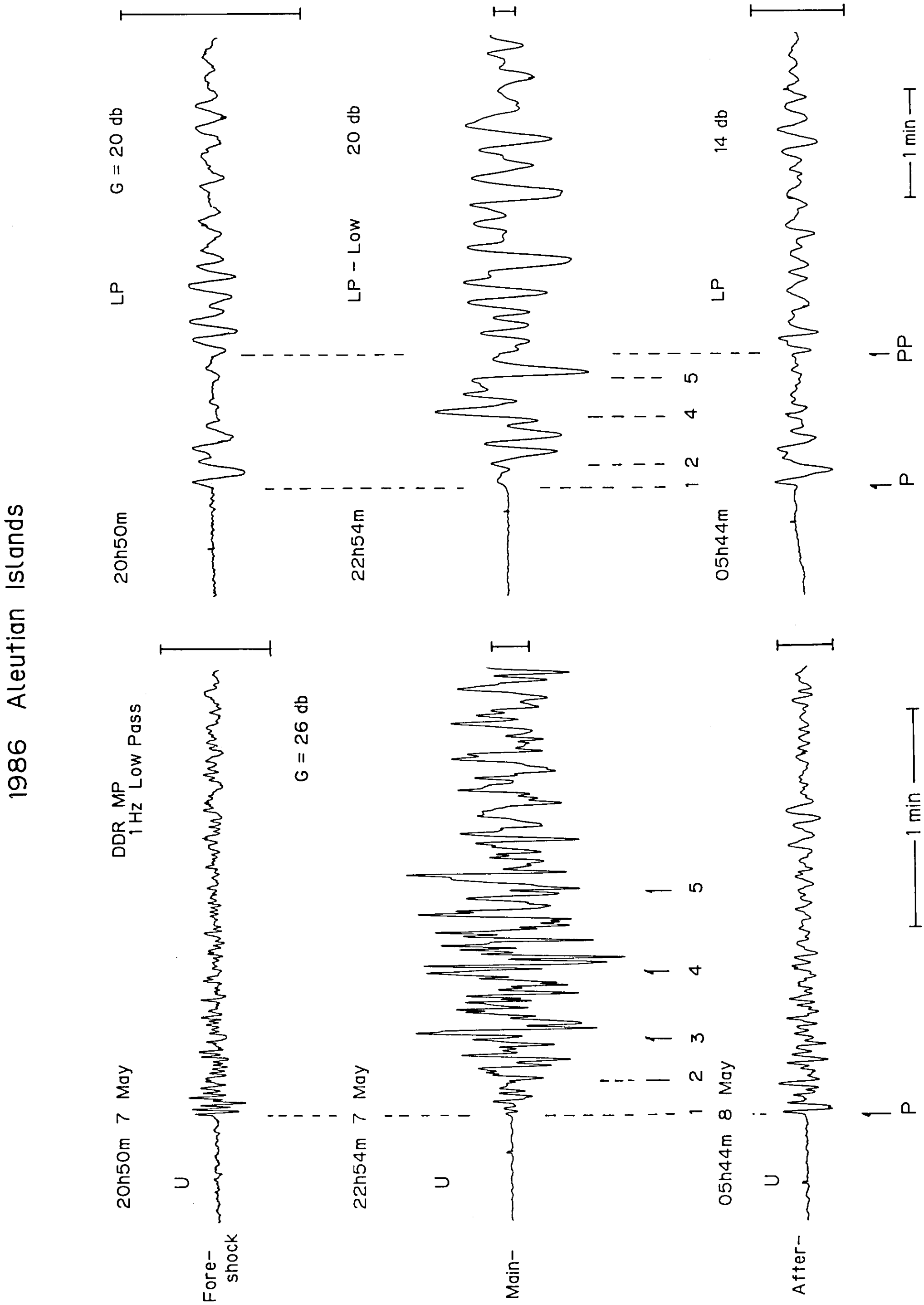
Origin Time		Epicenter		*h*	*Mb*	*Ms*
	d h m s	N	W	km		
May	07, 20 43 31.2	51°.38	174°.81	22G	6.1	6.0
May	07, 22 47 10.8	51.52	174.78	33N	6.4	7.7
May	08, 05 37 20.2	51.34	175.36	18G	6.0	6.2

Comments

1) The initial amplitude of the main shock on the MP seismogram is small compared with those of the foreshock and aftershock.
2) LP seismograms of foreshock and aftershock are similar in waveform and phase appearance, but their waveforms are quite different from that of the main shock.
3) *P* waveforms of the main shock consist of several phases indicated by numbers from 1 to 5.
4) Long-period waves with period of 40 sec are superimposed on the main shock seismogram.

These features are almost the same for the 1975 Hawaii earthquake shown in the previous figure.

Fig. 97


1986 Aleutian Islands
DDR MP
1 Hz Low Pass
G = 26 db
20h50m 7 May
22h54m 7 May
05h44m 8 May
U
Fore-
shock
Main-
After-
1 2 3 4 5
P
1 min
G = 20 db
LP
LP - Low
20 db
14 db
20h50m
22h54m
05h44m
1 2 4 5
PP
1 min

98. *P* waveform of large earthquake —in relation to aftershock activity—

Comparison of *P* waveforms obtained by MP-Z and LP-Z seismographs at DDR. The upper two traces show MP and LP seismograms for the event of Northern Celebes, and the lower two traces show those of Mindanao region. *N*: number of aftershocks during 24 hours after the main shock taken from the EDR of USCGS.

The focal parameters by ISC are as follows:

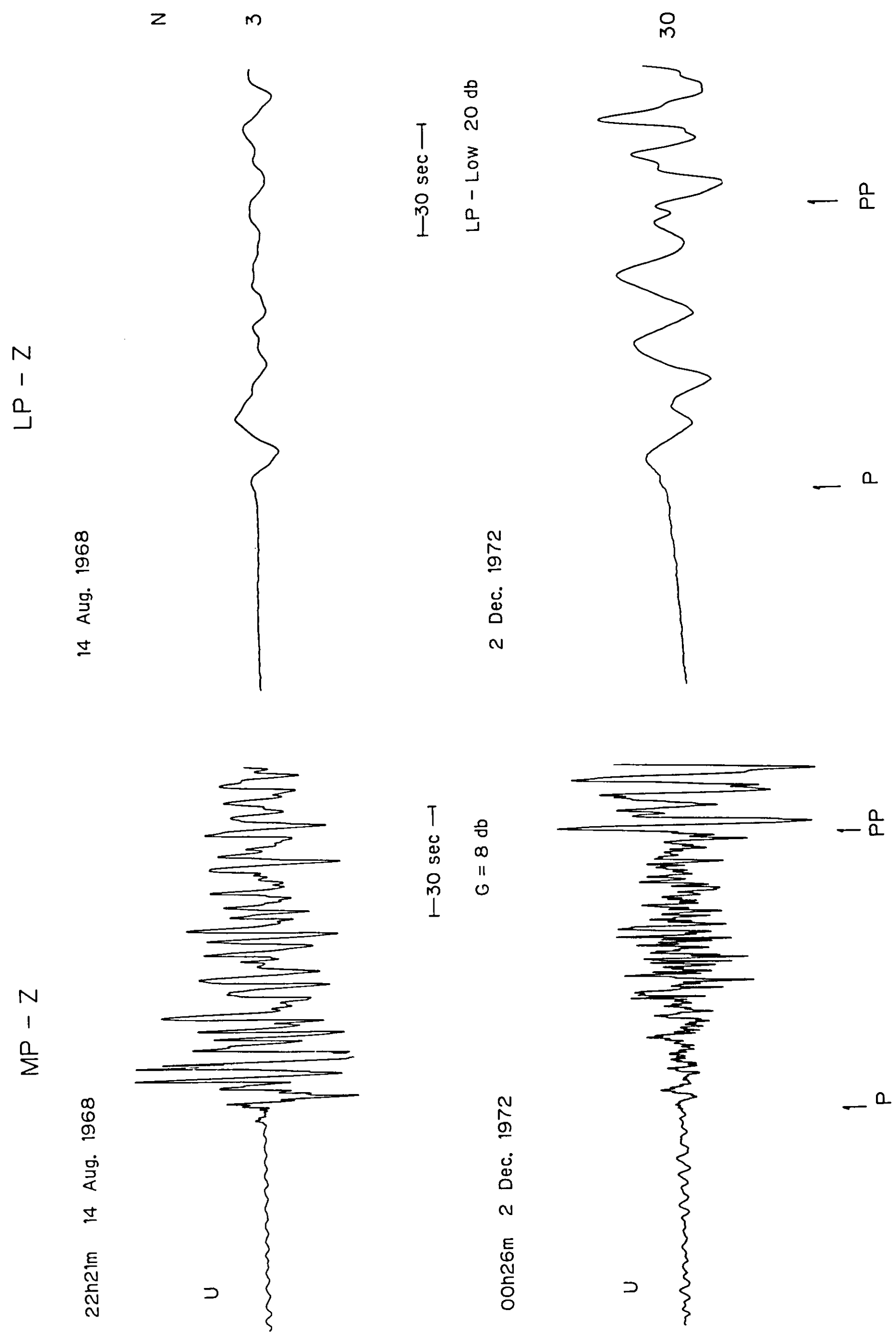
Origin Time	Epicenter		h	Mb	Ms	Δ
d h m s	N	E	km			deg
Aug. 14, 22 14 20.1	0°.06	119°.73	22	6.1	7.4	40.07
Dec. 02, 00 19 52	6.41	126.62	73	6.0	7.4	31.63

Ms: from USCGS.

Large variations of *P* waveforms are seen between the two events, although they have similar *Mb* and *Ms*:

1) The *P* wave amplitude of MP seismogram in the 1968 event is several times greater than that of the 1972 event.
2) The initial amplitudes of LP seismograms are almost the same for both events, but the predominant period of *P* waves in the 1972 event is several times greater than that of the 1968 event.
3) The aftershock activity is related to the predominant period of *P* waves. A similar tendency is seen for the other earthquakes (TSUJIURA, 1977).

Fig. 98


LP - Z
14 Aug. 1968
N
3
30 sec
LP - Low 20 db
30
2 Dec. 1972
P
PP
MP - Z
22h21m 14 Aug. 1968
U
30 sec
G = 8 db
00h26m 2 Dec. 1972
U
P
PP

99. Attenuation of coda waves from local earthquakes

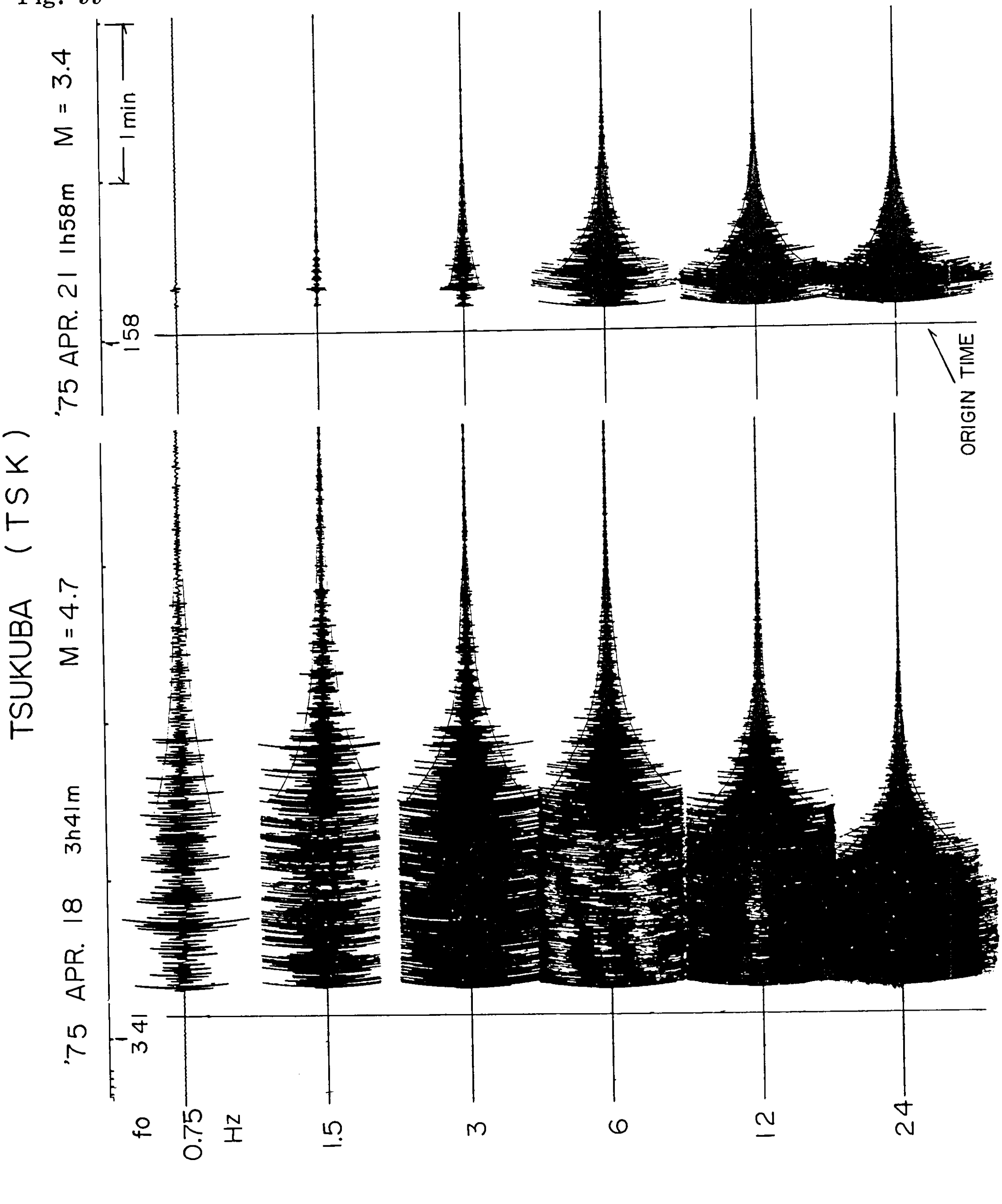
Filtered-seismograms from two local earthquakes with different magnitudes obtained by SP-Z seismograph at TSK. Numeral on the left-hand side shows the center frequency of each band-pass filter with one-octave bandwidth.

The coda waves in each frequency-band decrease with time in a regular manner. From the analysis of coda waves, some properties of coda decay were obtained.

Comments

1) The decay characteristics of coda waves in a given frequency-band are independent of the epicenter location and source size, and depend only on the lapse time measured from the origin time.
2) The apparent Q of coda waves obtained at TSK increases with frequency, approximately proportional to the square root of frequency, with values increasing from 200 at 1 Hz to 1500 at 24 Hz (TSUJIURA, 1978a).

Fig. 99


TSUKUBA (TSK)
'75 APR. 21 1h58m M = 3.4
1 min
158
ORIGIN TIME
'75 APR. 18 3h41m M = 4.7
3 41
fo
0.75 Hz
1.5
3
6
12
24

100. Dependence of coda excitation on local geology

Filtered-seismograms of the same event observed at TSK by SP-Z with two kinds of magnification and at ERI, where the seismometer is installed in the basement of the ERI building. The ground formation of TSK and ERI consists of granitic rocks and the Kanto loam layer, respectively. A relative difference of magnification among the filtered-seismograms is 1 : 10 : 3.5 as indicated in parentheses, respectively.

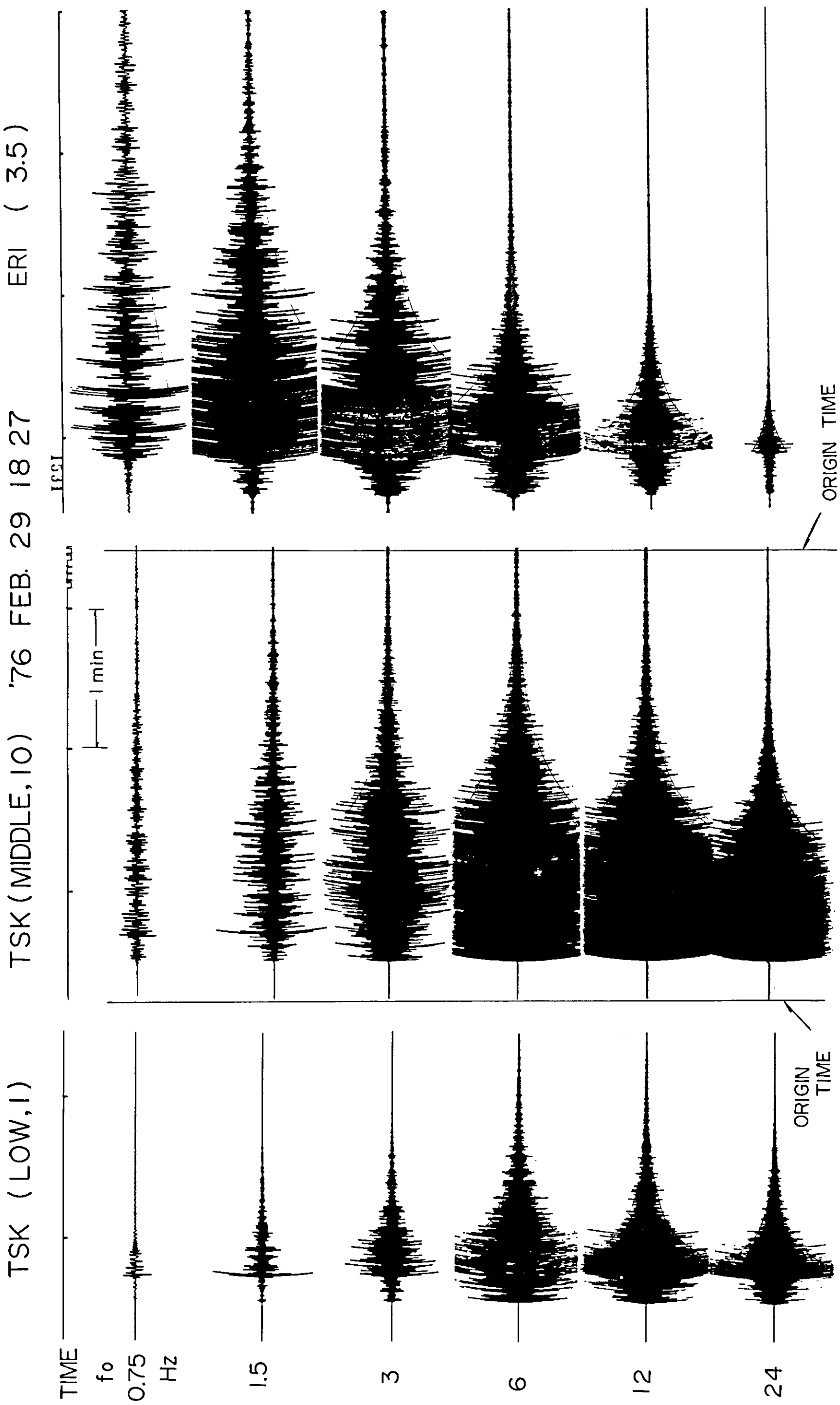
The focal parameters by JMA are as follows:

Origin Time	Epicenter		h	M	Δ
h m s	N	E	km		km
18 27 15.0	36°67	140°97	50	5.0	90 (TSK)

Comments

There is a strong amplitude-frequency dependence of coda excitation. The amplitude ratios of coda waves measured at the same lapse times between ERI and TSK are, on the average, 20 times at 0.75 Hz and less than 1/10 at 24 Hz (TSUJIURA, 1978a).

Fig. 100


TSK (LOW,1)
TSK (MIDDLE,10) '76 FEB. 29 18 27
ERI (3.5)
1 min
ORIGIN TIME
ORIGIN TIME
TIME
fo
0.75
Hz
1.5
3
6
12
24

4. Conclusion

In order to demonstrate the local and regional features of seismograms, including the waveform, spectrum and phase appearance, a seismogram collection has been made using the data of DDR station stored during the last two decades. One hundred samples of characteristic seismograms from local to teleseismic events are selected. Among these seismograms, some of them are already well known, however, there still includes some new phenomena.

The history of observation at DDR station is very short compared with the history of earthquakes. It is interesting to note that the seismogram features shown in this collection are a temporal phenomenon or characteristic of each region. As shown in Figs. 57, 66 and 68, earthquakes occurring at almost the same locations show similar waveforms independent of the time of occurrence and the seismic region. Such a phenomenon therefore suggests that the earthquakes occurring in a certain region reflected an inherent nature in each region.

Spectral differences of seismograms, however, are seen among the earthquakes in the same region (see Figs. 5, 47, 56 and 59). The earthquakes affect the influence of environmental conditions. It must be also noted that these differences are due to the temporal variation of stress condition or the local difference of tectonic nature in their regions.

Another interesting point of this collection is a comparison of the seismograms with those for other stations. If similar results are obtained, these features will remain as the source effects.

The seismograms hold a great variety of information. Although the seismograms presented here are not enough in each region, this collection will be useful not only as materials for study, but also for better understanding of earthquake phenomena.

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This is my final work at the Earthquake Research Institute, University of Tokyo.

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地 震 記 象 集

地震研究所　辻　浦　　賢

一般に，ある地震観測所で記録される地震記象は発震機構，伝播経路の影響により，又震源距離，震源の深さ等によっても異なり，多様な記象形態を示す.

今般，地震記象の地域性，深さの依存性，および特殊な地震記象の存在を明らかにするため，堂平地震観測所 20 年間の広帯域資料を用い，地震記象集 “Characteristic Seismograms” の編集を試みた.

ここで示した記象集は，近地地震から遠地地震について，地域別，深さ別，或は震源距離別に分類し，夫々特徴のある地震記象を選ぶと共に群発地震，前震，地下核実験等の特徴ある記録をも加え合計 100 枚の図として編集した. 得られた記象集には地域別，深さ別，あるいは震源距離に沿っての位相 (phase) 出現の様相，スペクトル，波形の相似性等の特徴が見られると共に今回新しく見出された現象も含まれる.

本資料は個々の地域について不充分であるものの，夫々の地域についての特徴を反映したものと考えられ，教材の補足として，又地震現象のよりよい理解のためにも有効であろうと考えられる. 更に資料の蓄積を待ってより充実した記象集の完成を希望するものである.