8. *Explosion-Seismic Observations in North-eastern Japan.*

By The Research Group for Explosion Seismology, Tokyo.*

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1. Introduction.

Our knowledge about the internal structure of the earth has been considerably enriched through the constant endeavour to revise the time-distance curves of seismic waves. But notwithstanding many brilliant achievements, the accuracy of time observations at routine stations has now reached the limit and we can expect no further development in this field without recourse to the statistical method. On the other hand, recent progress in the seismic exploration method gives promise of bringing the dead-lock in question to an end, and the highlight in recent seismology has been, in consequence, focused on this point. However, the thickness of the crust with which we have first to deal is about 50 km, so that the time-distance curve as far as 200 km or more must be determind with a higher accuracy. The explosives necessary for such explosion-seismic study amount to so much that we had such opportunities only on rare occasions. In Japan we have only one record of a blast of 20 tons by the navy on a south sea island. Unfortunately, we had no means to make observations at the surrounding ocean at the time.

2. Project of observation of Isibuti explosion.

In order to get 200,000 m^3 of rocks for the construction of the rock-fill dam, Isibuti, Wakayanagi-mura, Iwate Pref., about 20 km to the west of Mizusawa, a simultaneous explosion of 57 tons carlit had been planned to be detonated on 25th October 1950.

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It was the first time in Japan that such a large amount of explosive was set off at one time and the explosion was a golden opportunity to seismologists. Unfortunately, it was only ten days before the explosion when we were informed of it. We at once established a project of cooperative observation though restricted in time, instruments, personnel and budget.

Amplitudes of the ground at different epicentral distances were estimated by taking into consideration the data of previous explosion seismic observations and the observing stations, instruments and personnel were distributed as are shown in Fig. 1 and Table I. As are seen in the figure, the observing

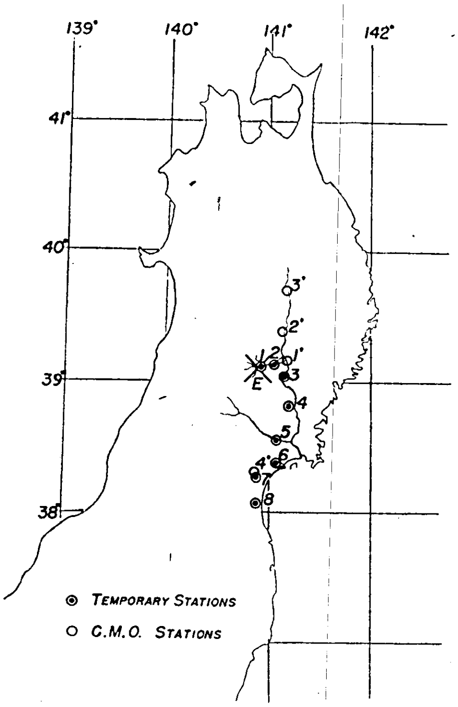

Fig. 1. Seismic observation stations for the Isibuti explosion.

stations were set up along the Tohoku railway line for transportation facilities and at the same time near the branch offices of the Tohoku Electric Supply Co., where telephone communications from the explosion point are available through private lines. No station was set up on the alluvial layers. Then, eight temporary stations were set up at about 20 km intervals starting from the Isibuti station which was 1.8 km from the explosion point as are shown in Fig. 1.

Table I. Isibuti explosion seismic observation.

(1950-X-25, 12 h 06 m 07 s. $\varphi=39^\circ 06' 21''$ N, $\lambda=140^\circ 51' 37''$ E, $h=323$ m.)

No.	Station	Coordinates	Elevation	Distance from shot	Observers	Time signal	Paper speed	Seismographs (Component)
1	Isibuti	39° 06′ 51″ N 140° 54′ 43″ E	m 300	km 1.89	Suyehiro, Aihara, Isikawa, Ogawa (C.M.O.)	JJY	mm/sec 10	Ishimoto accel. (H), $T=0.^s1$, $V=100$. Hagiwara displ. (H), $T=4.^s4$, $V=17$.
2	Wakayanagi	39° 07′ 49″ N 141° 03′ 56″ E	100	15.06	Tazima (E.R.I.)	Chronometer	2	Ishimoto accel. (HR, HQ, V) $T=0.^s1$, $V=100$.
3	Maesawa	39° 02′ 46″ N 141° 07′ 38″ E	30	21.21	Miyamura, Tuziura (E.R.I.)	JJY	4	Ishimoto accel. (HR, HQ, V) $T=0.^s08$, $V=200$.
4	Hanaizumi	38° 50′ 07″ N 141° 10′ 17″ E	45	38.42	Omote, Yamazaki, Oosawa (E.R.I.)	JJY	2	Ishimoto tromometers ($H2$), $T=1.^s0$, $V=230$. Ishimoto accel. (V), $T=0.^s1$, $V=100$.
5	Kogota	38° 33′ 18″ N 141° 03′ 32″ E	10	62.81	Akima (E.R.I.)	Chronometer	40	Hagiwara tromometer (V), $T=0.^s05$, $V=40000$.
6	Matusima	38° 23′ 11″ N 141° 04′ 33″ E	10	81.37	Tazime, Den (Geophys. Inst.)	JJY	3	Mov. coil transducers $T=0.^s1$, $G=10^8$ ($H2$, V.) Galva. YEW-D.
7	Sendai	38° 13′ 17″ N 140° 51′ 41″ E	67	98.24	Asada, Suzuki, Sima (Geophys. Inst.)	JJY	6	Mov. coil transducers $T=0.^s1$ ($V3$), $T=1.^s0$ ($H2$). $G=10^8$. Galva. YEW-D.
8	Watari	38° 01′ 52″ N 140° 51′ 18″ E	15	121.91	Kaneko, Huruya, Itikawa (Geol. Surv.)	JJY	7	Mov. coil transducers $T=0.^s1$ ($H2$, $V2$), $G=10^8$. Galva. YEW-D.

In order to determine the time of commencement accurately at each station, at six of the eight stations second-marks from the standard clock of the Tokyo Astronomical Observatory were placed on seismograms directly by the radio time signal, JJY (4 Mc). Others used chronometers checked by the NHK time signal at every hour. The firing time was fixed at 12 h 06 m 07 s, 25th October 1950 so as to be fit for the broadcast of the JJY time signal.

The speed of recording paper or film was 2 mm/sec at Wakayanagi and Hanaizumi, 3 mm/sec at Matusima, 4 mm/sec at Maesawa and more than 5 mm/sec at the other stations.

3. Explosion.

How the explosive was charged and detonated are described as follows. As shown in Figs. 2 and 3, seven large explosive chambers and eight small ones were dug at the height of 20 m above the adjacent river floor into the north-northeastern slope of the Saruiwa Rock, a massive igneous rock

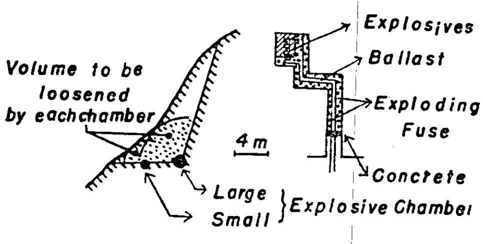

Fig. 2. Explosive chambers.

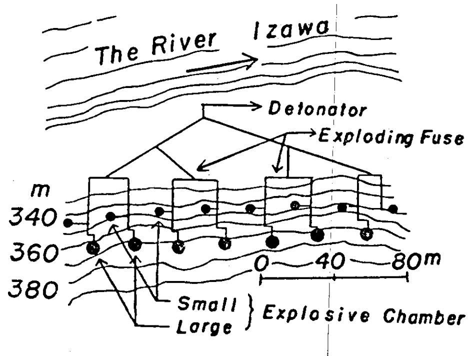

Fig. 3. Explosive chambers and the net of exploding fuse.

block. The explosive amounting to 57 tons was charged in these fifteen large and small chambers. At a distance of 300 m from the chambers, an electric detonater was placed, and an ignition switch was set at 400 m from the detonator. The detonator and each explosive chamber was connected with a fuse, each fuse having the same length so as to set off all the explosive at one time.

As scheduled beforehand, the electric switch was closed at 12h 06m 07s, 25th October 1950.[1] A series of photographs in the Plates (Figs. 4~5) will show us vividly the process of explosion. From the viewpoint of civil engineering, the blast was quite successful and nearly 300,000 m^3 of rocks were loosened. However, contrary to our expectations, sounds and vibrations were not strong. Seismic intensity was II at the epicentral distance of about 2 km, and beyond 15 km no vibration was felt. But, shocks were felt by some persons at Kurosawaziri, 30 km northeast from the explosion. Closer inquiries of the shock at various places is now under way by mail.

4. Results of observations.

Favoured by clear telephone communications from the explosion point to each station, exact ignition as scheduled, and perfect receiving of the radio time signal it was possible to register the ground oscillations excellently at all stations except Kogota. Table II shows the time of commencement

Table II. Arrival times of the Isibuti explosion tremors observed at eight temporary stations of the group.

No.	Station	Arrival times (12 h 06 m.)			
		P_2	P_1	S_1	S_2
		sec.	sec.	sec.	sec.
1	Isibuti { Accel.	—	8.31	8.52	—
	Isibuti { Displ.	—	8.31	8.61	9.27
2	Wakayanagi	—	10.80	12.46	(13.69)
3	Maesawa	—	12.04	—	—
4	Hanaizumi	14.47	15.25	19.0	20.0
5	Kogota	—	—	—	—
6	Matusima	21.43	—	—	—
7	Sendai	24.5	—	35.9	37.2
8	Watari	28.0	—	—	—

1) According to a witness, the switch-in seemed to have been somewhat later than the predetermined time.

at each station checked quite independently by each observer. Seismograms at several stations are shown in Figs. 6 and 7. Fig. 8 indicates travel-time

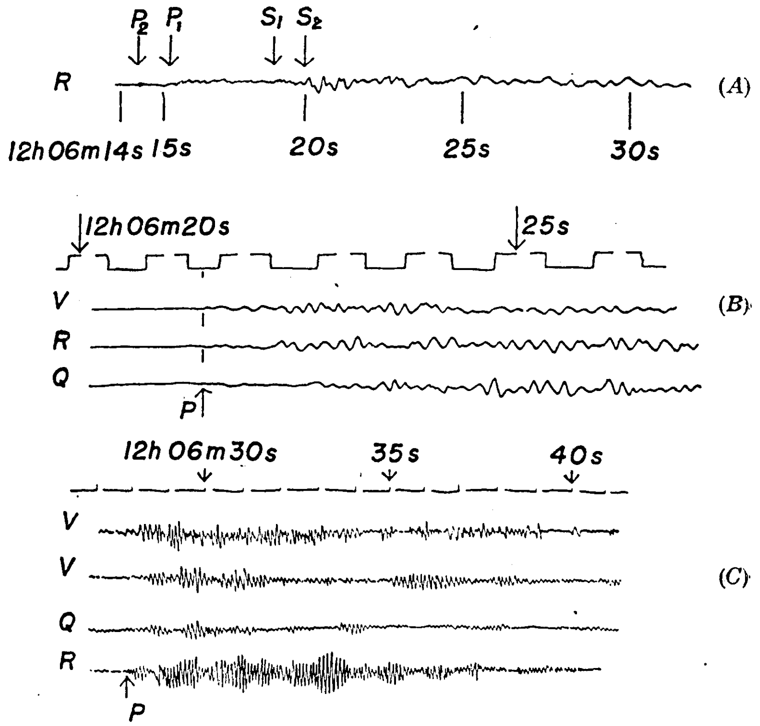

Fig. 7. Seismograms at Hanaizumi (*A*), Matusima (*B*), and Watari (*C*).

curves drawn from the above data. Considering the presence of second marks from a standard clock on most of the records and the high speed of recording papers, we believe that the accuracy of these readings are much higher than one tenth of a second. As shown clearly in the diagram, the times of commencements at Isibuti, Wakayanagi, and Maesawa seem to lie exactly in a straight line, and those of Matusima, Sendai and Watari also seem to lie in another line. A weak initial phase at Hanaizumi lies just on the former line and the following stronger onset lies on the latter line. These phases are named P_1 and P_2 respectively. Least square solutions of these lines give the velocities 5.26 ± 0.007 km/sec and 6.12 ± 0.017 km/sec and intercept times 7.97 ± 0.032 sec and 8.23 ± 0.24 sec after 12h 06m for P_1 and P_2 respectively.

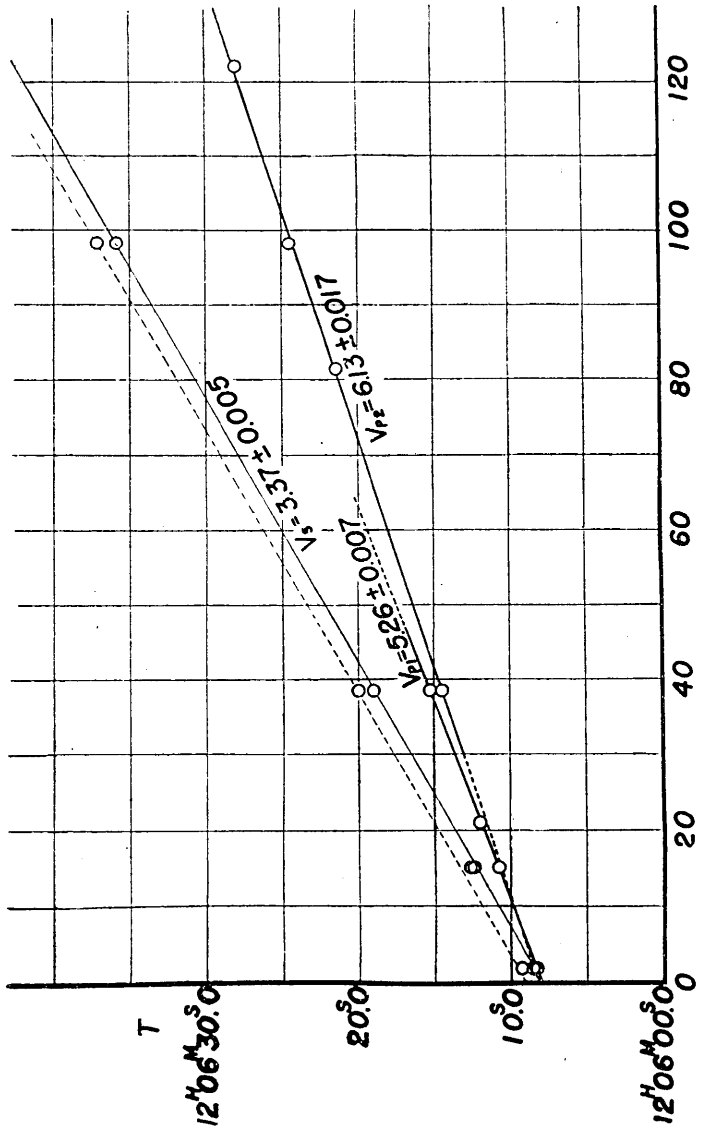

Fig. 8. Travel-time curves from the Isibuti explosion data.

The two lines intersect with each other at an epicentral distance of 9.5 ± 9.74 km, and if we assume the existence of a uniform and horizontal layer, we have 1.3 ± 1.27 km for the thickness. The velocities above mentioned, 5.26 km/sec and 6.13 km/sec are nearly the same as 5.0 km/sec and 6.1 km/sec in the granitic and the intermediate layers respectively as determined by T. Matuzawa from the earthquake data in Japan. But if such interpretation is to be approved, the unexpectedly small thickness of the first (granitic) layer is hard to interpret, and if the basaltic layer is to be located at such a shallow depth, the geological fact that no outcrop of such rock has yet been found in the vicinity seems also unexplainable. Another alternative explanation of these observed facts may be found in the difference in azimuths of the near and far stations where P_1 and P_2 phases were clearly observed separately, if we neglect the difference of the origin times of these waves. But the accuracy, as seen from the probable errors and the appearence of these two phases at Hanaizumi, is not in favour of such alternative explanation. We must therefore refrain from giving the conclusion for the present.

As to the other phases following the P phase, though clearly observed at respective stations as they were, almost all of them could not be seen as waves propagated with definite velocities. However, there could be found only one particular phase at Wakayanagi, Hanaizumi and Sendai, which respectively lies in a straight line indicating a velocity of 3.37 ± 0.005 km/sec. This may be interpreted as a kind of S-wave. Furthermore, a clear phase appearing slightly later than the last phase is also identified at Isibuti, Hanaizumi and Sendai, and constitutes a travel-time line running parallel to the above line with a lag of about 1 second. The remarkable impetus of this phase on the seismogram at Isibuti is to be noted. On examining the cinematographic film taken at the very instant of the explosion, the following consideration might be accepted as an alternative interpretation of the generating mechanism of elastic waves. (See Figs. 4, 5) First, at the time of explosion, a big destruction occurred around the place where the explosives had been charged, and the waves were radiated in all directions. Then, one moment later, by tbe sliding down of a large amount of loosened rocks, secondary shear waves were generated. Thus the S-wave generated by this last mechanism may correspond to the last phase in the diagram of travel-time curves. It is also to be mentioned that the impact of the falling rocks may also be capable of generating considerable waves, since the potential energy released will amount to as large as 8×10^{17} ergs by the fall of 10 m. This amount is comparable with the energy from the explosives which is estimated at 2.4×10^{18} ergs. Therefore this may also serve as an alternative explanation of the generation of the later phases.

5. Concluding remarks.

Now we may conclude from the above statement that the crustal structure in NE Japan is somewhat different from what we have expected on the previous knowledge as deduced from the observations of natural earthquakes in other parts of Japan. The velocities of the P_1 and P_2 phases we have obtained are very near to those of $\overline{P}$ and P^* waves, but the thickness of the surface layer seems too small to be ascribed to that of the granitic layer.

The wonderfully good alignment of the travel-time plot is of course due to the observational accuracy due to the second mark of JJY from a standard clock of the Tokyo Astronomical Observatory, as directly recorded on the seismograms at most of the stations as well as the high speed of the recording papers, but we must ascribe it also to the unexpected smallness of the difference in the effect of the underground structure.

The apparently poor definition of the S phases and surface waves may also be due to the smallness of natural periods of seismometers and the recording galvanometers used through necessity.

6. Acknowledgment.

We have been very much obliged to the construction agencies of the Isibuti Dam, the Tohoku Electric Supply Co., the JJY Broadcasting Station and the provincial authorities at each of our station, which have been much helpful in the present observations. Thanks are also due to Prof. T. Matuzawa for his kind encouragement and guidance in the course of our study.

8. 東北日本における爆破地震動の觀測

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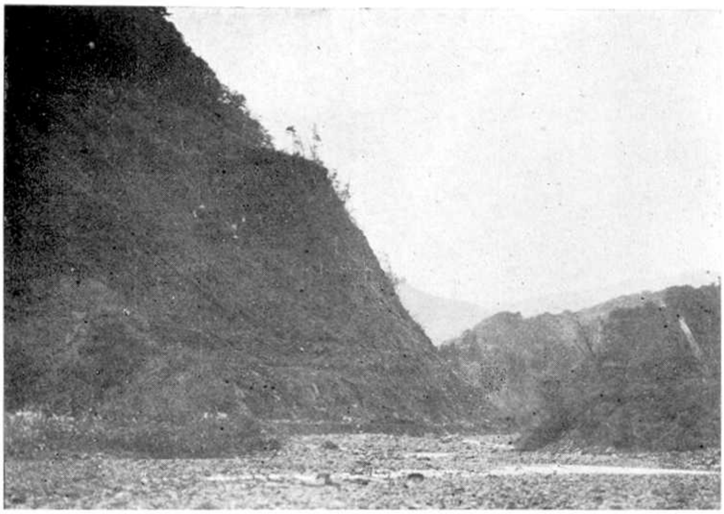
1950年10月25日岩手縣膽澤郡若柳村石淵（水澤町の西約20km）に，東北地方建設局と西松組とにより建設中の石塊堰堤の築堤用石塊採取のためおこなわれたカーリット57トンの一斉爆破に際し，われわれは爆破點よりの距離1.8kmから121kmにわたる間に8ケ所の臨時觀測點をもうけて，この爆破による震動の觀測をおこなつた。觀測計畫の概要は第I表のとおりで，爆破點および各觀測點の位置は第1圖にしめした。爆破の方法は第2,3圖のごとき計畫にしたがい，導爆索の長さを一定にして，一齊に爆破するようにした。第4,5圖の一連の寫眞はよくその爆破狀況をしめしている。若干の地點における震動記象の複寫を第6圖，第7圖にかゝげる。初動および二三の位相の發震時は第II表にあり，これらの走時曲線は第7圖にしめす。震源にちかい4點にあらわれる，速度5.26±0.007km/secのP_1波と，とおい4點にみられる，速度6.13±0.017km/secのP_2波の兩直線は，震源より約10kmあたりでまぢわり，速度5.26km/secのうすい層が，速度6.13km/secの地殼のうえにのつていることをしめす。しかし兩直線の交點の震源距離と5.26km/secの層のあつさとは，計算によれば夫々9.5±9.74km，1.3±1.27kmとなるので，精度がわるく，したがつて，このような表面の層の存在もまだきわめて確實とはいえない。あるいわ，爆破點にちかい點は大体その東方に，遠い點は南方にあたるので，方向による傳播速度のちがいを考えることもできるかもしれない。これらの點に關しては，いまの材料の精度ではこれ以上決定的なことはいえないので，なお今後の觀測を期待して準備している。

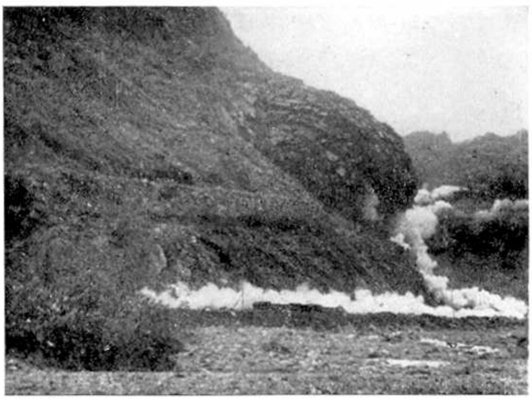
S波にあたる位相は觀測されなかつたところがおゝいので，はつきりしたことはいえないが，一應3.37±0.005km/secの速度がえられた。これをS_1とするとき，さらに，これに約1秒おくれて位相S_2が，第8圖に破線でしめしたごとく，觀測され，石淵の變位計などでは非常にはつきりしたものである。爆破によりおこつた崩壞のはじまるときに生じたねぢり波ではないかと考えられる。

本觀測ははじめての經驗であつて，しかも非常に時間的余裕がすくなく，準備不充分でおこなつたのであつたが，さいわいにして，かなりの成果をおさめることができた。多大の便宜を與えられた東北地方建設局，西松組，東北配電株式會社，電波廳標準電波發射所および各觀測點の所在官民各位に對して深く感謝する。なお，今回の研究に對し，つねに激勵と指導とをあたえられた松澤教授にも感謝したい。

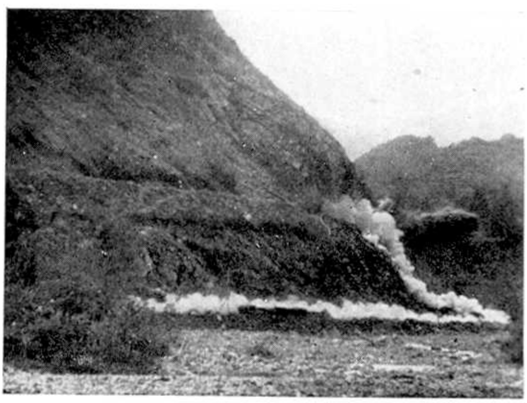


A

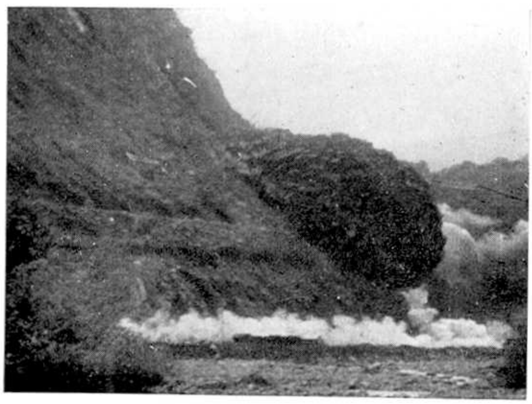
B



D



C



E

Fig. 4. Isibuti Explosion (I) A: Before the explosion. (By courtesy of the Press Asahi) B→E: Process of the explosion (From the Yomiuri News Reel). Cut interval between B and C, C and D, D and E, and E and F (Fig. 5) are 15, 15, 15, and 30 cuts respectively. Film speed was about 0.04 sec. per cut.

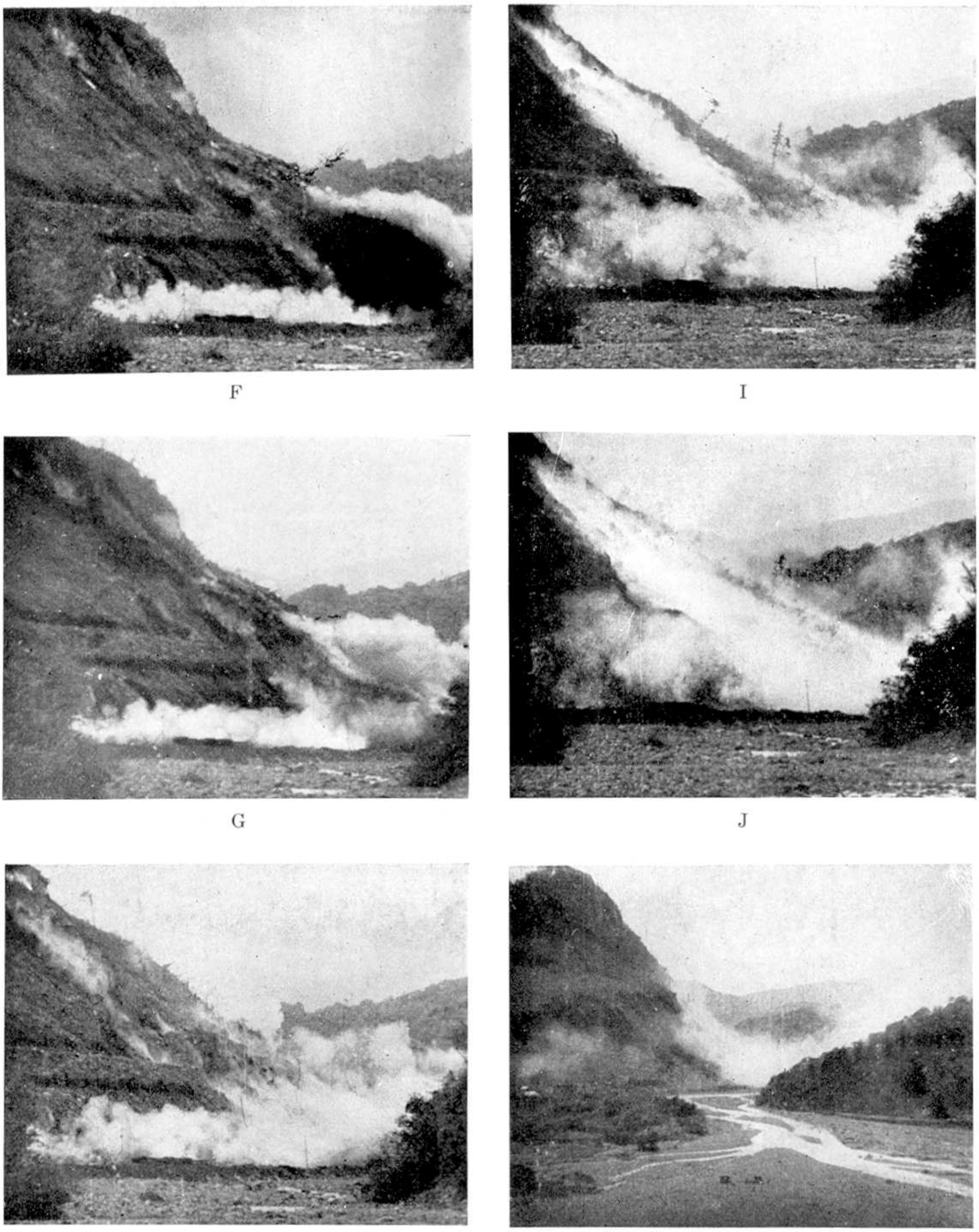


Fig. 5. Isibuti Explosion (II) F→J: Process of the explosion (From the Yomiuri News Reel). K: After the explosion (From the Yomiuri News Reel). Cut interval between E (Fig. 4) and F, F and G, G and H, H and I, and I and J are 30, 10, 95, 115, and 85 cuts respectively. Film speed was 0.04 sec. per cut.

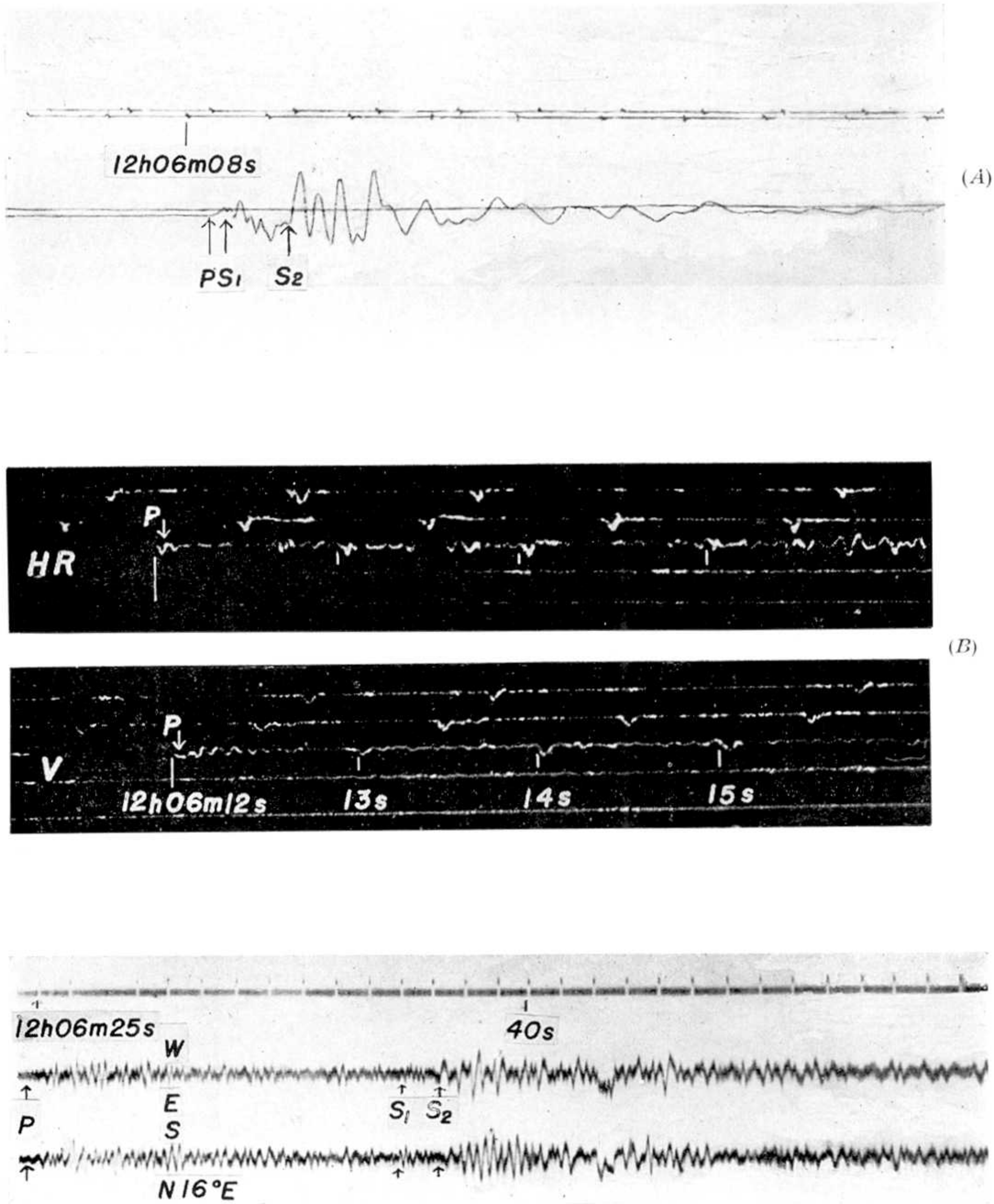


Fig. 6. Seismograms at Isibuti (*A*), Maesawa (*B*), and Sendai (*C*).

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