# 45. *The Fifth Explosion Seismic Observations carried out in North-eastern Japan.*

By the Research Group for Explosion Seismology.*

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## 1. Introduction

At 3 h 4 m 57.074 sec., Sept. 13, 1953, the second big blast was operated at the Kamaisi Mine of the Nippon Iron Works. The Research Group for Explosion Seismology made the observation which was the fifth opportunity in North-eastern Japan.

The blast operation was made in a similar way at a spot adjacent to the previous one[1]. The general features of the blast may be summarized as follows: (1) the aim was to remove dangerous gangue rocks as a safety measure, (2) the amount of explosives was 42 tons, (3) the blast was operated in seven steps, at nominal intervals of 20 milliseconds. However, according to our observation, it took 84 milliseconds instead of 120 milliseconds from the first to the last step.

A blast which is operated successively in several steps is less effective in generating elastic waves in the ground than a simultaneous blast

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1) The Research Group for Explosion Seismology, *Bull. Earthq. Res. Inst.*, **32** (1954) 79.

with the same amount of explosives used. Taking this fact into account, we laid out the most sensitive instruments at every 20 km. from $\Delta=170$ km. The main purpose of the present observation was focussed upon ascertaining the existence of a layer of 8.2 km./sec. which had been expected in the past experiment[2]. No stations were set up farther than $\Delta=332$ km. and to the west of the blast point.

In addition to these stations, a special station was established at Umanokiuti, $\Delta=4.63$ km., to make observations of reflected waves.

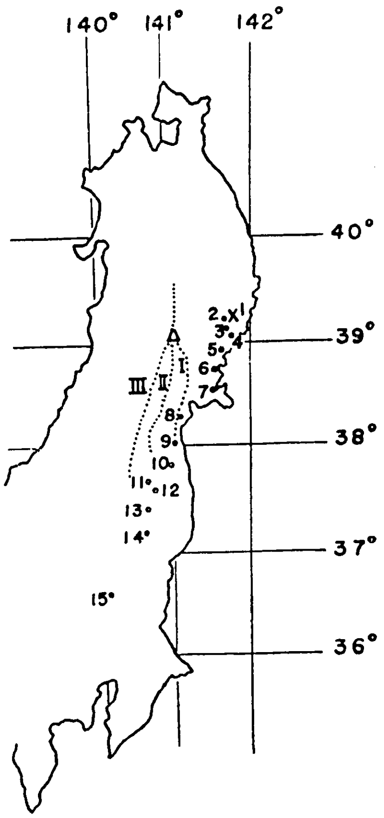


Fig. 1. Seismic observation stations for the 2nd Kamaiši explosion.
- △: Isibuti
- I: The 1st seismic explosion observation.
- II: The 2nd seismic explosion observation.
- III: The 3rd seismic explosion observation.

## 2. Observations

Stations, epicentre, seismographs and observers are listed in Table I, and the distribution of stations is shown in Fig. 1. The electromagnetic seismographs principally used were of proper frequency of 3 c/s and those of 10 c/s and 1 c/s were also supplementarily used. In Mukaiyama, Kawamata, Siraiwa, Nogisawa and Motegi, two or three seismographs were connected in series in order to increase the sensitivity for the seismic waves relative to the noise. As for the amplifier, some new types were employed. In Kanayama a smoked-paper recorder converted from a pen-recording galvanometer was used, with quite satisfactory results.

For time keeping, in addition to receiving directly the radio time signals, we also had the J. J. Y. especially broadcast in medium frequency band by the Nippon Hōsō Kyōkai (N.H.K.) in cooperation.

2) The Research Group for Explosion Seismology, *loc. cit.*, 1).

Table I.

| | Station | λ (E) | φ (N) | Δ km | Electro-magnetic Seismograph | Observers |
|---|---|---|---|---|---|---|
| 1 | Shot point | 141°41′32″.9 | 39°17′39″.9 | 0~2 | 10 c/s Vert.<br>E.T.L. | Mori, Kojima |
| 2 | Umanokiuti | 38 15.4 | 17 24.4 | 4.63 | SIE-P-11. | Yamazaki, Kobayashi (Naota), Koike |
| 3 | Nakasone | 39 10.4 | 11 56.4 | 11.2 | 3 c/s Vert. | Mikumo, Nakagawa, Tsushima |
| 4 | Sakari | 42 46. | 04 48. | 23.92 | 3 c/s Vert. | Shima, Shibano, Yanagisawa |
| 5 | Kesenuma | 34 31.0 | 38 53 57.4 | 45.04 | 3 c/s Vert., Hor. | Matsumoto (T), Karakama |
| 6 | Sizugawa | 26 35.2 | 40 24.4 | 72.25 | 3 c/s Vert.<br>1 c/s Hor. | Tanaka, Suzuki (T) |
| 7 | Onagawa | 27 26.9 | 26 14.7 | 97.32 | 3 c/s Vert., Hor. | Noritomi, Takagi, Osaka |
| 8 | Mukaiyama | 140 51 32.4 | 14 33.7 | 137.38 | 3 c/s Vert., Hor.<br>1 c/s Hor. | Usami, Uzu, Ogawa |
| 9 | Funaoka | 46 43.5 | 02 50.7 | 159.6 | 3 c/s Vert. | Kobayashi (Naoyoshi), Saito |
| 10 | Kanayama | 47 53.1 | 37 53 46.0 | 173.67 | 3 c/s Vert., Hor. | Akima, Matsumoto (H) |
| 11 | Ōsasao | 25 17.9 | 48 16.3 | 199.04 | 3 c/s Vert. | Kasahara, Sato (R) |
| 12 | Kawamata | 37 07.4 | 40 39.0 | 202.46 | 3 c/s Vert. | Tazime, Asano, Akamatsu |
| 13 | Siroiwa | 29 31.7 | 29 37.3 | 225.71 | 3 c/s Vert. | Den, Hasegawa, Kato |
| 14 | Nogisawa | 25 05.2 | 10 05.8 | 261.04 | 3 c/s Vert.<br>1 c/s Hor. | Murauchi, Asanuma, Uchida |
| 15 | Motegi | 11 42.1 | 36 33 08.9 | 331.59 | 3 c/s, 0.7 c/s Vert. | Suzuki (Z), Mine, Ishigaki |

## 3. Results of Observation

Fortunately, the first motion could be clearly identified in most stations, and a phase corresponding to $S$ was also identified in almost every station.

The data are tabulated in Table II, and the travel-time curves in Fig. 2. Reading was made independently by several persons, and no appreciable discrepancy was found.

Table II.

Shot time: $03^h04^m57^s.074$

| Station | $\Delta$ km | P | | S | |
|---|---|---|---|---|---|
| | | I | II or II′ | I | II or II′ |
| 1 | 0~2 | | | | |
| 2 | 4.63 | $3^h 04^m 57^s.976$ | | | |
| 3 | 11.2 | 59.10 | | | |
| 4 | 23.92 | 05 01.15 | | $05^m 04^s.48$ | |
| 5 | 45.04 | 04.65 | | 10 .78 | |
| 6 | 72.25 | 09.03 | | | |
| 7 | 97.32 | 13.10 | | 25.24 | |
| 8 | 137.38 | 20.00 | | 37.48 | |
| 9 | 159.6 | 23.07 | | | |
| 10 | 173.67 | | $05^m 25^s.20$ | | $05^m 47^s.45$ |
| 11 | 199.04 | | | | |
| 12 | 202.46 | | 28.89 | | 54.13 |
| 13 | 225.71 | | 32.38 | | 59.53 |
| 14 | 261.04 | | | | 06 06.54 |
| 15 | 331.59 | | 46.1 | | |

The equations of travel-times derived by the method of least squares are:

$$\text{I}: \quad t=\frac{\Delta}{6.05\pm0.03}+(-2.83\pm0.05)\,,$$

$$\text{II}: \quad t=\frac{\Delta}{7.27\pm0.22}+(1.22\pm0.85)\,, \qquad \text{(sec. and km.)}$$

and

$$\text{II}': \quad t=\frac{\Delta}{7.55\pm0.10}+(2.23\pm0.42)\,.$$

I corresponds to the direct wave, and both II and II′ to the refracted wave. The Funaoka Station happened to be situated nearly on the intersection of Line I and Line II, and therefore this point was omitted in deriving the equation. Since the time accuracy in the farthest station Motegi is relatively low owing to the disturbance caused by the preceding

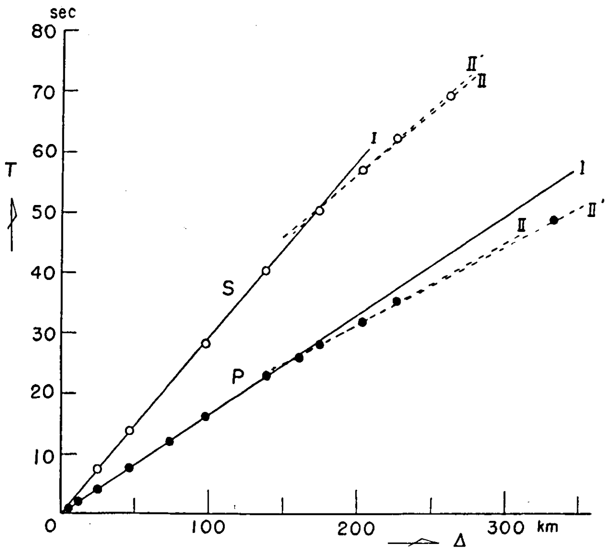


Fig. 2. Travel-time curves obtained from the 2nd Kamaisi explosion.

natural earthquake, this station was excluded in deriving equation II, and included in equation II′. Assuming that the layers are horizontal, the depths are:

from I and II $\qquad Z_{12} = (22.2 \pm 4.9)$ km.

from I and II′ $\qquad Z_{12'} = (25.6 \pm 2.2)$ km.

As for the velocity in the upper layer, the value in the previous experiment was 6.19 km./sec., and that in the present blast is 6.05 km./sec. In the southern profile of the second Isibuti blast it was 5.91 km./sec. and in the eastern profile, 6.08 km./sec.[3] In the third Isibuti blast, in the southern profile the velocity was 5.98 km./sec. Some differences are found as stated above[4]. As for the lower layer, the velo-

3) The Research Group for Explosion Seismology, *Bull. Earthq. Res. Inst.*, **30** (1952), 279.

4) The Research Group for Explosion Seismology, *Bull. Earthq. Res. Inst.*, **31** (1953), 281.

city of 8.2 km./sec. which was considered most probable in the previous experiment could not be found, but a velocity which may correspond to the 7.37 km./sec. which was considered the next most probable in the previous experiment was found. Therefore the difference in computed depths in the present and previous experiments is of an order of 10 km. Though these differences may partly be due to errors in observation, they mostly arise from the inadequate assumption that the layers are horizontal. Therefore the velocities derived so far are all apparent ones, and by assuming some adequate structure the differences are supposed to be explained reasonably. Our future study will be aimed at this problem.

The travel-time curve of the phase corresponding to $S$ is also shown by a broken like,

$$\text{I}:\quad t=\frac{\varDelta}{3.46\pm0.03}+(-2.42\pm0.25)\ ,$$

$$\text{II}:\quad t=\frac{\varDelta}{4.75\pm0.14}+(11.65\pm1.46)\ ,$$

and

$$\text{II}':\quad t=\frac{\varDelta}{4.57\pm0.09}+(9.68\pm0.97)\ .$$

In this case, the Kanayama Station coincides with the break point of the curve, therefore II excludes the station and II′ includes the station on the assumption that the first motion is the refracted wave.

Thus the depths are

from I and II $Z_{12}=(35.8\pm4.0)$ km.

and from I and II′ $Z_{12'}=(32.4\pm2.9)$ km.

which are about 10 km. greater than those computed from $P$ waves.

Fig. 3 is the record of reflected waves. By reducing the weathered layer correction, it is found that 12 components indicate nearly the phase, and the phase, therefore, is undoubtedly the reflected wave from below. Its travel-time is 7.33 sec., and the depth derived from the formula

$$(6.05\ \text{km./sec.}\times7.33)/2=\{(5\ \text{km./2})^2+Z^2\}^{1/2}$$

is 22.13 km. This value agrees fairly well with the depth $Z_{12}=22.2$ km. which is derived from I and II of $P$ wave. A phase clearly recorded shortly after the first motion is still to be definitely interpreted. Other phases due to multiple reflections or reflection at a supposed discontinuity of 32–35 km. in depth are not yet identified.

Though reflection method is very popular in seismic prospecting, reflected waves from a depth of scores of kilometres have very rarely been recorded. Therefore, the present result is of great importance, and this method seems to be a promising one in the future explosion seismology.

## 4. Summary

In the present experiment, effort of observation was concentrated in a region to the south of the blast point and with $\Delta$ within 300 km. From $P$ waves, a layer of 6.05 km./sec. should overlie a lower layer of 7.2 or 7.6 km./sec. with a corresponding thickness of 22 or 25 km. This result is sufficiently supported by the observation of reflected waves. From $S$ waves, a layer of 3.46 km./sec. should overlie a layer of 4.5 or 4.8 km./sec. with a corresponding thickness of 32 or 36 km.

As stated before, discrepancies in the results of the past several experiments arise probably from the inadequate assumption that the crustal structure is uniformly horizontal. The accumulation of data made so far may be sufficient for deduction of a more complicated structure which must be nearer the real state. This deduction should be made with all the available data by taking the geological and gravitational evidences into consideration.

## 5. Acknowledgement

Our sincere gratitude goes to the following organizations for their kind cooperations. Without them, successful results would not have been obtained. They are Tokyo Central Station, Sendai Central Station and Morioka Station of N.H.K., Kamaisi Iron Works, Tohoku District Construction Office of the Ministry of Construction, Sendai Central Headquarters and Morioka Central Headquarters of National Police, Morioka Administrative Office of National Railroad, Morioka, Kamaisi and Kassi Telephone Offices, and the village and town offices where our stations were established. The Radio Time Signal Committee, the Broadcast Station of Standard Frequency and the Institute of Astronomy of Tokyo University gave us important helps for this experiment.

Financial aid for this experiment was partly granted by the Ministry of Education.

Note: The interpretation in this paper is based on the present observations alone, and other series of observations in the same region are entirely disregarded. A general analysis on all the available data has partly been presented orally before the general convention of I. U. G. G. in Rome, 1954. A printed publication shall follow in the near future.

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## 45. 東北日本に於ける第 5 回爆破地震動観測

爆破地震動研究グループ

1953 年 9 月 13 日に日鉄鉱業釜石鉱業所に於いて前回の 1952 年 12 月 7 日の大爆破に引続き第 2 回の爆破作業が実施せられた. 爆破は前回同様落盤による災害発生防止のため脈石除去を目的とし, 場所は前回の隣接地点で薬量は総計約 42 ton である. 但し爆発は計画によれば 20 ms づつおいて 7 段に分けてなされ, 観測によると初段より終段まで 84 ms を要した. 爆破時刻は前回迄と同様な方法により, オッシログラムより $3^h\,04^m\,57.074^s$ と求められた.

地震動観測は, 前回予想せられた 8.2 km/sec の速度の検討を主眼とし南方測線のみ 15 点で行い, 使用計器は略前回同様である (第 I 表, 第 1 図). 今回は, 各点で良好な記録が得られ主な位相の読みは第 II 表の如くで, 走時曲線は第 2 図に示されている. 直線として最小自乗法で求めた初動に対する式は次の如くである. (単位は $\Delta$: km; $t$: sec.)

$$\text{I}: \quad t=\frac{\Delta}{6.05\pm0.03}+(-2.83\pm0.05)$$

$$\text{II}: \quad t=\frac{\Delta}{7.27\pm0.22}+(1.22\pm0.85)$$

$$\text{II}': \quad t=\frac{\Delta}{7.55\pm0.10}+(2.23\pm0.42)$$

不連続面の深さ:

I, II より $Z_{12}=(22.2\pm4.9)$ km.

I, II′ より $Z_{12'}=(25.6\pm2.2)$ km.

最も遠い茂木は誤差 0.1 s 以内であるが時間の精度が稍々悪いため, II はそれを含めて計算した式であり, II′ はそれを除いて求めた式である. この結果, 上層の速度は, 各観測毎に多少の差異があり, 叉, 前回の 8.2 km/s の速度は認められない事が判つた. この様な点に関し, 我々は, 東北地方に於いてかなりの資料を集めたので今後統一的に考えてみる事が必要である.

叉, 今回は S 波に相当する位相もかなり明瞭に認められ, 最小自乗法で求めた式は次の如くである.

$$\text{I}: \quad t=\frac{\Delta}{3.46\pm0.03}+(-2.42\pm0.25)$$

$$\text{II}: \quad t=\frac{\Delta}{4.75\pm0.14}+(11.65\pm1.46)$$

$$\text{II}': \quad t=\frac{\Delta}{4.57\pm0.09}+(9.68\pm0.97)$$

不連続面の深さ:

I, II より $Z_{12}=(35.8\pm4.0)$ km.

I, II′ より $Z_{12'}=(32.4\pm2.9)$ km.

II, II′ を求めた意味は, 金山が丁度 I, II の交点付近に当り, II はそれを除いて計算した式であり, II′ は $P$ 波の結果よりそれを含めて求めた式である. $P$ 波に比して精度が劣る事は否定出来ないが, 上の如く定め得た意義は大きいものと考えられる.

更に今回は反射波の記録をとるために $\Delta=4.67$ km の馬木内に観測点を設けたが, 反射波をとら

[The Research Group for Explosion Seismology.]  [Bull. Earthq. Res. Inst., Vol. XXXIII, Pl. XCVII.]

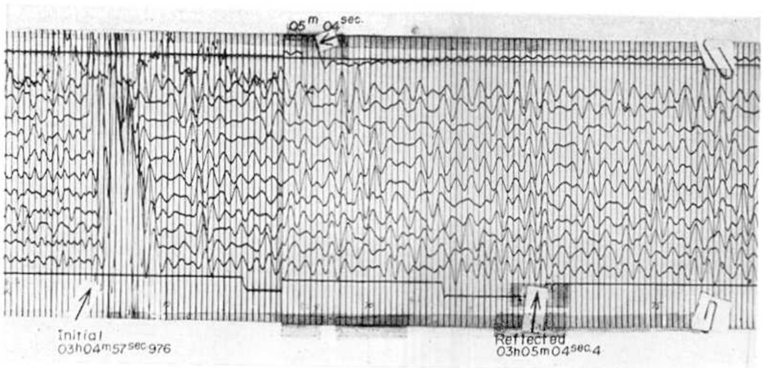


Fig. 3. Record of Reflection Wave at Umanokiuti.

(A)

(B)

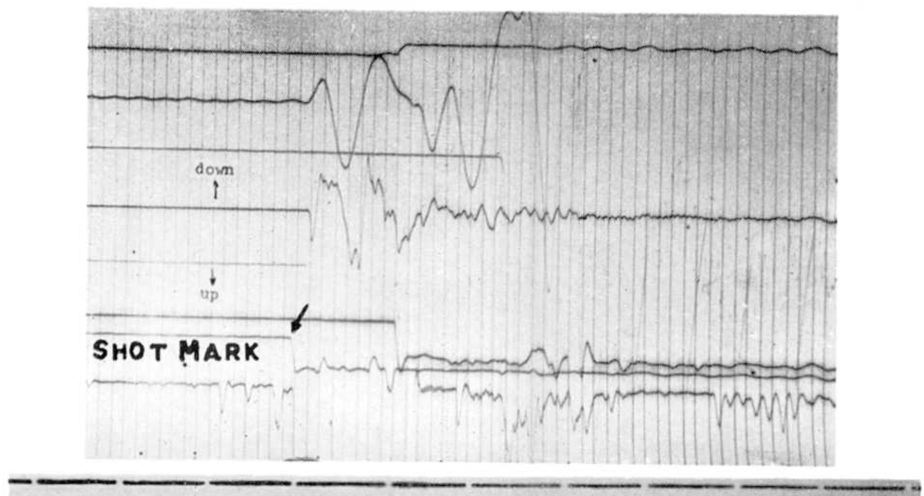


Fig. 4. Seismograms obtained at Shot point (A) and Nakasone (B).

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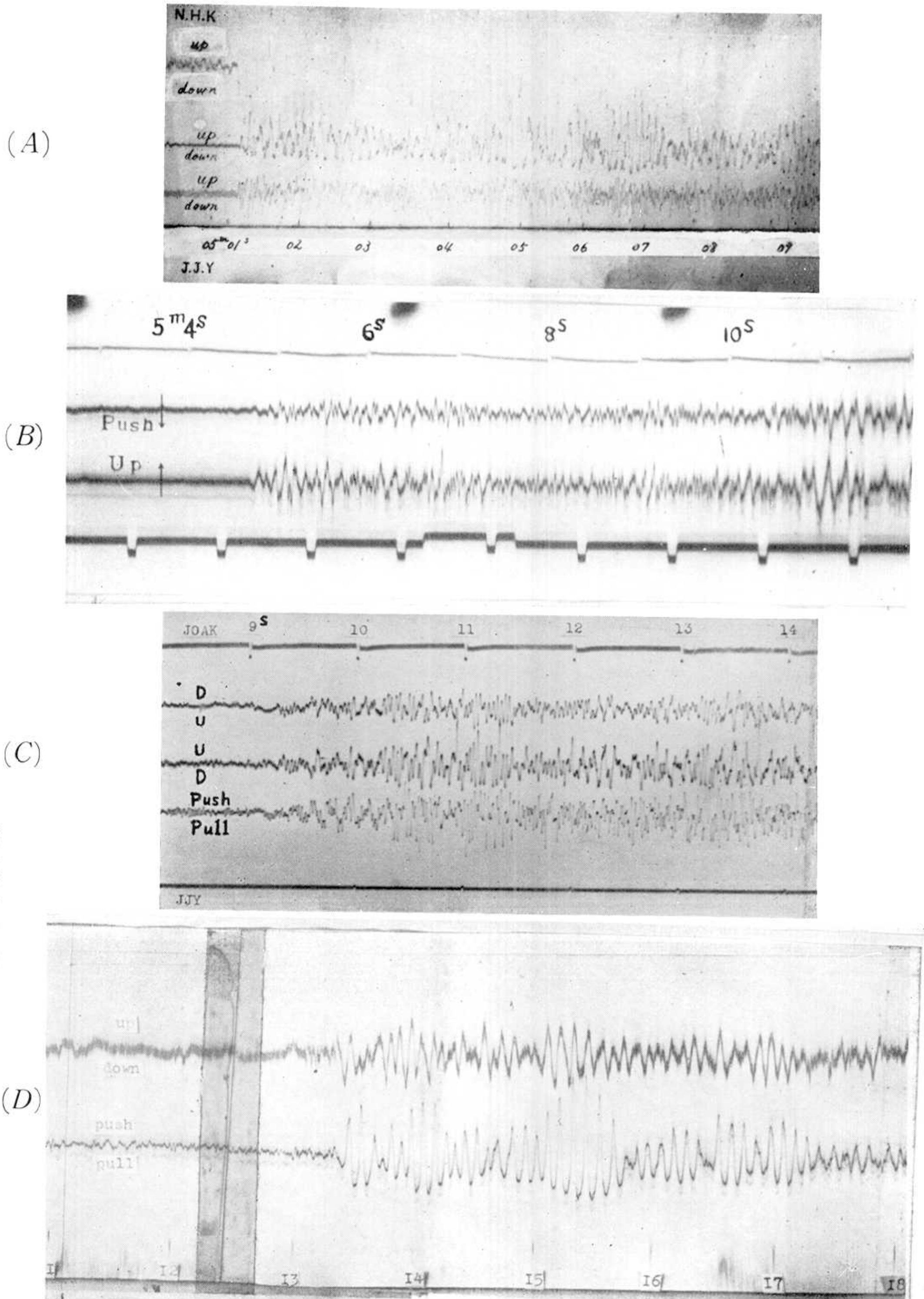


Fig. 5. Seismograms obtained at Sakari (*A*), Kesennuma (*B*), Sizugawa (*C*) and Onagawa (*D*).

(A)

(B)

(C)

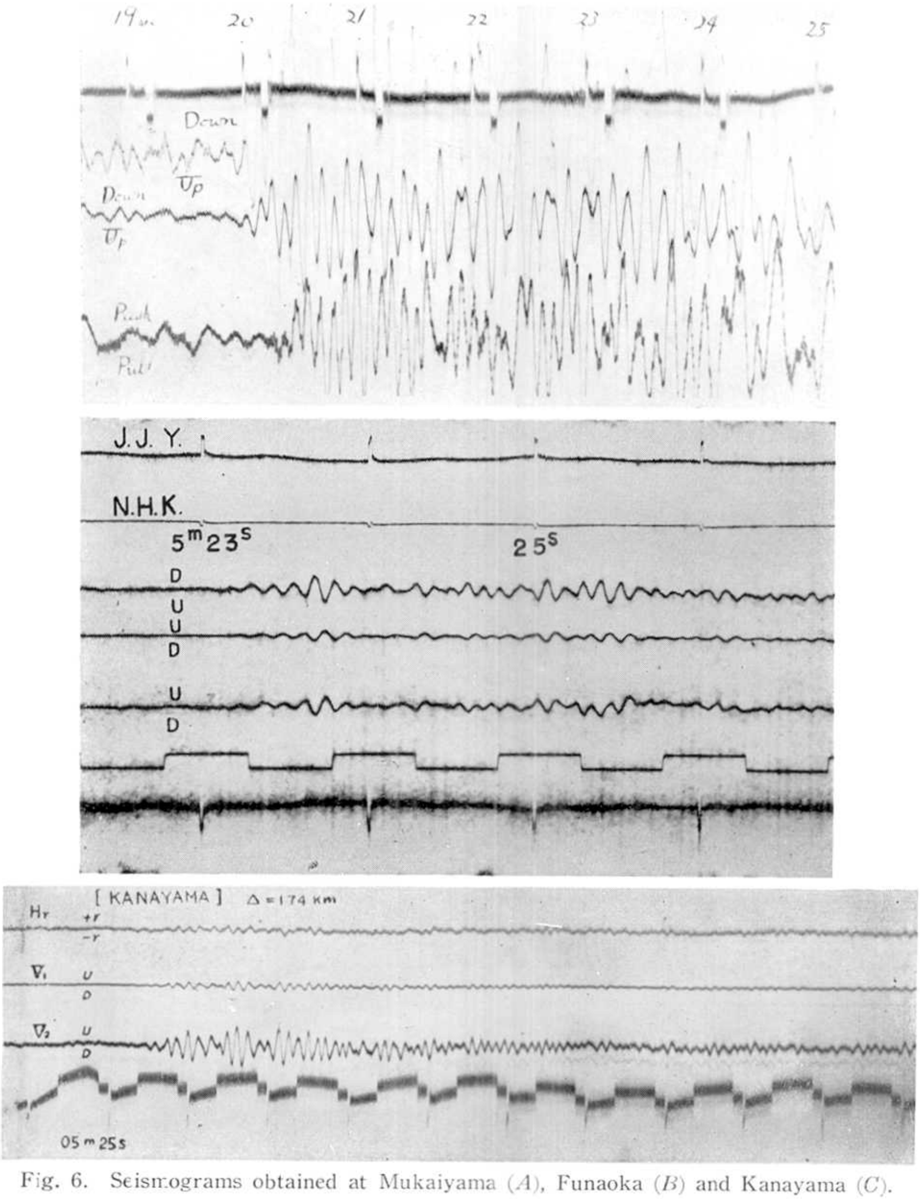


Fig. 6. Seismograms obtained at Mukaiyama (*A*), Funaoka (*B*) and Kanayama (*C*).

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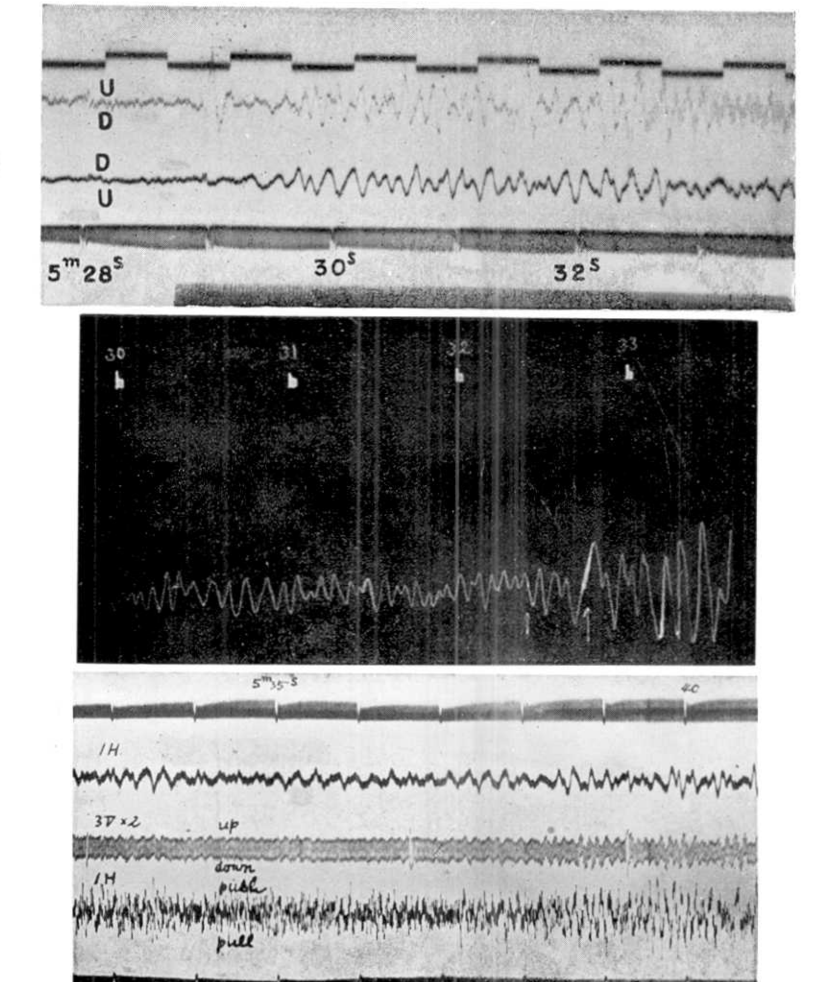


(A)

(B)

(C)

(D)

Fig. 7. Seismograms obtained at Kawamata (*A*), Siroiwa (*B*), Nogisawa (*C*) and Motegi (D).

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える事に成功し，その走時は 7.33 秒でこれより反射面の深さは 22.13 km と求められ，$P$ 波より求めた深さ $Z_{12}$=22.2 km と非常によく一致した結果が得られ，今後新しい有力な手段として大いに期待している．

尚，今回の実験についても前回同様多大の御協力を賜つた日鉄鉱業釜石鉱業所；N.H.K. 東京中央放送局，仙台中央放送局，盛岡放送局；建設省東北地方建設局；国警仙台管区本部，同岩手県本部；盛岡鉄道管理局；電々公社盛岡電話局，釜石電話局，甲子郵便局；各観測点所在官民各機関及び各観測班附属機関関係者各位に篤く御礼申し上げる次第である．

尚，本研究経費の一部は文部省科学研究費によるものである．記して謝意を表する．

註 尚，本報告に於ける結果は，今回の観測のみを用いて独立に整理されたものである．今迄東北地方で合計 5 回の爆破地震動の観測が行われているが，その全部の資料を統一的に説明する地殻構造は既に求められ，1955 年 9 月 ローマに於ける I.U.G.G. の総会で発表せられており，近き将来印刷される．