ROYAL OBSERVATORY, HONG KONG

Technical Note (Local) No. 63

INTERPRETATION OF SEISMOGRAMS OF EARTH TREMORS FELT IN HONG KONG, 1979-1991

by

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Symbols

ISC	:	International Seismological Centre
WDCA	:	World Data Centre A for Solid Earth Geophysics
SSB	:	State Seismological Bureau, Beijing, China
NEIC	:	National Earthquake Information Centre
HKC	:	Station code of the WWSSN seismograph station at the Royal Observatory Headquarters
CCHK	:	Station code of the seismograph station at Cheung Chau
THK	:	Station code of the seismograph station at Tsim Bei Tsui
YHK	:	Station code of the seismograph station at Yuen Ng Fan
δ or	:	Epicentral distance measured in km or degree latitude

1. Introduction

In order to monitor earthquakes occurring in the vicinity of Hong Kong, the Royal Observatory set up in 1979 a network of three short-period seismographs at Cheung Chau (CCHK), Tsim Bei Tsui (THK) and Yuen Ng Fan (YHK) (Fig. 1.1). The instruments used are Teledyne Geotech model S-13 seismometers (Fig. 1.2). They continuously record the vertical motion of the Earth. The station and instrument descriptions are given in Table 1.1.

During 1979 - 1991, a total of 21 felt tremors were reported by local residents. The epicentral distances range from within the Hong Kong territory to over 1000 km away. The seismic phases appearing on the seismograms are routinely analysed. This report documents the techniques used and presents results of the analysis. It is hoped that the report can serve as a handy reference for the analyst to recognize characteristics of seismic waves generated in various areas around Hong Kong.

A glossary of commonly used seismological terms is given in Appendix I. The terminology used in the classification of earthquakes according to focal depth and epicentral distance is given in Appendix II.

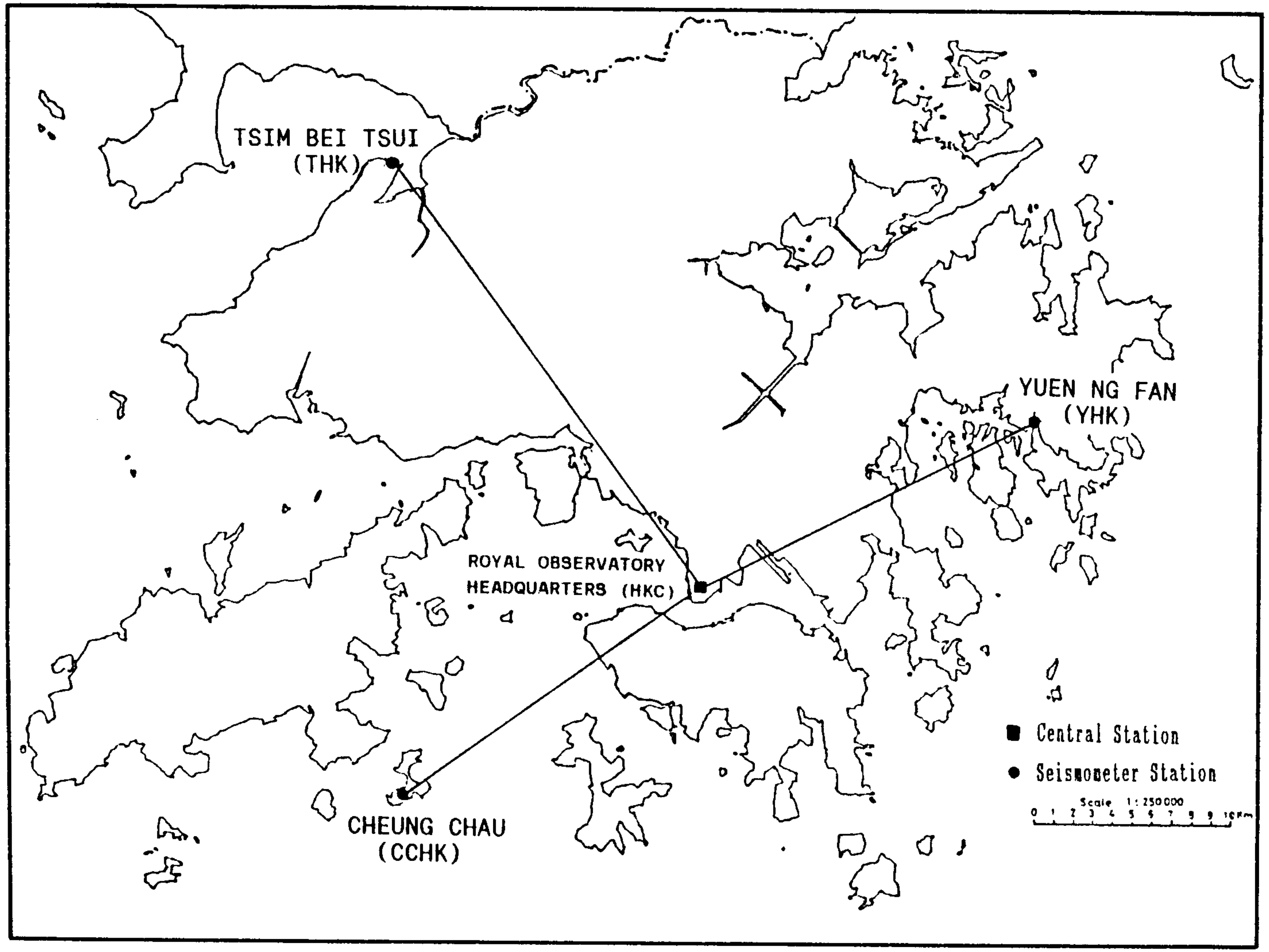

Fig. 1.1 The Hong Kong short-period seismograph network

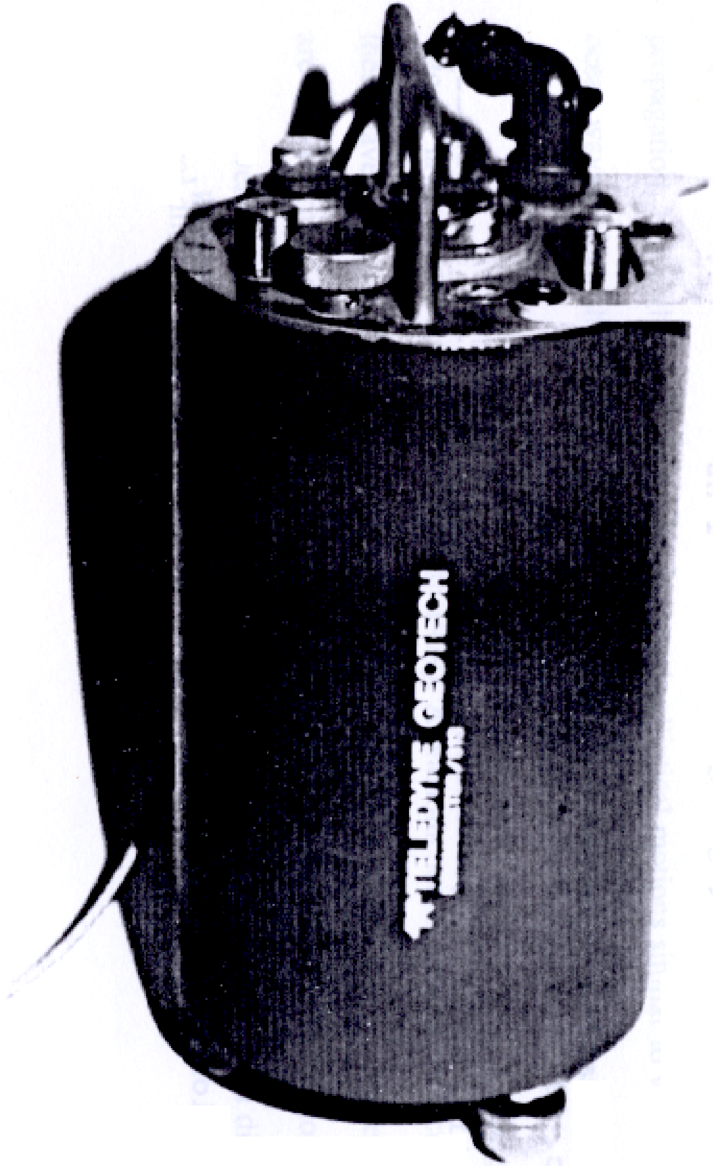

Fig. 1.2a A Teledyne Geotech Model S-13 Seismometer.

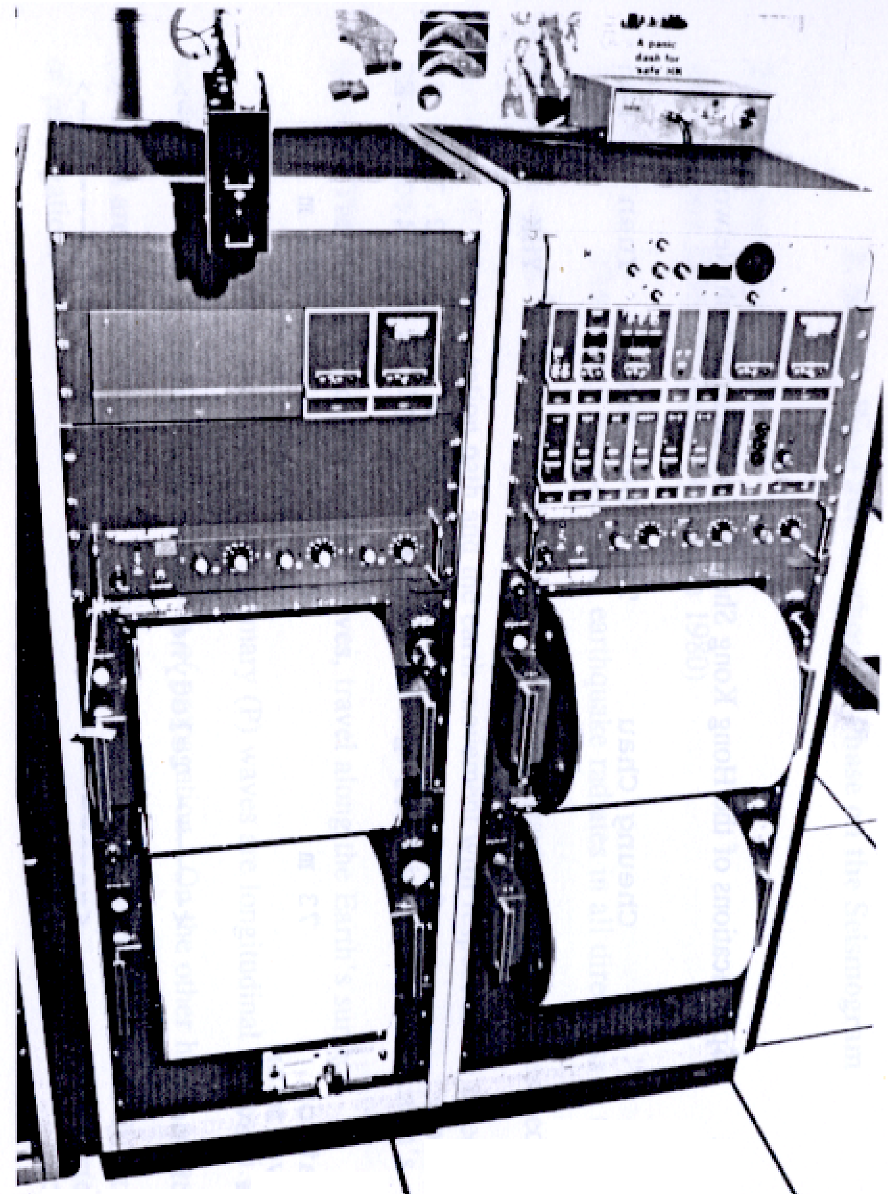

Fig. 1.2b Helicorders at the Royal Observatory Headquarters.

Table 1.1 Specifications of the Hong Kong Short Period Seismograph Network

Station	Cheung Chau	Tsim Bei Tsui	Yuen Ng Fan
Code	CCHK	THK	YHK
Location	22.2029 N 114.0243 E	22.4878 N 114.0093 E	22.3792 N 114.3354 E
Elevation (above mean sea level)	73 m	4 m	87 m
Instrument	<------ Teledyne Geotech: Model S-13 ------>		
Recording System	<--------------- Pen and Ink -------------->		
Measured Component	<----- Vertical Movement of the Earth ----->		
Natural Frequency	<----------------- 1 Hz ------------------>		
Magnification (Dec. 1991)	5748	7159	8495
Inertial Mass	<---------------- 5Kg ± 1% --------------->		

*Location of Royal Observatory Headquarters : 22.3036N, 114.1719E

2. Seismic Wave and Earthquake Phase on the Seismogram

2.1 Different Kinds of Seismic Wave

(Ref: Richter 1958, Hodgson 1964, Lam 1980)

The energy released by an earthquake radiates in all directions in the form of seismic waves. There are four basic kinds of seismic waves which are classified according to the propagation path and the earth movement with respect to the direction of propagation (Fig. 2.1). Two of them are **body waves** that travel through the Earth's interior. The other two, called **surface waves**, travel along the Earth's surface.

Among the body waves, primary (P) waves are longitudinal waves, i.e. the earth movement is parallel to the direction of propagation. On the other hand, secondary (S) waves are transverse waves, i.e. the earth movement is perpendicular to the direction of propagation.

The two kinds of surface waves are Love (LQ) waves and Rayleigh (LR) waves. Love waves are shear waves which move the ground from side to side in a horizontal plane parallel to the Earth's surface, but at right angles to the direction of propagation. Rayleigh waves consist of retrograde elliptical motions similar to wind-driven ocean waves which shake the ground both vertically and horizontally.

In addition to the above, there are special waves which propagate along low velocity layers in the Earth's interior (Bath 1979). A phenomenon of internal reflection, these waves are termed channel waves or guided waves. In a broad sense, surface waves are also a form of channel waves. The energy of channel waves is concentrated along certain levels and as a result, wave propagation can extend over a long horizontal distance. Such waves diminish rapidly outside the 'channel'.

A seismogram shows more or less prominent displacements corresponding to the onsets of a number of specific pulses. These pulses include those due to the P and S waves, or due to waves that have suffered reflection or change of wave type at discontinuity surfaces (see Section 2.2). Such displacements mark the **phases** of the seismograms. Each phase is an indicator of a particular type of wave travelling along a particular path.

Fig. 2.2 is a seismogram recorded at the Royal Observatory showing P, S, channel and surface waves generated by an earthquake near the east coast of Honshu, Japan in December 1987. It can be seen that S waves have slightly longer periods than P waves and that surface waves have the longest periods.

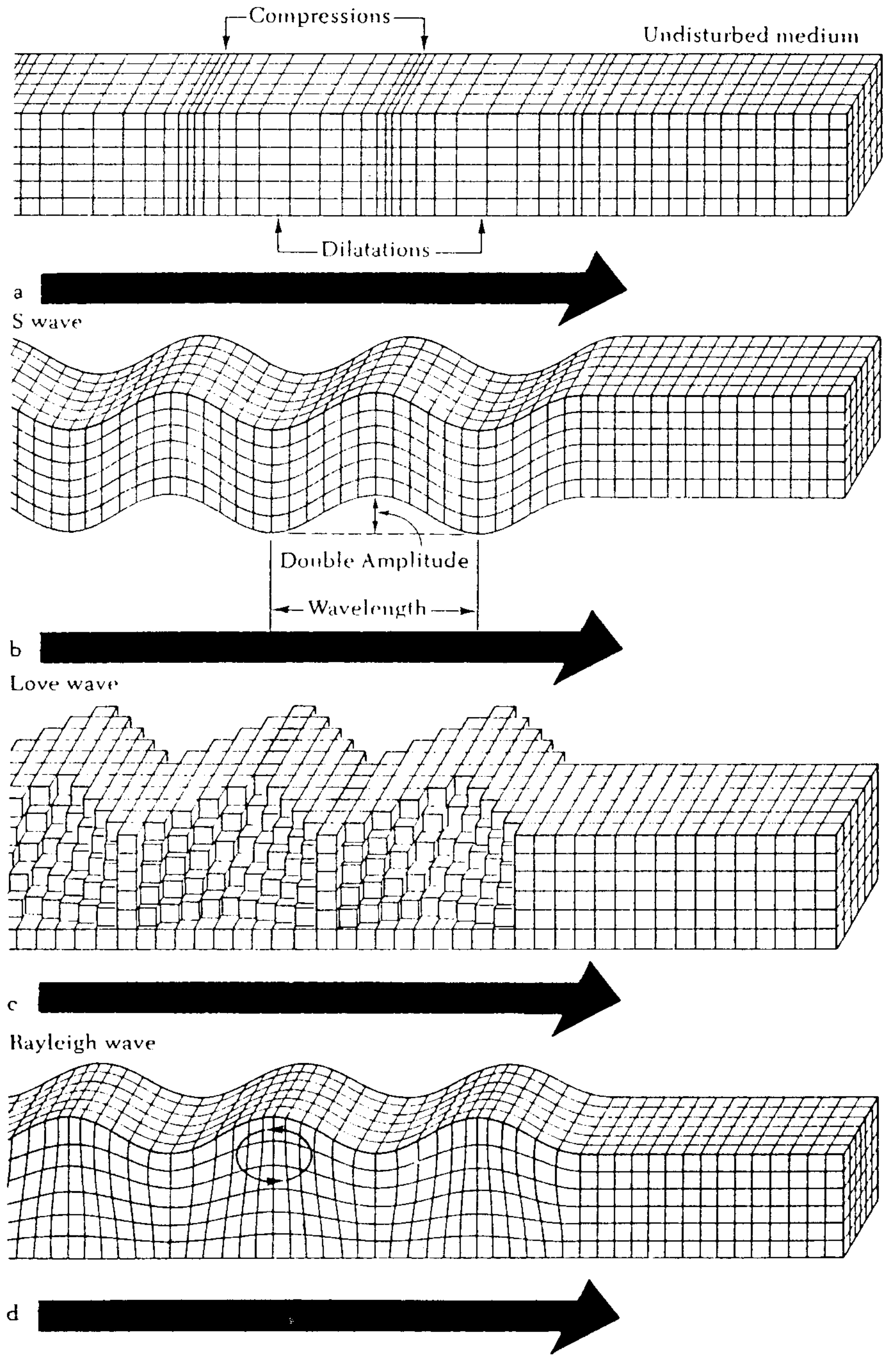

Fig. 2.1 The forms of ground motion near the ground surface in four types of earthquakes waves (Bolt 1978).

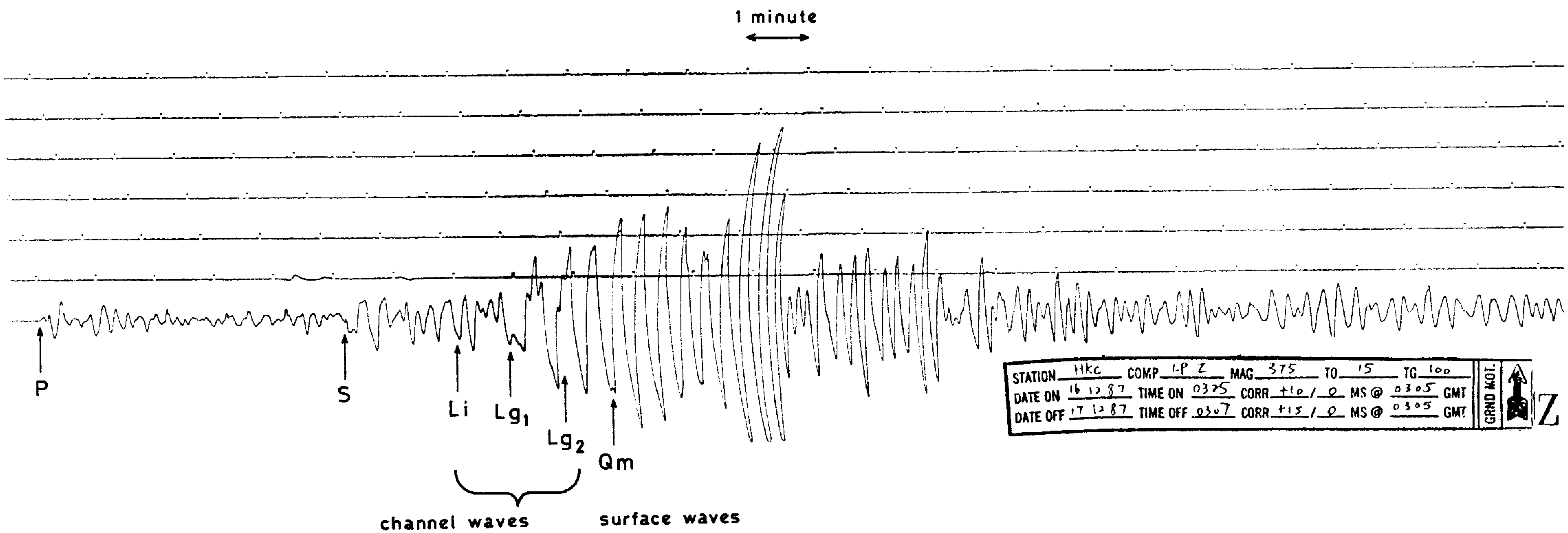

Fig. 2.2 Long-period seismograms recorded in Hong Kong showing P, S, channel and surface waves generated by a magnitude 6.0 (Mb) earthquakes near the east coast of Honshu, Japan (35.4°N, 140.2°E), on 17 December 1987.

2.2 **Internal Structure of the Earth**

As mentioned in Section 2.1, the path of seismic waves are affected by discontinuities inside the Earth. As illustrated in Fig. 2.3, the Earth's interior can be divided into the following three main parts (Bath 1979):-

i. The Earth's crust : too thin to be more than a line in the scale of drawing;

ii. The Earth's mantle : the upper mantle and the lower mantle;

iii. The Earth's core : the outer core and inner core.

Of special interest are two discontinuities within the crust that affect propagation of near and local earthquake waves: the Conrad discontinuity and the Mohorovicic discontinuity. Fig. 2.4 shows a typical crustal cross-section.

There are geographical variations in the depth of these discontinuities. Whereas in Tibet the depth of the Mohorovicic discontinuity is over 70 km, along the south China coast it decreases to about 30 km (Fig. 2.5).

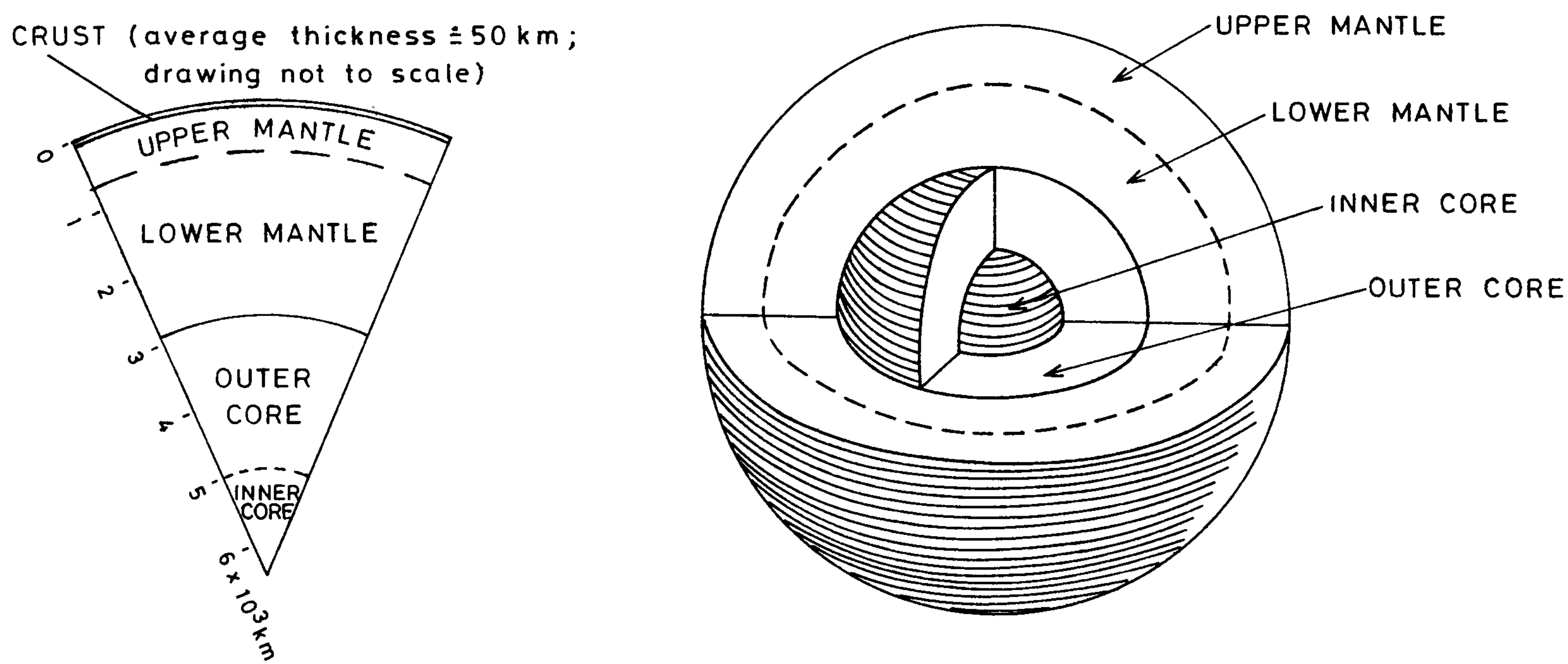

Fig. 2.3 Schematic drawings of the internal structure of the Earth.

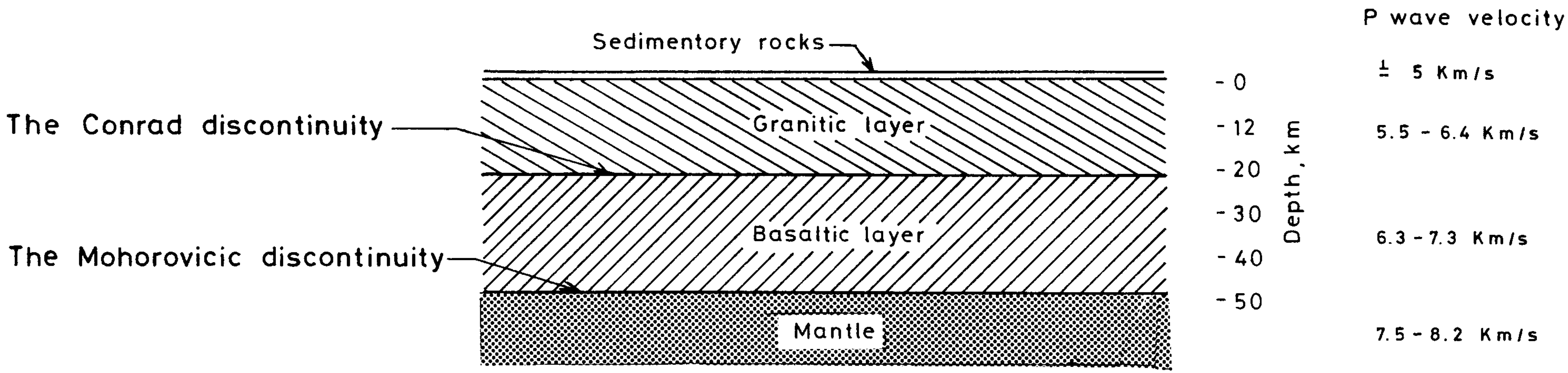

Fig. 2.4 A typical crustal cross-section (Hodgson 1964, Willmore 1979).

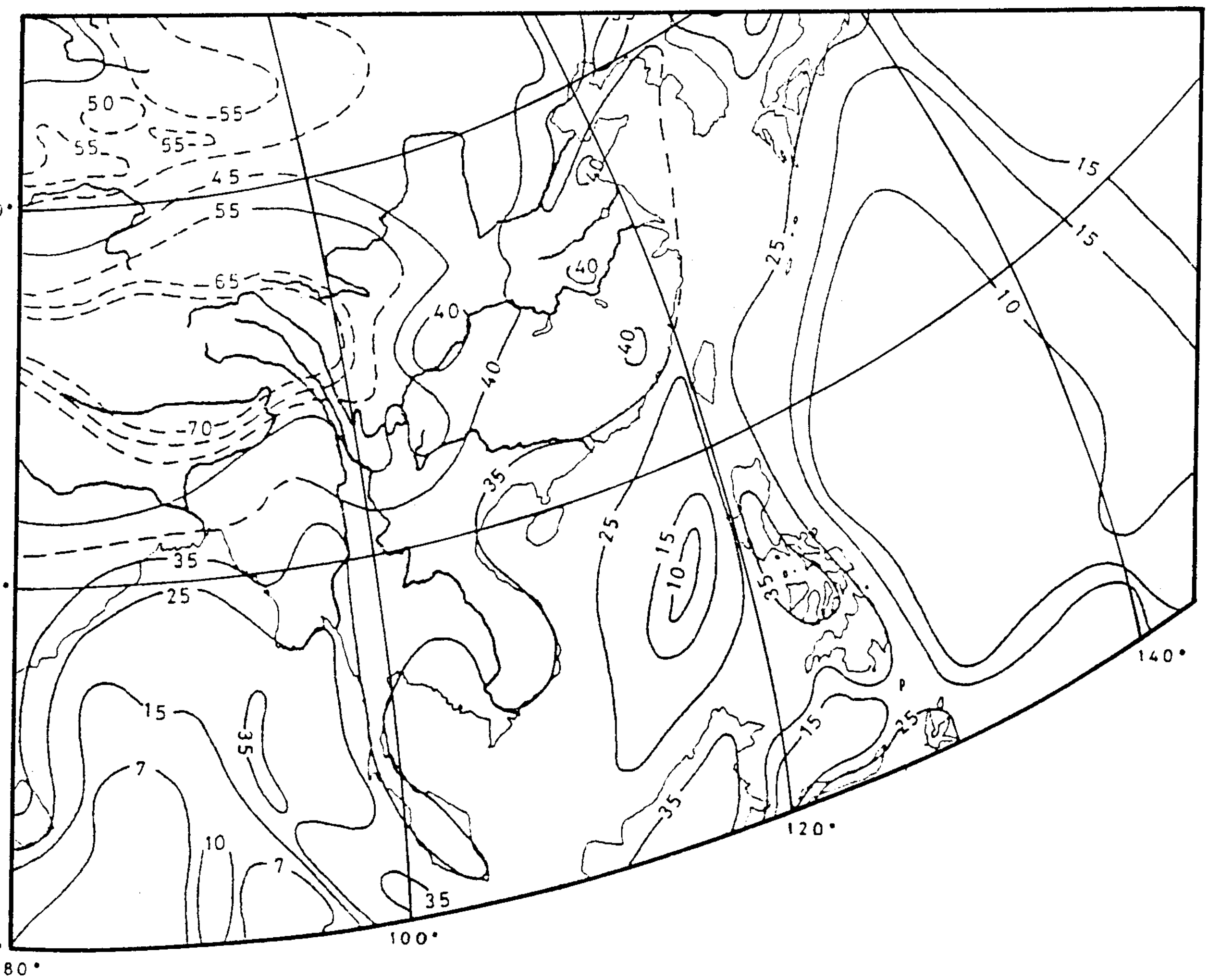

Fig. 2.5 Depth of the Mohorovicic interface in East Asia. Solid line shows the actual depth. Dotted line show the estimated depth.

2.3 Nomenclature of Seismic Phases Generated by Near and Local Earthquakes

(Ref: Richter 1958, Bath 1979, Willmore 1979 and Zhang 1986)

For earthquakes originating from the upper part of the crust, i.e. shallow earthquakes, waves which travel directly to the detector are called **direct waves**. Symbols for these are Pg and Sg, as shown in Fig. 2.6. In the same figure, P_C and S_C denote waves reflected from the Conrad discontinuity while P* and S* denote waves refracted from the same discontinuity. In the same way, P_M, S_M and Pn, Sn denote waves reflected and refracted from the Mohorovicic discontinuity respectively. Pn and Sn waves are sometimes described as **head waves**. This is because for epicentral distances exceeding 1.2° (133 km), Pn and Sn waves arrive before other P and S phases, respectively.

Apart from the body waves, channel waves and surface waves may also appear on the short-period seismograms (Zhang 1986). The earthquake of northern Vietnam (Section 4.1) is an illustrative example. Channel waves observed in the case include πg and Lg. πg is longitudinal wave whereas Lg is transverse wave. Both travel in the low-velocity granitic layer. Short period channel waves typically propagate through a continental crust. Such waves do not propagate through the ocean, e.g. from the Philippines (Xu and Zhou 1982).

For a deep-focus earthquake, special types of reflection will take place at the surface of the Earth near the epicentre (Fig. 2.7). Small letters p and s, as in pP, pS, sS and sP, are used to denote these **depth phases** which have undergone a reflection at the Earth's surface. Whereas pP and sP are P and S waves reflected from the surface as P waves, pS and sS are those reflected as S waves.

For notations of different phases, please refer to Appendix III.

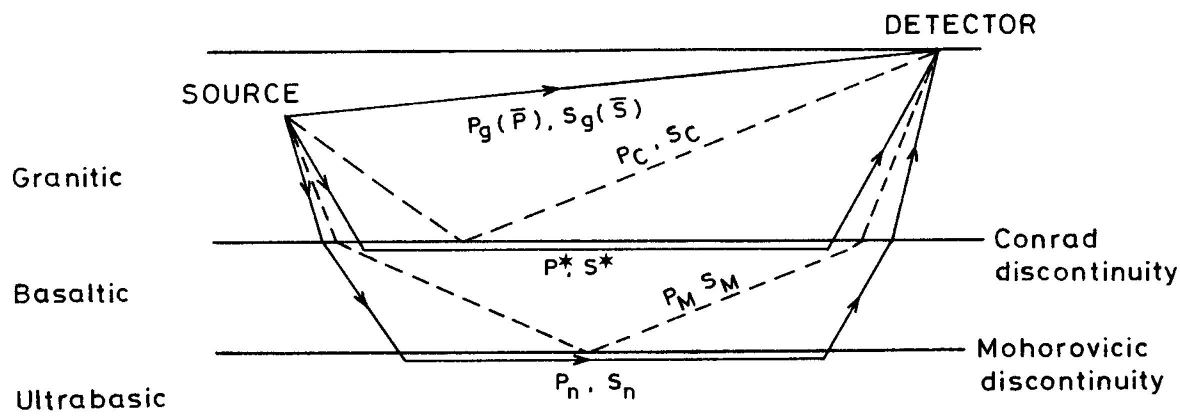

Fig. 2.6 Seismic waves propagating in the Earth's crust.

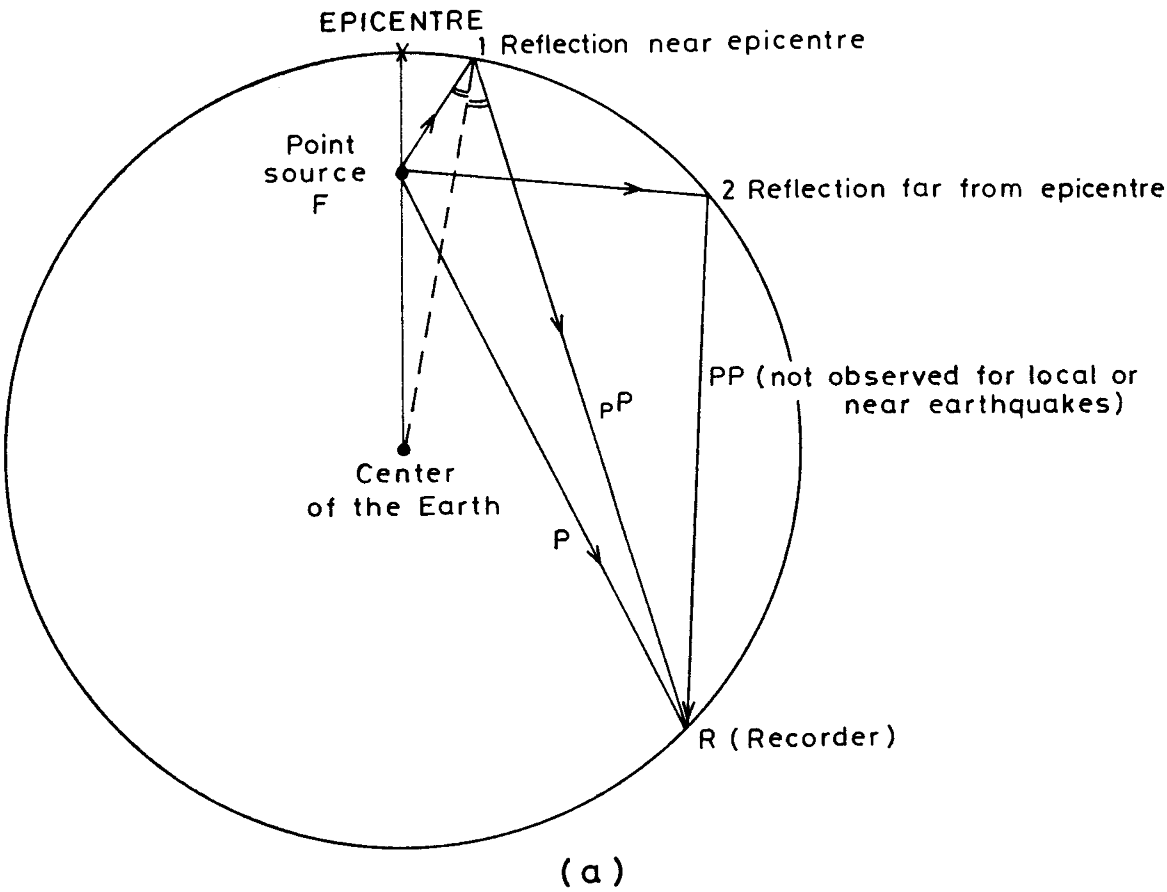

Fig. 2.7a Schematic illustration of pP and P waves (Bolt 1981). For simplicity, rays are drawn as straight lines.

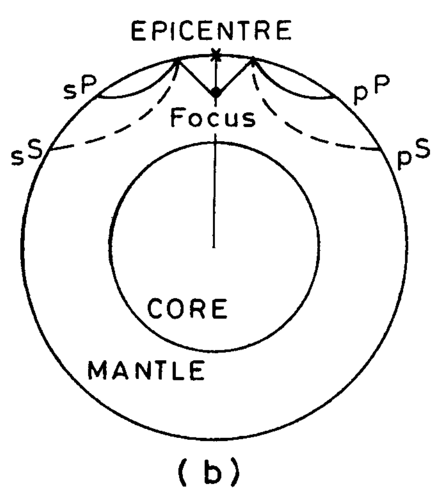

Fig. 2.7b Paths of depth phases. Solid lines show longitudinal waves, dotted lines show transverse waves (Richter 1958).

3. Some Techniques in Identifying Seismic Phases Generated by Near and Local Earthquakes

(Ref: Bolt 1978, Fu et al. 1980, Xu and Zhou 1982, Zhang 1986, Zhao 1987)

3.1 Arrival Times of Different Phases

The average velocity of each wave type differs from one another. Although seismic waves are generated at the same time when the earthquake occurs, they arrive at an observing station at different times. In general, primary (P) waves arrive first, followed by the secondary (S) waves. Then come the channel waves or surface waves (Fig 2.2). The greater the distance covered by the waves, the greater the time separation among them.

3.2 Determination of P Phase

The easiest phase that can be determined is the P wave, as it is the first to arrive and the trace on the seismogram is normally in a relatively undisturbed state prior to its arrival.

3.3 Determination of S Phase

The second phase to look for is the S wave. This can usually be distinguished by a sudden change in frequency and/or amplitude of the prevailing waveform. Once the time interval between the arrivals of S and P, usually denoted as S-P, is determined, the epicentral distance can be estimated using a standard travel-time table.

3.4 Determination of Other Phases

Once the epicentral distance is found, the approximate arrival times of other phases can also be estimated using the same travel-time table. Based on these estimated times, the arrival time of a phase can then be determined by scrutinising the changes in waveform characteristics on the seismogram. When there is some degree of uncertainty in determining a phase or arrival time, the phase will be identified with brackets.

3.5 Travel-Time Table

The commonly used travel-time tables are the Jeffreys-Bullen Table (1970) and the table prepared by the State Seismological Bureau of China (SSB 1980). They are compiled on the basis of differences in the seismic wave velocity. These tables are used extensively in the present study.

3.6 Evidence of the Arrival of a Phase

In seismogram analysis, the usual clues that a new phase has arrived are a sudden increase in amplitude or a change in frequency. 'White gaps' may appear on a densely written seismogram at the time when the frequency changes. The leading edge of such a gap gives the onset time of a phase. When a second phase arrives and superimposes on the first phase, a sudden change in the direction of the recorded trace can often be observed.

3.7 Amplitudes of Different Phases

The amplitudes of P waves are usually smaller than those of the S waves. For near and local earthquakes, Pg is much smaller than Sg. Except for deep focus earthquakes, surface waves have the greatest amplitudes. Compared with direct waves, refracted and diffracted waves are generally weaker.

3.8 Characteristics of Deep Focus Earthquakes

In general, high frequency components of seismic waves are more attenuated during their propagation through the body of the Earth. As the attenuation of seismic waves is less in the mantle than in the crust, the high frequency components of deep focus earthquakes propagate much farther than those of shallow earthquakes. As a result, wave periods are usually shorter for deep focus earthquakes, as compared with shallow quakes at the same epicentral distance. For deep earthquakes, the angle of the rays arriving at the surface is usually large. Individual phases therefore have sharper onsets and are well developed. The surface wave is however very weak, and is sometimes absent.

3.9 Comparison of Phase Data Determined from Different Stations

Due to the different geographical locations of the three local stations (Fig. 1.1), the arrival times for a certain phase of an earthquake registered at the three seismographs will normally be different. Their order of arrival will give an indication of the direction from which the seismic wave comes. As an example, for an earthquake located to the north of Hong Kong, the P phase will first be registered at THK, then at YHK and lastly at CCHK. The time differences S-P will also be shortest as recorded at THK and longest at CCHK. Comparison of data among the three stations therefore provides a useful indication of phase identities.

4. Analysis of Felt Tremors

The 21 tremors felt in Hong Kong during 1979-1991 occurred respectively in Guangdong, Jiangxi, Taiwan, Luzon of the Philippines, northern Vietnam, as well as within the territory of Hong Kong (Fig. 4.1-2). The farthest one recorded so far was located in northern Vietnam near the Vietnam-China border, just over 1100 km from Hong Kong.

Parameters, such as epicentral position, magnitude, focal depth and origin time for most of these earthquakes were post-analysed by various international seismological centres. These centres include the International Seismological Centre (ISC) in U.K., National Earthquake Information Centre (NEIC) of U.S.A., State Seismological Bureau (SSB) and Guangdong Seismological Bureau (GSB) of China. In the present study, seismic phases were identified for each of the felt earthquake events as recorded in Hong Kong, with reference to earthquake parameters published by the above centres. The intensity of each case, as felt in Hong Kong, were expressed in the Modified Mercalli Scale.

Since seismic waves emanating from the same area usually exhibit similar waveform characteristics, the felt tremors were grouped according to their epicentral positions.

For the convention in reporting a phase, please refer to Appendix IV.

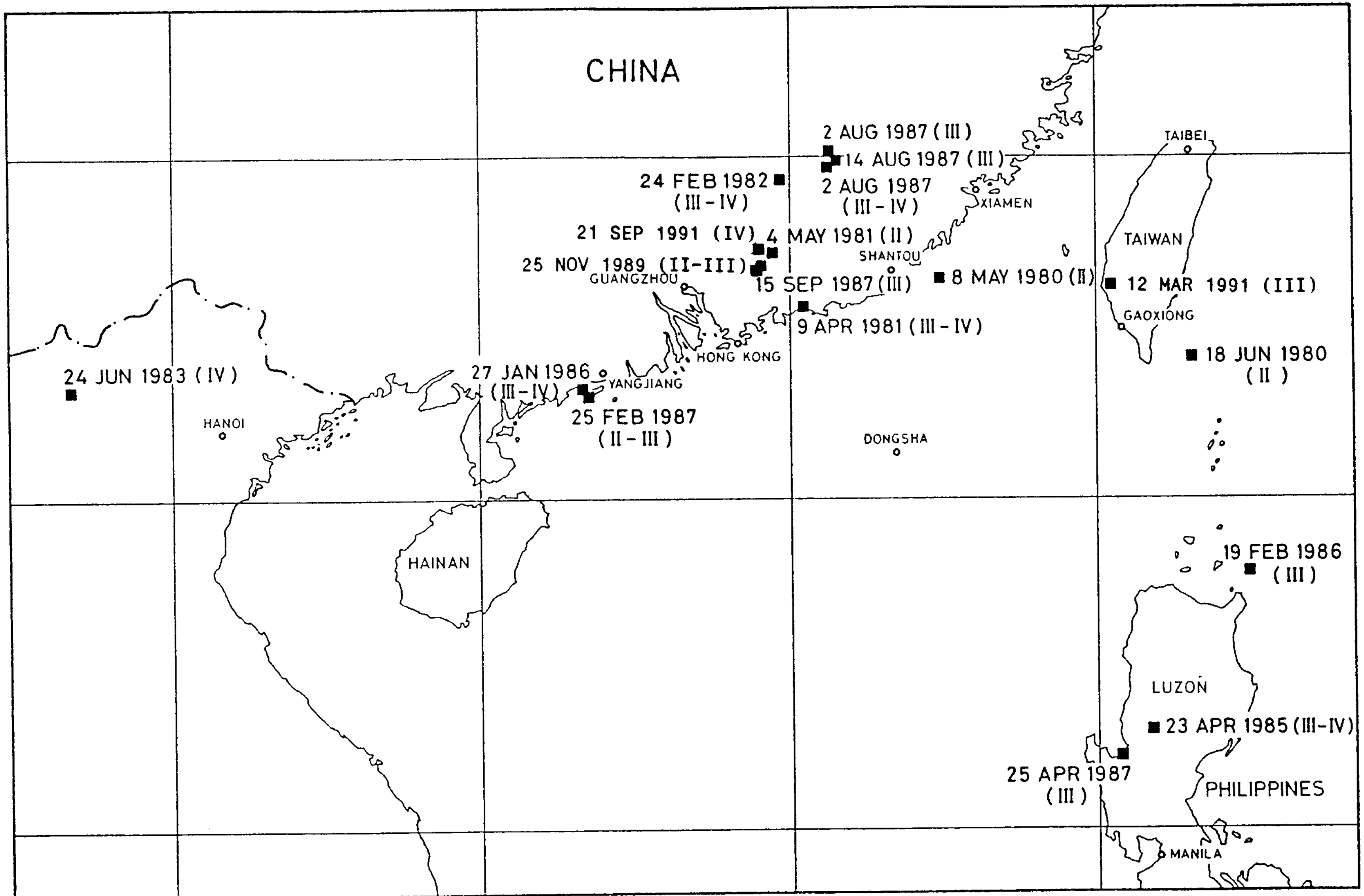

Fig. 4.1 Epicentres of felt tremors, 1979-1991.

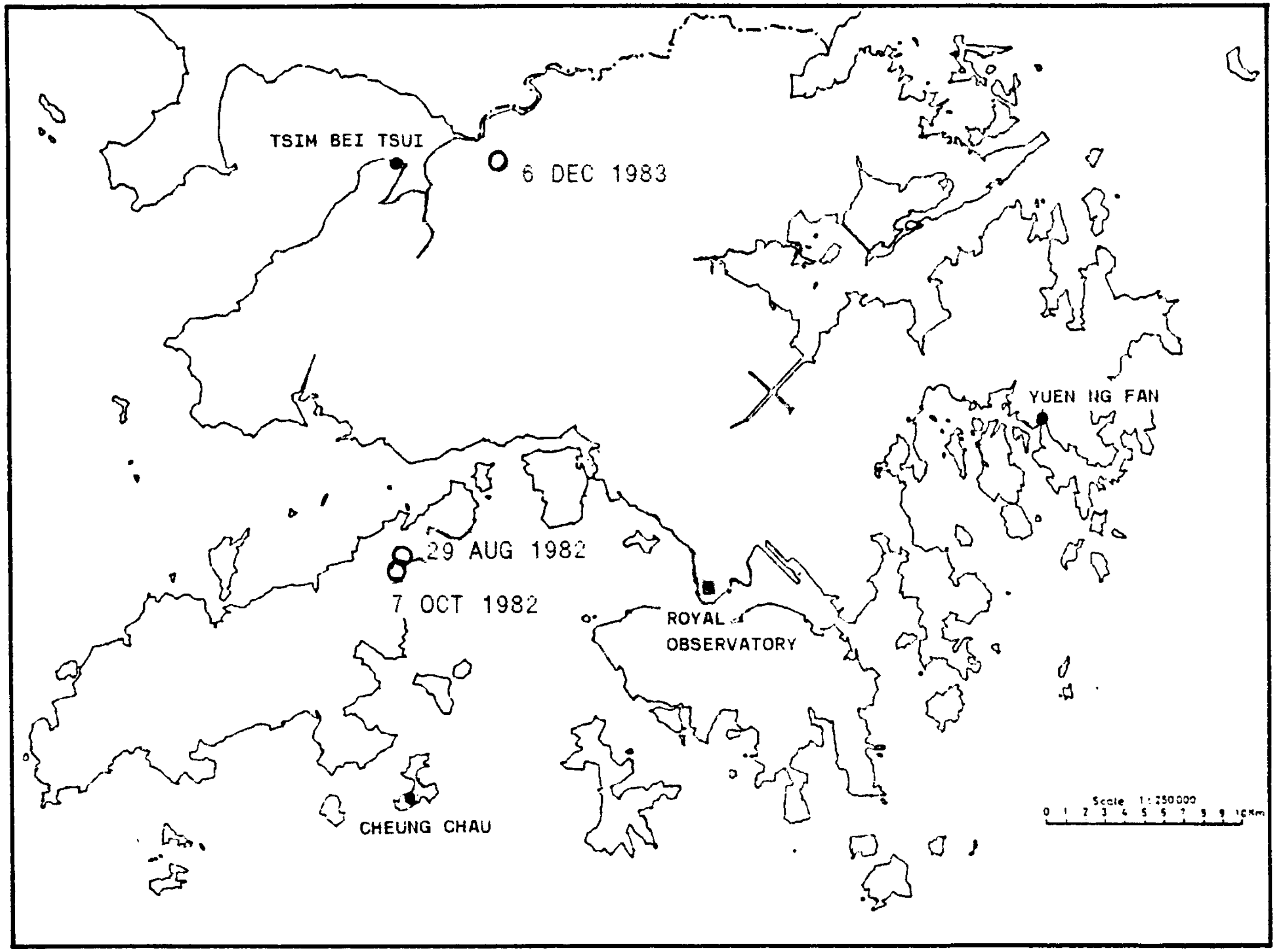

Fig. 4.2 Epicentres of felt tremors located within the Hong Kong territory, 1979-1991.

4.1 Occurring in Northern Vietnam on 24 June 1983 (Fig 4.3) Epicentral distance = 10.1°

This was the farthest earthquake felt in Hong Kong between 1979 and 1991. It occurred in the northern part of Vietnam near the border of China. The epicentre was about 10.1° (1120 km) west of Hong Kong (Fig. 4.1). Seismograms of the earthquake are shown in Fig. 4.3.

For seismic waves traversing a continent, the phases (arriving at the observing station) to look for, in addition to the P and S phases, were the channel waves πg and Lg. Phases following the P phase were identified and confirmed using the SSB Table (1980).

On the record of CCHK (Fig. 4.3), the onset of the vibration marked the arrival of the P wave. Following this, at some point on the trace there was a sudden increase in amplitude, coupled with a phase change. This indicated the arrival of another wave, subsequently identified to be πg.

Following πg, channel waves Lg1 and Lg2 manifested themselves as sudden changes in the wave frequency and the amplitude. Similar to πg, these two waves were also channel waves traversing through granitic layers in the continental crust. The S phase did not stand out on the trace.

In a similar way, phases of P, πg and Lg1 identified for records of THK and YHK (Fig. 4.3). With larger magnification settings in the seismographs at THK and YHK, the large surface and channel waves exhibited amplitude saturation on the record. As the vertical component of Lg2 is usually very strong (Zhang 1986), amplitude saturation prohibited its identification from these two records.

The phase arrival times (x) and their time references from P (x-P) were also listed in Table 4.1. For each phase, the corresponding epicentral distance was worked out using SSB table. The results of the time difference πg-P suggested an epicentral distance of about 11.5° which was about 1° larger than the values deduced from other phases. This may be explained by the fact that the travel time table is not exactly true and there were also some errors in picking the different phases.

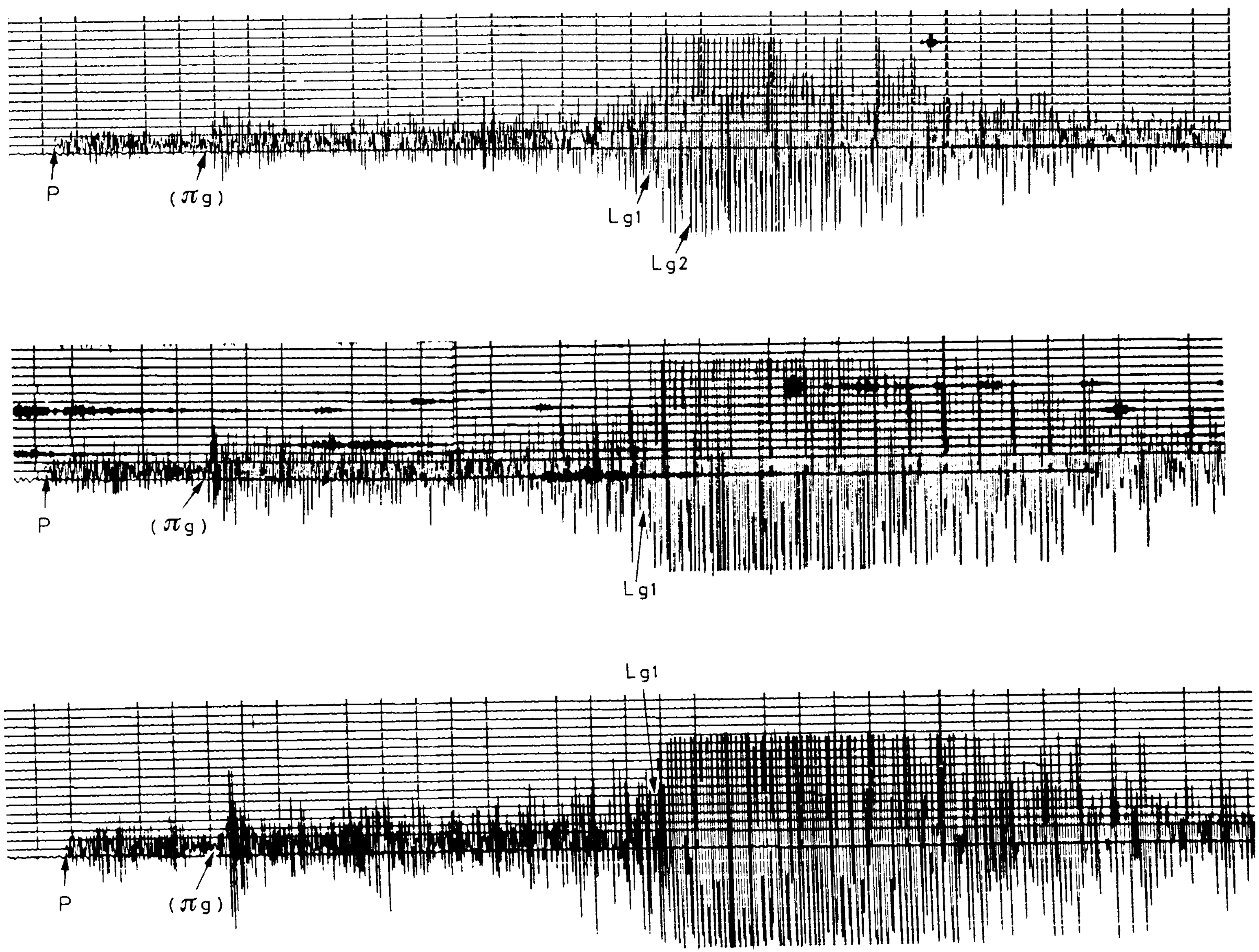

Fig. 4.3 Seismogram of felt tremor located in northern Vietnam (24.6.83).

Table 4.1 : Phase data for the earthquake located in northern Vietnam

Date	:	24.6.1983
Location	:	Northern Vietnam
Intensity	:	IV

ISC Data:-

Epicentre	:	21.77N 103.31E (δ=10.1°)
Depth	:	18 km
Magnitude	:	6.0Mb, 6.5Ms (See Appendix I.iv)
Origin Time	:	07:18:22.3 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-P** mmss.s	**δ** °
CCHK	eP	072043.1	---	---
(δ=9.9°)	(πg)	2127.5	0044.4	11.4
	Lg1	233(5.3)	0252.2	10.3
	Lg2	2345.4	0302.3	10.0
THK	eP	072043.1	---	---
(δ=9.9°)	(πg)	2128.1	0045.0	11.5
	Lg1	2334.6	0251.5	10.4
YHK	eP	072046.8	---	---
(δ=10.2°)	(πg)	2131.3	0044.5	11.5
	Lg1	2338.0	0251.2	10.3

4.2 **Luzon, Philippines**

Since 1979, there were a total of three felt earthquakes located near Luzon, Philippines. Channel waves through the continental crust, such as the πg and Lg waves observed for the Vietnam earthquake (Section 4.1), were not observed because of the presence of the South China Sea between Luzon and the south China coast.

Among the three events, the earthquake of 23 April 1985 and that of 25 April 1987 were of intermediate depth and the epicentres were close to one another. The seismograms of these two events exhibited very similar characteristics. As will be elaborated, one of the depth phases, the sP phase, provides a good indication of the focal depth.

4.2.1 **Earthquake on 23 April 1985 (Fig.4.4), Epicentral distance = 9.3°, Focal depth = 181 Km**

The onset of the P phase was of the 'emersio' type (See Appendix IV). Compared with YHK and CCHK, the onset time at THK lagged by 3 s, because the station is farther away from the earthquake source.

In contrast to the P waves, the S wave arrived about 2 minutes later, with a sharp increase in amplitude. Epicentral distances deduced from S-P differences were quite consistent (see Table 4.2a).

Of interest to note is the sP waves which came between P and S waves and were observed at YHK and CCHK. These are S waves reflected as P waves from a point at the surface near the epicentre (Fig. 2.7). The value of sP-P varies very slowly with the epicentral distance and is only sensitive to the focal depth. For CCHK and YHK, the time differences sP-P were estimated to be 46.6 s and 46.2 s respectively (Table 4.2a). From travel-time tables in SSB (1980), these time differences of sP-P suggested a focal depth of 199-202 km, deviating slightly from the ISC value of 181 km.

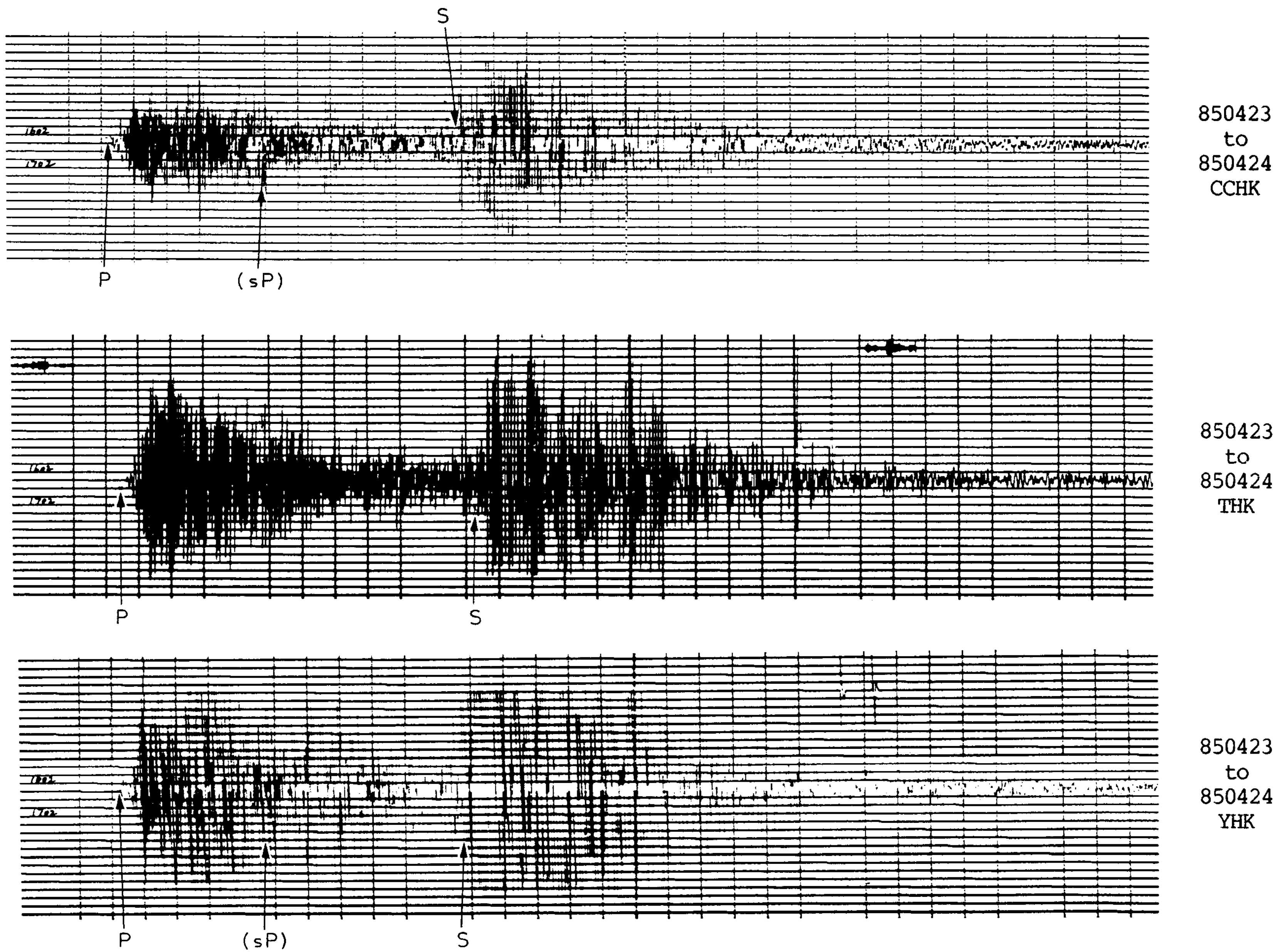

Fig. 4.4 Seismogram of felt tremor located in the region of Luzon (23.4.85).

Table 4.2 : Phase data for the earthquakes located in the region of Luzon

Table 4.2a

Date	:	23.4.1985
Location	:	Luzon, Philippines
Intensity	:	III-IV

ISC Data:-

Epicentre	:	15.32N 120.63E (δ=9.3°)
Depth	:	181 km
Magnitude	:	6.3Mb
Origin Time	:	16:15:11.0 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-P** mmss.s	**δ** °
CCHK	eP	161722.5	---	---
(δ=9.3°)	(sP)	1809.1	0046.6	---
	S	1908.7	0146.2	9.6
THK	eP	161725.3	---	---
(δ=9.5°)	S	1912.4	0147.1	9.7
YHK	eP	161721.3	---	---
(δ=9.2°)	(sP)	1807.5	0046.2	---
	S	1906.2	0144.9	9.5

4.2.2 **Earthquake on 25 April 1987 (Fig. 4.5), Epicentral distance = 8.5°, Focal depth = 100 km**

The earthquake origin of this event was very close to that of 23 April 1985 (Section 4.2.1). Again, the seismograph at THK registered the onset of P waves later than the other two stations.

Deduced from SSB travel-time tables (1980), the S-P differences observed for the three stations suggested an epicentral distance of about 8.3° which differed slightly from the ISC value of 8.5°.

Trailing the P phase by about 4 s was a distinct but unidentifiable phase. It was denoted as 'i' according to established practices.

The sP phase was discernible from the YHK trace only. It appeared as a white gap which signified a phase change. According to SSB(1980), the sP-P time difference for YHK suggested that the focal depth was about 119 km which also differed slightly from the ISC value of 100 km.

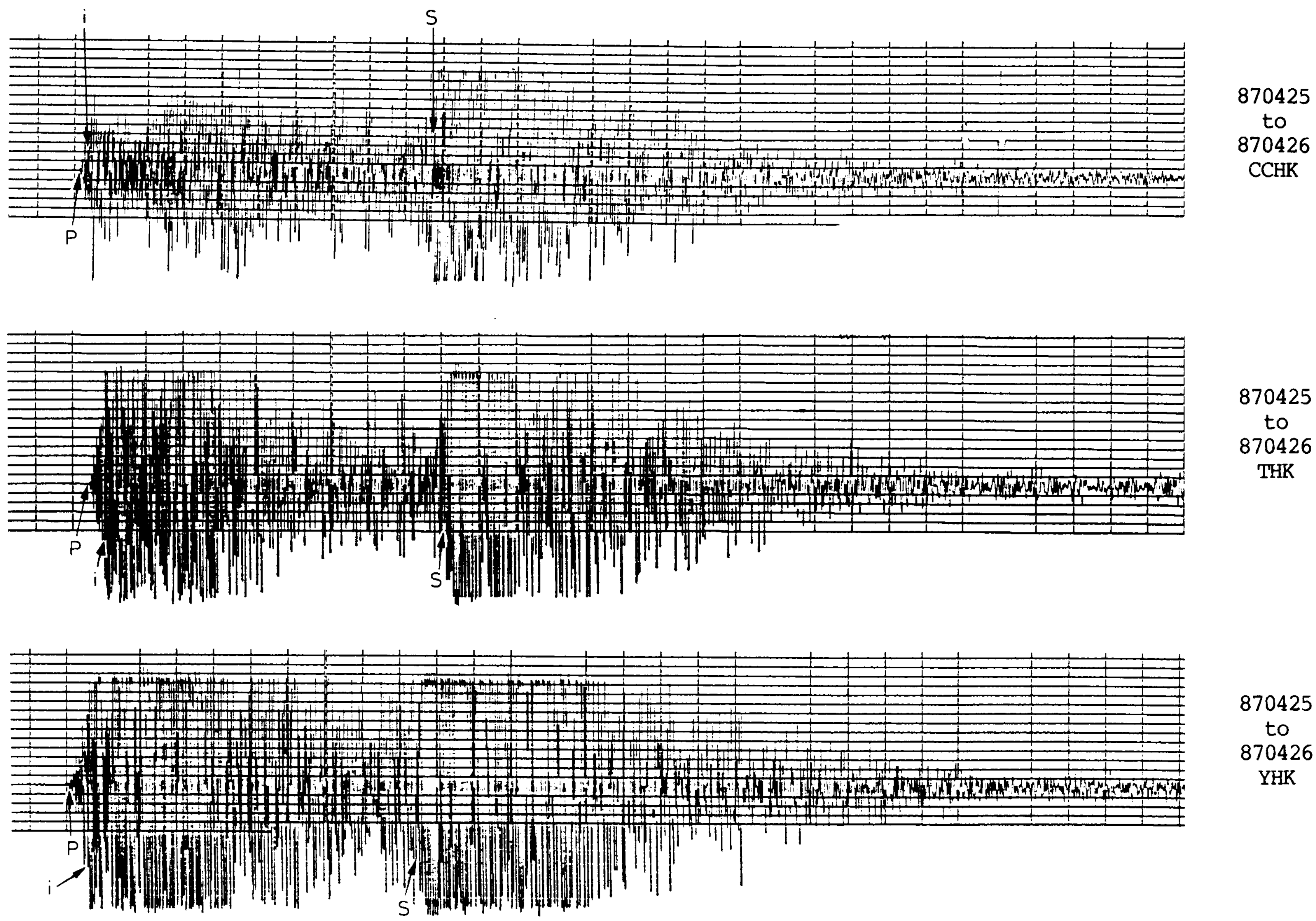

Fig. 4.5 Seismogram of felt tremor located in the region of Luzon (25.4.87).

Table 4.2b

Date	:	25.4.1987
Location	:	Luzon, Philippines
Intensity	:	III

ISC Data:-

Epicentre	:	16.01N 120.24E (δ=8.5°)
Depth	:	100 km
Magnitude	:	6.3Mb
Origin Time	:	12:16:51.3 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-P** mmss.s	**δ** °
CCHK	+iP	121851.5	---	---
(δ=8.5°)	i	1855.1	0003.6	---
	iS	2027.6	0136.1	8.4
THK	+iP	121854.6	---	---
(δ=8.7°)	i	1858.8	0004.2	---
	iS	2030.7	0136.1	8.4
YHK	+iP	121850.5	---	---
(δ=8.5°)	i	1854.6	0004.1	---
	(sP)	1920.6	0030.1	---
	S	2024.7	0134.2	8.4

4.2.3 **Earthquake near the northern coast of Luzon on 19 February 1986 (Fig. 4.6)**
Epicentral distance = 7.5°, Focal depth = 39 km

The fairly distinct and large amplitude onset on all the three records suggest that the first arrival was a direct wave and the event was not a shallow one. This was confirmed from an ISC estimated value of 39 km, for the focal depth which is below the Mohorovicic discontinuity given in Fig. 2.5. Hence, refracted phases, such as Pn and P*, are not expected to appear.

From the sP - P time difference, the focal depth was estimated to be about 50 km, which is a little larger than the ISC value.

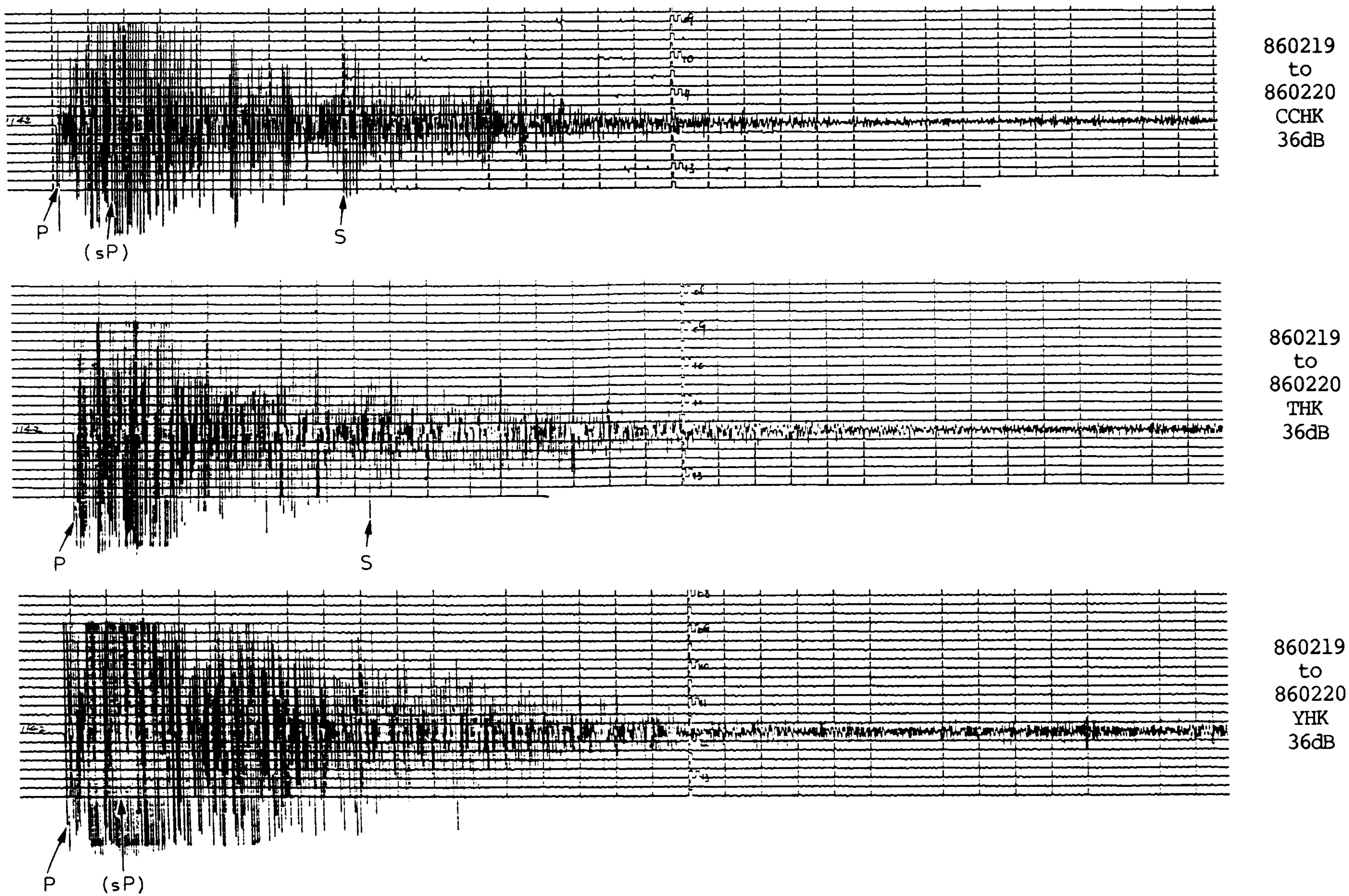

Fig. 4.6 Seismogram of felt tremor located in the region of Luzon (19.2.86).

Table 4.2c

Date	:	19.2.1986
Location	:	Near northeast coast of Luzon, Philippines
Intensity	:	III

ISC Data:-

Epicentre	:	18.98N 121.39E (δ=7.5°)
Depth	:	39 km
Magnitude	:	5.7Mb; 5.8Ms
Origin Time	:	11:40:23.1 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-P** mmss.s	**δ** °
CCHK	-iP	114211.0	---	---
(δ=7.6°)	(sP)	4226.2	0015.2	---
	S	4329.9	0118.9	7.0
THK	-iP	114212.6	---	---
(δ=7.7°)	(S)	4334.0	0121.4	7.2
YHK	-iP	114208.1	---	---
(δ=7.4°)	(sP)	4223.8	0015.7	---

4.3 **Taiwan Region**

There were three felt earthquakes located in the region of Taiwan : (i) off the coast of southern Taiwan; (ii) in the Taiwan Strait near the mainland; and (iii) in southern Taiwan.

4.3.1 **Off the Coast of Southern Taiwan, 18 June 1980 (Fig. 4.7), Epicentral distance = 6.7° Focal depth = 71 km**

Since the THK Seismograph was unserviceable at that time, only records from CCHK and YHK were available.

From the ISC data, the focal depth for this event is 71 km, which is below the Mohorovicic discontinuity indicated in Fig. 2.5. Therefore there should be no refracted phases.

Only the P and S phases can be identified on the seismograms.

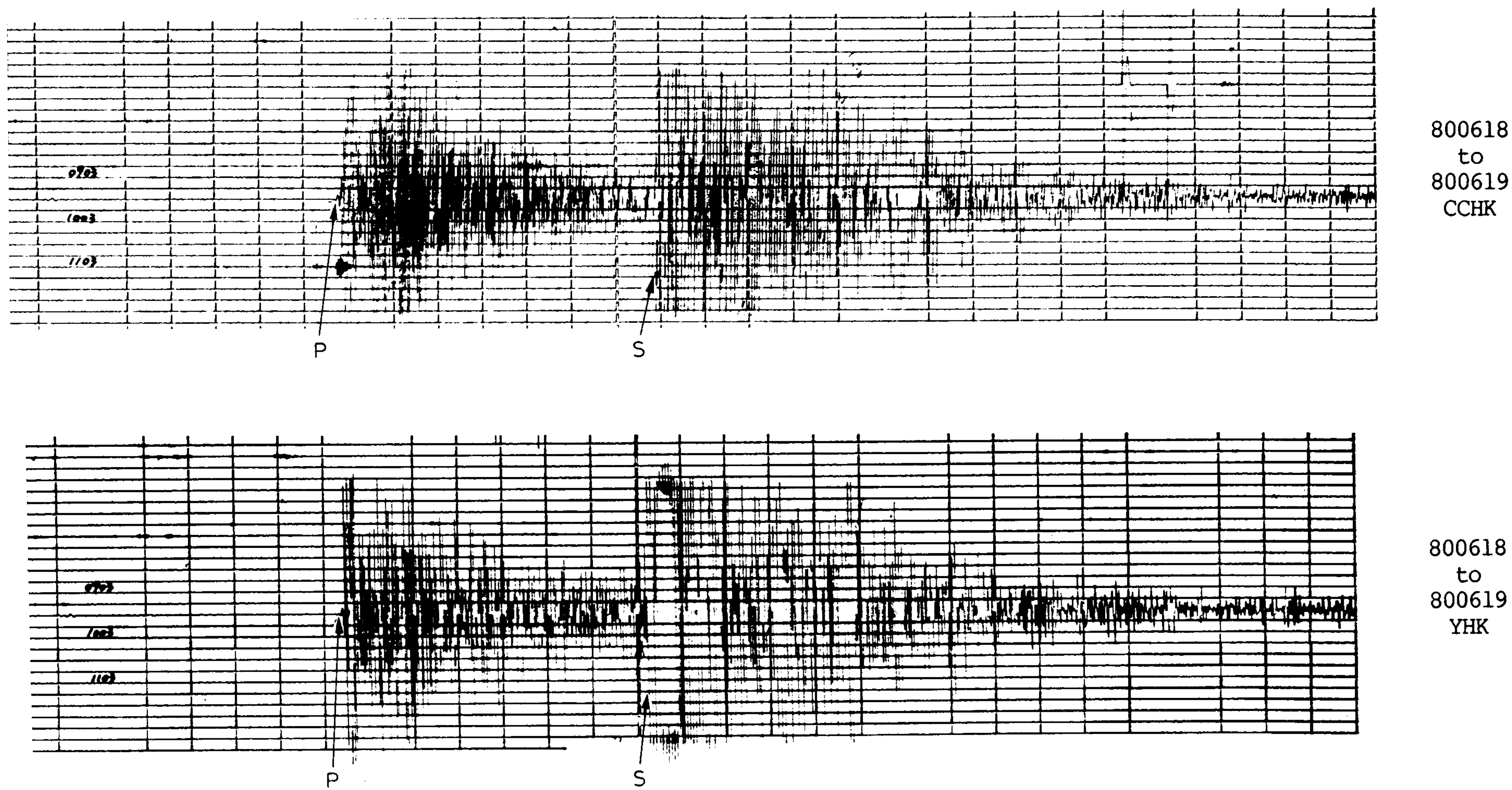

Fig. 4.7 Seismogram of felt tremor located in off the coast of south Taiwan (18.6.80).

Table 4.3 : Phase data of the earthquakes located in the Taiwan region

Table 4.3a

Date	:	18.6.1980
Location	:	Off the coast of southern Taiwan
Intensity	:	II

ISC Data:-

Epicentre	:	22.01N 121.44E (δ=6.7°)
Depth	:	71 km
Magnitude	:	5.7Mb
Origin Time	:	09:32:20.7 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-P** mmss.s	**δ** °
CCHK	eP	093356.4	---	---
(δ=6.9°)	iS	3509.0	0112.6	6.2
THK		unserviceable		
YHK	eP	093353.4	---	---
(δ=6.6°)	iS	3501.3	0107.9	6.1

4.3.2 **Taiwan Strait, 8 May 1980 (Fig. 4.8), Epicentral distance = 3.2°, Focal depth = 0 km**

Although the Pn wave as recorded at the three stations was very weak in this case, it could still be picked out from the background microseisms. The onset was of the 'e' type. The Sg phase was however of a large amplitude and could easily be identified.

On the record of THK, there was some noise when the signal was transmitted through radio. Such noise masked part of the wave between Pn and Sg. However, the P* was still visible where a slight increase in amplitude was observed.

Prior to the P*, there was an unidentified phase 'i' where a significant change in amplitude occurred. This could not be the P* because the time difference i-Pn of 2.9 s would give an epicentral distance of 2.5°, which disagrees with the result deduced from Sg-Pn.

From the record of YHK, the Pg phase was placed where a slight change in frequency occurred.

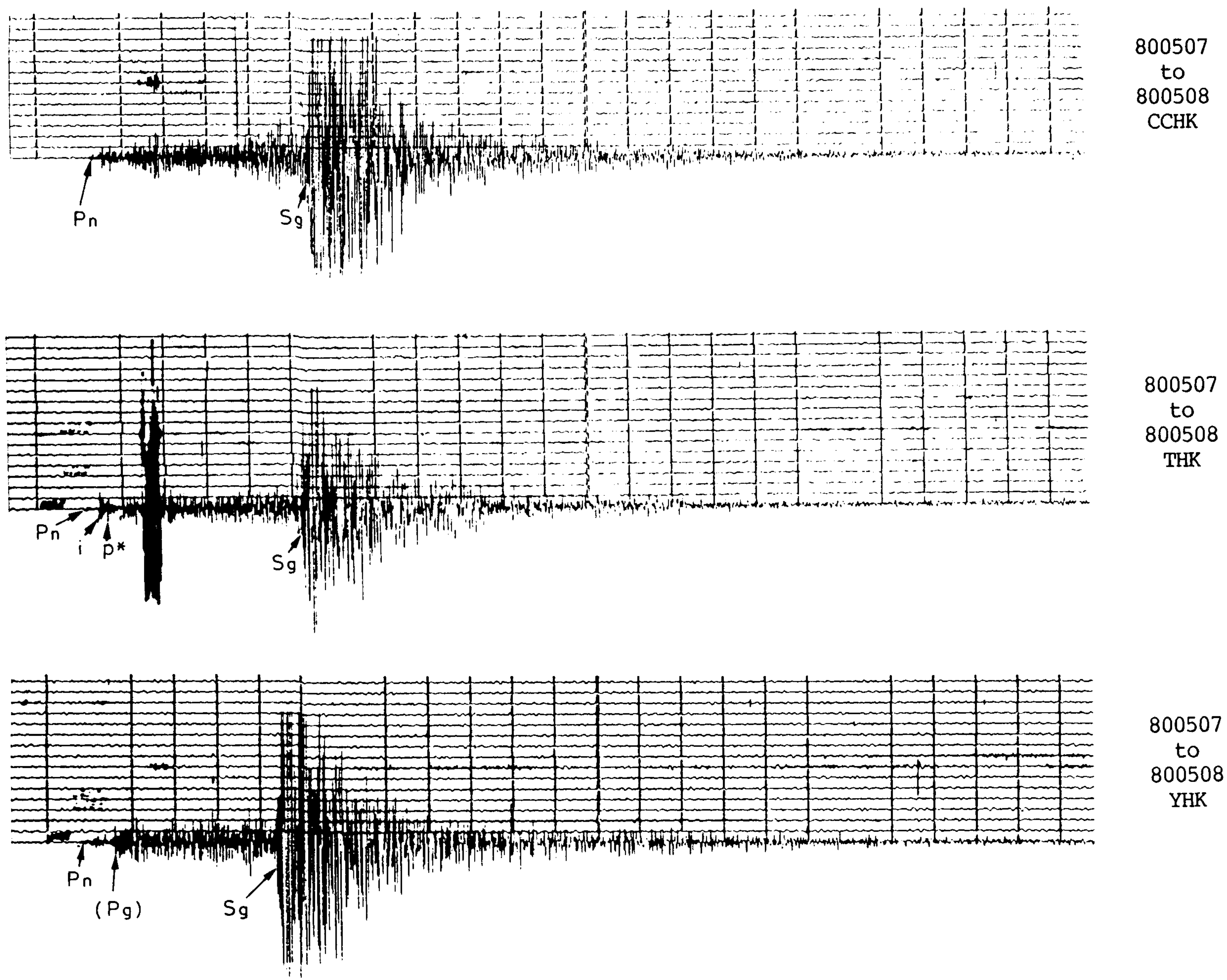

Fig. 4.8 Seismogram of felt tremor located in Taiwan Strait (8.5.80).

Table 4.3b

Date	:	8.5.1980
Location	:	Taiwan Strait
Intensity	:	II

ISC Data:-

Epicentre	:	23.42N 117.43E (δ=3.2°)
Depth	:	0 km
Magnitude	:	4.2Mb
Origin Time	:	02:37:08.9 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	ePn	023802.2	---	---
(δ=3.4°)	iSg	3854.7	52.5	3.2
THK	ePn	023801.6	---	---
(δ=3.3°)	P*	3806.5	04.9	3.2
	iSg	3852.4	50.8	3.2
YHK	ePn	023757.5	---	---
(δ=3.0°)	(Pg)	3810.4	12.9	3.5
	iSg	3843.8	46.3	3.1

4.3.2 **Southern Taiwan, 12 March 1991 (Fig. 4.9), Epicentral distance = 5.5°, Focal depth = 17 km**

This earthquake was located north of Tainan, southern Taiwan.

The appearance of the three seismograms was similar. After the first arrival of Pn, the P* appeared as a sudden increase in amplitude. However, it was not possible to locate the Pg.

Following P*, the Sn was placed where a change occurred in both frequency and amplitude. The Sg was registered just before the amplitude became saturated.

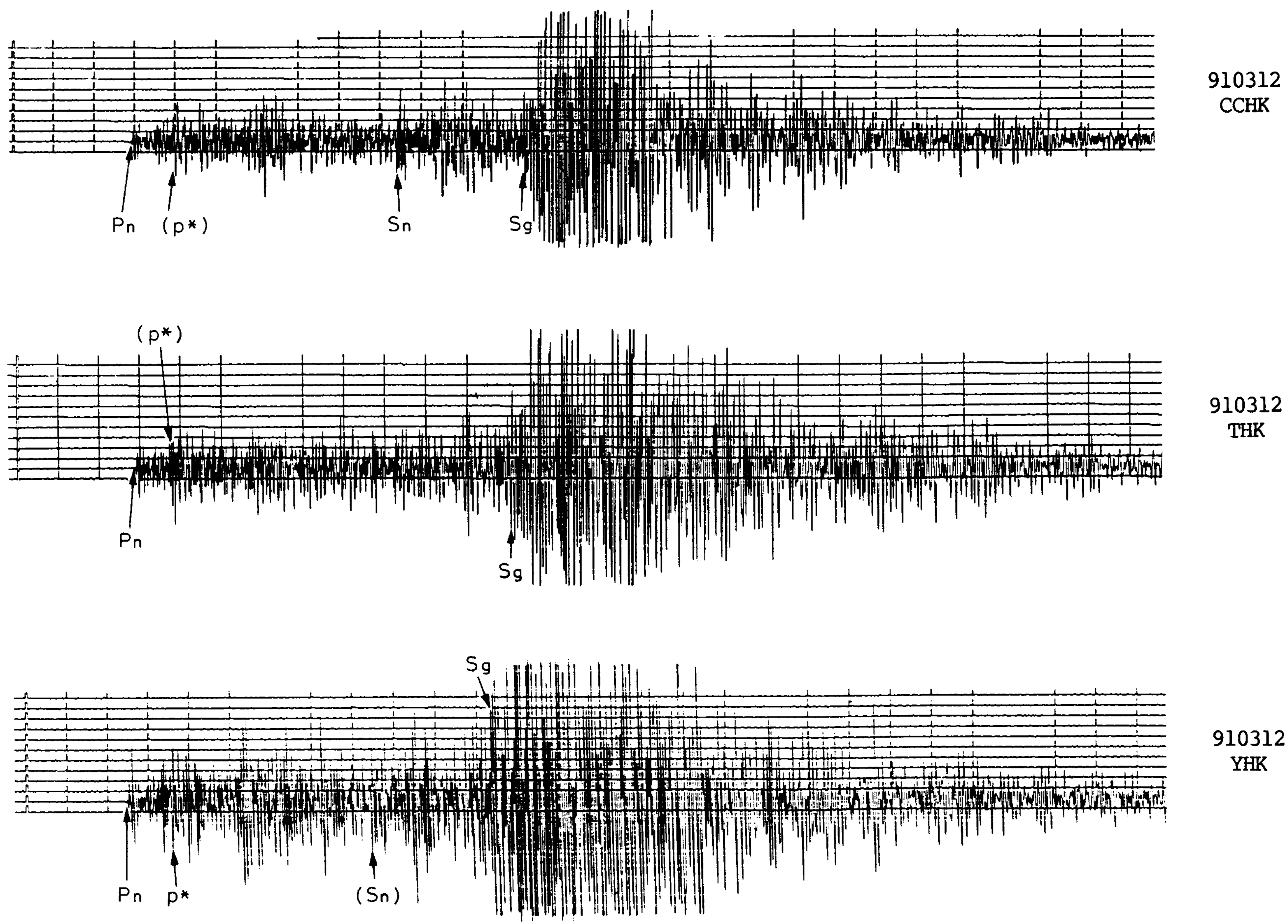

Fig. 4.9 Seismogram of felt tremor located in Southern Taiwan (12.3.91).

Table 4.3c

Date	:	12.3.1991
Location	:	Southern Taiwan
Intensity	:	III

NEIC Data:-

Epicentre	:	23.16N 120.05E (δ=5.5°)
Depth	:	17 km
Magnitude	:	5.6Mb; 5.2Ms
Origin Time	:	06:04:05.0 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** mmss.s	**δ** °
CCHK	ePn	060529.3	---	---
(δ=5.6°)	(P*)	0539.5	0010.2	5.0
	Sn	0633.8	0104.5	5.5
	Sg	0704.1	0134.8	5.3
THK	ePn	060528.7	---	---
(δ=5.6°)	(P*)	0538.5	0009.8	4.9
	Sg	0700.4	0131.7	5.3
YHK	ePn	060524.8	---	---
(δ=5.3°)	P*	0535.2	0010.4	5.1
	(Sn)	0623.8	0059.0	5.0
	Sg	0652.8	0128.0	5.2

4.4 Xunwu (尋烏), Jiangxi,(江西) August 1987 (Fig. 4.10 - 4.12) Epicentral distance = 3.0° - 3.1°, Focal depth = 7 - 10 km

During August 1987, there were three felt earthquakes located in the area of Xunwu, Jiangxi just north of Guangdong. The earthquakes originated from an active fault line where an earthquake of magnitude over 6 occurred before 1900 (Fig. 4.13).

As the seismograms of the three events were similar, we discuss here only the one that took place at around 23 UTC, 2 August 1987 in which more phases showed up. Phase data for the other two can be found in Table 4.4a and 4.4c respectively.

23 UTC, 2 August 1987

Even though affected by amplitude saturation on parts of the seismogram, most of the major phases normally associated with near shallow earthquakes could still be identified.

This event is in contrast with the earthquake occurring in the Taiwan Strait (Section 4.3.2). The epicentral distances of the two events differed by just about 1.5°, yet in the case of Taiwan Strait earthquake, only the P* phase of TBT and the Pg phase of YHK were discernible.

The estimated epicentral distances of the Xunwu earthquakes were fairly consistent : on average 3.0° - 3.1°.

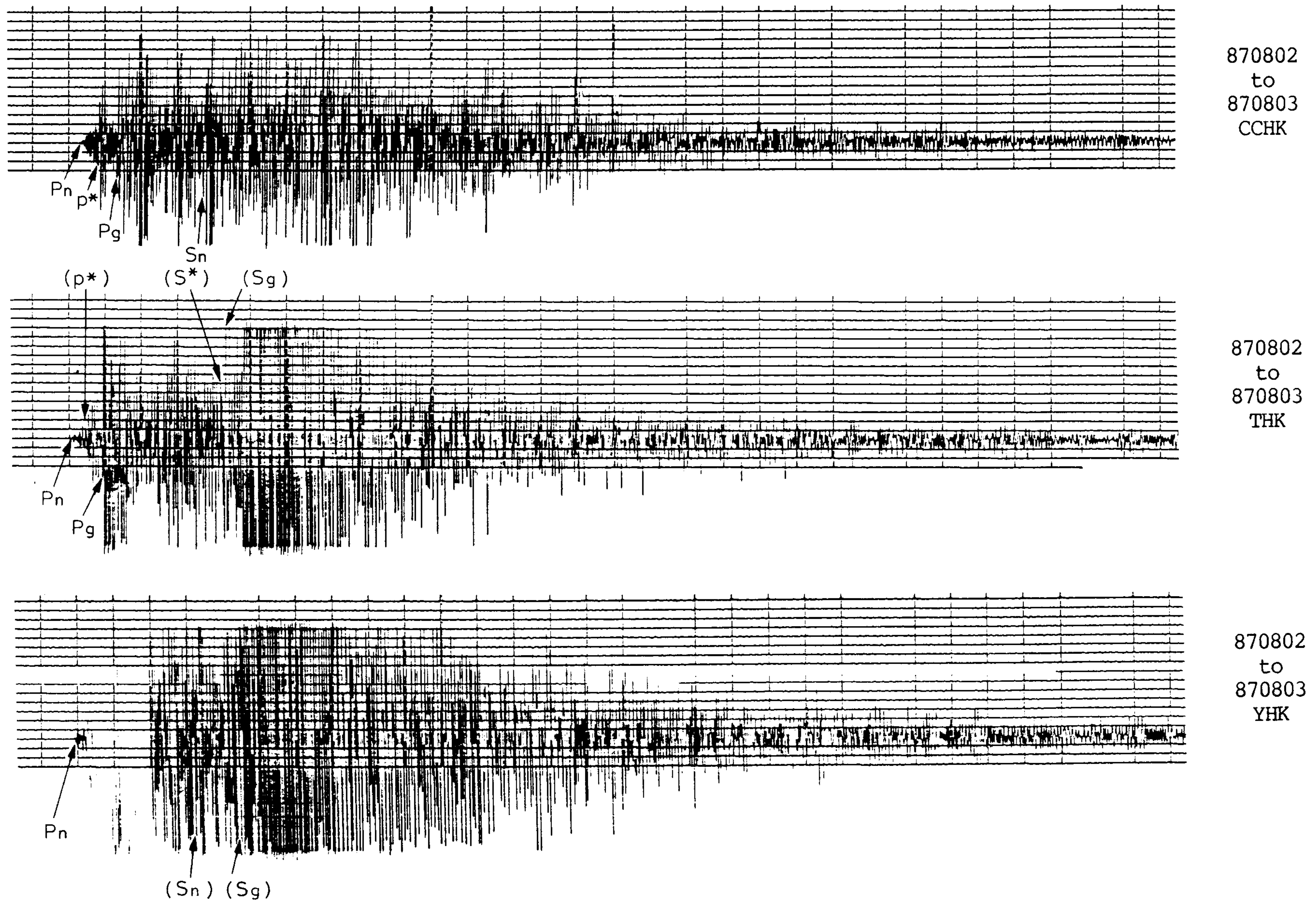

Fig. 4.10 Seismogram of felt tremor located in Xunwu, Jiangxi (09UTC, 2.8.87).

Table 4.4 : Phase data for the earthquakes located in Xunwu, Jiangxi

Table 4.4a

Date	:	2.8.1987
Location	:	Xunwu, Jiangxi
Intensity	:	III-IV

ISC Data:-

Epicentre	:	24.97N 115.61E (δ=3.0°)
Depth	:	7 km
Magnitude	:	5.0Mb; 4.8Ms
Origin Time	:	09:07:33 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	ePn	090823.4	---	---
(δ=3.1°)	iP*	0828.3	04.9	3.2
	iPg	0833.6	10.2	3.0
	Sn	0857.5	34.1	2.7
THK	Pn	090820.7	---	---
(δ=2.9°)	(P*)	082(4.4)	03.7	2.8
	iPg	0829.0	08.3	2.7
	(S*)	0901.7	41.0	2.9
	(Sg)	0904.0	43.3	2.7
YHK	ePn	090819.4	---	---
(δ=2.8°)	(Sn)	0852.0	32.6	2.6
	(Sg)	0904.5	45.1	3.0

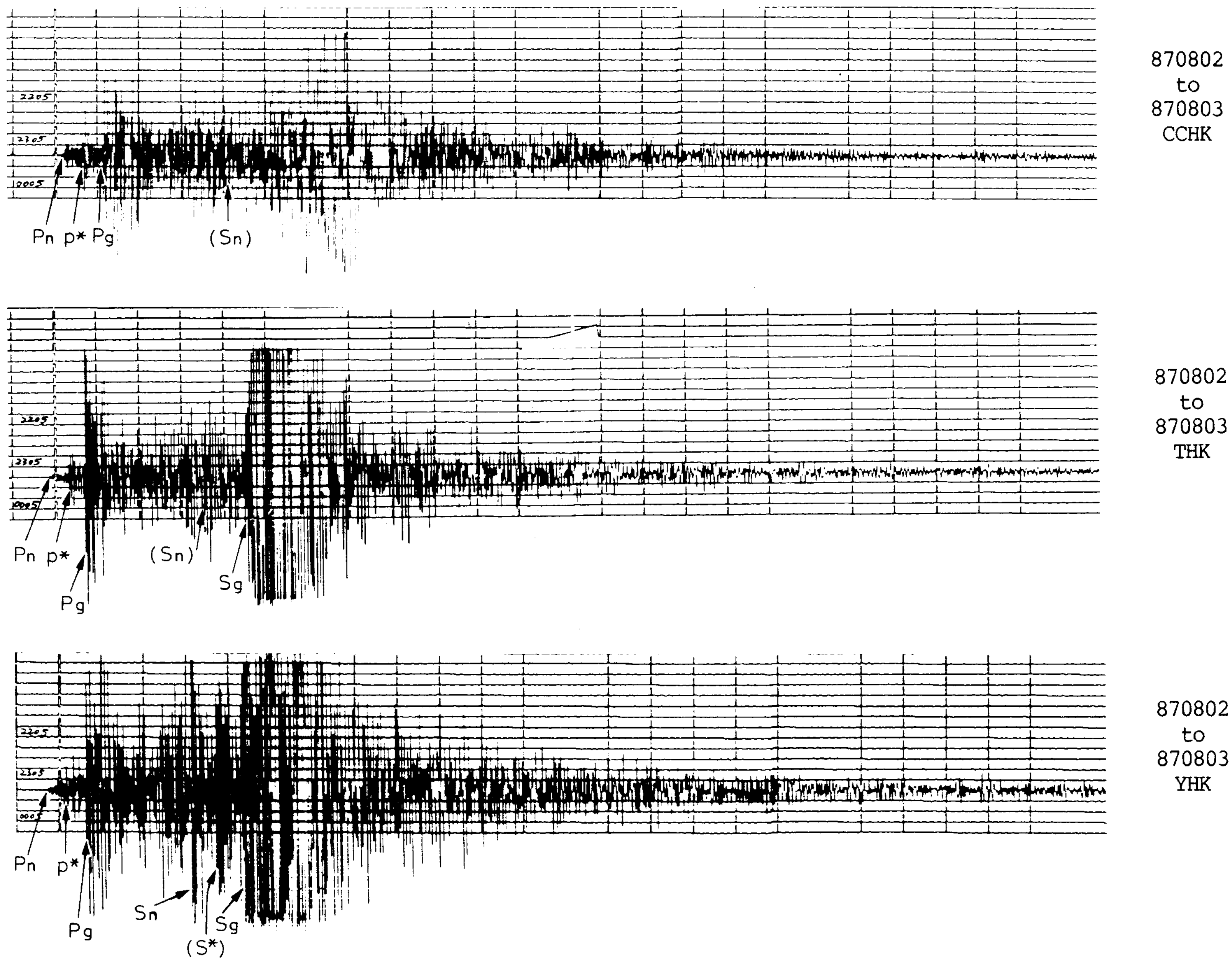

Fig. 4.11 Seismogram of felt tremor located in Xunwu, Jiangxi (23UTC, 2.8.87).

Table 4.4b

Date	:	2.8.1987
Location	:	Xunwu, Jiangxi
Intensity	:	III

ISC Data:-

Epicentre	:	25.13N 115.50E (δ=3.1°)
Depth	:	10 km
Magnitude	:	4.9Mb
Origin Time	:	23:19:11 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	ePn	232002.0	---	---
(δ=3.2°)	P*	2007.0	05.0	3.2
	iPg	2011.4	09.4	2.9
	(Sn)	2041.2	39.2	3.2
THK	ePn	23195(8.7)	---	---
(δ=3.0°)	iP*	2003.3	04.6	3.1
	iPg	2006.8	08.1	2.6
	(Sn)	2035.1	36.4	2.9
	iSg	2044.8	46.1	2.9
YHK	ePn	231957.3	---	---
(δ=3.0°)	P*	2001.7	04.4	3.0
	iPg	2006.5	09.2	2.8
	Sn	2031.1	33.8	2.7
	(S*)	2037.1	39.8	3.0
	iSg	2043.9	46.6	2.9

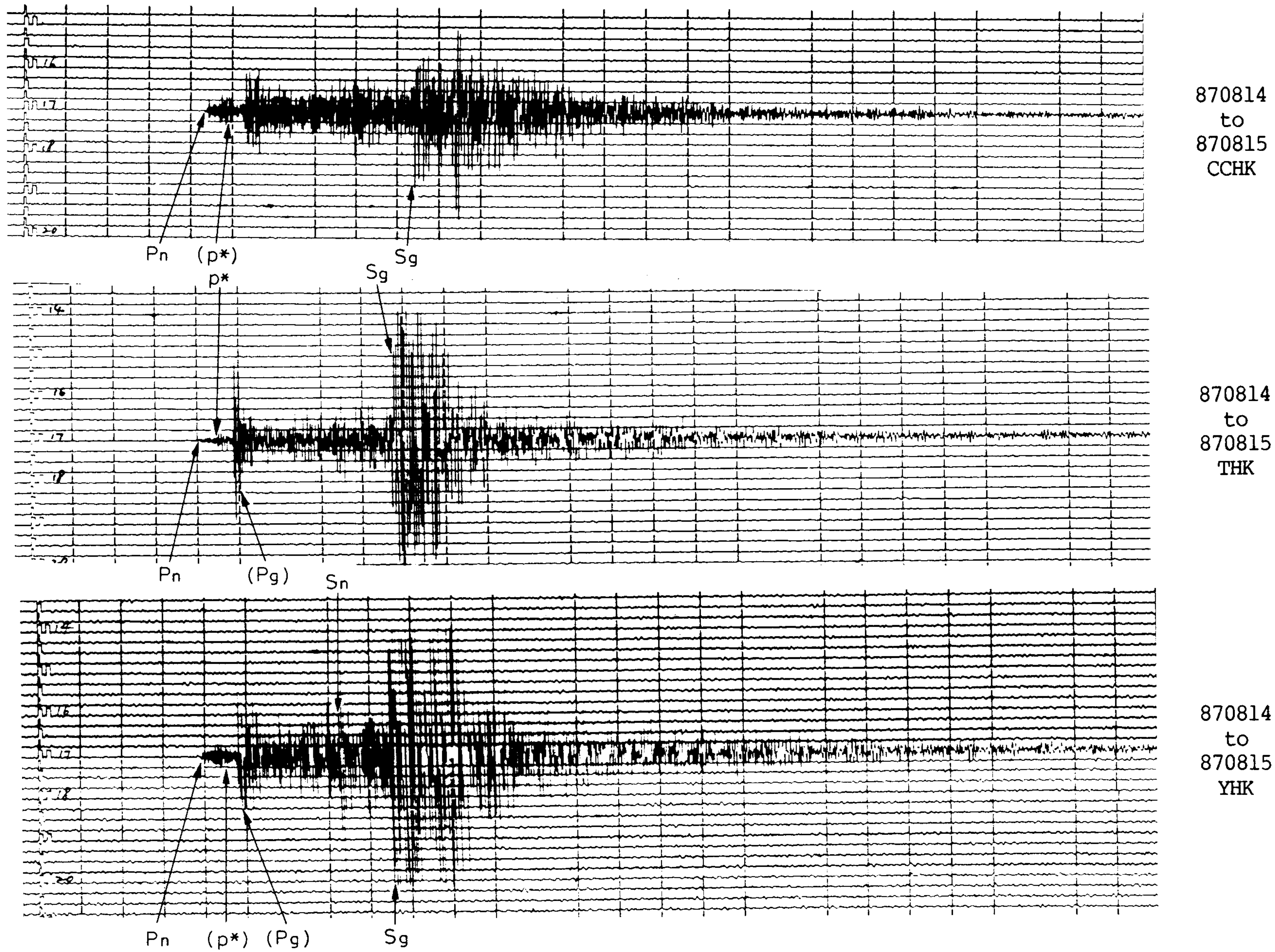

Fig. 4.12 Seismogram of felt tremor located in Xunwu, Jiangxi (l7UTC, 14.8.87).

Table 4.4c

Date	:	14.8.1987
Location	:	Xunwu, Jiangxi
Intensity	:	III

ISC Data:-

Epicentre	:	25.11N 115.56E (δ=3.1°)
Depth	:	10 km
Magnitude	:	4.4Mb
Origin Time	:	16:59:51.9 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	Pn	170043.9	---	---
(δ=3.2°)	(P*)	0048.5	04.6	3.1
	iSg	0134.3	50.4	3.0
THK	Pn	17004(0.2)	---	---
(δ=3.0°)	P*	0044.9	04.7	3.1
	(Pg)	0049.7	09.5	2.9
	iSg	0127.1	46.9	2.9
YHK	Pn	170039.1	---	---
(δ=3.0°)	(P*)	0044.9	05.8	3.5
	(Pg)	0048.9	09.8	3.0
	Sn	0112.2	33.1	2.6
	iSg	0124.9	45.8	2.8

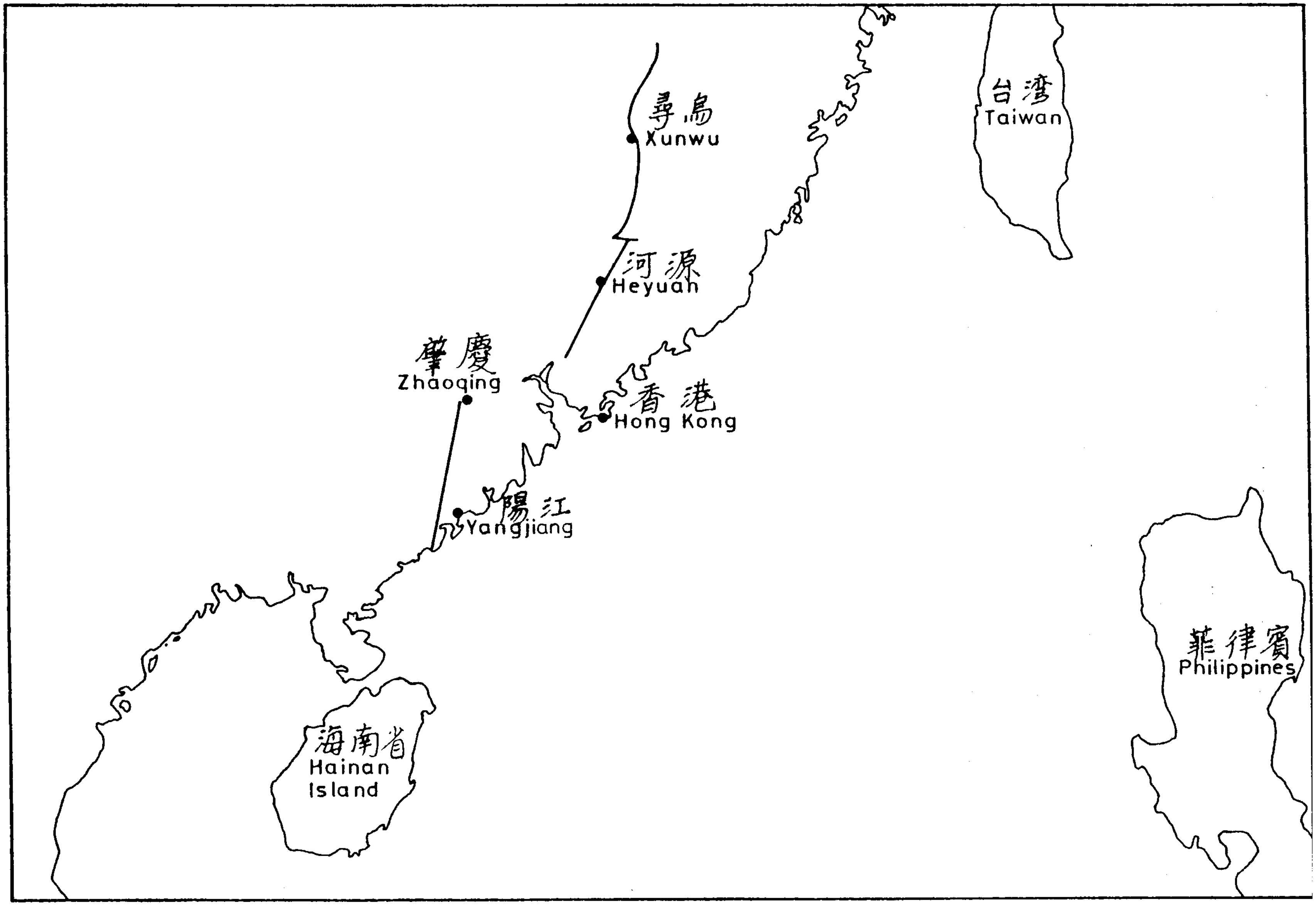

Fig. 4.13 Fault lines in <u>South China</u> associated with the earthquakes around Xunwu, Heyuan, and Yangjiang.

4.5 Longnan (龍南), Jiangxi, 25 February 1982 (Fig. 4.14), Epicentral distance = 2.6°, Focal depth = 5 km

The earthquake was located near Longnan, Jiangxi, about 100 km to the west-southwest of Xunwu. For most part of the seismograms the amplitude was saturated. Only the Pn and Pg phases could be identified.

There was a blank on the records lasting about 6 to 7 s. This was caused by an interruption in the radio transmission of signals.

Microseisms at CCHK were especially strong that day, due to strong winds after the passage of a cold front.

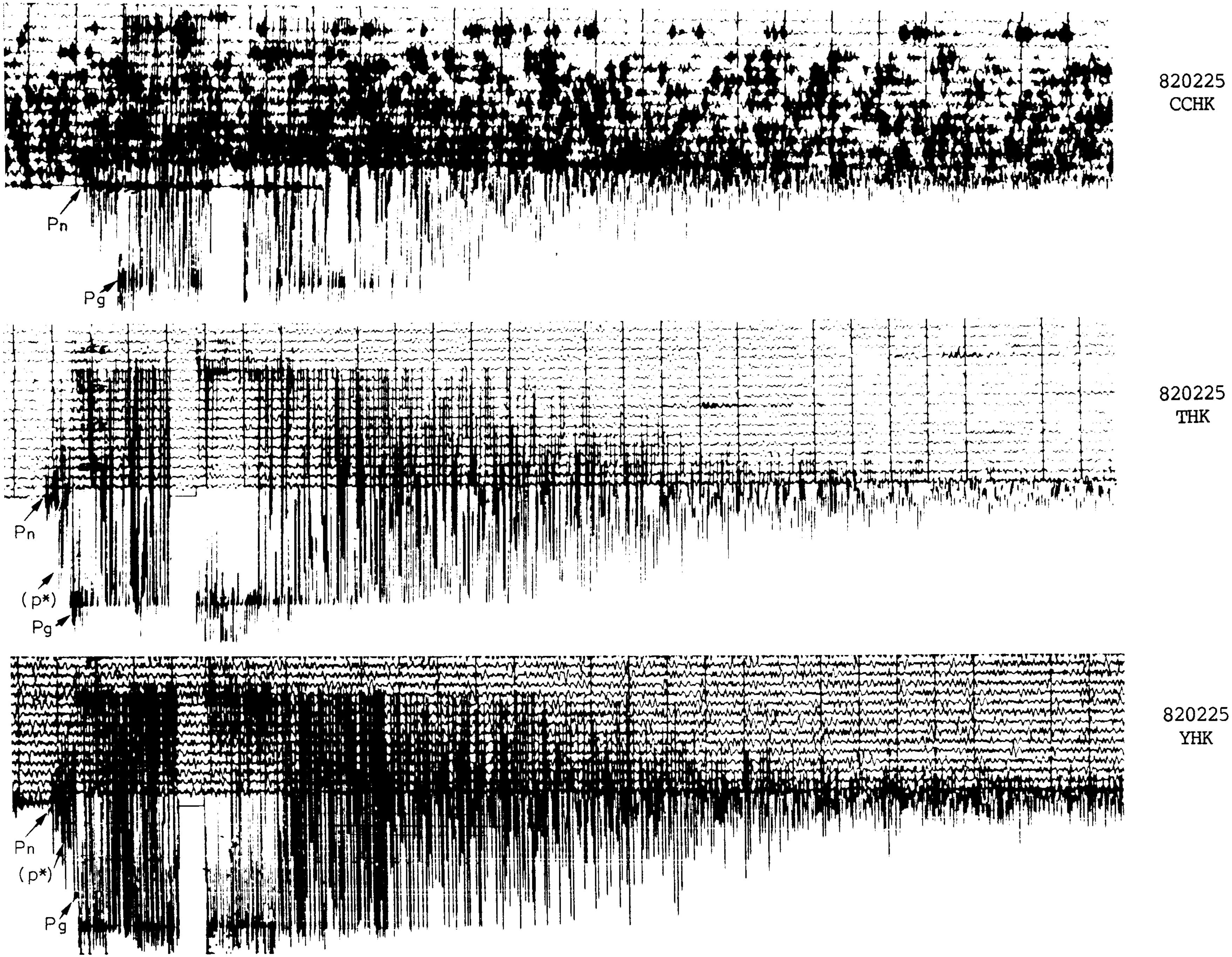

Fig. 4.14 Seismogram of felt tremor located in Longnan, Jiangxi (25.2.82).

Table 4.5 : Phase data for the earthquake located in Longnan, Jiangxi

Date	:	25.2.1982
Location	:	Longnan, Jiangxi
Intensity	:	III-IV

ISC Data:-

Epicentre	:	24.80N 114.76E (δ=2.6°)
Depth	:	5 km
Magnitude	:	4.4Mb; 3.9Ms
Origin Time	:	00:39:08 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	iPn	003951.7	---	---
(δ=2.7°)	Pg	3959.2	07.5	2.5
THK	-iPn	003948.0	---	---
(δ=2.4°)	i(P*)	3950.5	02.5	2.4
	iPg	3954.4	06.4	2.4
YHK	iPn	003948.1	---	---
(δ=2.5°)	(P*)	3950.6	02.5	2.4
	Pg	3954.9	06.8	2.4

4.6 Yangjiang (陽江), Guangdong (Fig. 4.15-16), Epicentral distance = 2.3° -2.4°, Focal depth = 0 km

Yangjiang is located near one of the seismically active areas in south China. An intensively active fault runs from Zhaoqing (肇慶) to Yangjiang in a northeast to southwest orientation (Fig. 4.13).

During the period 1979-1991, there were two felt earthquakes occurring near the area: one on 27 January 1986 and the other one 25 February 1987. As the seismograms of these two events exhibited a high degree of similarity, only the event on 27 January 1986 is discussed here.

27 January 1986

The onset of the seismic wave train was marked by the Pn phase emerging as a small ripple on the seismogram. About 4 s later the Pg phase arrived impulsively, with a large amplitude. The start of the clipped (saturated) waves on the THK and YHK records signified the Sg phase.

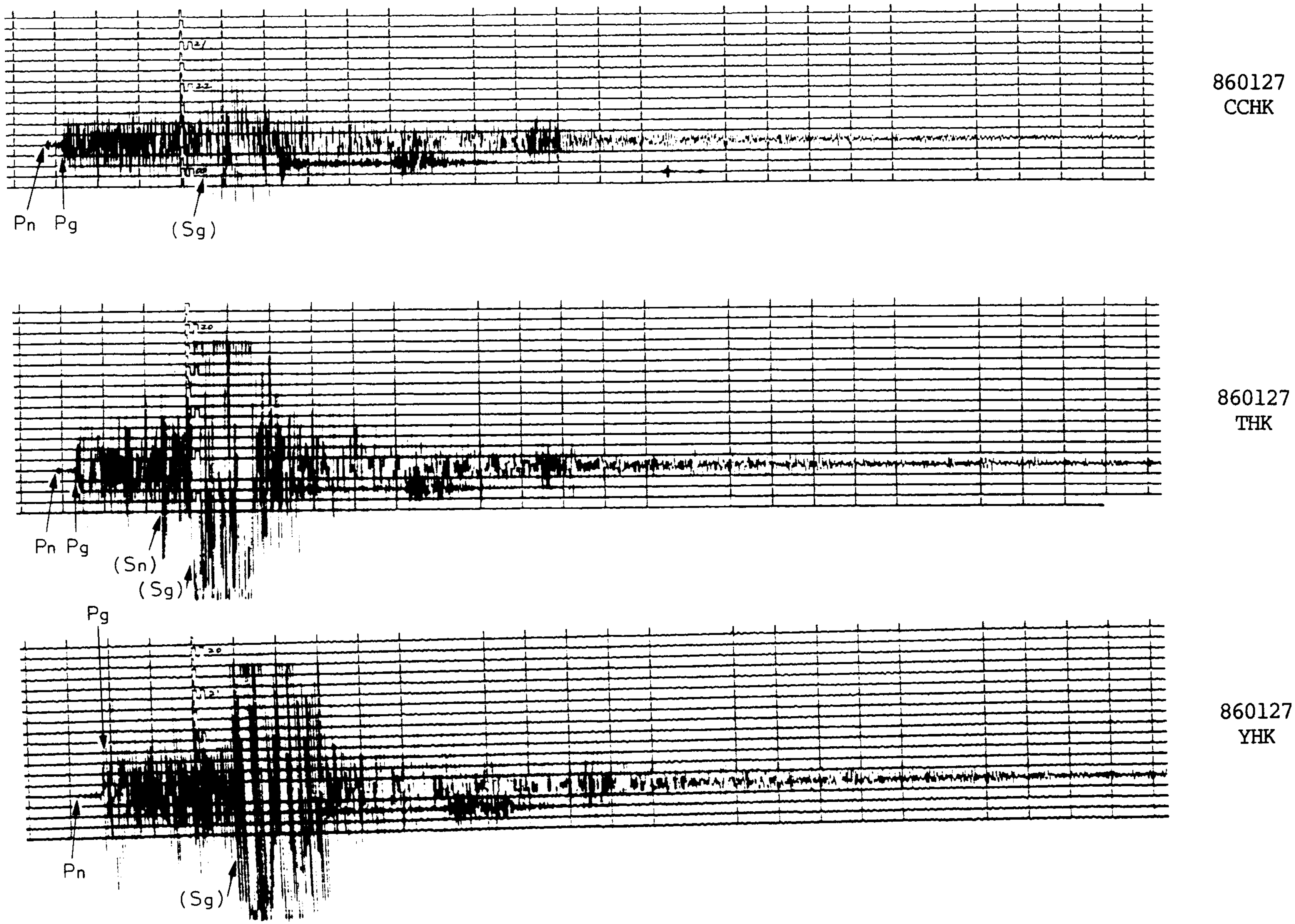

Fig. 4.15 Seismogram of felt tremor located in Yangjiang, Guangdong (27.1.86).

Table 4.6 : Phase data for the earthquakes located in Yangjiang, Guangdong

Table 4.6a

Date	:	27.1.1986
Location	:	Yangjiang, Guangdong
Intensity	:	III-IV

ISC Data:-

Epicentre	:	21.67N 111.75E (δ=2.3°)
Depth	:	0 km
Magnitude	:	4.5Mb
Origin Time	:	23:13:50.3 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	iPn	231427.7	---	---
(δ=2.2°)	iPg	1431.9	04.2	2.0
	(Sg)	1504.1	36.4	2.5
THK	ePn	231428.1	---	---
(δ=2.3°)	iPg	1433.1	05.0	2.1
	(Sn)	1453.8	25.7	2.0
	i(Sg)	1501.2	33.1	2.2
YHK	ePn	231432.0	---	---
(δ=2.5°)	iPg	1437.9	05.9	2.3
	i(Sg)	1509.4	37.4	2.4

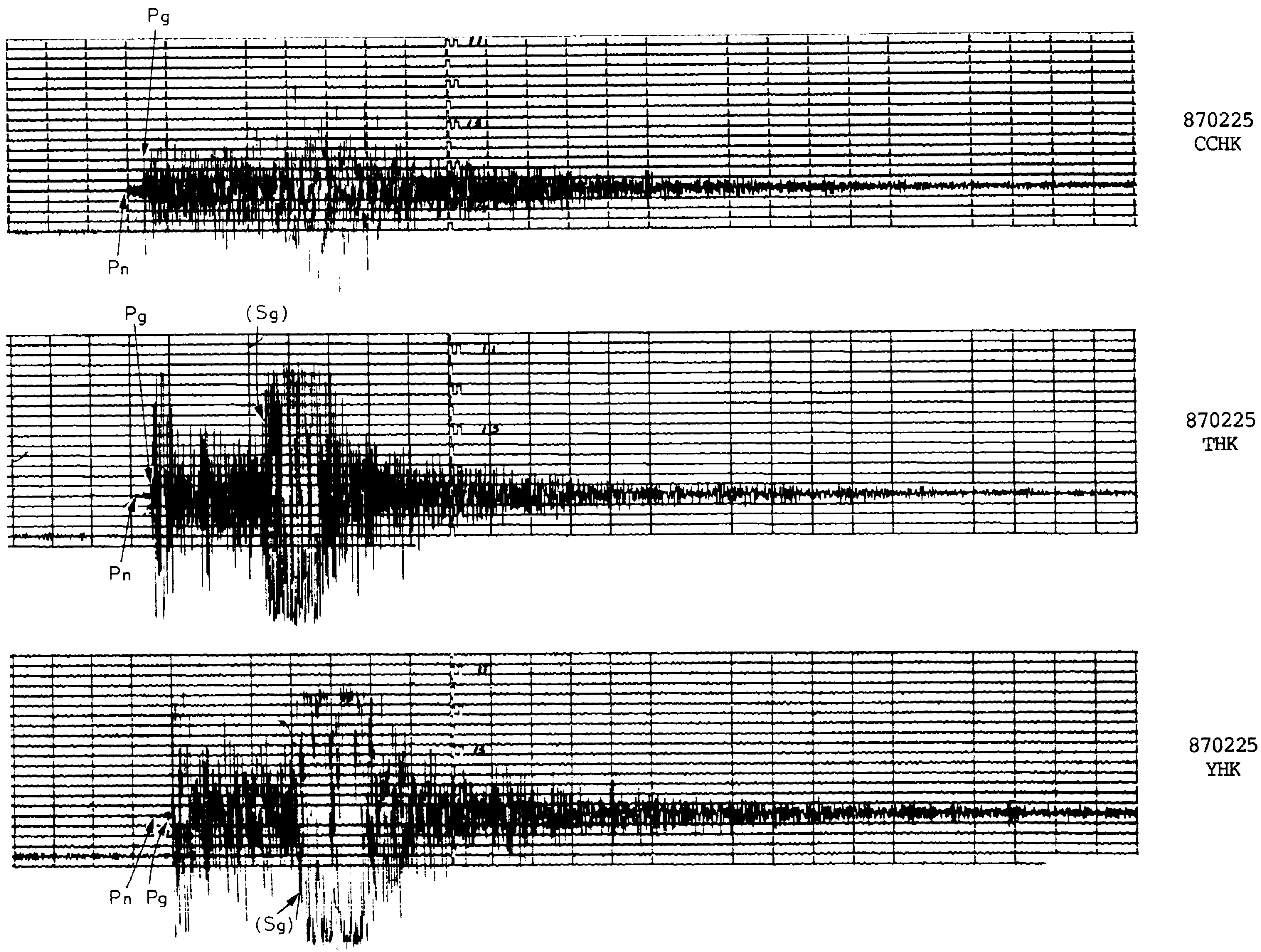

Fig. 4.16 Seismogram of felt tremor located in Yangjiang, Guangdong (25.2.87).

Table 4.6b

Date	:	25.2.1987
Location	:	Yangjiang, Guangdong
Intensity	:	II-III

ISC Data:-

Epicentre	:	21.74N 111.68E (δ=2.4°)
Depth	:	33 km
Magnitude	:	4.1Mb
Origin Time	:	14:28:05.4 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	iPn	142839.9	---	---
(δ=2.2°)	iPg	2843.9	04.0	1.9
THK	ePn	142840.8	---	---
(δ=2.3°)	iPg	2845.1	04.3	2.0
	i(Sg)	2913.7	32.9	2.2
YHK	ePn	142845.8	---	---
(δ=2.5°)	iPg	2849.8	04.0	1.9
	i(Sg)	2921.5	35.7	2.4

4.7 Heyuan (河源), Guangdong (Fig. 4.17-20), Epicentral distance = 1.5° - 1.6°, Focal depth 0 - 33 km

Heyuan is one of the seismic active areas within the Xinfengjiang (新豐江) reservoir region. After impounding began in 1959, a number of earthquakes were induced in the area (Ding et al 1982, Yan and Zhang 1984). A magnitude 6.1 earthquake occurred in 1962 and was felt in Hong Kong with intensity V (Lam 1980).

The place is about 1.4° from Royal Observatory Hong Kong. This is just about the distance at which the direct waves and refracted waves interfere with each other. The order of arrivals for different phases may vary from one local station to another.

There were four earthquakes located in the area during 1979-1991. As the records exhibited similar characteristics, only the one occurring in May 1981 is discussed here.

4 May 1981

As the epicentre was in the NNE direction from Hong Kong, the nearest station to the epicentre was YHK and the farthest station was CCHK. As measured from CCHK, epicentral distance was about 1.7°. As a result, the refracted waves (Pn) should arrive slightly earlier than the direct waves (Pg). For THK and YHK, the epicentral distances were 1.5° and Pn preceded Pg by about 1 second.

On the seismograms of all three stations, it can be seen that there were two distinct wave packages. Zhang (1986) suggested that the strongly reflected waves P_M and S_M should be expected in this range of epicentral distances. These two packages were therefore reckoned to be associated with P_M and S_M waves respectively.

The strong single pulse before S_M was identified to be Sg phase.

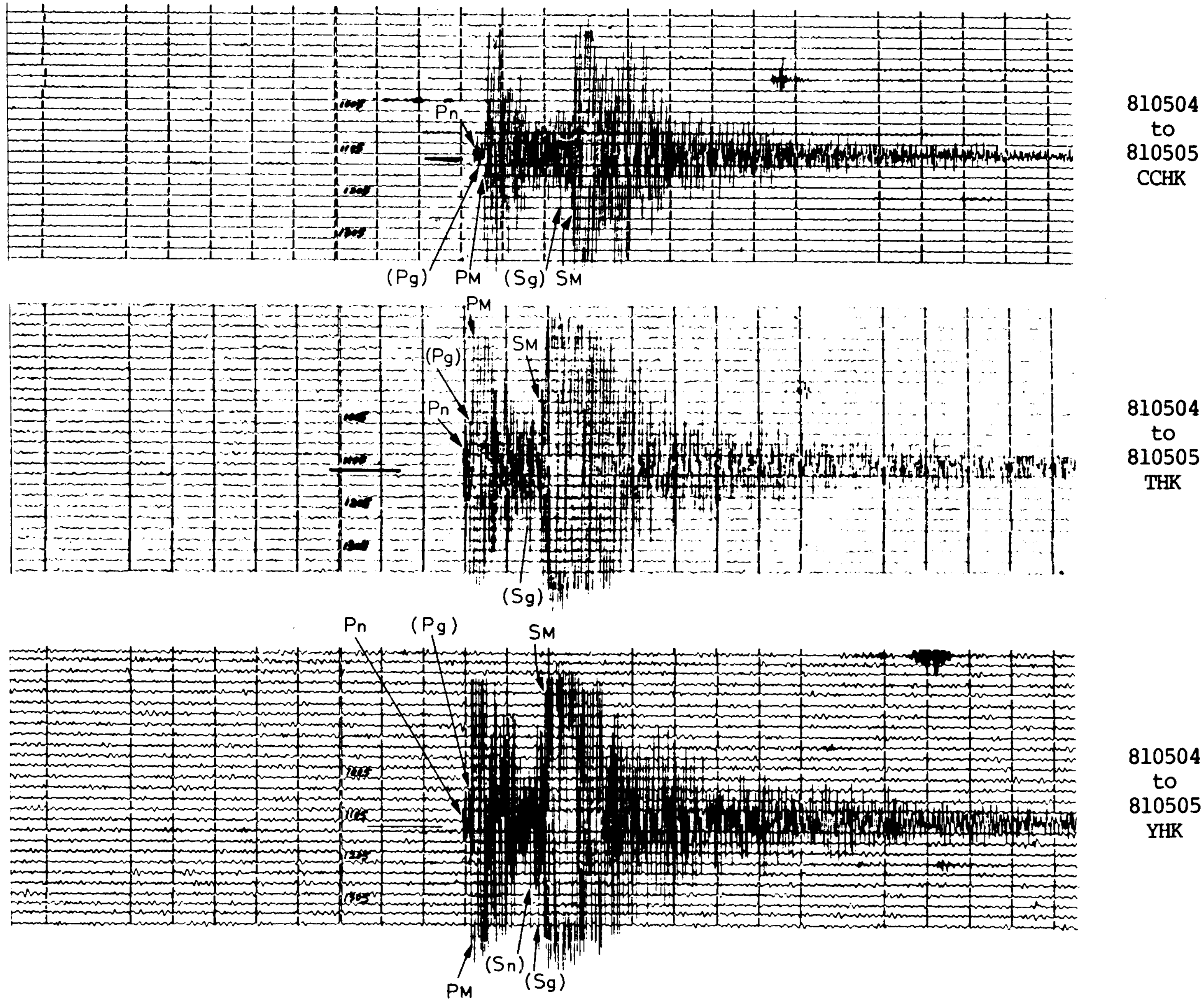

Fig. 4.17 Seismogram of felt tremor located in Heyuan, Guangdong (4.5.81).

Table 4.7 : Phase data for the earthquakes located in Heyuan, Guangdong

Table 4.7a

Date	:	4.5.1981
Location	:	Heyuan, Guangdong
Intensity	:	II

ISC Data:-

Epicentre	:	23.82N 114.70E (δ=1.6°)
Depth	:	0 km
Magnitude	:	4.8Mb
Origin Time	:	11:05:04.8 UTC

Station	Phase(x)	Time(UTC) hhmmss.s	Time Difference x-Pn ss.s	s o
CCHK	+iPn	110533.0	---	---
(s=1.7o)	(Pg)	0534.3	01.3	1.4
	iP_M	0535.7	02.7	---
	(Sg)	0553.9	20.9	1.5
	iS_M	0557.0	24.0	---
THK	+iPn	110529.5	---	---
(s=1.5o)	(Pg)	0530.7	01.2	1.4
	iP_M	0531.1	01.6	---
	(Sg)	0545.2	15.7	1.1
	iS_M	0548.1	18.6	---
YHK	+iPn	110529.2	---	---
(s=1.5o)	(Pg)	0530.0	00.8	1.4
	iP_M	0531.2	02.0	---
	(Sn)	0545.6	16.4	1.1
	(Sg)	0547.5	18.3	1.3
	iS_M	0550.8	21.6	---

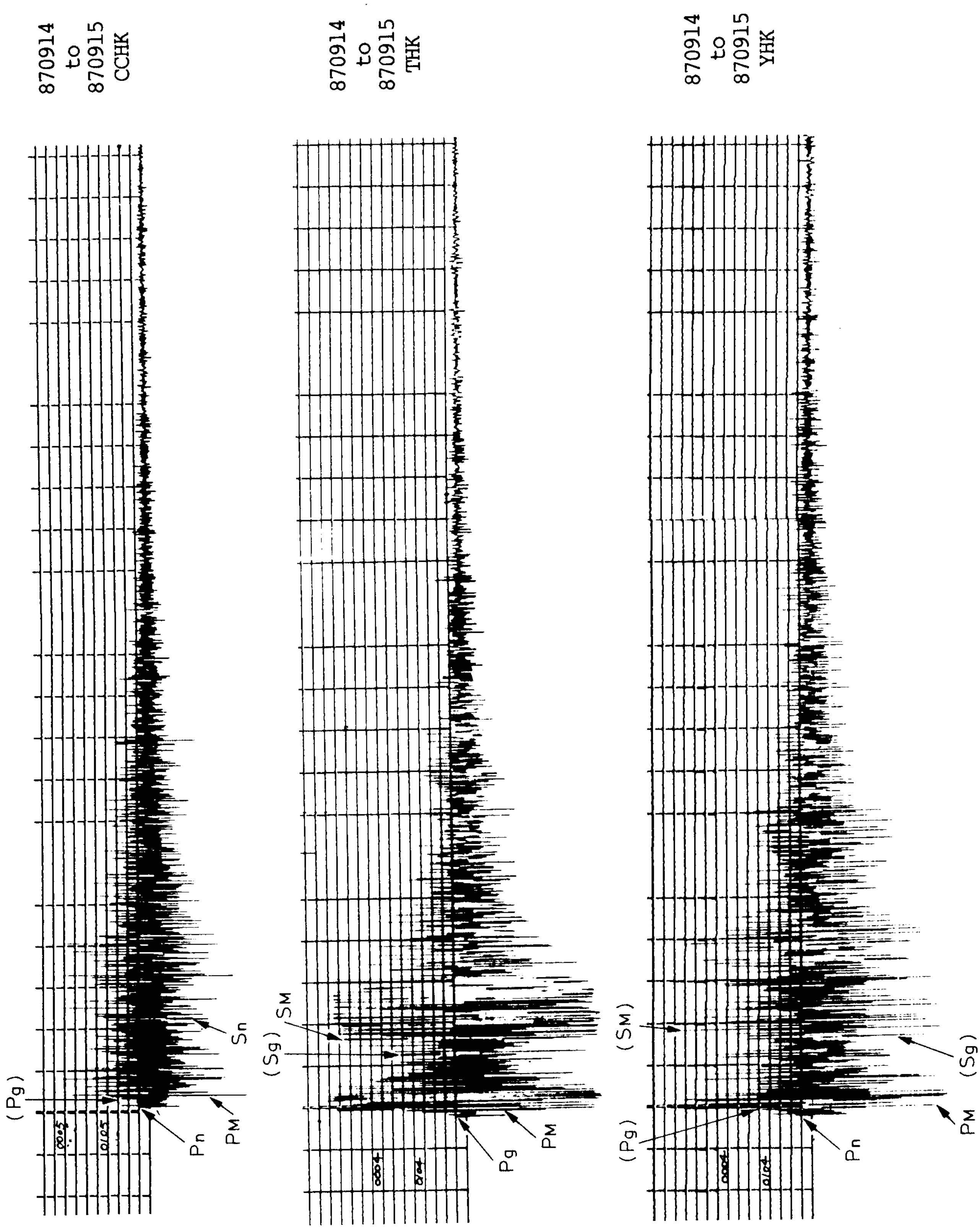

Fig. 4.18 Seismogram of felt tremor located in Heyuan, Guangdong (15.9.87).

Table 4.7b

Date	:	15.9.1987
Location	:	Heyuan, Guangdong
Intensity	:	III

ISC Data:-

Epicentre	:	23.79N 114.53E (δ=1.5°)
Depth	:	15 km
Magnitude	:	4.7Mb
Origin Time	:	02:04:32.7 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	+iPn	020501.2	---	---
(δ=1.7°)	(Pg)	0503.3	02.1	1.6
	P_M	0504.1	02.9	---
	Sn	0522.5	21.3	1.6
			x-Pg	
THK	+iPg	020457.5	---	---
(δ=1.4°)	iP_M	0458.7	01.2	---
	(Sg)	0513.3	15.8	1.2
	iS_M	0516.2	18.7	---
			x-Pn	
YHK	+iPn	020457.8	---	---
(δ=1.4°)	(Pg)	0459.0	01.2	1.4
	P_M	0459.9	02.1	---
	(Sg)	0516.7	18.9	1.4
	(S_M)	0518.6	20.8	---

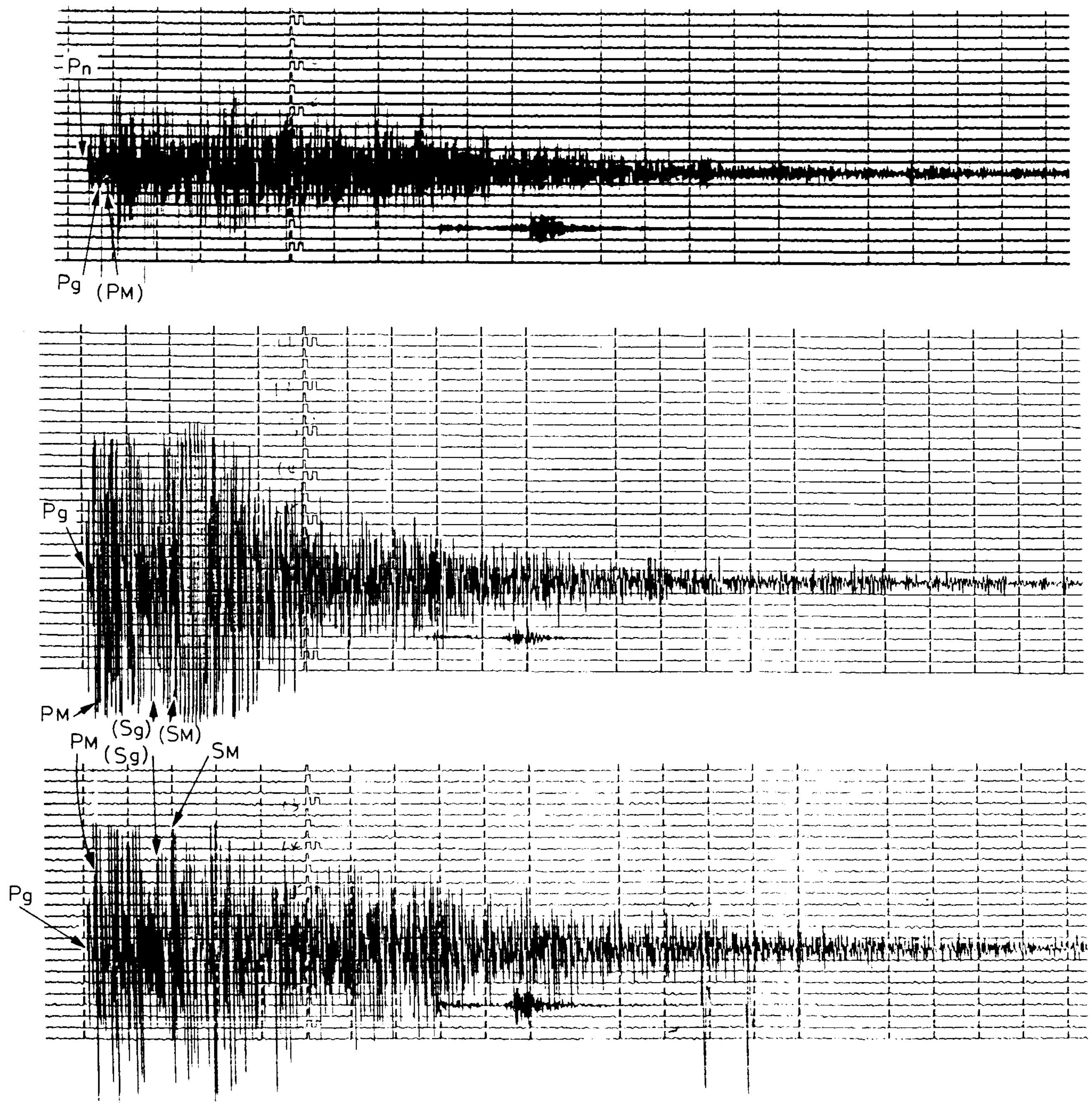

Fig. 4.19 Seismogram of felt tremor located in Heyuan, Guangdong (25,11.89).

Table 4.7c

Date	:	25.11.1989
Location	:	Heyuan, Guangdong
Intensity	:	II - III

ISC Data:-

Epicentre	:	23.72N 114.52E (δ=1.5°)
Depth	:	15 km
Magnitude	:	5.0Mb
Origin Time	:	16:13:47.4 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	+iPn	161414.4	---	---
(δ=1.6°)	(Pg)	1416.4	02.0	1.6
	(P_M)	1418.8	04.4	---
			x-Pg	
THK	+iPg	161411.0	---	---
(δ=1.3°)	P_M	1412.5	01.5	---
	(Sg)	1425.5	14.5	1.1
	(S_M)	1430.6	19.6	---
			x-Pn	
YHK	+iPg	161410.8	---	---
(δ=1.4°)	P_M	1412.2	01.4	---
	(Sg)	1426.7	15.9	1.2
	S_M	1429.8	19.0	---

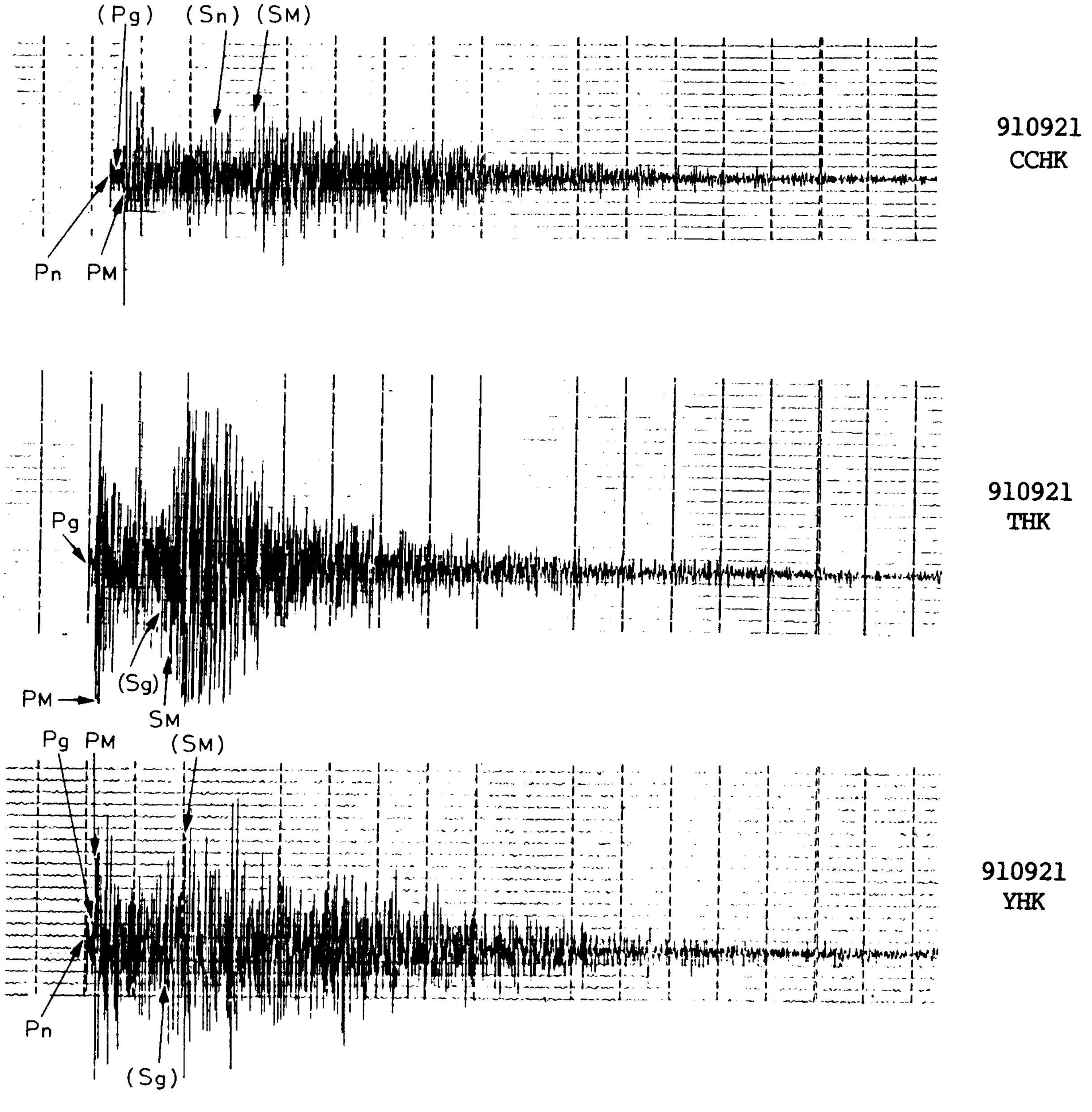

Fig. 4.20 Seismogram of felt tremor located in Heyuan, Guangdong (21.9.91).

Table 4.7d

Date	:	21.9.1991
Location	:	Heyuan, Guangdong
Intensity	:	IV

NEIC Data:-

Epicentre	:	23.85N 114.49E (δ=1.6°)
Depth	:	33 km
Magnitude	:	4.2Mb
Origin Time	:	15:37:06.4 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pn** ss.s	**δ** °
CCHK	+iPn	153733.7	---	---
(δ=1.7°)	(Pg)	3735.9	02.2	1.6
	P_M	3736.7	03.0	---
	(Sn)	3754.3	20.6	1.5
	(S_M)	3808.1	34.4	---
THK	+iPn	153730.1	---	---
(δ=1.4°)	iP_M	3731.7	01.6	---
	(Sg)	3745.1	15.1	1.2
	S_M	3747.2	17.1	---
YHK	+iPn	153730.4	---	---
(δ=1.5°)	Pg	3731.5	01.1	1.4
	P_M	3732.0	01.6	---
	(Sg)	3746.1	15.7	1.1
	(S_M)	3850.3	19.9	---

4.8 Haifeng (海豐), Guangdong, 9 April 1981 (Fig. 4.21), Epicentral distance = 1.3°, Focal depth = 0 km

During the period from January to May 1981, a swarm of small earthquakes occurred in the region of Haifeng Xien (Wei et al. 1982). Of these, the strongest one occurred on 9 April and was felt in Hong Kong.

Although a part of the waveform was missing on the records of CCHK and THK, Pg and Sg phases could still be identified. As shown on the YHK seismogram, the waves recorded during the first 30 s were especially strong. This is typical of a very near earthquake. Since the focus and the observing station were most probably not within the same layer, or channel, of the geological structure, channel waves after the S waves were not recorded.

The difference in first arrival times at the three stations gave a clue to the bearing of the earthquake. The time differences Sg-Pg (Table 4.8) also confirmed that epicentre was closer to YHK than CCHK and THK.

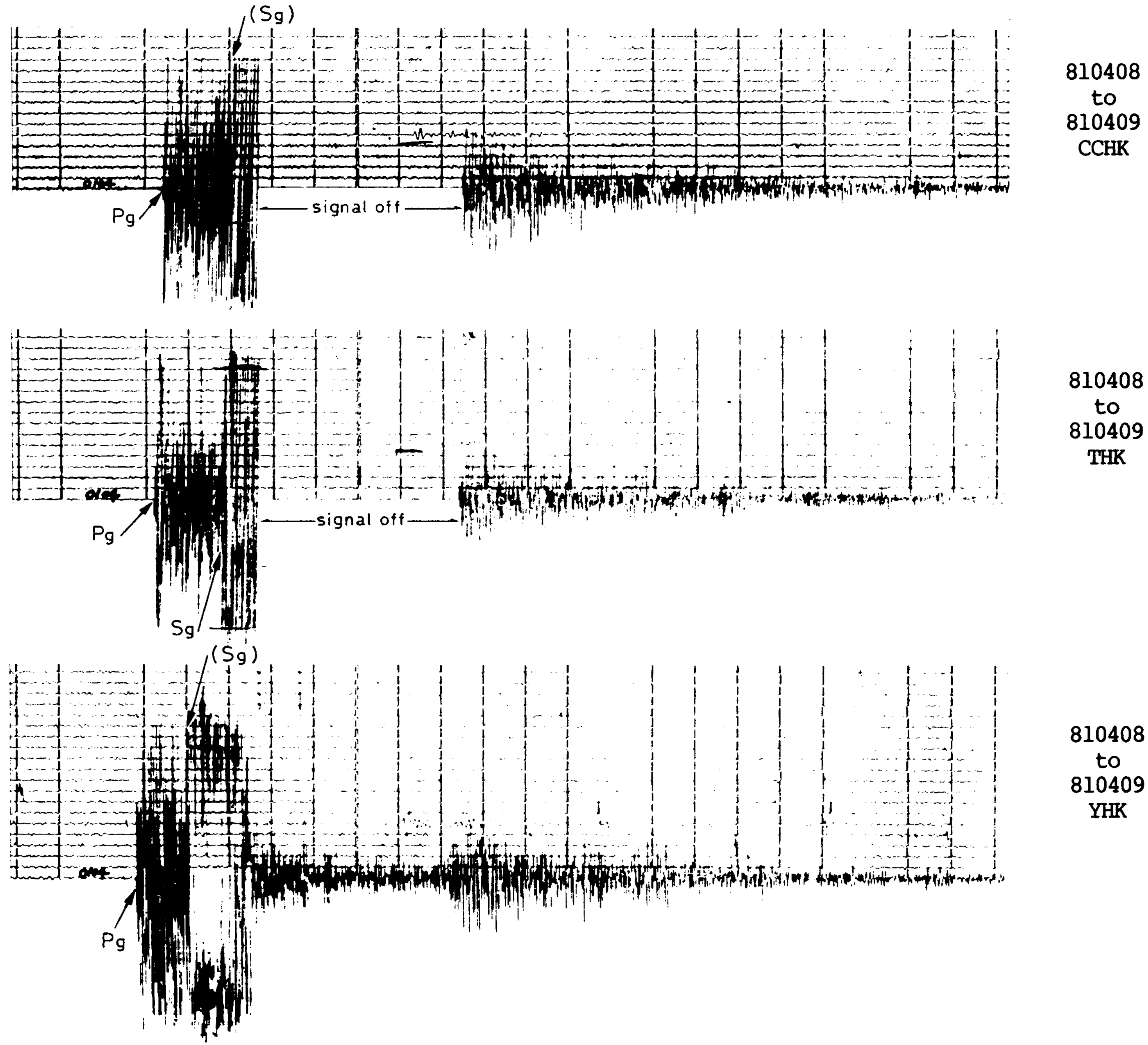

Fig. 4.21 Seismogram of felt tremor located in Haifeng, Guangdong (9.4.81).

Table 4.8 : Phase data for the earthquake located in Haifeng, Guangdong

Date	:	9.4.1981
Location	:	Haifeng, Guangdong
Intensity	:	III-IV

ISC Data:-

Epicentre	:	22.97N 115.43E (δ=1.34°)
Depth	:	0 km
Magnitude	:	not available (SSB: 4.0Ms)
Origin Time	:	01:03:44.8 UTC

Station	**Phase(x)**	**Time(UTC)** hhmmss.s	Time Difference **x-Pg** ss.s	**δ** °
CCHK	iPg	010414.5	---	---
(δ=1.5°)	(Sg)	0430.9	16.4	1.3
THK	-iPg	010411.9	---	---
(δ=1.4°)	Sg	0427.8	15.9	1.2
YHK	-iPg	010408.1	---	---
(δ=1.2°)	(Sg)	0419.9	11.8	0.9

4.9 Local Tremors (Fig. 4.22-24), Epicentral distance = 0.2°

Local earthquakes are tremors with epicentral distances less than 100 Km (Appendix II). A total of three local tremors were felt by residents during the 1979-1991. The recorded vibrations only lasted for about 1 - 2 minutes. The waveform looked densely packed and the period was short, of the order of 0.05 - 0.1 s. Since all three cases exhibited such characteristics, only the tremor of 6 December 1983 is discussed here.

6 December 1983 (Fig. 4.21)

The first arrival was the P phase, emerging sharply. The first motion was well defined and registered +1.21 μm (up), +1.58 μm (up) and -0.70 μm (down) at CCHK, THK, YHK respectively. The first two were compressional and the third one was dilatational, indicating that the tremor was not caused by explosion, which would give rise to compressional waves at the onset at all stations.

The S phase at THK stood out clearly on the trace, while that at YHK was not too certain. It could not be identified on the CCHK record. The ground motions corresponding to the waves of maximum amplitudes were 1.47 μm, 3.47 μm and 1.09 μm at CCHK, THK and YHK respectively. On the whole, amplitudes of phases recorded at THK were also the greatest among the three stations, indicating that the epicentre was much closer to THK than the other two stations.

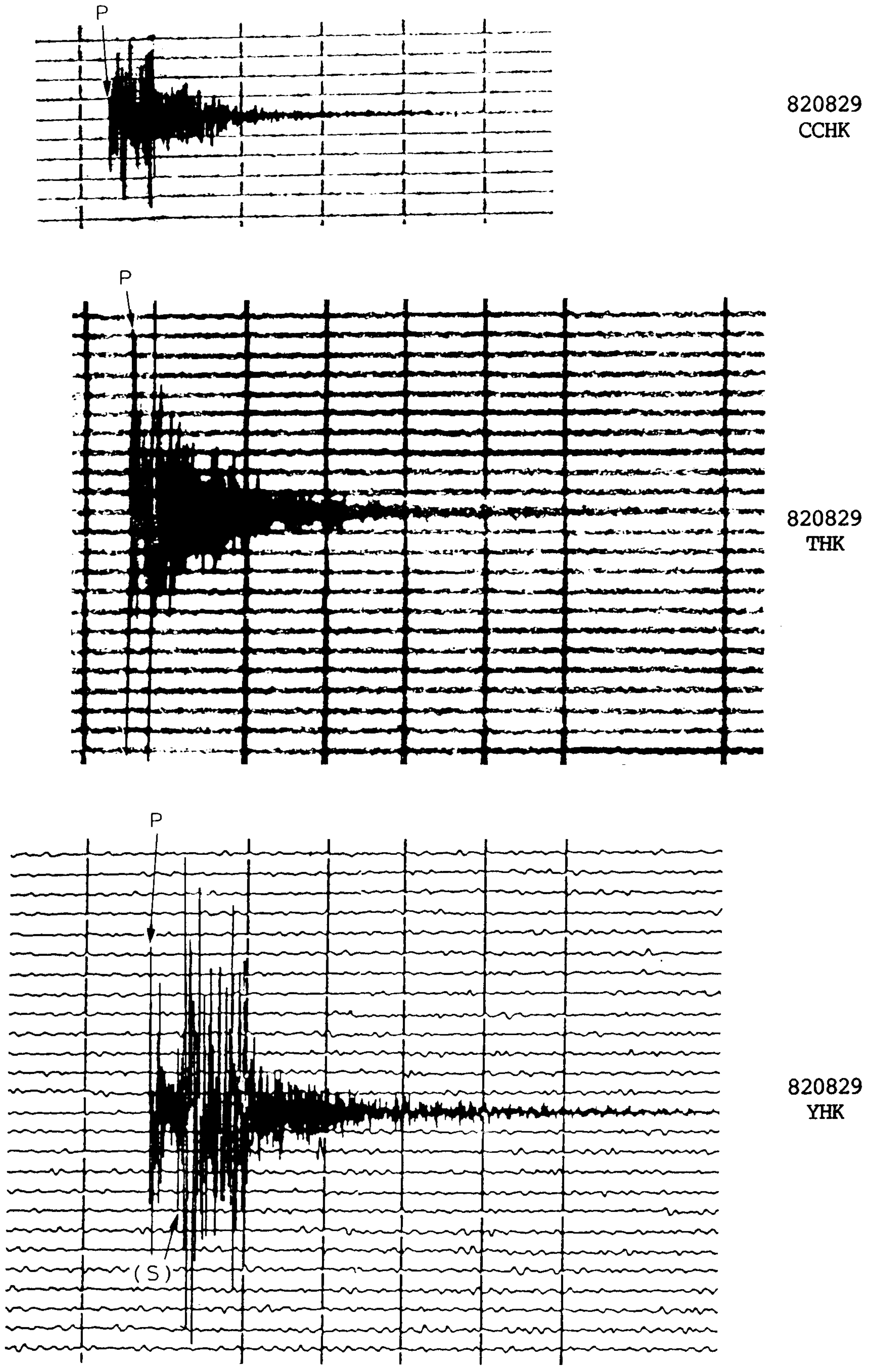

Fig. 4.22 Seismogram of local felt tremor (29.8.82).

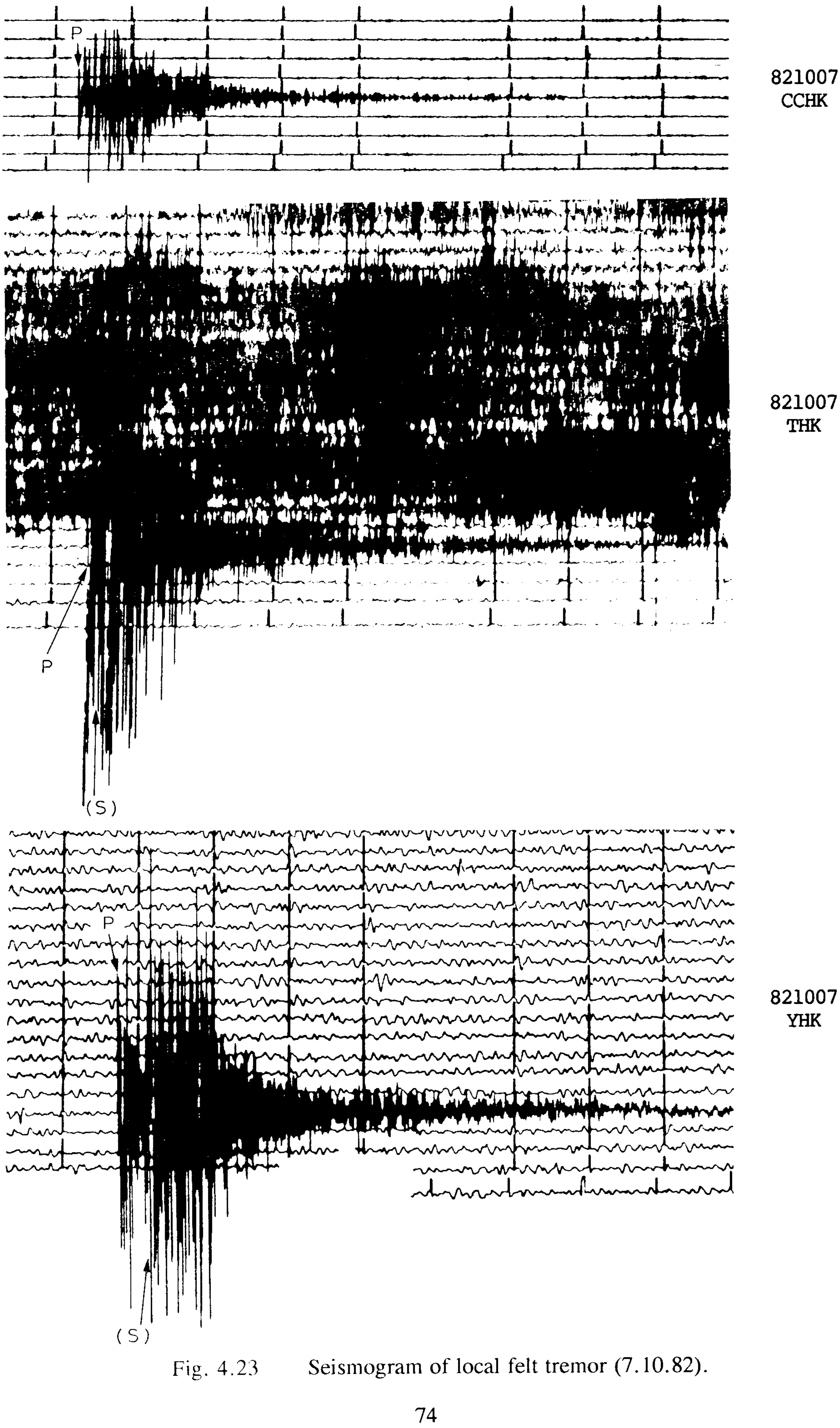

Fig. 4.23 Seismogram of local felt tremor (7.10.82).

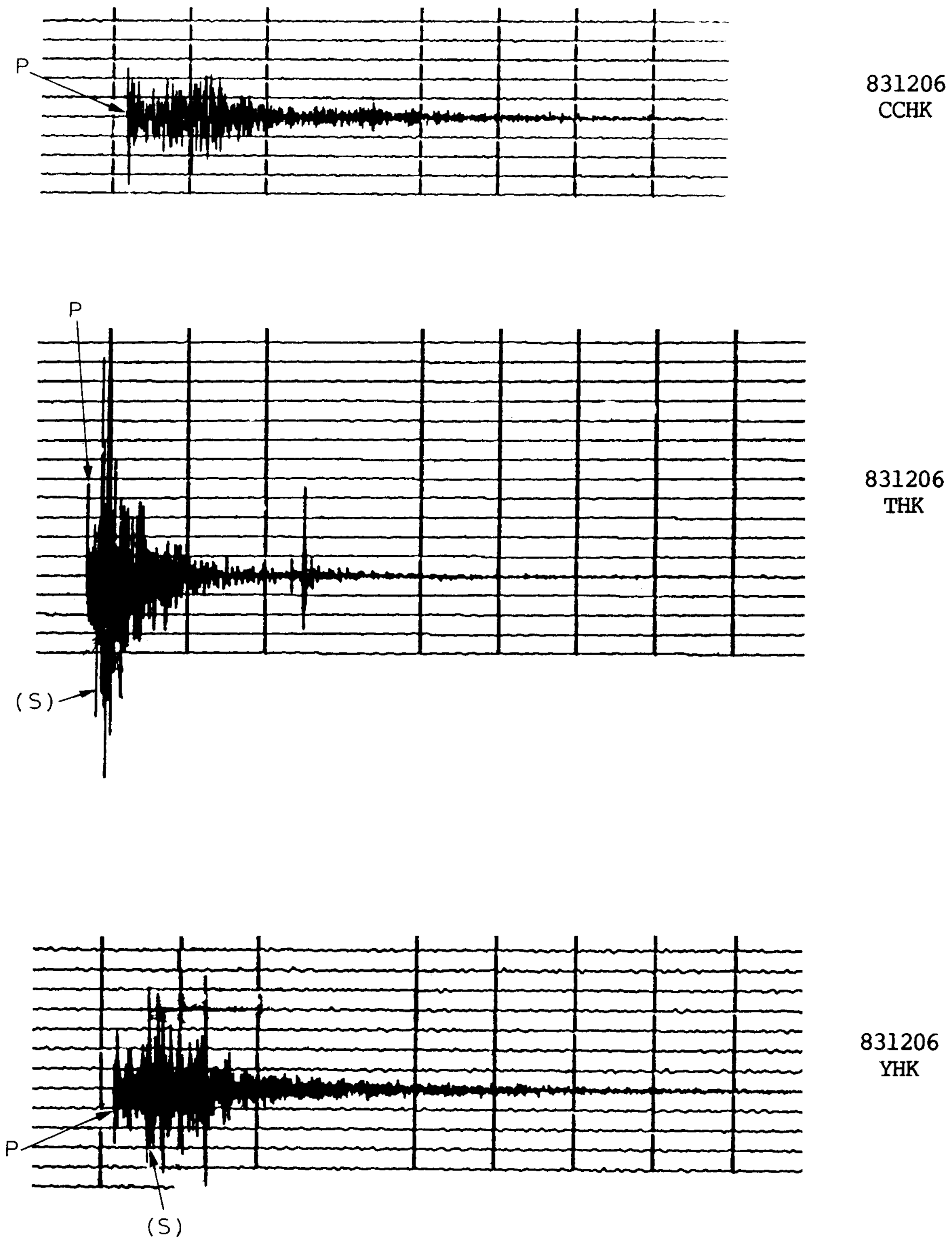

Fig. 4.24 Seismogram of local felt tremor (6.12.83).

Table 4.9 : Phase data for the local felt tremors
Epicentral distance = 0.2°

Table 4.9a

Date : 29.8.1982
Location : Lantau Island, Hong Kong
Intensity : III-IV

Station	Phase(x)	Time(UTC) hhmmss.s	x-P s.s
CCHK	+iP	202253.7	---
THK	+iP	202255.6	---
YHK	+iP	202258.1	---
	i(S)	2301.6	3.5

Table 4.9b

Date : 7.10.1982
Location : Lantau Island, Hong Kong
Intensity : III-IV

Station	Phase(x)	Time(UTC) hhmmss.s	x-P s.s
CCHK	+iP	141313.1	---
THK	+iP	141314.8	---
	i(S)	1318.1	3.3
YHK	+iP	141317.3	---
	i(S)	1320.9	3.6

Table 4.9c

Date : 6.12.1983
Location : Mai Po, Hong Kong
Intensity : IV

Station	Phase(x)	Time(UTC) hhmmss.s	x-P s.s
CCHK	+iP	142531.8	---
THK	+iP	142527.2	---
	(S)	2528.5	1.3
YHK	-iP	142531.6	---
	(S)	2535.7	4.1

5. Conclusion and Discussion

Twenty-one locally felt earthquakes occurring during 1979 - 1991 were analysed in this report. As earthquakes occurring in the same geographical area exhibited similar waveform characteristics on the seismogram, the earthquake events were classified according to their geographical distribution into a number of regions: northern Vietnam, Luzon (the Philippines), Taiwan, Jiangxi and Guangdong (China). Such classification enables an easy reference by the analyst during near or local earthquake events.

Results of the analysis show that the characteristics of the seismic phases vary with (a) the epicentral distance, and (b) the geological or physical structure that separates the earthquake source and the seismograph station.

As an illustration of effect (b) above, at comparable epicentral distances the Vietnam earthquake exhibited channel waves not observable on the Luzon earthquakes. Similarly, the Xunwu (Jiangxi, China) earthquakes displayed most of the major phases associated with near shallow earthquakes, contrasting the Taiwan Strait earthquake which was at comparable distance.

Effect (a) above is evident at shorter epicentral distances. At distances of about 1.2 degrees latitude there was a change in the first arriving phase from refracted waves to direct waves. While refracted waves showed up first on the seismograms of the Longnan and Yangjiang earthquakes, they gave way gradually to direct waves from the earthquakes near Heyuan, which happened to be at a distance of 1.5 degrees as measured from CCHK and at the critical distance of 1.2 degrees as measured TBT. The changeover was complete at smaller distance, as in the case of Haifeng earthquake and in the case of local tremors located within Hong Kong.

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廣東省地震局 <<廣東省地震目錄>>

廣東省地震局 廣州台每月地震觀察報告

Appendix I

Glossary

(Ref: Richter 1958, Bolt 1978, Bath 1979)

i. Compression and Dilatation

Terms used in connection with longitudinal waves, as in acoustics. They refer to the nature of the motion at a given point, usually a recording station. When the ray emerges to the surface, displacement upward and away from the hypocentre corresponds to compression, the opposite to dilatation.

ii. Epicentre and Hypocentre (Focus)

The subterranean point where the earthquake occurs is the hypocentre, or focus. The point vertically above it on the earth's surface is the epicentre. (Fig. I.1)

iii. Epicentral Distance

Surface distance measured from the epicentre to the observing station. It is expressed in km, and sometimes in degrees of latitude ($1° = 111$ km).

iv. Magnitude and Intensity

Magnitude is a measure of the amount of energy released in an earthquake while intensity refers to the degree of shaking at a specified place. The estimation of an earthquake's magnitude is based mainly on the amplitudes and periods of earth movement recorded by the seismograph. If the magnitude is determined from the amplitude and period of the surface wave, it is denoted as Ms. Yet, if parameters of the body wave is used, the magnitude determined is Mb.

The intensity, on the other hand, is determined from reported effects of the tremor on human beings, furniture, buildings, geological structures etc. Unlike the magnitude which has a unique value for a particular earthquake, the intensity of an earthquake at a place depends on the epicentral distance, the depth of focus and the intervening and local earth structure and the type of fault motion that caused the earthquake.

v. Microseism

The recorded lines on a seismogram are never without some small wiggles. These occur because the seismograph is so sensitive that it is able to detect the continuous, yet imperceptible, background noise of the earth. These tiny shakings, called microseisms, arise from many local disturbances: traffic on streets, wind in trees, and other natural movements such as the breaking of the surf on the beach.

vi. Origin Time and Travel (Transit) Time

Origin time is the instant at which the earthquake occurs and seismic waves are liberated at the hypocentre. Travel time is the elapsed time between the origin time and the arrival of a given seismic wave at a specified point, usually a seismograph station.

vii. Seismograph and Seismogram

A seismograph is an instrument which writes a permanent continuous record of earth motion. The record is called a seismogram.

viii. Seismometer

A seismometer is a seismograph whose physical constants are known so that the true ground motion can be calculated from the seismogram. However, seismometer is sometimes referred to as the pendulum part of an electromagnetic seismograph assembly, which actually reproduces the earth's motion.

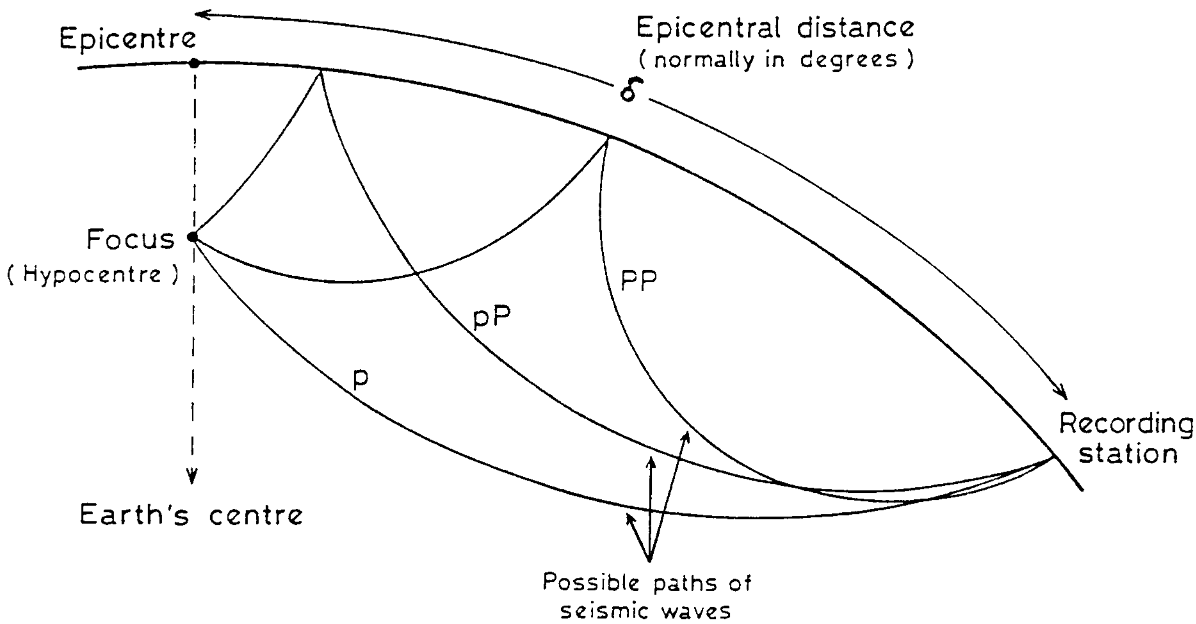

Fig. I.1 Epicentre and hypocentre.

Appendix II

Classification of Earthquakes

(Zhang 1986)

The appearance of a seismic record has a close relation with the type of earthquake. There are two ways of classification :-

i. Earthquakes classified according to focal depth

- Shallow : depth < 60 km;
- Intermediate : depth in the range of 60-300 km;
- Deep : depth > 300 km, the deepest one may reach 700 km.

ii. Earthquakes classified according to epicentral distance

- Local : $\delta < 100$ km ($< 1°$);
- Near : 100 km $< \delta <$ 1000 km (1-10°);
- Distant : $\delta > 1000$ km (over 10°).

Appendix III
Nomenclature of Seismic Phases
(Willmore 1979, Zhou 1980)

Near Earthquake Phases (Fig. 2.6)

1. **Pn, Sn**

   Longitudinal and transverse waves refracted below the Mohorovicic discontinuity (head waves);

2. **Pg(P), Sg(S)**

   Waves in the upper crust (direct waves);

3. **P*(Pb), S*(Sb)**

   Waves in the lower crust or along the Conrad discontinuity;

4. **$P_M(P_{11})$, $S_M(S_{11})$**

   Waves reflected from the Mohorovicic discontinuity.

Phases of Distant Shallow Earthquakes

5. **P, S**

   Direct longitudinal and transverse waves.

Phases of Deep-focus Earthquakes (Fig. 2.7)

Waves leaving the focus in an upward direction, and reflected at surface near to the epicentre are described by the small letters 'p, s' as follows:

6. **pP, sP**

   P or S waves reflected from the surface as P waves;

7. **pS, sS**

   P or S waves reflected from the surface as S waves.

Surface Waves and Channel Waves

8. **L**

   Long waves, unidentified, the beginning of the surface wave group;

9. **G**

   A group of long-period Love waves often in the form of a large pulse for transoceanic paths;

10. **LQ**

Love waves (see Section 2.1);

11. **LR**

Rayleigh waves (see Section 2.1);

12. **Lg**

Crustal channel wave with characteristics similar to surface waves. It travels only continental paths; in research papers the subdivisions is more detailed (Lg1, Lg2);

13. **Lm, Qm, Rm**

Waves of maximum amplitude in the surface group;

14. **πg**

Longitudinal channel waves; travel in the low velocity granitic layers in the crust;

15. **Rg**

Channel waves of the Rayleigh type; travels in the granitic layers in the crust;

16. **M2**

High harmonic waves within the Rayleigh waves.

Appendix IV

Convention in Reporting a Phase

In reporting phase data, letters 'i' and 'e' are used for coding the first motion of a phase. These two letters denote the clarity and accuracy in the determination of a phase. 'i' stands for impetus or sharp onset and 'e' stands for emersio or gentle onset (Simon 1968, Willmore 1979, Zhao 1986). When the angle between the onset of a phase and the zero line is less than 45°, letter 'e' is put in front of the symbol of phase. When the angle is greater than 60°, the letter 'i' is used. No letter notation is required for angles between 45° and 60° used (Fig.IV.1).

For phases distinctly visible on the seismogram but yet unidentifiable, they will be coded with letters 'i' or 'e' only according to their onset angles.

The direction of first motion for the phase is reported according to the International Seismological Centre's convention (Willmore 1979):-

'+' = short-period compression;

'-' = short-period dilatation;

'1' = long-period compression;

'2' = long-period dilatation;

blank = first motion not given.

A phase may therefore be denoted as '+iP', '-eP', '1iP', '2eP' and etc. If a phase is determined with some degree of uncertainty, it will be enclosed with brackets, such as (P) and (S).

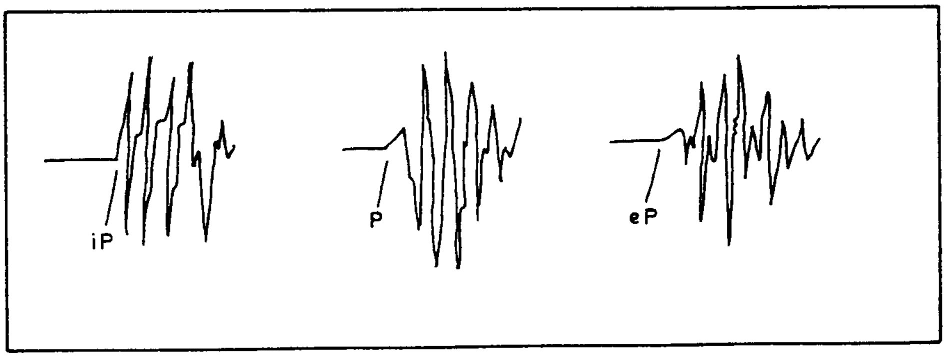

Fig. IV.1 Use of 'i' and 'e' in phase coding.

Appendix V

List of Earth Tremors in Hong Kong, 1979-1991

DATE	RECORDED TIME	INTENSITY	MAG			LAT	LONG	DIST	DIR	LOCATIONS
dd/mm/yy	UTC		ML	MS	MB	[N]	[E]	(km)		
08/05/80	0238	II	4.5	4.0	4.2	23.42	117.43	360	ENE	Taiwan Strait
18/06/80	0934	II	**	5.5	5.7	22.01	121.44	750	E	Off the coast of southern Taiwan
09/04/81	0104	III-IV	4.2	**		22.97	115.43	150	ENE	Haifeng, Guangdong
04/05/81	1105	II	4.8	4.3	4.8	23.82	114.70	175	NNE	Heyuan, Guangdong
24/02/82	1639	III-IV	**	3.9	4.4	24.80	114.76	285	NNE	Longnan, Jiangxi
29/08/82	2023	III-IV	1.5	**	**	22.30	114.00	17	W	Lantau Island, H.K.
07/10/82	1413	III-IV	1.5	**	**	22.30	114.00	17	W	Lantau Island, H.K.
24/06/83	0721	IV	**	6.5	6.0	21.77	103.31	1120	W	Northern Vietnam
06/12/83	1425	IV	1.5	**	**	22.50	114.05	25	NNW	Mai Po, H.K.
23/04/85	1617	III-IV	**	**	6.3	15.32	120.63	1030	SE	Luzon, Philippines
27/01/86	2314	III-IV	**	5.1	4.5	21.67	111.75	260	WSW	Yangjiang, Guangdong
19/02/86	1142	III	**	5.8	5.7	18.98	121.39	835	ESE	Near N.E. coast of Luzon, Philippines
25/02/87	1429	II-III	**	5.2	4.1	21.74	111.68	265	WSW	Yangjiang, Guangdong
25/04/87	1219	III	**	6.2	6.3	16.01	120.24	945	SE	Luzon, Philippines
02/08/87	0908	III-IV	**	4.8	5.0	24.97	115.61	330	NNE	Xunwu, Jiangxi
02/08/87	2320	III	**	5.8	4.9	25.13	115.50	340	NNE	Xunwu, Jiangxi
14/08/87	1701	III	**	4.8	4.4	25.11	115.56	340	NNE	Xunwu, Jiangxi
15/09/87	0205	III	**	4.6	4.7	23.79	114.53	170	NNE	Heyuan, Guangdong
25/11/89	1614	II-III	5.1	4.1	5.0	23.72	114.52	160	NNE	Heyuan, Guangdong
12/03/91	0605	III	**	5.2	5.6	23.16	120.05	610	E	Southern Taiwan
21/09/91	1537	IV	4.8	**	4.2	23.85	114.49	175	N	Heyuan, Guangdong