40. *A Short Discussion on Ripples in Earthquake Shocks. (Aftershocks of the Boso-Oki Earthquake.)*

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1. Introduction

A great earthquake took place on the Pacific coast of Japan on November 26, 1953, and the shocks were felt severely in the central and eastern parts of the Japan Islands. According to the report of the Central Meteorological Observatory of Japan[1], the earthquake, named the Boso-Oki Earthquake showed a magnitude as large as that of the Great Kwanto Earthquake of 1923 and was located as follows:

longitude......141°51.8′ E,

latitude....... 34° 3.3′ N,

depth......... 84.2 km.

In the vicinity of the origin many aftershocks took place which were observed by the network stations of C.M.O. as well as by our stations located around Tokyo. In the Seismological Bulletins and the other report[2] we can find detailed descriptions of the occurrence of aftershocks, namely, the numbers of monthly occurrence, the locations and other necessary data of aftershocks of considerable magnitude. As shown in Table I, aftershocks occurred most frequently in November and December of 1953 and became less active in the following several months. Although the seismic active area was not so close to the land, through the seismological network of high density we could

Table I. Numbers of monthly occurrence of aftershocks.

1953	November	420
	December	215
1954	January	39
	February	42
	March	7
	April	7
	May	11

(after C.M.O.)

1) *Seismological Bulletin, C.M.O.*, No. 35, 36, 37, 38.

2) W. INOUYE, *Quart. Journ. Seis., C.M.O.*, **19** (1954), 8.

determine the locations of each shock of considerable magnitude. Table II shows these aftershocks whose origins were reported with an accuracy of 0.1° both in longitude and in latitude. As to the depths, most aftershocks occurred at places 20 to 50 km under the earth's surface, while a few occurred in places very shallow or deeper than 60 km. From these results, we may infer that the shadowed space of conical shape (Fig. 2) was severely affected by the main shock resulting in numerous aftershocks which took place there. If this supposition is reasonable, the present case of aftershocks offers useful materials in studying the physical properties of the so-called seismic-active regions. Suppose the said regions have some properties differing from the surrounding area (which is not severely affected by the main shock and is thus non-active), seismic waves passing through this area may be affected and may have peculiar features differing from those which do not pass through it.

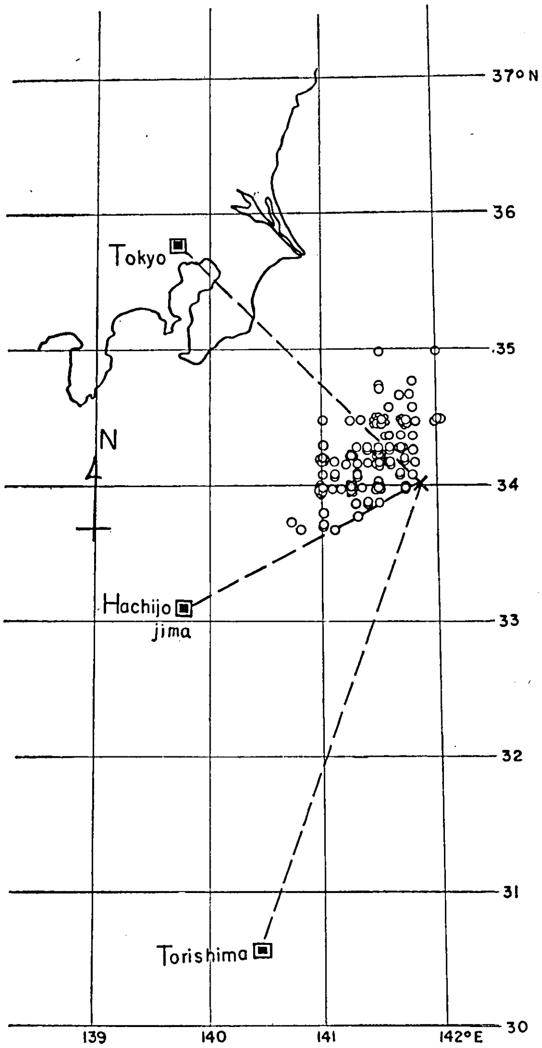

Fig. 1. Locations of the seismic active region and stations.

×: main shock, ○: aftershocks.

(after C.M.O.)

We shall, therefore, compare the two groups of seismograms, one corresponding to waves traveling through the active region and the other corresponding to waves passing through normal areas only. Prof. Matuzawa deter-

Table II. Aftershocks.

No.	Time (G.M.T.)	Location		Magnitude	Type of ripples		
		φ	λ		Tokyo	Hachijo-jima	Torishima
1114	Nov. 26^{th} 23^{h} 36^{m}	$24^{\circ}.2$ N	$141^{\circ}.6$ E	r	C	—	C
1115	00 03	34.4	141.8	r	C	A	B
1117	10 47	34.2	141.8	r	C	C	C
1119	02 24	34.5	141.5	s	A	A	—
1120	03 24	34.3	141.5	r	A	—	—
1124	05 04	34.5	141.6	s	A	A	—
1126	08 14	34.3	141.6	r	C	B	C
1127	08 20	—	—	r	—	—	—
1131	11 36	34.5	141.5	u	B	A	—
1139	27 00 01	34.0	141.5	m	B	B	—
1143	11 30	34.3	141.6	r	A	B	—
1144	18 31	33.8	141.0	s	A	A	—
1145	28 02 10	34.0	141.3	u	C	B	—
1147	04 25	34.2	141.5	u	B	B	—
1154	29 04 07	34.8	141.8	u	C	C	C
1156	30 03 40	34.6	141.6	u	C	C	—
1157	13 43	34.5	141.5	m	B	B	B
1208	Dec. 2 06 10	34.1	141.1	u	A	B	—
1209	09 47	33.7	141.1	r	B	B	B
1215	3 21 40	34.1	141.0	m	A	—	—
1217	5 09 41	34.3	141.4	r	A	A	B
1218	14 54	34.0	141.2	u	A	A	—
1219	17 20	34.2	141.3	u	A	B	—
1220	18 39	34.2	141.6	m	A	A	—
1235	20 21 20	34.3	141.0	m	A	A	—
1236	21 02 42	34.1	141.0	m	A	A	—
1313	Jan. 18 14 45	33.9	141.4	r	A	—	—
1416	Feb. 22 06 11	34.3	141.7	r	A	—	—
1417	10 26	34.1	141.7	r	A	—	—
1425	23 51	34.2	141.1	r	A	—	—

mined formerly the underground structure[3] which is considered most suitable in interpreting the travel times of earthquakes in the Kwanto district. A schematic view of the result is shown in Fig. 2, in which are drawn ray-paths for transversal waves generated from origins whithin (A) and without (B) the active region, at the same time.

3) T. MATUZAWA, K. YAMADA and T. SUZUKI, *Bull. Earthq. Res. Inst.*, **7** (1929), 241.

Waves from origins A and B will travel along the common path DEF making the first (S) arrival at a station 200 or 300 km distant from the origin. However, the wave from A must travel along the path ACDE while the wave from B travels along BDE, and the different paths ACD and BD is the reasonable condition which interprets some differences found commonly between seismograms of group A and B.

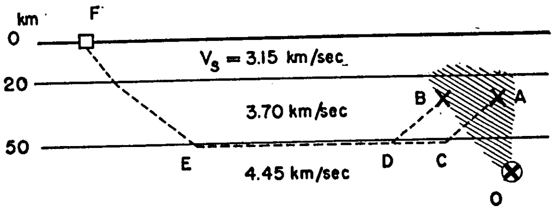

Fig. 2. Seismic wave paths from the active region.
⊗: main shock, ×: aftershocks, □: station.

For the present purpose, aftershocks with focal depths of 20 to 50 km look most suitable, since in the case of the other aftershocks which are located in shallower or deeper places it is difficult for us to decide if the wave paths from them travels through the shadowed region or not. Aftershocks listed in Table II are those which satisfy the above-stated condition.

2. Ripples in seismograms

It is a well known phenomenon in seismology that some seismograms show remarkable vibrations of very short period superposing on fundamental motions of longer period. This kind of phenomenon of "ripples" has been left unstudied for a long time. According to K. Kanai, who has developed his study on this phenomenon recently[4], "the wave form of ripple is due to the multiple reflection of seismic waves in the surface layer, when waves with period equal to or shorter than the natural period of the surface layer are found among the incident seismic waves." In the present case of aftershocks, we also found clearly ripples in seismograms, of which some were remarkable and some faint. For example, Figs. 4 and 9 illustrate typical seismograms obtained at Tokyo University. Although seismograms No. 1115 and No. 1235 have large amplitudes which are comparable to each other, the former shows far less amplitudes of ripples than the latter.

4) K. KANAI, *Bull. Earthq. Res. Inst.*, **32** (1954), 361.

To develop our discussion on the character of ripples, we have to prepare a certain scale which indicates the magnitude of ripples relatively to that of fundamental vibrations. For this purpose, we shall define the ripple factor as follows:

$$r=(a_r/a_f)\times 100\,(\%)\ ,$$

where a_r and a_f means respectively the maximum amplitude of ripples and fundamental vibrations, both being measured in the same part of the seismogram. In this way we can find a time series of ripple factors for the succeeding parts of the seismogram under our test. The problem of separating ripples from the original trace is, however, not a simple one, as we have no convenient filters (mechanical or electronical) which can filtrate wave of necessary range of frequencies accurately. Fortunately,

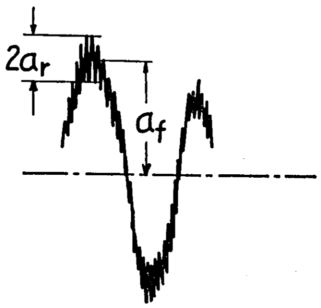

Fig. 3. Determination of ripple factors.

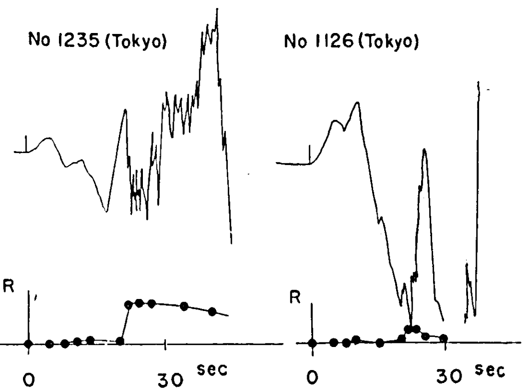

Fig. 4. Typical seismograms and ripples.

clear seismograms obtained with long period pendulums at Tokyo University suggest the possibility of estimating ripple factors even without special instruments. That is, as ripples show far shorter periods than the period of fundamentals, we can easily see the double amplitudes of ripples at each extremity of fundamental events in seismograms. This method of separation will not give a high accuracy to the result but still it will be of use for rough estimation of ripples (see Figs. 3 and 4). Figs. 4 and 5 illustrate amplitudes of ripples separated from the original in this way, and in them we notice remarkable increase of ripples at the beginning of S-phase. This fact may be understood well from the standpoint of Kanai's theory and instead of treating the whole part of seismograms, it may be allowed to limit our discussions to the said part. The numbers in Fig. 5 indicate the ripple factor determined in this way for each seismogram.

Throughout the active period of aftershock occurrence, we could determine factors r for only several shocks from seismograms obtained at Tokyo, and it was considered to be difficult for us to carry out our studies on such few examples. Thus we had to use more seismograms of smaller aftershocks (*f.i.* Fig. 10). In this case ripple factors could not be determined accurately, and classification of them had to be done on a more rough scale. Three types were considered as the indicator of ripples for these seismograms of smaller amplitudes, namely,

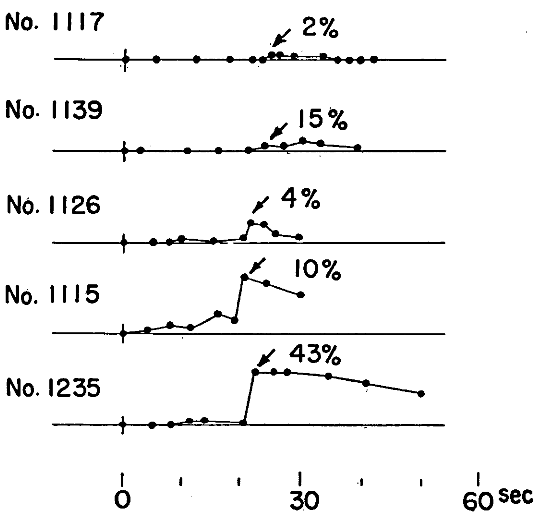

Fig. 5. Amplitudes of ripples in seismograms (Tokyo).

type A : seismograms of remarkable ripples (ripple factors for the first S-wave exceeding 25%),

type B : seismograms of moderate ripples ($25\% > r \geqslant 10\%$),

and type C : seismograms of faint ripples ($10\% \geqslant r$).

By comparing it with typical seismograms of larger amplitudes, we could determine to which type a seismogram belongs even when the ripple factor was unmeasurable. Types were determined for 29 aftershocks in total, as are listed in Table II. Figs. 10, 11 and 12 show representative seismograms belonging respectively to the said three types.

3. Discussion

To show the results more clearly, epicenters of aftershocks classified into three types of ripples are plotted in Fig. 6. It should be noticed that most of the aftershocks of type A are located only in the northwestern (or inner side) part of the active region, while shocks of type C are found most frequently in the southeastern (or outer side) part of the region. Shocks of the intermediate type B can be seen in the central part. Before entering into further discussion, we should go over the mechanism of generation of ripples[5]. As was discussed in the last chapter, seismic waves making the first S-arrival at Tokyo traveled along the path DEF, which is believed to be also the path for all aftershocks under our test. Referring to Kanai's conclusion, we may suppose, in the present case, that the remarkable increase of ripples in the beginning part of S-phase was induced by incidence of the initial S-wave from the lower layer to the surface. With this supposition as well as the condition of the wave path DEF being common to all shocks, we shall come to the following conclusion: a) ripple factors (or ripple types A, B, C) determined on the surface should be understood as characteristic indicaters of waves propagated along the lower layer from their origins, and b) it is more natural to explain the causation of different ripple types by conditions in the seismic active region than by conditions of propagation, which are considered to be almost common to both types.

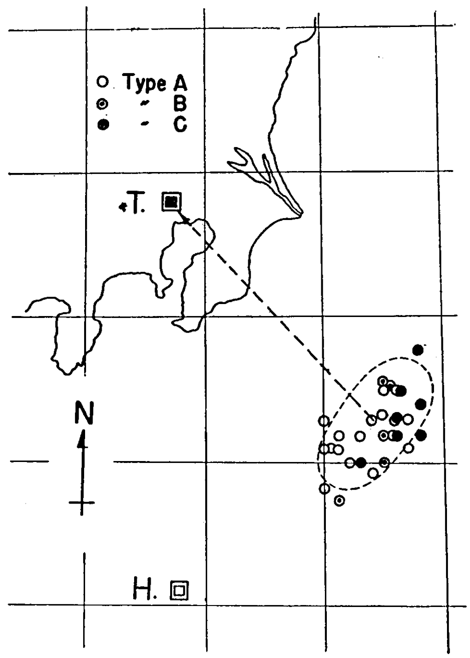

Fig. 6. Distribution of ripple types based on seismograms at Tokyo.

In this meaning of ripple factors, the following two possibilities will be considered to interpret the result illustrated in Fig. 6. They are,

a) aftershocks in the southeastern part of the active region occur initially with low ripple factors to be observed as type A at Tokyo while those in the northwestern part occur with higher ripple factors, and

b) all the aftershocks occur initially with equivalent ripple factors, and it is the absorption or the other effect of the active region that modifies the factor larger or smaller in the course of wave propagation.

To find out which of the two is more probable, further discussion must be done on various points of the phenomena. It would be useful

5) K. KANAI, *loc. cit.*, 4).

to ascertain if ripple types determined from seismograms at Tokyo show the distribution identical with those determined at other stations. That is, if explanation b) holds good, aftershocks must show another ripple type at stations located in a different direction from the centre. And if a) holds good the ripple types should be determined equivalently at stations of different directions. Seismograms of Hachijo-jima and Torishima were considered most suitable for this purpose (Fig. 1). Torishima is located on the opposite side of Tokyo 350 km distant from the active region while Hachijo-jima is 150 km to the west of the centre. Both stations, however, were not equipped with seismometers with natural period as long as that of Tokyo, so we had to determine the ripple types with instruments of shorter period (4 sec). As can be seen in Figs. 11 and 12, vibrations of longer periods were not recorded at these stations so clearly as at Tokyo and the determination of the ripple types was somewhat a difficult task. In Table II are listed the ripple types of aftershocks recorded at the two stations for reference, but these results should be understood as only a rough approximation. We see in the table or in Figs. 7 and 8 that the aftershocks which were found to be of types A, B, or C at Tokyo seem to correspond generally to those of other stations. This fact suggests that the explanation a) is more probable than the other. In other words, the systematic distribution of ripple types in the active region seems to be interpreted more plausibly from the viewpoint of initial conditions of occurrence of each aftershocks than from a certain effect (as supposed in the last chapter) of the active region on the characters of seismic waves passing through it. Special absorption of higher frequencies in the said region, however,

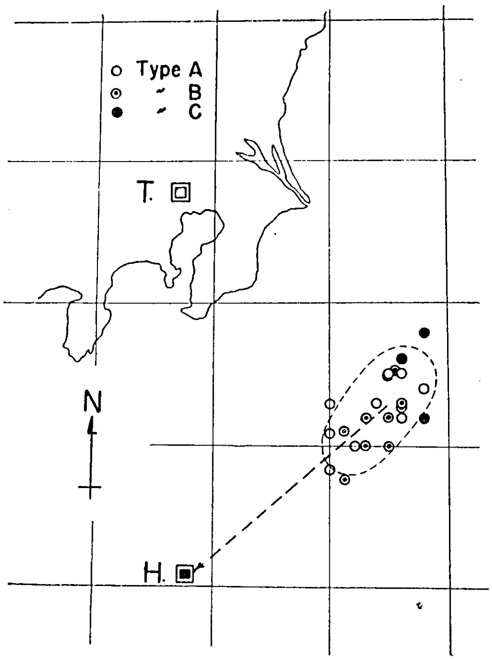

Fig. 7. Distribution of ripple types based on seismograms at Hachijo-jima.

is not the only abnormality which can be imagined in the region affected greatly by the main shock, and other possible case should be investigated in parallel with the present one. We must, however, remember that the locations of aftershocks were not determined so accurately in the case of the Boso-Oki Earthquake, and that we could not use the seismograms of Hachijo-jima and Torishima obtained through long-period seismometers. Both conditions provided unavoidable uncertainties in the determination of ripple types. Aftershocks occurring in the land area are considered to be most suitable for obtaining accurate conclusions on the present project.

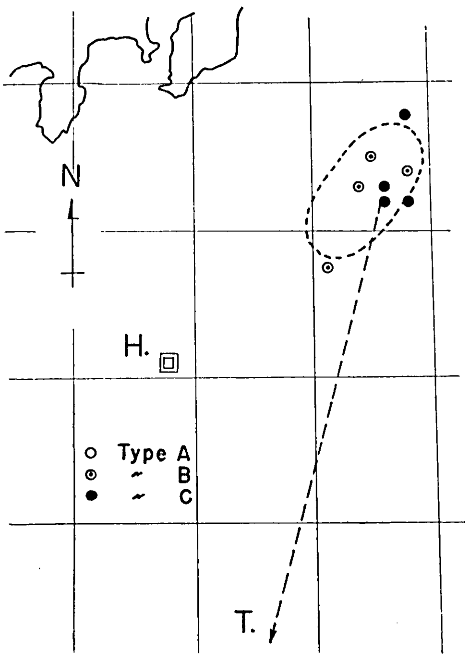

Fig. 8. Distribution of ripple types based on seismograms at Torishima.

4. Concluding remarks

Ripples in aftershocks of the Boso-Oki Earthquake of November 26, 1953 were studied to find out special effects of the "seismic active region" on the propagation of seismic waves passing through it. As to ripple types, aftershocks which brought seismic waves of remarkable ripples to Tokyo were located most frequently in the inner side of the active region and most of the shocks with faint ripples were found in the outer side of the same region. Although it is possible to explain the result by an abnormally remarkable absorption of rapid vibrations in the said region, it was considered more natural to explain it by the initial condition of generation of ripples given at each origin of aftershocks. Because seismograms obtained at Hachijo-jima and Torishima showed the distribution of ripple types which is similar with that obtained at Tokyo.

The author considers that the problem on the property of the seismic active region should be investigated furthermore. A group of aftershocks occurring in the land area would be more suitable for the present purpose, since locations of each origin could be determined more accurately and observations made under the best condition in that case.

The present author owes very much to the Seismological Division of C.M.O. as well as to the Observation Branch of this institute, which both kindly offered necessary seismograms at his request. He wishes to express hearty thanks to them and to Prof. T. Hagiwara of this institute, who showed an interest in this study and kindly put various facilities at the author's disposal.

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40. 地震動に含まれる短週期震動（リップル）について
―― 房総沖地震の余震の場合 ――

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比較的近い地震の記象を見ると，リップルともいうべき顕著な短週期震動が長週期震動に重畳している場合がある．余震のように限られた区域に発生する地震群を離れた地点で観測すると，伝播経路がほとんど同一と見なされるので，上記のリップル成分を調べることによつて，余震活動域の性質を知る可能性が考えられる．

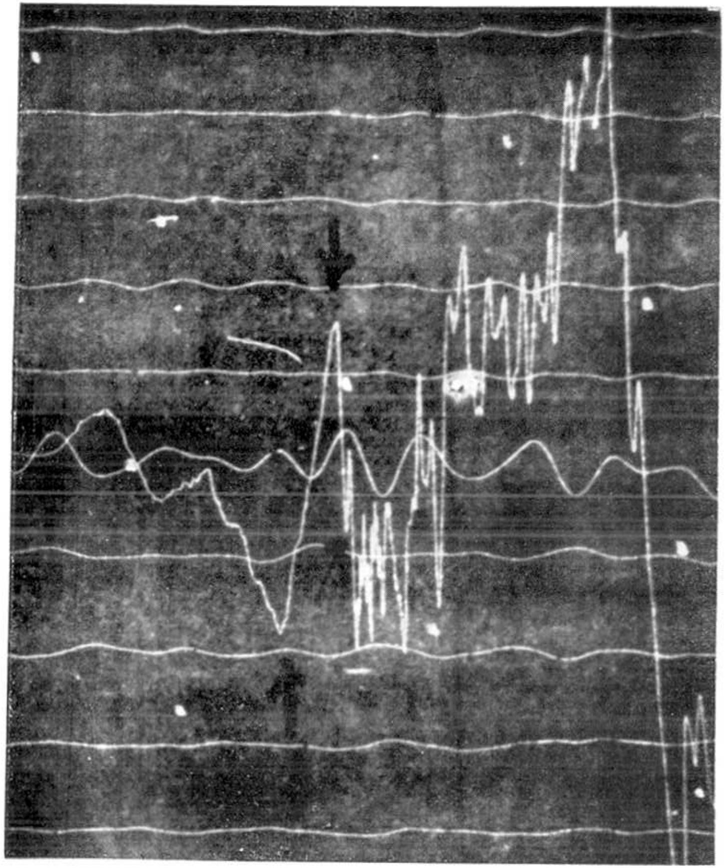
各余震のリップルの大小を相対的に表示する量としてリップル率（及びリップル型）をとり，房総沖地震に伴う余震の東京（本郷）における変位記象を分類して見ると，余震域の外側（北東側）に位置する余震は低いリップル率を示し，内側のものは高いリップル率を示するいう系統的な分布が見出された．地震波の伝播経路がこの場合殆んど共通であることを考え合わせると，次の説明が想定される．即ち，

a)　余震の発震機構（リップル成分に関しての）そのものが，上記のような傾向をもつているとするか，

b)　リップル成分に関する発震機構においてはどの余震も大差なく，上記の傾向が生ずるのは，余震活動域一帯の特性（例えばその中を通過する地震動の短週期成分を特に減衰させるというような）によるものである，と考える

かである．この点を判断する目的で八丈島及び鳥島での記象（簡単微動計による）を調べたところ，a）の説明の方が有力らしく思われる．

[Bull. Earthq. Res. Inst., Vol. XXXIII, Pl. LXXXIV.]



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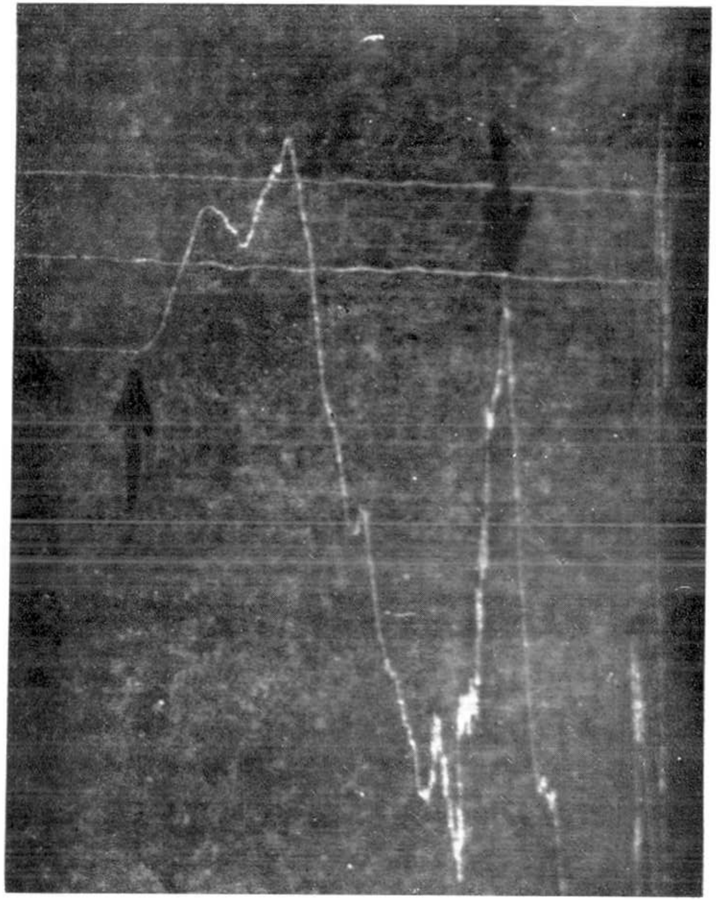

Type "C". No. 1126.

Fig. 9. Typical seismograms of high and low ripple factors (Tokyo). (original ×4)

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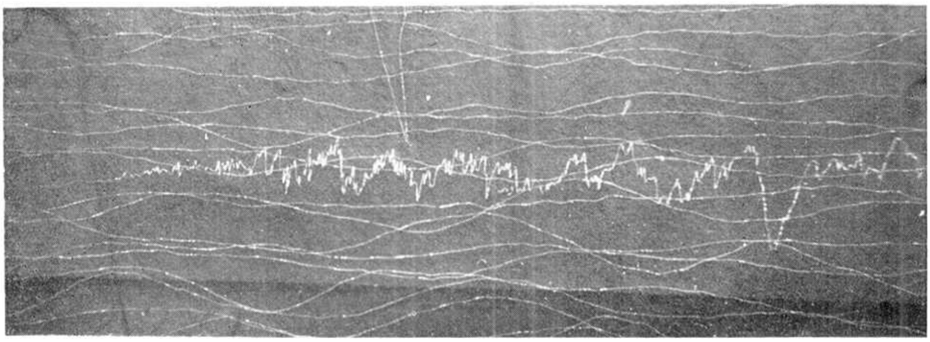

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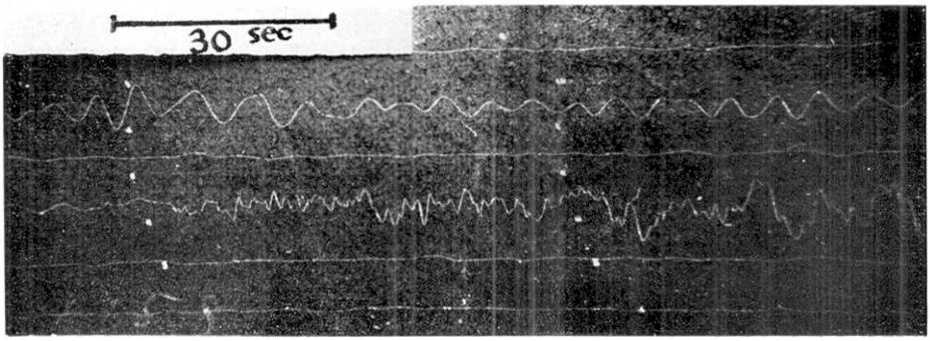

Type "B". No. 1158

Type "C". No. 1154

Fig. 10. Seismograms classified into three types of ripples (Tokyo). (original ×2)

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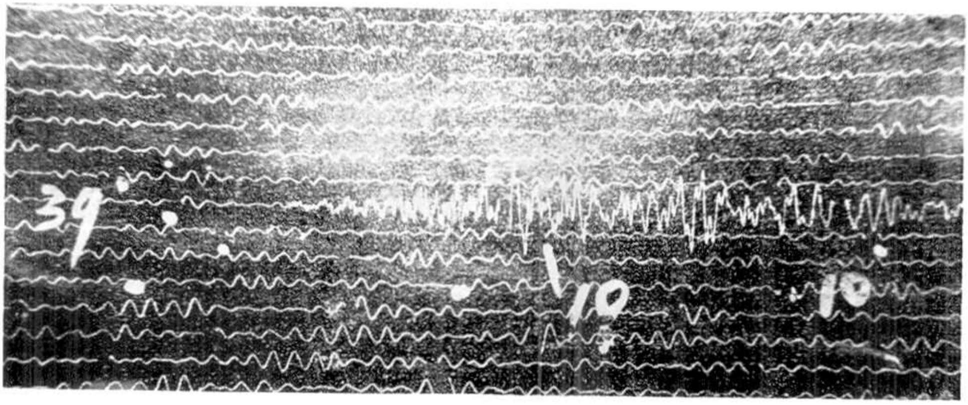

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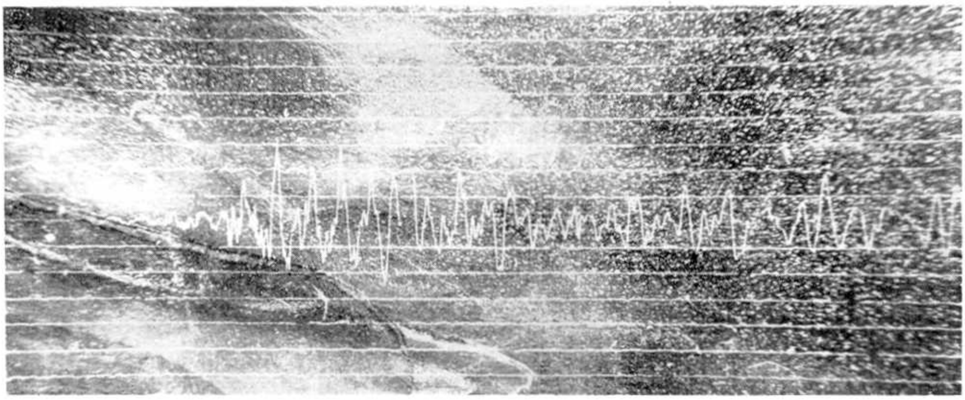

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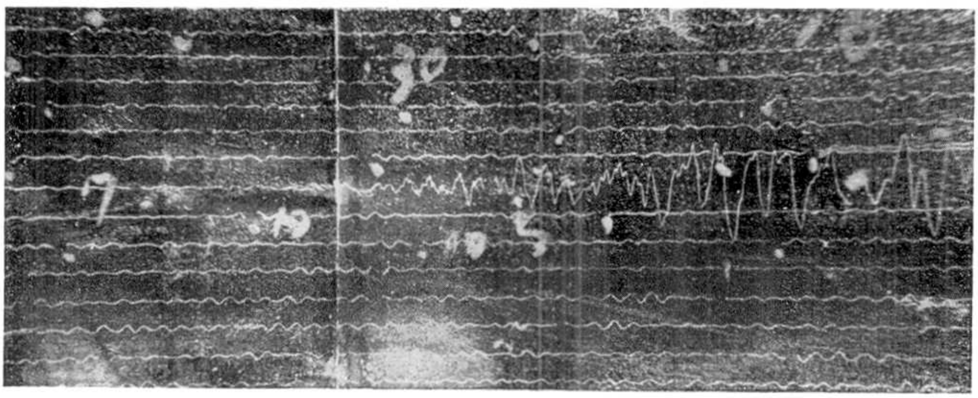

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Fig. 11. Seismograms classified into three types of ripples (Hachijo-jima). (original ×2)

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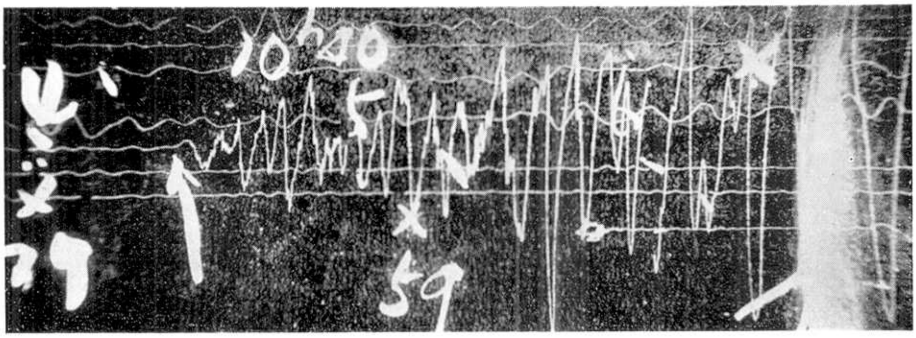
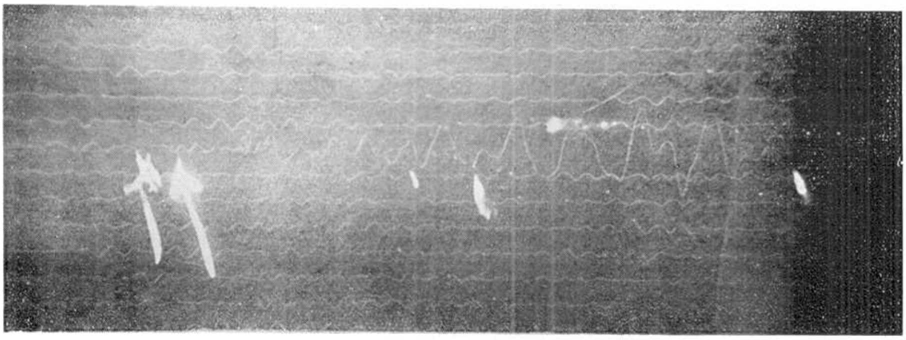


Type "B". No. 1115



Type "C". No. 1154

Fig. 12. Seismograms classified into three types of ripples (Torishima). (original ×2)
No seismograms of type "A" were recorded.

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