Micro-Seismometric Study on Eruptions of the Volcano Aso[1]
(Part II of the Geophysical Studies on the Volcano Aso)

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(Received October 20, 1935)

1. Introduction

Volcanic earthquakes are generally of minor scale, but owing to the shortness of their periods of earth-vibrations they are very noticeable to one standing in the neighbourhood of their epicenters. Thus it was probably well known in olden times to inhabitants in volcanic regions that certain volcanic districts are often visited by volcanic earthquakes during a period of eruption, while in other cases a number of premonitory earthquakes take place before a violent eruption, especially when it occurs after a long period of quiescence. After the eruption has started and when its activity is sufficiently violent, the volcanic tremors are noticeable even to people in the neighbourhood of a volcano. At the beginning of the present century, seismographs came into use for the study of volcanic activity, and the premonitory earthquakes of a volcanic eruption as well as the earth-tremors accompanying it were naturally the first problem of investigators. Thus it was reported in the case of the recent great eruptions of the volcanoes Usu-san[2], Sakurajima[3], and Taal[4], that the frequency of occurrence of premonitory earthquakes attained a maximum one day or half a day preceding the first outburst. In the case of the eruption of Usu-san in 1910, Omori mentions that in the course of the eruptions, a gradual upheaval of the earth's crust took place at a northern part of the foot of the volcano, which ended in the new formation of a hill of 155 m. height, and earth-tremors were almost continuously observed with varying amplitude of from 2μ to 86μ about in parallel with the volcanic activity. Interested by the result of observations

1. An abstract of this paper was read at the Annual Meeting of the Physico-Mathematical Society of Japan, Kyôto, 1931 Nov. and Tôkyô, 1934 April. 2. F. Omori: Bull. Imp. Eqke. Invest. Comm. V (1911). 3. F. Omori: Do. VIII (1922). 4. M. S. Masó: The eruption of Taal volcano Jan. 30, 1911.

at Usu-san, he gave a higher magnification to his seismographs at his Asama-yama volcano-station, where the eruptions are of different type from that of the above-mentioned volcano, and he came to the conclusion that "[1]it seems that the opening of a period of great eruptive activity of the volcano is announced by strong seismic disturbances 10 months or 1.5 years beforehand" and "[2]These micro-tremors are probably the result of the activity of the volcano, which made throughout the day under consideration explosions and detonations." Generally speaking the volcanic eruption is a stage of relatively short duration in the sequence of volcanic phenomena and follows a very long and slow process that has gone on under the volcano, in which volcanic mass and energy are gradually accumulated. Of whatever state of conditions the physical and chemical process of the volcanic phenomena might be, it is quite difficult to conceive an abrupt jump from the earlier state of conditions, in which mass and energy very slowly accumulate, to the subsequent eruption, in which they are rapidly discharged from the crater. During the time of transition from the one to the other state of conditions above described, work must be going on leading to the eruption, and the rate of flow of mass and energy, in a very wide sense, under the volcano must be gradually increasing, far beneath the crater bottom, the conditions resembling what is called "yielding" in a problem of elasticity, before a body breaks under constantly increasing stresses; and it is difficult for me to conceive a volcanic process going on during this transition stage without accompanying volcanic tremors, to which in some cases so-called premonitory earthquakes should be added, every eruption thus being foretold by the volcano itself. Bearing the above conceptions in mind we undertook micro-seismometric studies of eruptions in our Volcanological Laboratory on Aso, and the results of our studies on the nature and character of volcanic micro-tremors and eruption-earthquakes based on the results of observations with specially prepared micro-seismographs, were given in the preceding 'Part I of the Geophysical Studies on the Volcano Aso[3].' The present paper deals with the volcanic micro-tremors and earthquakes and the tilting of the earth-crust in parallel that occurred in the latest eruptive activity of the volcano, and shows that things have gone in a way not contrary to

1. F. Omori: Bull. Imp. Eqke. Invest. Comm. VII (1914) p. 208. 2. F. Omori: Do. VI (1912) p. 134. 3. These Memoirs, A, 18 (1935) 255-294.

our expectations. As to the micro-seismometers used and observing stations the reader is referred to the preceding paper, Part I.

2. Activity of the Volcano Aso in recent years

The Volcano Aso, which is situated in the middle part of the island of Kyûsyû, is one of the most active volcanoes in Japan. From very early historical times to to-day the center of activity has been Naka-dake, the middle one of the five central cones rising in the famous great caldera of the volcano. On the top of Naka-dake there are four craters separated by walls and lying roughly in the direction N25°W. They are named the First, the Second, the Third, and the Fourth in consecutive order from the north. According to historical records, there have been about one hundred eruptions of Naka-dake in the past thousand years, with frequent outflows of mud and ejections of fragments of rock and dust, but no trace of lava-flow has been found in historical time. The center of activity of Naka-dake is not confined to one definite crater but has shifted many times even since the beginning of the Meiji era, and statistics show that violent eruptions have a tendency to occur close to a period of maximum or minimum number of sun-spots. The last activity of the Fourth Crater began with the first sudden eruption which took place at 11^h on April 1, 1927, and when the Wiechert seismographs were set up at the new Aso Volcanological Laboratory in May 1929, it was still in progress, tremendous quantities of dusts and vapours being frequently ejected, and occasionally fragments of rock. The activity lasted till the last eruption on Nov. 7, 1929. After that a long repose period of about one year occurred, but an isolated violent eruption of the same crater occurred on Sept. 5, 1930 and thereafter the volcano was again in repose. In September 1932 the First Crater showed some activity and became gradually more and more active and finally entered an explosively active stage in December of that year. The center of activity had been shifted from the Fourth to the First, and in the spring of the following year terrible eruptions of the Second Crater occurred together with eruptions of the First, which were followed by repeated eruptions of the two craters till the end of the year. After this the volcano was again very quiet, and still remains so.

3. Micro-tremors and activity of the volcano during June–November 1929

The activity of the Fourth Crater which began on April 1, 1927 attained a maximum in Dec. 1928 and then gradually decreased in strength; it lasted till the last eruption on Nov. 7, 1929, constantly emitting volcanic smoke and vapour in different degrees of magnitude, and frequently ejecting lava fragments and dusts. When our seismometric observations were began in May 1929, the activity was already decreasing, but the Wiechert seismographs incessantly recorded volcanic micro-tremors, recorded as continuous trains of irregular waves of ca. 1–2 mm. in double amplitudes on smoked paper. They were of periods of ca. 1 second which we have described as micro-tremors of the first kind in the preceding paper. Fig. 1 shows portions of the records of the Wiechert seismograph obtained at our Volcanological Laboratory

Fig. 1. Portions of the records obtained from the Wiechert horizontal component seismograph at the Volcanological Laboratory on June 19–20, 1929. (Time between two consecutive marks = 1 min.)

	T_0	v	V
Instrumental Constants:	10.0 sec.	4 : 1	200

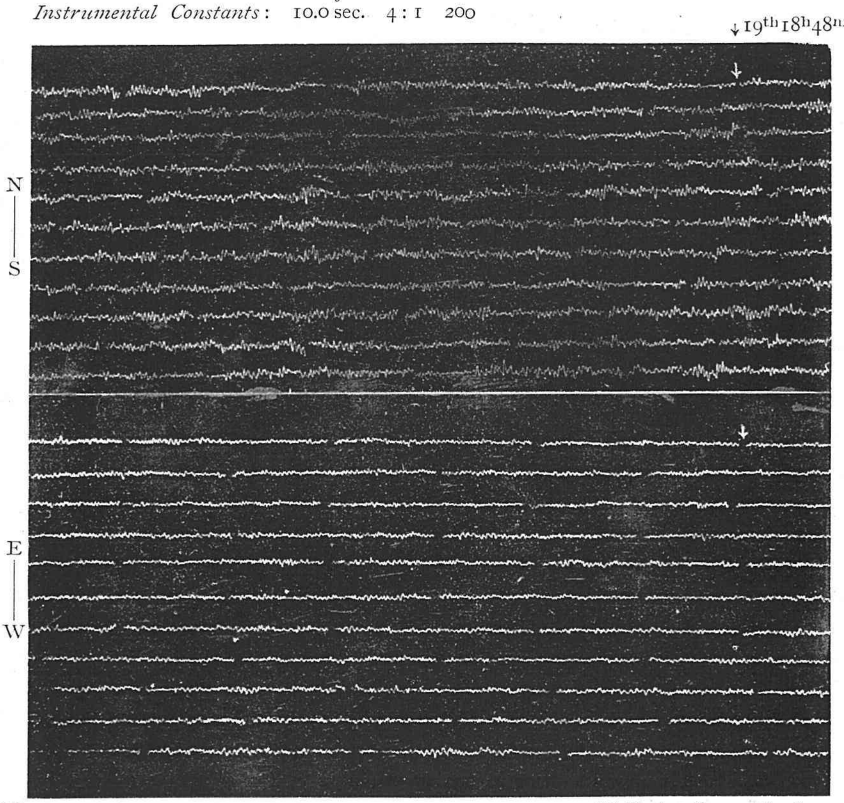

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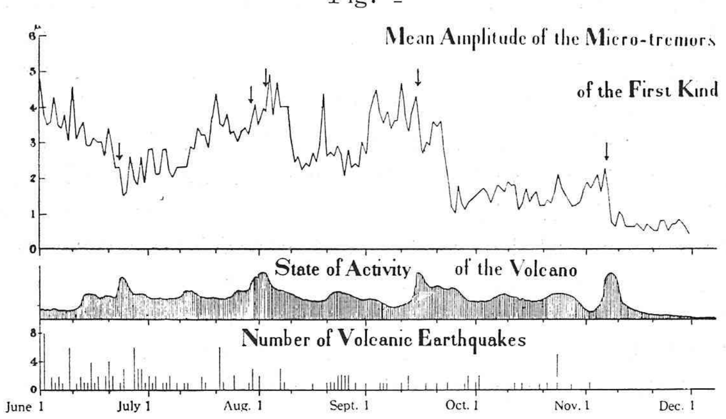
Fig. 2



on June 19–20, 1929. The daily mean amplitude of the micro-tremors recorded by the Wiechert seismograph during June–Nov. 1929 is given in Table 1 on p. 56 and shown in Fig. 2.

The state of activity of the volcano was roughly estimated from daily observations of volcanic smoke and vapour sketched or photographed at the Aso Volcanological Laboratory. When some notable difference in the state of activity of the volcano was observed, we hurried up to the summit to observe the state of activity of the craters in detail. The remarks given in Table 1, and rough estimations of the degree of activity in an arbitrary unit shown in Fig. 2 were based on the data obtained in this manner. The arrows in Fig. 2 indicate the time of eruptions in which red-hot fragments of rock were thrown out. As will be seen in Fig. 2 the daily mean amplitude of the micro-tremors was about 4 microns at the beginning of June, and decreased gradually to about 2μ at the end of the month, while the activity of the volcano was opposite in course, increasing gradually in strength from the beginning of the same month and attaining a maximum on the 23rd, on which day violent eruptions of the Fourth Crater occurred, red-hot fragments of rock being ejected.

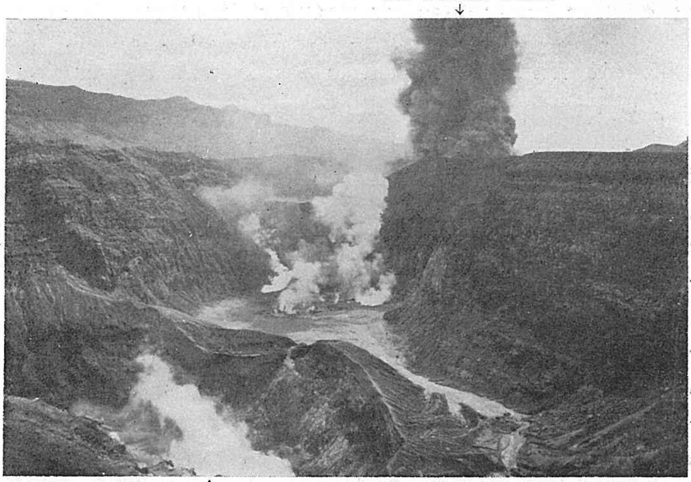
The daily mean amplitude of the micro-tremors, which was ca. 2μ at the beginning of July, began to increase again from July 13, at first rapidly and then gradually to ca. 4μ at the beginning of the following month, but the activities of the volcano did not increase in parallel with this change, and the strong eruptions, in which red-hot fragments of lava were thrown out, took place on July 30 and Aug. 3, about 10 days after the daily means of the amplitude of the micro-tremors had attained a maximum. The daily mean amplitude of the micro-tremors decreased rapidly on Aug. 9–11 from 4μ to 2.4μ, maintaining nearly the same lower value till the end of the month with the exception of Aug. 19, on which day a rapid rise and fall took place. On Sept. 1–2 the daily mean amplitude of the tremors increased rapidly to 4.2μ, but the volcano remained very quiet, only emitting slight smoke and vapour, and nearly the same state of things continued till Sept. 14, on which day strong eruptions of the Fourth Crater took place, red-hot fragments of rock being ejected. The amplitudes of the tremors began to decrease, gradually at first and then rapidly, to ca. 1.5μ at the end of the same month. One more procedure of things of a similar type was repeated before the eruptions on Nov. 7 with which the volcano came to rest. The daily mean amplitude of the micro-tremors which was only ca. 1.2μ during Oct. 28–30, increased to 1.9μ on Nov. 1 and then after keeping nearly the same value till Nov. 6, decreased rapidly to ca. 0.6μ on Nov. 8, while the volcano began to emit a great deal of black smoke on the evening of Nov. 4 and finally strong eruptions of the Fourth Crater took place during Nov. 6–7, the last eruptions of the Fourth Crater of the active period of 1927–1929, after which the volcano was in perfect repose, and early in January of the following year we found a hot water pool filling the mouth of the vent.

The above observations lead us to the conclusion that the micro-tremors of the first kind increase in amplitude one week or more before an explosive eruption with ejection of red-hot rock fragments

Fig. 3. An eruption of the Fourth Crater on Nov. 6, 1929. Looking southeast from the northwestern rim of the First Crater.

the Fourth Crater ↓

the Second Crater→



↑ the First Crater

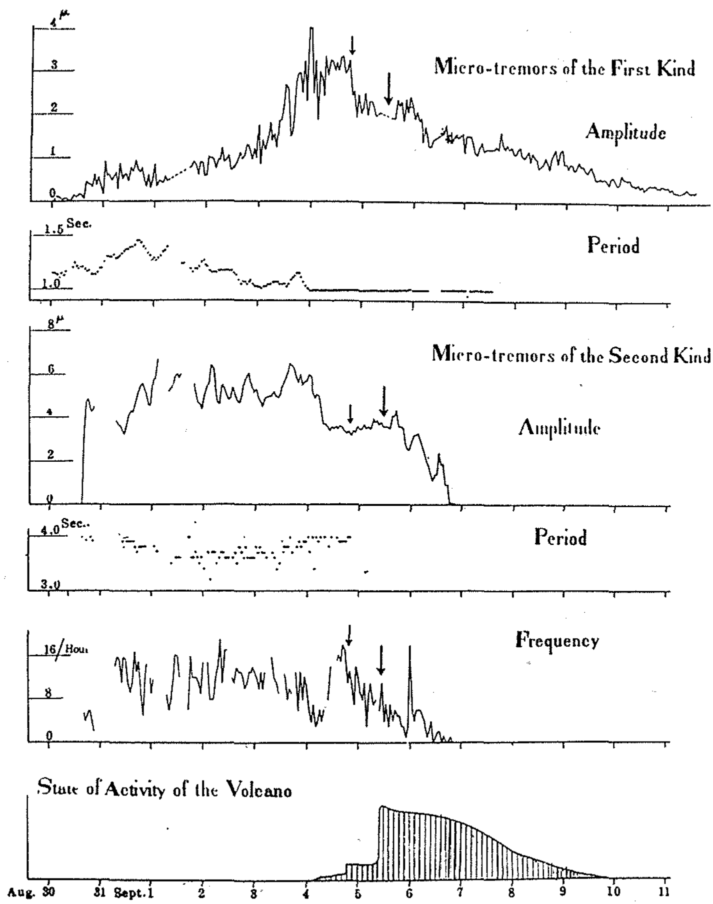
takes place. During the tail stage of the described active period of the volcano we had four repetitions of similar character. This is similar to the results of observations made by previous investigators in cases of the last great explosive eruptions of Usu-san, Sakurajima, and Taal, the only difference being that the micro-tremors in our case take the place of the premonitory earthquakes in the latter,—a result not contrary to our expectations.

4. Micro-tremors and eruptions of the Fourth Crater during Sept. 5–8, 1930.

After the last eruption of the Fourth Crater on Nov. 7, 1929 the volcanic micro-tremors of the first kind decreased gradually in amplitude and finally ceased to occur in continuous trains, but continued intermittently, several wave-groups of fairly regular waves per hour, and of a fraction of a micron in double amplitudes occurring to the end of the year. In the following year the same state of things continued both as regards amplitude and frequency till the end of August. During this period the volcano was also very quiet, only traces of vapour rising at times from the pools of the First, the Second, and the Fourth Crater. On Aug. 30, 1930 a wave-group consisting of several regular waves of ca. 5.5μ in double amplitude, and of periods of ca. 4.0 seconds, was first recorded at 16^h02^m on our Wiechert seismographs, and after that wave-groups of nearly the same amplitude were recorded several times per hour ;—these were the volcanic micro-tremors of the second kind studied in the preceding paper.[1]

The micro-tremors of the first kind also began to increase rapidly both in amplitude and frequency on the same day, Aug. 30, and finally became a continuous train of irregular waves on Sept. 1, but were on some occasions accompanied by micro-tremors of the second kind and on which cases the train of micro-tremors of the first kind consisted of somewhat regular waves of even more than 10μ in double amplitudes. The hourly mean of amplitudes and periods of the micro-

Fig. 4

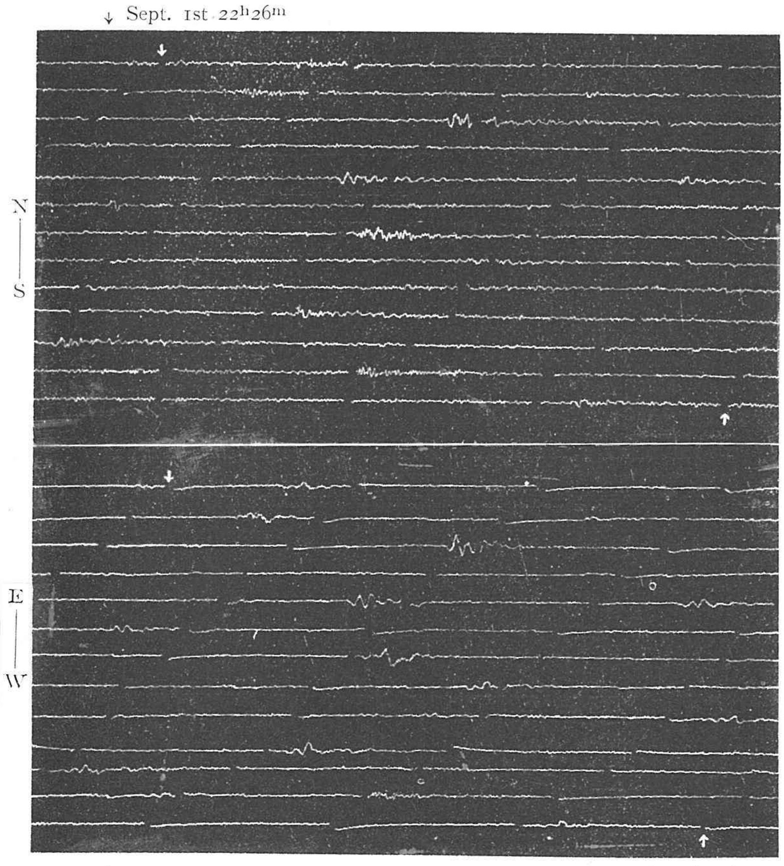


1. Loc. cit.

tremors of the first and the second kind, and the frequency of occurrence per hour of the latter tremors observed by the Wiechert seismographs during Aug. 30—Sept. 11, 1930 are given in Table 2 and shown in Fig. 4. Fig. 5 shows portions of records obtained from the Wiechert seismograph at our Laboratory on Sept. 1, 1930, when the micro-tremors of the second kind were very large but those of the first kind were not yet large, except those accompanied by tremors of the second kind. Fig. 6 shows a portion of a record of the micro-tremors of the first and the third kind obtained by the short period

Fig. 5. Portions of records obtained from the Wiechert seismograph on Sept. 1–2, 1930. (Time between two consecutive marks = 1 min.)

Instrumental constants: T_0 10.0 sec. μ^2_0 0.81 V 200



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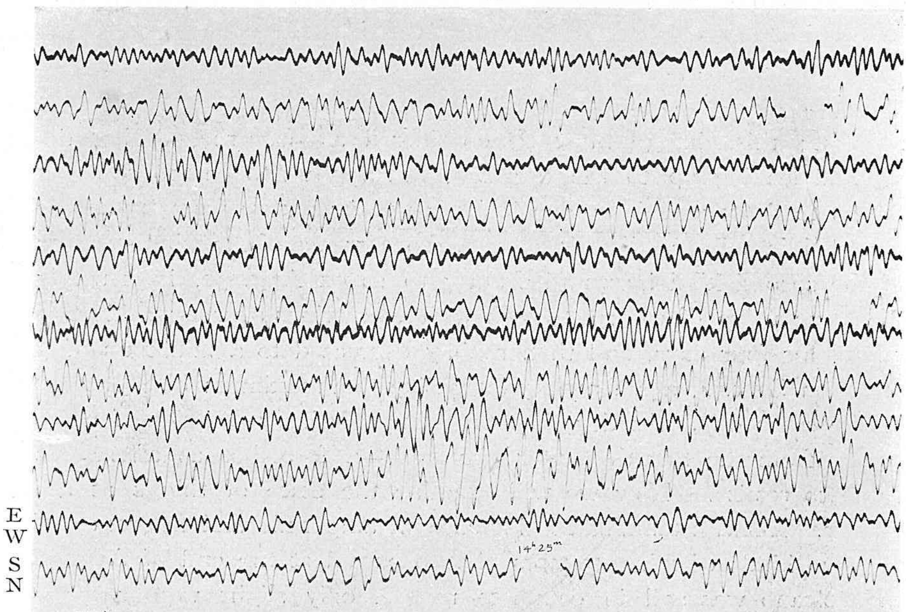
micro-seismographs S_A at our Volcanological Laboratory on Sept. 5, 1930.

As shown in Fig. 4 the mean amplitude of the micro-tremors of the first kind which was ca. 0.4μ on Aug. 30, increased, at first gradually and then rapidly, from ca. 1μ on Sept. 3 to ca. 4μ on the following day when they reached a maximum, while their mean period increased, first from ca. 1.2 seconds on Aug. 30 to ca. 1.4 seconds

Fig. 6. A portion of a record obtained from the short period micro-seismographs S_A at our Volcanological Laboratory on Sept. 5, 1930. Thick curves: E-W component, Light curves: N-S component.

	T_0	μ^2_0	T_1	μ^2_1	k	V_m
Instrumental constants:	0.55 sec.	0	0.55 sec.	0	16100	12300



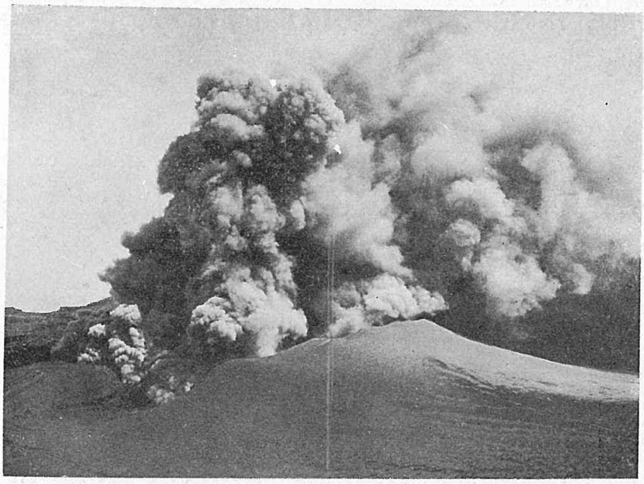
20 sec. (½× the original record)

on the following day, but then decreased gradually to ca. 1.0 second on Sept. 4. These differences of mode of variation between the amplitude and the period of the micro-tremors are to be noticed and show, as seems to the author, that the depth of center of the disturbances generating the micro-tremors gradually became shallower during Aug. 31 — Sept. 4, till finally the sudden surface eruption occurred.

The micro-tremors of the second kind increased slightly in amplitude, from ca. 4.5μ on Aug. 30 to ca. 6.0μ on Sept. 1. The amplitude then remained constant, except for a few minor fluctuations, for three days, but began to decrease rapidly early on the morning of Sept. 4, on which day the micro-tremors of the first kind attained their maximum amplitude. Meanwhile the mean period of the micro-tremors of the second kind had taken an opposite course to that of their amplitudes, decreasing at first gradually from 4.0 seconds on Aug. 30 to 3.5 seconds on Sept. 1, and afterward remaining at nearly the same value for two days, then increasing again to ca. 4.0 seconds on Sept. 4. As reported in the preceding paper, the micro-tremors of the second kind are a kind of surface wave probably generated by the oscillation of the magmatic reservoir, and so the variation of their periods should be considered as due to changes in the internal conditions of the magmatic reservoir. But in this case, a change in the physical and chemical conditions in and near the vent should also be taken in account; this change must be considered as occurring during the internal leading up to the eruption, but appears to be too complex for us to draw a definite conclusion as to its nature from the above recorded data alone. The frequency of occurrence of the micro-tremors of the second kind increased from 5 to 10 on Aug. 30, kept nearly the same value of ca. 10, though with fluctuations over a considerable range, for four days, and then rapidly decreased to a minimum of 3 at 4^h on Sept. 4, again rapidly increasing to a maximum of 18 at 17^h of the same day. At this time the first preliminary emission of white smoke from the Fourth Crater occurred,—a foreteller as afterwards came to realize. Now we will examine the state of things at the craters. Notwithstanding the increase in amplitude and frequency of the two kinds of micro-tremors that occurred at the end of August, the volcano was still in complete repose, only slight vapour rising from the pools of the First, the Second, and the Fourth Crater. On Sept. 2 we noticed for the first time that the temperature of the water in the pool of the Fourth Crater was beginning to rise and at 17^h on the 4th we had the first preliminary emission of white smoke from the Fourth Crater. At this time the micro-tremors of the first kind, which had been at maximum amplitude for about one day, began to decrease rapidly in amplitude while the micro-tremors of the second kind had already decreased rapidly in amplitude half a day before. The amplitudes of the micro-tremors of the first kind which abruptly decreased from ca. 3.3μ to ca. 2.2μ after the preliminary emission of white smoke did not show any notable change for more than a day, while the tremors of the second kind also remained at nearly the same amplitude, though their frequencies continued to decrease.

The volcano, on the contrary, became gradually more and more active and it was 6 days after the micro-tremors began to be recorded on Aug. 30, and 17 and 19 hours after the tremors of the first and the second kind respectively had begun to decrease abruptly in amplitude, that we had a violent eruption of the Fourth Crater at 11^h30^m on Sept. 5. A large amount of muddy hot-water was effused over the crater rim and red-hot lava blocks of ca. 200 kgs. weight were thrown out to a horizontal distance of ca. 500 m. and abundant quantities of volcanic dusts and vapours to a height of ca. 1,000 m. above the rim. Minor eruptions continued from the Fourth Crater till Sept. 8, large quantities of volcanic dusts being continuously and red-hot fragments of rock frequently, ejected. Nevertheless the micro-tremors of the second kind decreased rapidly, both in amplitude and frequency, after the great outburst, and ceased to appear on the Wiechert seismograms soon after midnight on the 6th. This fact seems to show that the magmatic reservoir, whose oscillations, in the author's view, generate the tremors of the second kind, had already exhausted too much active energy to cause further eruptions, and the remaining activities of the volcano were nothing more than residual effects. At 13^h on the 8th of the month the last eruption of secondary scale occurred, red-hot rock fragments being ejected to a horizontal distance of ca. 150 m., after which the activity of the crater rapidly diminished. On Sept. 10 the dust emission ceased, only slight vapour being emitted accompanied by feeble rumblings at times, and after some time had passed the hot water pool gradually reappeared in the

Fig. 7. An eruption of the Fourth Crater on Sept. 7, 1930.



basin of the crater. Unlike the micro-tremors of the second kind, the decay of the micro-tremors of the first kind, which are considered to be generated by internal eruptions of volcanic gases, was slow and gradual, considerable amplitudes being maintained even after the surface eruptions of the volcano had ceased, and months passed before the instruments of very high magnification ceased to record a trace of remaining activities. In the period of waning volcanic activity, Sept. 7–10, the micro-tremors recorded were mainly of the first kind in considerable amplitudes, those of the second kind being lacking and therefore the records obtained at this time resemble those obtained in the period of waning activity in 1929.

The micro-tremors of the third kind seem to be a kind of Rayleigh waves generated by surface eruptions and internal eruptions at very shallow places, as already described in previous paper[1]. Their amplitudes recorded by the short period micro-seismographs S_A at our Laboratory were ca. 0.25, 1.3, and 0.4 microns on Sept. 1, 5, and 9 respectively and the values, though fragmentary, seem to show a change in parallel with the variation of the surface activity of the volcano, as is to be expected from the nature of the tremors. Now we come to the interpretation of the above observed facts and to some conclusions concerning the process of the volcanic eruptions: The volcanic mass and energy accumulated up to the latest period of the maximum number of sun-spots were almost exhausted by a series of eruptions during that period, and after the last eruption on Nov. 7, 1929 of secondary scale, the vent of the Fourth Crater closed up, probably not very far below the mouth, and the temperature of the crater bottom soon began to cool so that there was a pool of hot water early in January of the following year. The micro-tremors of the first kind disappeared in the Wiechert seismograms, and those of the second kind had already disappeared months earlier than this. Months passed during which the former tremors were only recorded by our micro-seismographs S_A of very high magnification, not continuously but intermittently in several wave-groups per hour, and the latter tremors, of the second kind, probably also existed though they were not observed, for our G-type instruments[2] had not as yet been finished. During this period the volcanic mass and energy, imprisoned in the reservoir by the closing of the vent, and probably of not very insignificant in amount, were gradually increased by continual new

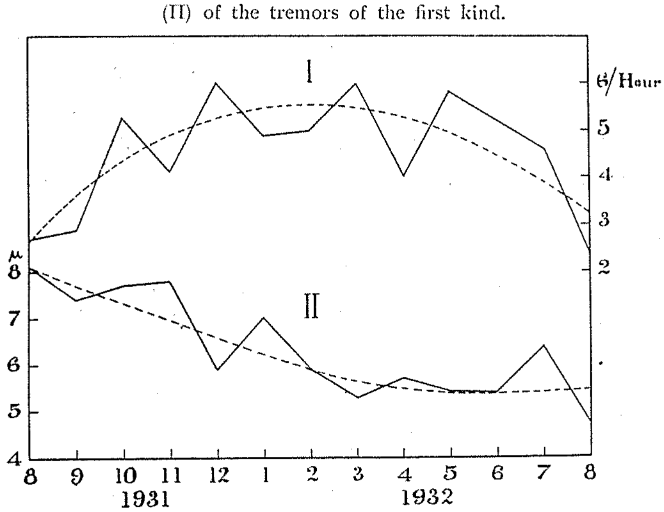
1, 2. Loc. cit.

supplies from the source of deeper origin, and finally a stage was reached when it was possible to begin work in an increased speed to make a way through the vent for eruption, when the micro-tremors of the two described kinds began to be recorded by our Wiechert instruments on Aug. 30, 1930.

Generally speaking, the period of any kind of tremors has a tendency to increase with the amplitude, and a part of the reason why the period of micro-tremors of the first kind which was ca. 1 second before that date began to increase to ca. 1.2 seconds in August 30 and then reached ca. 1.4 seconds in the following day can be sought in this general character of the tremors, or in the fact that there occurred simultaneously the micro-tremors of the second kind in a considerable degree of amplitude and frequency. But the author of the present paper thinks that the described increase in the period of the tremors of the first kind, as well as the increase of the tremors of the second kind in amplitude and frequency, was due to some yielding, in a very wide sense, which occurred somewhere near the junction of the vent and the reservoir, and with such yielding alone the work to make a way to eruption may begin to increase its rate. The change of period of the tremors of the first kind to decrease, contrary to the further increase in amplitude till early hours on Sept. 4 is decidedly due to the rising of the center of disturbance, causing the tremors under consideration, through the volcanic vent, and both the amplitude and frequency of the tremors of the second kind were little disturbed thereby. The physical and chemical nature of the volcanic process actually going on in the described stage is too complex to be estimated, but there seems to be a reason for thinking that the increase in amplitude of the tremors of the first kind and the rise of its center of disturbance will not continue till the moment of the first eruption, but that they will cease for a time before its occurrence, for there will be a stage in the course of drilling a path for explosion through the vent, when the yielding due to the pressure existing there, becomes easier, finding or creating outlet, upwards or sideways, for vapours to escape. At this time the amplitude of the micro-tremors of the first kind will reach a maximum, and the amplitude and frequency of those of the second kind will begin to decrease owing to relief of the load in the volcanic reservoir, and after some hours we will have a small explosion of white smoke (mainly vapours) as an indication that the path drilled upwards to eruption has reached an area just below the surface of the crater bottom, a time being only left for the coming eruption. As soon as the vent is open, the amplitudes of the micro-tremors of the first kind will begin to decrease rapidly owing to the rapid escape of vapours in the vent, without much disturbance of the tremors of the second kind which have already decreased in amplitude. A rapid flow of mass and energy into the vent or to its immediate vicinity will occur, in consequence, suddenly increasing the frequency of the latter tremors. At this stage violent eruptions are about to take place, and when once started they will be repeated so long as the accumulated mass and energy are sufficient to maintain them, and fluctuations in amplitude of the corresponding tremors will occur in a manner that will be described in a later paragraph. But when the mass and energy are about to be exhausted, the tremors of the second kind should decrease rapidly in amplitude and frequency and finally disappear, notwithstanding the surface eruptions still produced by some residual energy in upper parts of the reservoir. On the other hand the decrease in amplitude of the tremors of the first kind will be gradual owing to their mode of occurrence, and even after the stoppage of surface eruptions, these tremors will still have a certain degree of frequency and intensity corresponding to the internal eruption in shallower parts of the vent or its vicinity.

5. Micro-tremors in the repose period of the volcano during Oct. 1930—Aug. 1932

Fig. 8. Mean frequencies (I) and mean maximum amplitudes (II) of the tremors of the first kind.



Throughout this period the volcano was in perfect repose, slight vapour only rising from the pools of the First, the Second, and the Fourth Crater from time to time, except for the one short period of Nov. 23-27, 1931, during which we saw the water of the pool of the First Crater boiling vigorously and with considerable noise. Observations of the volcanic micro-tremors with the use of our S_B type micro-seismographs were made generally for two hours at first every day, and then every other day, from Aug. 1931 at our Volcanological Laboratory. The monthly means of the observed daily maximum amplitudes, periods, and frequencies of occurrence of the tremors of the first kind are given in the following Table and shown in Fig. 8;

Table 3

	A	*T*	*F*		*A*	*T*	*F*
	μ	sec.			μ	sec.	
1931 Aug.	0.81	1.01	2.7	1932 Mar.	0.53	1.11	6.0
Sept.	0.74	1.05	2.9	Apr.	0.57	1.07	4.0
Oct.	0.77	1.05	5.3	May	0.54	1.01	5.8
Nov.	0.78	0.99	4.1	June	0.54	0.95	5.2
Dec.	0.59	1.04	6.0	July	0.64	1.01	4.6
1932 Jan.	0.70	1.01	4.9	Aug.	0.47	1.05	2.4
Feb.	0.59	1.06	5.0				

Fig. 8 seems to show clearly a seasonal variation for the frequency of occurrence of the tremors of the first kind and probably for the amplitude too, though slight in degree.

Observations of the tremors of the second kind with the micro-seismographs G_A, adjusted so as to have the maximum magnification of ca. 2,800 at nearly the same period of the tremors, were begun in May 1932 and the following table gives the monthly mean of the observed values till August of the year;

	Ampl.	*V/H*	Period	Frequency per hour
	μ		sec.	
1932 May	2.40		4.08	3.3
June	1.74		4.21	3.5
July	1.71	1.20	4.34	3.5
Aug.	1.61	1.35	5.84	2.7

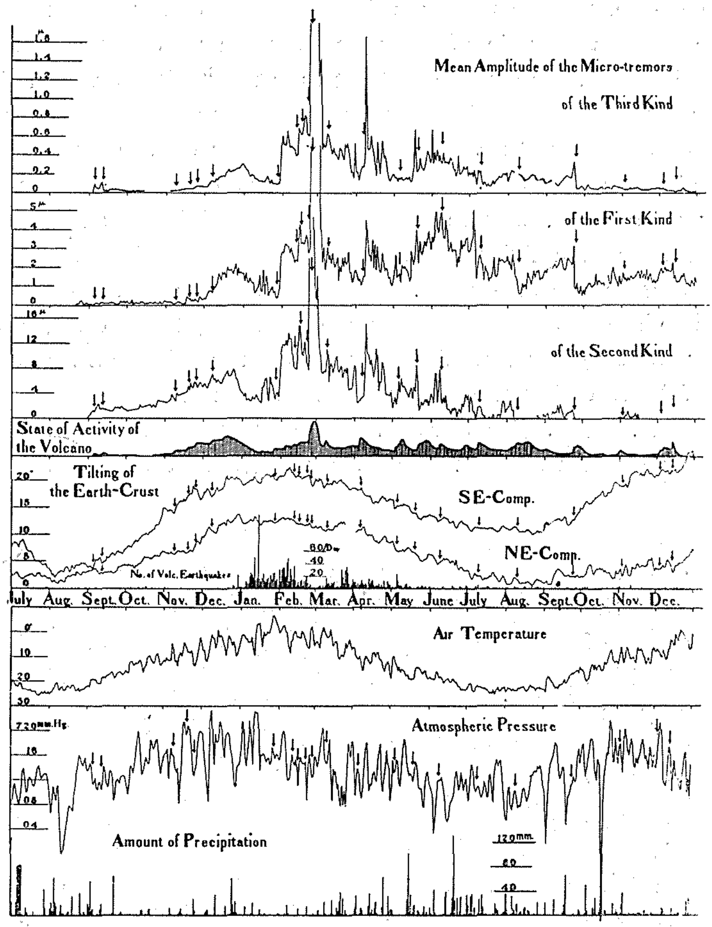
The gradual increase in period from 4.08 to 5.84 seconds for four months seems to show that some preparation were going on in the magmatic reservoir generating these tremors for the coming great activity which will be described in the following article.

6. Micro-tremors and the great activity of the volcano during September 1932 – December 1933

After two complete years' repose as described above, the volcano began to show traces of slight activity and entered a step-wise increase on Sept. 4, 1932. Up to this time three years had already passed since the beginning of our seismometrical observations in May, 1929, micro-seismographs of very high magnifications had already been at work, and the general character of the micro-tremors of volcanic origin were already known to us, as described in Part I of the report. We had also learned how the micro-tremors develop with a change of volcanic activity, and it was very fortunate to us that the great activity now to be described was rather waited, and observed completely to the first time, with these preparations both in instruments as well as in knowledge, except that the tiltmetric observations still were provisional, the special observing room for the purpose not having as yet been finished. The activity increased gradually in strength and the eruptions attained a maximum violence in Dec. of the same year, red-hot blocks of rock being frequently ejected to a horizontal distance of ca. 300 m. from the vent of the First Crater. The volcano then showed a considerable diminution of activity for about two months, and it was of great interest for us that, during this short space of time a great many volcanic earthquakes occurred in this district. They were indeed ca. 1,500 in number, and at the end of Feb. 1933, terrible eruptions of the Second Crater took place together with the First, probably the greatest outburst since the beginning of the Meiji era, large lava-blocks of ca. 3 tons weight being ejected to a horizontal distance of ca. 1 km. Since then, the volcano has diminished its activity gradually in a step-wise manner up to the end of the same year, though eruptions of considerable strength were frequently repeated.

The daily mean amplitudes of the micro-tremors of the first, the second, and the third kind, together with the daily numbers of the volcanic earthquakes recorded by the Wiechert seismographs at the Volcanological Laboratory are given in Table 4 and shown in Fig. 11 together with the daily mean positions of the two pendulums of the tiltmeter of Rebeur's type and the results of meteorological observations. The period of the micro-tremors of the second kind is nearly the same as that of ordinary microseisms and when the amplitude of the latter is not small it is not easy to get an accurate value for the former, but there need be no fear of error, for the recorded horizontal displacements of the ordinary microseisms are nearly the same in amplitude both for the N–S and the E–W components, while those of the tremors of the second kind are practically confined to the E–W component. Thus observed data given in Table 4 refer only to tremors which were not disturbed by ordinary microseisms. The remarks given in the Table are from the data obtained at the Laboratory as have been done since 1928, together with the observations at Kusasenrigahama, 3.1 km. west from the crater, at which place we get not only a view of the entire crater rim but even ejections of rock fragments can be observed on fine days. As examples, a portion of a record of the micro-tremors of the third kind, obtained by the short period micro-seismographs S_E at the Laboratory on May 7, 1933, is reproduced in Fig. 9, Plate I and portions of records obtained from the Wiechert

Fig. 11



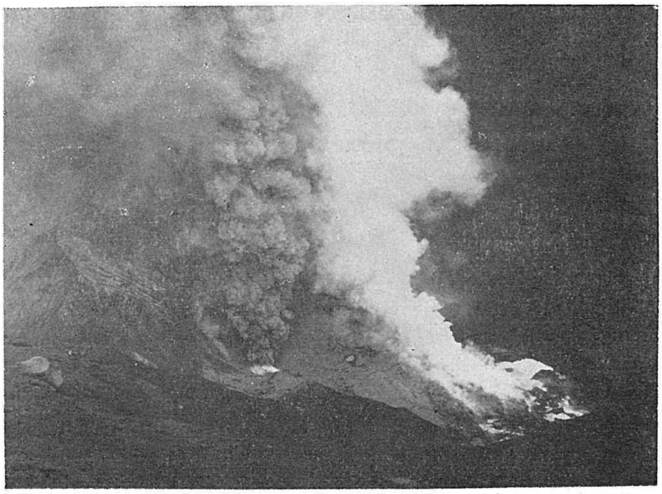
(The arrows indicate the time of beginning of eruption-groups.)

instruments on Feb. 25, 1933 in Fig. 10, Plate II; on this day the amplitudes of the volcanic micro-tremors were the greatest ever observed at our Volcanological Laboratory.

7. Micro-tremors and small eruptions of the First Crater in September 1932

We shall now describe the results of micro-seismometric observations in parallel with the great activity of the volcano, and this section refers to the stage at the very beginning of the eruptions. At the end of Aug. 1932 the micro-tremors of the first kind began to increase gradually both in frequency of occurrence and in number of waves in each group, though their maximum amplitudes were not increased. But the mean amplitude of the tremors which was 0.15μ on Aug. 25 decreased to less than 0.03μ on Sept. 4, at 11^h30^m on which day the First Crater began to emit black smoke calmly and without any noise from a new small vent at the western corner of the crater bottom. The diminution of the amplitude of tremors on this occasion was in the normal manner, and the quiet emission of black smoke was the first indication of activity in the violently active period of the volcano after a long repose of 2 years. After that the volcano continued to emit much more black smoke for the following three days, and after stopping for two days, again emitted black smoke on Sept. 10–11. On the following day the crater emitted slight vapour only instead of black smoke. Fig. 12 shows the state of emission of black smoke from the vent of the First Crater, photographed on Sept. 11, 1932. As shown in Fig. 11 the variation of the observed amplitude of the micro-tremors of the third kind was nearly in parallel with that of the activity of the volcano during this period, and micro-tremors of the second kind observed, which attained a maximum amplitude of ca. 2μ on quiet days of Sept. 8–9, decreased slightly in amplitude on the following active days of 10–11th, all of which is in accordance with our previous experience. But, contrary to the diminution in activity of the volcano, the micro-tremors of the second kind did not decrease in amplitude, which remained at ca. 1 7μ, with a tendency to increase than to decrease, showing that further active eruptions were in preparation.

Fig. 12



(Photo. Hayashi)

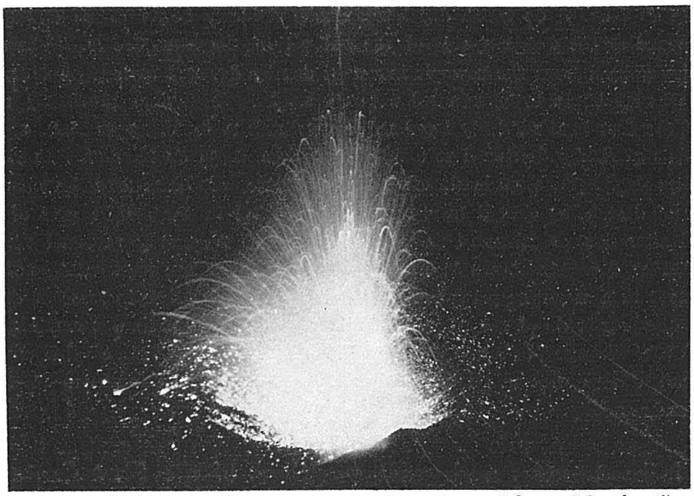
8. Micro-tremors and small eruptions of the First Crater in November 1932

The volcano remained in repose during Sept. 12–Nov. 6, with exceptions of two short periods, Sept. 17–19 and Oct. 26–27, during which periods slight black smoke was emitted quietly without noise. The micro-tremors of the third kind changed their amplitudes nearly in parallel with the variation of activity just described, but those of the first kind kept nearly the same amplitude throughout this repose period, while those of the second kind began to show an increase of amplitude from the beginning of Oct. On Oct. 26 the rate of increase of the amplitude of the last named tremors became more rapid, and on Oct. 30 the tremors of the first kind also suddenly increased their mean amplitude to ca. 0.2μ. The latter tremors soon decreased in amplitude, at first gradually and then rapidly, to a minimum of ca. 0.01μ on Nov. 7, on which day black smoke suddenly began to be emitted from a new pit formed at the southern side of the old pit of the First Crater. The amount of black smoke emitted from the new pit increased day by day and at last, on Nov. 19, some fragments of rock began to be mingled with the smoke. Two days previously the micro-tremors of the first kind suddenly increased in amplitude to ca. 0.42μ on Nov. 17, and then the amplitude gradually decreased to a minimum of ca. 0.15μ on Nov. 26. At about 7^h on the preceding day, 25th, a moderate eruption took place, moderate-sized fragments of rock and plenty of dust being ejected from a new vent formed in the middle part of the First Crater and after this, eruptions of the same degree were frequently repeated till midnight of the following day. As shown in Fig. 11 the amplitude of the micro-tremors of the third kind increased in a step-wise manner in parallel with the step-wise increase of the volcanic activity. The amplitude of the tremors of the second kind which was a minimum of ca. 2.8μ on Nov. 9 increased to 4.3μ on 18th and then kept nearly the same value until the end of the month, though with minor fluctuations running opposite in course to the fluctuations of the volcanic activity.

9. Micro-tremors and great eruptions of the First Crater in December 1932

As mentioned in the foregoing two paragraphs, the volcano showed a certain degree of activity of minor scale for three months from the beginning of September to the end of November, the degree of its strength being rather too trifling to be described in detail, as is seen from the smallness of the amplitudes of the tremors of the first and third kinds. But it is important to notice that, during this period, the amplitude of the tremors of the second kind was constantly increasing, which shows that something was going on a large scale in the magmatic reservoir or elsewhere in connection. The frequencies of occurrence began to increase rapidly on Dec. 3, and finally they became continuous trains of regular waves on Dec. 6, increasing in amplitude at the same time. The amplitude of the tremors of the first kind increased from 0.3μ on Dec. 2 to a maximum of 0.78μ on 6th and then slightly decreased to 0.64μ on the following day. At about 14^h on the same day a violent eruption occurred, a considerable mass of lava-blocks being thrown out to a height of about 300 m. above the mouth of the vent. After that the eruption of the First Crater increased in strength and frequency of occurrence day by day. Especially for the three days of Dec. 17–19, the eruptions, frequently repeated, were so violent that large red-hot blocks of rock of ca. 1 ton weight were ejected to a horizontal distance of ca. 300 m. over the crater rim. Fig. 13 is a photograph of an eruption of the First Crater taken at about 22^h on Dec. 17, 1932 at the western

Fig. 13



(Photo. Murakami)

crater rim. An eruption at 19^h30^m of the next day, 18th, was one of exceeding violence and some sight-seers who went too near the crater could not escape without being injured by ejected fragments of rock. The maximum amplitude of the eruption-earthquake of this explosion recorded at our Volcanological Laboratory was ca. 0.65μ in double amplitude. On Dec. 19 the present writer, standing on the western rim of the First Crater, observed whitish red molten lava—probably ca. 1,000°C,—welling up and down at intervals of about 1 second at the mouth of the vent. Eruptions were repeated with rather feeble detonations at irregular intervals, sometimes every 5–6 minutes and at other times only every 20–30 seconds. The amount of the ejectamenta was not great at a single eruption and their directions of projection were not definite but varied from eruption to eruption.

Generally speaking, the amplitudes of the three kinds of tremors described increased constantly up to the last mentioned eruptions, though with fluctuations in the tremors of the first and the second kind, a characteristic phenomenon that we have frequently observed. The tremors of the first kind showed that they had reached a maximum in amplitude, but the course of variation of the amplitude of the tremors of the second kind did not show any culmination of activity in the great eruptions of the month. Near the end of the year the amplitude of the tremors of the second kind suddenly decreased from 6.1 μ on Dec. 28 to 3.5 μ on Jan. 2, and three days later, those of the first kind also began to decrease rapidly in amplitude from Dec. 31. If the things were as described in the preceding articles, such a decrease in amplitude of the tremors, especially those of the second kind, would generally be followed by great eruptions, but the gradual decrease in volcanic activity which began on Dec. 20 remained unchanged both in the end of the year as well as in the beginning of the following year, diminishing more and more as time passed, though volcanic dusts and occasionally small fragments of rock were still constantly ejected. Things were very different to our previous experience, and instead of an increase in eruptive activity we had frequent occurrences of volcanic earthquakes, which will be described in the following paragraph.

10. Swarm of volcanic earthquakes and the volcanic activity

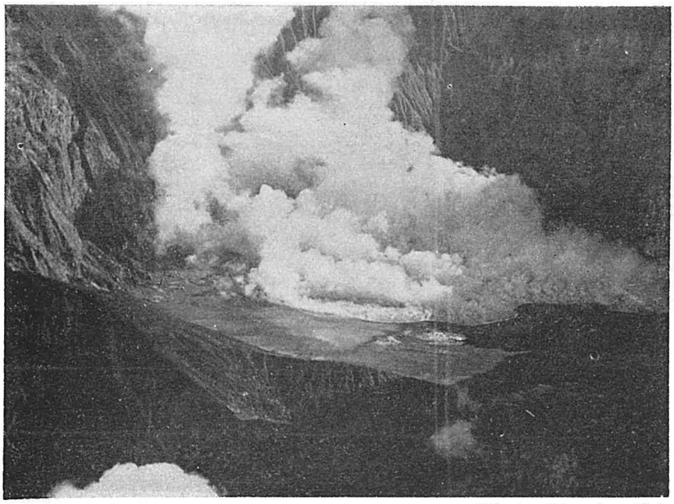
Volcanic earthquakes originating inside the old large caldera are generally rather few in number. Their intensity and frequency of occurrence gradually increased from Dec. 28, 1932 day by day and attained a maximum of frequency on Jan. 14 of the following year, 1933, on which day the number of volcanic earthquakes recorded by the Wiechert instruments at our Volcanological Laboratory was 89, and the actual number was probably far greater (probably more than 120), but a considerable number failed to be recorded at the times when the recording pens were displaced by strong shocks. After this the daily number of volcanic earthquakes observed by the same instruments was ca. 20–30 at the beginning of the following month and then decreasing gradually from day to day towards the middle of February. Meanwhile the activity of the volcano was rather subdued from the beginning of the year, only black smoke being emitted occasionally from the First Crater with feeble rumblings and slight vapour from the pool of the Second Crater until the middle of Feb., at which time the latter crater began to increase in activity, first effusing mud on Feb.

11 and then emitting black smoke from 19^h on Feb. 15. Near the end of Feb. the daily number of the recorded volcanic earthquakes was only 2 or 3 and it was about two months after the volcanic earthquakes began to be frequently recorded, that we had terrible eruptions of the Second Crater which began to take place on the early morning of Feb. 24. The volcanic earthquakes in question are nothing more than those, if described in usual way, of the premonitory of the terrible explosions on Feb. 24, and the variation of their frequency of occurrence resembles to that of the tremors of the second kind, and the significance of their mode of occurrence should be considered in connection with the results of observations of volcanic micro-tremors as well as those of the tiltmetric observations made at our Volcanological Laboratory. We shall return to a further discussion of the described earthquakes after a description of micro-tremors during the great eruption-period, given in the following two paragraphs.

11. Micro-tremors and activity of the volcano during Jan. 1 – Feb. 24, 1933

Amplitudes of the tremors of the first and second kinds which dropped to minimums after the occurrence of the described swarm of earthquakes, began to increase again in the middle of January, but at the end of the month they decreased rapidly in amplitude to minimums on Jan. 27, on which day a strong eruption of the First Crater took place at about 14^h, some fragments of rock being ejected to a horizontal distance of ca. 300 m. and after that the First Crater maintained its activity at nearly the same intensity, constantly emitting black smoke and occasionally ejecting fragments of rock, till the end of the following month. Fig. 14 is a photograph of the Second Crater taken in Jan. 1933, showing the state of the crater before the great eruptions occurred in the following month. On Jan. 30 the amplitudes of the tremors of the first and second kinds again increased greatly from ca. 0.5μ to ca. 2.6μ for the former kind and from ca. 4μ to 10μ for the latter and they again decreased rapidly on Feb. 10. On the following day the Second Crater showed the first indication of the comming great eruptions, effusing mud to a height of about 4 m. above the crater bottom. After that the Second Crater, whose pool dried up, gradually increased in activity and finally at about 19^h on the 15th began to emit a great deal of black smoke, while the amplitudes of the tremors of the two kinds increased on the 14th and soon began to decrease to minimum value on the 23rd, on the afternoon on which day the rate of increase of activity of the Second Crater began to be accelerated. The variation of the amplitude of the micro-tremors of the third kind was nearly in parallel with that of the tremors of the

Fig. 14



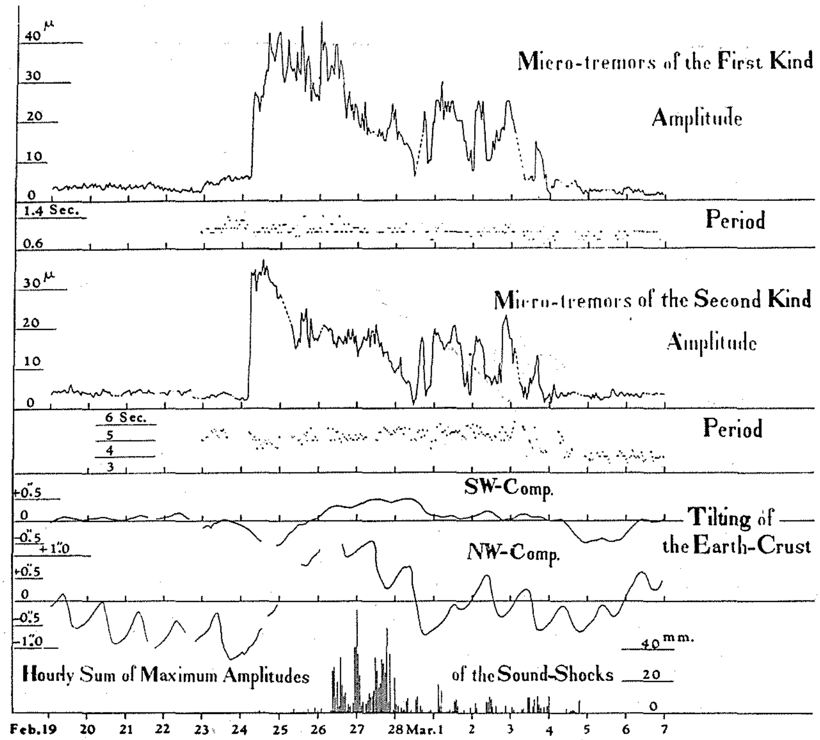
(Photo. Murakami)

first kind. A partial reason for this parallelism is probably given by observational errors, for owing to the large amplitude of the latter tremors the accurate evaluation of the recorded amplitude of the former tremors, the period of which is only half that of the tremors of the first kind, was very difficult in spite of the favourable nature of their oscillating directions;—the oscillatory displacements of the tremors of the first kind are far predominant in the N–S component, while those of the tremors of the third kind are nearly the same in both components.

12. Micro-tremors and great eruptions of the Second and the First Crater during Feb. 24—March 4, 1933

As amplitudes of the tremors observed in this period were too large to be given in Fig. 11 together with the other smaller values, and as, moreover, a much more detailed study is desirable, the hourly mean amplitudes and periods of the tremors of the first and second kinds observed by the Wiechert instruments, mean positions of the pendulums of the tiltmeter and hourly sum of the maximum amplitudes of the sound-shocks recorded during this period are shown in the following Fig. 15. On Feb. 23 the wave-form of the tremors of the second kind became very irregular with a somewhat elongated period

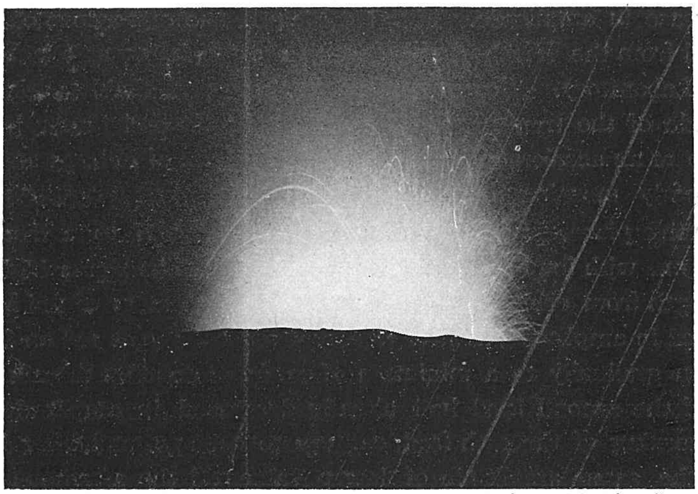
Fig. 15



and in the evening of the same day the period of those of the first kind was also elongated slightly, the amplitudes of the latter tremors had already decreased in the evening of the 21st and again increased slightly early in the morning of the 23rd, while those of the former tremors had decreased since the evening of the 22nd. From 5^h27^m on Feb. 24 the micro-tremors of the first and the second kind suddenly increased in amplitude from ca. 6μ to 23μ for the former tremors, and from 5μ to 34.5μ for the latter in only 25 minutes. The tremors of the second kind kept their amplitude at the upper value for about half a day and soon after the evening of the same day began to decrease rapidly in amplitude to ca. 17μ on the morning of the following day, while the tremors of the first kind, after increasing in amplitude to a maximum of ca. 40μ, kept their maximum value with some minor fluctuations for about two days and from daytime on the 26th began to decrease in amplitude. Fig. 10, Plate II shows portions of records obtained from the Wiechert seismographs on Feb. 25 at our Volcanological Laboratory. Corresponding to these remarkable variations of amplitude of the tremors, the activity of the Second Crater began to increase at an accelerated rate from the afternoon of Feb. 23 and finally in the early morning of the following day violent eruptions of the crater took place, fragments of rock being ejected to a distance of ca. 200 m., with loud detonations, repeated eruptions increasing rapidly in strength from eruption to eruption. Micro-tremors of the first kind decreased in amplitude, at first rapidly from ca. 40μ at 14^h on Feb. 26, and then gradually to a minimum of ca. 6μ at noon on the 28th, while those of the second kind had already decreased in amplitude in the early morning of the 25th from ca. 34μ to ca. 17μ, and after keeping nearly the same amplitude of lower value till the afternoon of the 27th, rapidly decreased to a minimum amplitude of ca. 0.7μ at noon of the following day.

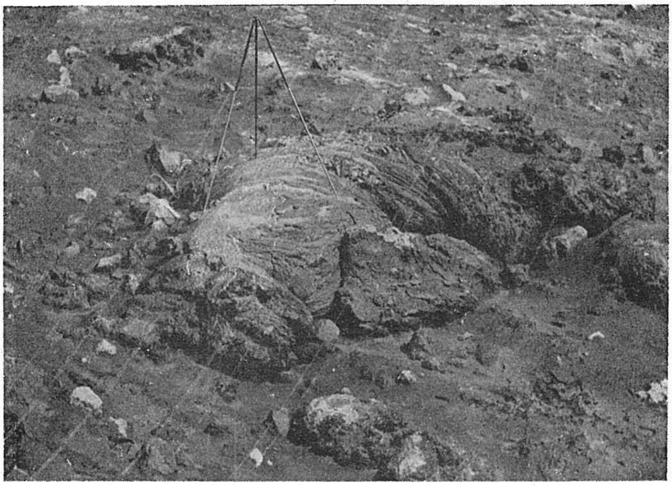
On the contrary, as will be seen from Fig. 15, the intensity of eruptions increased rapidly from daytime on the 26th and attained a maximum in the evening of the following day, at which time the eruptions, mainly of the Second Crater, were so violent that a considerable number of red-hot lava blocks of ca. 20 tons weight were frequently ejected to Sunasenrigahama, ca. 600 m. south therefrom, and blocks of ca. 3 tons weight to a horizontal distance of ca. 1 km. or more, with severe detonations, some of them being heard even at Beppu, ca. 60km. NNE of the volcano. Fig. 16 is a photograph of an eruption of the Second Crater at 0^h44^m on Feb. 28, 1933 taken at our Hondô Observing Room and Fig. 17 is a photograph of one of the largest lava-blocks which fell on the western slope of Naka-dake, ca. 500 m. west of the crater. On Feb. 28 the Second Crater greatly decreased both in the intensity and frequency of eruption, while the eruptions of the First Crater began to be frequently repeated with nearly the same intensity as that of the Second Crater at the same time. Throughout the following three days eruptions of the two craters were repeated, though gradually decreasing in frequency and intensity, red-hot lava blocks of ca. 10 tons weight being ejected frequently to a horizontal distance of ca. 400 m. and of ca. 800 m. at times. As to the distribution of the ejectamenta as well as considerations on the mechanism of the eruption, the reader is referred to the

Fig. 16



(Photo. Murakami)

Fig. 17



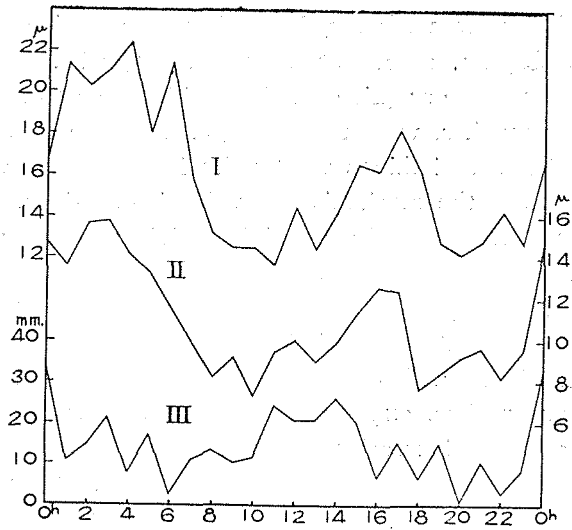
(Photo. Hayashi)

preceding paper, Part I.[1] At about 11^h on March 2 the present writer observed the crater bottoms, standing on the western crater-rim during a short repose interval of ca. 20 minutes, but, instead of finding whitish red molten lava at the mouth of the vents of the First and Second Crater as in the case of the eruptions of the former crater in Dec. of the preceding year, he saw deep and enlarged vents, from

1. Loc. cit.

which plenty of white smoke was rising. Almost all the molten lava in the upper part of the vent seems to be thrown out in violent eruptions such as the present one, and so the molten lava was deep in the vent during the short repose interval. The sequence of an eruption observed at the southern rim of the Fourth Crater, ca. 600 m. south from the Second, on March 2 was as follows; at the very beginning a flash, and emission of black smoke at the mouth of the vent, then ejection of lava-fragments, outrunning the black smoke, and ejections of fragments of rock lasted for 6-8 seconds. 1.9 seconds in the mean after the flash, the detonation was heard, from which its velocity of propagation is calculated as being ca. 330 m./sec., if the flash and the detonation started at the same moment at the mouth of the vent which was ca. 100 m. below the crater rim. Amplitudes of the tremors of the first and second kinds, though fluctuating over wide ranges, as shown in Fig. 15, did not change in mean during the three days of Feb. 28–March 2, but on the following day, the 3rd, they began to decrease to ca. 3μ for both tremors in the early morning of the 4th, on which latter day the eruptions of the two craters decreased greatly in strength and frequency from the early morning, but in the evening the last violent eruptions of this short period of great eruptions took place. On March 5 the eruptions of the two craters ceased, but quantities of vapour rising from the craters, especially from new steep slopes formed by the ejectamenta along the south and southeastern internal walls of the Second Crater, were so abundant that we could not see the bottoms of the craters. Microtremors of the first and the second kind decreased gradually in amplitude, with some minor fluctuations, day by day from March 4 show-

Fig. 18



ing that the activity of the volcano was in the declining stage. The means of hourly mean amplitudes of the tremors of the first (I) and the second (II) kind and hourly sums of the recorded maximum amplitudes of the sound shocks (III) during the four days of Feb. 28–March 3, in which period the activity of the volcano was of nearly the same degree, were as shown in Fig. 18. The tremors of the first kind changed in amplitude semi-diurnally, with two maximums at 4^h and 17^h and two minimums at 10^h and 21^h, and those of the second kind also changed in amplitude nearly in parallel with a slight advance of phase of ca. 1 hour. The mean hourly sum of the recorded maximum amplitude of the sound shocks as described in the following paragraph, and the corresponding intensity of eruption of the volcano also changed semi-diurnally, but the maximums were at 14^h and 0^h, and the minimums at 6^h and 20^h. These semi-diurnal variations of the tremors and the volcanic activity are to be considered as due to certain effects of atmospheric pressure on the volcano, which is particularly sensitive in its active period when its eruptive energy has reached the saturation point.

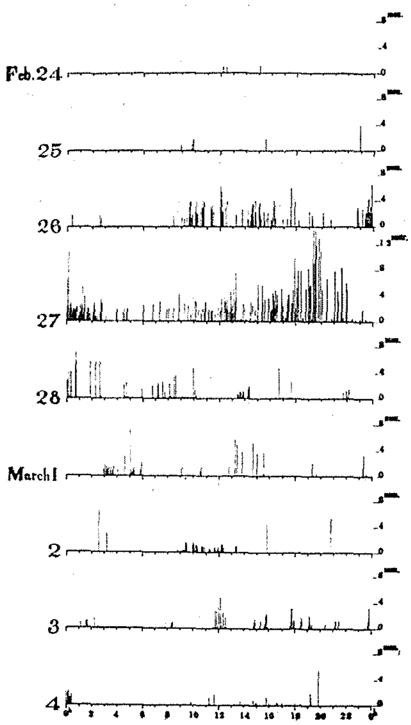
13. Micro-tremors and volcanic activity during the described great eruption-period, the occurrence of the swarm of volcanic earthquakes being taken into consideration together with the tilting of the ground

So far we have described the micro-tremors and volcanic activity of Aso from the very beginning of the active period of great explosion on Sept. 4, 1932, up to March 5, 1933 when about to enter its declining stage. The eruptive activity in this case, accompanied by many volcanic earthquakes, were the most general case of eruptive activity of the volcano and things went quite in accordance with our general conceptions of the mechanism of volcanic eruptions. A few days before the first indication of very slight activity in the First Crater, micro-tremors began to be recorded showing that the accumulation of volcanic mass and energy were already sufficient to begin to find a way to eruption. Three months passed till the end of November during which period the feeble activity and micro-tremors were generally in accord with our previous experience, but the tremors of the second kind were constantly increasing their amplitude in mean, indicating greater activity in future. Near the end of November the accumulation of volcanic mass and energy under the volcano reached such a degree as to cause great increase in amplitude of the micro-tremors of the first, the second and the third kind, and, as will be described in a future paragraph, the tiltmeter set in our Laboratory began to record a tilting of the ground, as if the earth's crust in the neighbourhood of the crater of the volcano was gradually upheaved from the end of Nov. 1932, the rate of upheaval increasing day by day, and at last we had the violent eruptions in the middle of December, as already described. Near the end of the year, 1932, the tremors of the first and the second kind began to fall rapidly, everything appearing to foretell the approach of a great eruption. But by this time we had the swarm of volcanic earthquakes instead, as already described. The stresses in the crust (in this locality), in conjunction with the condition of the magmatic reservoir, were such that they could not resist a further accumulation of volcanic mass and energy in or near the reservoir, and consequently yieldings occurred which took the form of a swarm of earthquakes. The yielding in such cases necessarily means a flow of mass and energy tending toward the origins of earthquakes in general, and therefore a relief of pressure in the magmatic reservoir or its immediate vicinity, as well as a decrease in eruptive activity and falls in amplitude of the volcanic micro-tremors are the result. It was as if the volcano had found new craters in place of the existing one. Yielding of the earth's crust frequently occurred in the district extending to the west of the crater, as will be described in a future paragraph. The internal conditions of the earth's crust were now such that it could hold against a much higher pressure, and the further accumulation of mass and energy in the reservoir began to find a path toward the crater as the weaker places yielded, and escaped as eruption. This was the state of things at the end of Jan. 1933. Still further accumulations of mass and energy continued, but they now found two paths, one towards the crater and the other towards the places where yieldings occurred in the form of earthquakes. Volcanic micro-tremors began to increase and the eruptive activity of the crater also, but the number of earthquakes began to decrease from the middle of February, the internal conditions of the crust enabling it to stand against the increasing pressure. Thus the eruption could be expected to be more violent than any we had before the occurrence of the swarm of earthquakes. As shown in Fig. 15, the ground of the Laboratory began to tilt up towards the east from its mean position on Feb. 19 and the tilting constantly increased in degree, and micro-tremors occurred in the manner already described, and we had the outburst of great eruptions on Feb. 24, on which day the sense of tilt of the ground was reversed, the west-upward tilt attaining a maximum value on the most active days of Feb. 26–27 and then gradually returned to its mean position :—a result of the escape of accumulated mass and energy by repeated great eruptions. The depression of the crust to a position somewhat above its original one was in the manner normal for such occurrences.

14. Sound shocks caused by the great eruptions during Feb. 24–March 4, 1933

Sound shocks caused by violent eruptions were recorded by the Wiechert and our G_4 type vertical component seismographs, even at our Volcanological Laboratory, 7.5 km. west of the crater. Fig. 19, Plate III is a reproduction of a portion of a record obtained from the Wiechert vertical component seismograph on Feb. 27–28, 1933 and the time of occurrence and the maximum amplitude of the sound shocks recorded by the above named instrument are shown in Fig. 20.

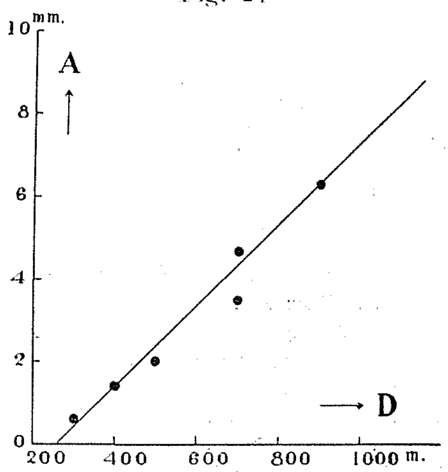
Fig. 20



The sound shock recorded at the Laboratory begins with a downward motion of the ground without a single exception, corresponding to the compressional displacement of the air wave, and the ratio of the initial to the next backward motion was not constant but varied over wide ranges from 1 : 1 to 1 : 5

On March 4 several sound shocks were recorded by an ordinary Richard barograph, which was adjusted to register in parallel with the pens of the seismograph on one and the same recording drum of the Omori tremor recorder set at our Hondô Observing Room at the summit. The initial motions of the barometric disturbances caused by the eruptions, thus observed, were always of abrupt compressional displacement. The relation between the amplitude of barometric disturbances at the summit and that of sound shocks at the foot is not simple, though the number of the observed data is not sufficient to draw any conclusion, but it seems to show that the form of the pressure waves caused by the eruptions was not constant, but varied greatly from eruption to eruption, especially between eruptions of the First Crater and those of the Second. This is also suggested by the diversity of the observed ratio of the initial to the next backward displacement of the sound shocks recorded at the Laboratory. The relation between the recorded maximum amplitudes of the sound shocks of eruptions and the maximum horizontal distances to which fragments of rock were thrown out by the corresponding eruptions, is given in Fig. 21 and, as shown in the figure, the maximum amplitude of the recorded sound shocks is proportional to the maximum horizontal distance of the projections. So we may consider Fig. 20 as a record showing the intensity of the eruptions together with their time distribution, though all such relatively minor eruptions as those in which fragments of rock were ejected to a horizontal distance of less than 300 m. were missed, for the maximum amplitude of the corresponding sound shock was too small to be observed on records, which recorded tremors of much larger amplitude.

Fig. 21



15. Micro-tremors and eruptions of April 5-6, 1933

After the last eruption of the great eruption-period on March 4, the volcano was relatively quiet, only emitting continual white smoke and occasional dusts with feeble rumblings throughout the month except on the 9th, on which day one strong eruption of the Second Crater occurred at 16^h09^m. The amplitude of the tremors of the first kind, which kept nearly the same value of ca. 2.0μ from March 5, began to decrease to a minimum value of 1.2μ on the 27th and then, after a slight rise on the 31st and April 1, rapidly fell to a minimum of 1.0μ on April 5, on which day a violent eruption of the Second Crater took place at 19^h50^m. The amplitude of the tremors of the second kind, which was decreasing gradually from March 5 with some minor fluctuations, suddenly decreased from 8.2μ to 4.5μ on March 27, and then after a rapid rise to 8.4μ on March 31, again fell to 2.4μ on April 3, two days after which the eruptions began, while the frequency of occurrence and the intensity of volcanic earthquakes which increased greatly during March 22–27, decreased at the very beginning of April. The eruptions of the Second Crater, which began on April 5, were repeated till midnight of the following day, large volumes of black smoke being continuously emitted and fragments of rock occasionally ejected with loud detonations. After that the volcano diminished in activity day by day except for April 9, on which day one strong eruption occurred at about 19^h.

16. Micro-tremors and activity of the volcano during May – December, 1933

During this declining period there were seven remarkable eruption-periods as follows:

1. *Eruptions of May 4–8, 1933.* The volcano began to increase in activity at the end of April and on May 4 the eruptions of the First Crater began to occur. Thereafter the strength of eruptions gradually increased till the 8th, on which day red-hot lava blocks were thrown out from the First Crater to a horizontal distance of ca. 300 m. and from the Second Crater to ca. 100 m., and after this the eruptions decreased gradually as time passed, though volumes of black smoke were constantly emitted and fragments of rock occasionally thrown to a short distance until the next active period of May 18.

2. *Eruptions of May 18–30, 1933.* The First Crater suddenly increased in activity, frequently ejecting fragments of rock on May 18, and the Second Crater also, on the 22nd. After that the eruptions were repeated, those of the former crater being most severe during 15^h–$16^h 30^m$ on May 29, fragments of rock being ejected to a distance of ca. 250 m.

3. *Eruptions in June* 1933. At the beginning of June the two craters diminished greatly in activity. On June 8 moderate eruptions occurred and continued for several days, small fragments of rock being ejected at times. Owing to a succession of rainy and cloudy days detailed observations of the volcanic activity could not be made in the second half of June, but on the nights of the 27th and 29th of the month we observed a red cloud lit up by the crater-glow and caused by the molten lava, ejected or lying at the mouth of the vent. Such a bright crater-glow which was observed even at our Laboratory, has happened only when violent eruptions were frequently repeated, and the state of activity of the volcano at such times may be inferred therefrom.

4. *Eruptions of the First Crater during July 9–13, 1933.* From the beginning of July the volcano increased in activity and on the night of the 9th strong eruptions began to be frequently repeated with loud detonations. The eruptions were continuously repeated until the 13th of the month, and after that the volcano constantly emitted black smoke and dusts from the First Crater with feeble rumblings, without ejections of fragments of rock.

5. *Eruptions of the First Crater during Aug. 9–18, 1933.* From the beginning of August the First Crater gradually increased in activity, some small fragments of rock being occasionally ejected to a short distance, and from midnight of Aug. 9 strong eruptions were frequently repeated till the 18th of the month. The strongest eruptions took place during the three days 15th–17th, lava-blocks of ca. 200 kgs. weight being ejected to a horizontal distance of ca. 250 m. over the northern crater wall at times. On Aug. 19 the strong eruptions ceased and after that the First Crater constantly emitted white smoke and occasionally volcanic dusts and small fragments of rock.

6. *Eruptions of the First Crater during Sept. 25–28, 1933.* From the middle of September the volcano was quiet, only emitting slight black smoke from time to time from the First Crater, with feeble rumblings. On Sept. 25 violent eruptions began to take place with loud detonations, the sound shocks of which were recorded by the Wiechert instrument at our Laboratory. Strong eruptions lasted till 28th of the month, the strongest one taking place at 14^h on that day, on which occasion lava-fragments were thrown out to a distance of ca. 300 m. Strong eruptions ceased at the end of the month and throughout the following month the volcano was in repose, only emitting white smoke from the First and the Second Craters and, rarely, black smoke and slight dusts from the former.

7. *Eruptions of the First Crater of Nov. 1–2, Dec. 2–5 and Dec. 13, 1933.* Small eruptions of the First Crater took place frequently on Nov. 1–2, small fragments of rock being

ejected to a distance of less than 100 m. After that the volcano was again in repose throughout the month. On Dec. 2 small eruptions of the First Crater began to take place and gradually increasing in strength, attained their maximum violence on Dec. 5, on which day many small fragments of rock were thrown out to a distance of ca. 100 m. On the following day the eruption ceased and the volcano was again in repose. On Dec. 13 strong eruptions of the First Crater suddenly took place and lasted throughout the day, lava-blocks of ca. 200 kgs. weight being ejected to a distance of ca. 150 m. This eruption was the last of the great eruptive period of 1932–1933. Since then the volcano has been in perfect repose, only emitting slight vapour at times. The vent of the Second Crater was gradually buried by old volcanic ashes and dusts pouring into it, and a sandy bottom appeared in the following year. The volcano is now in repose, the present state of the four craters being as shown in the following photographs, taken on May 23, 1935.

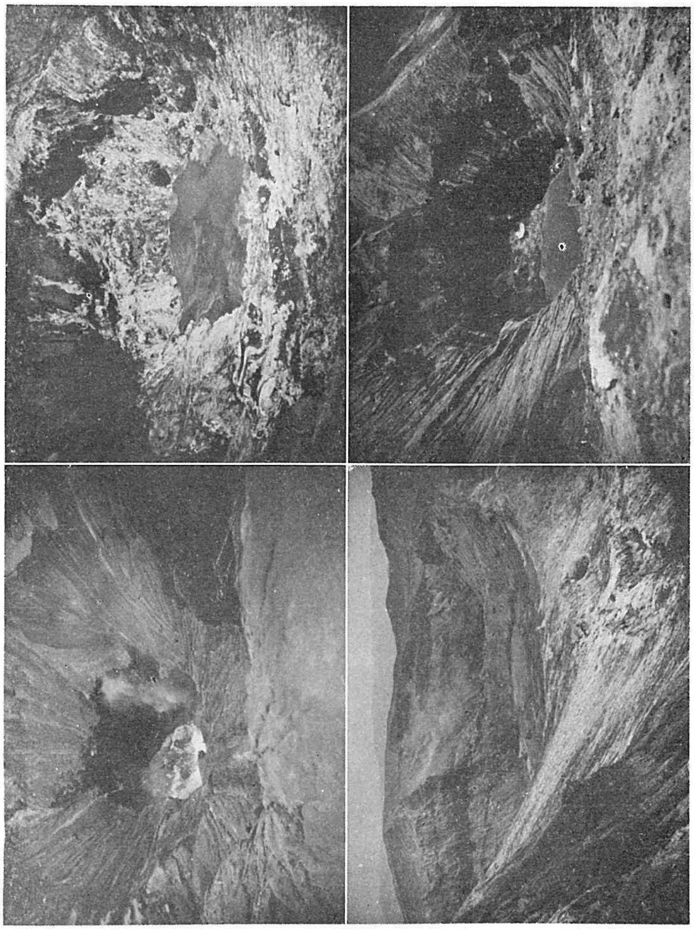


Fig. 22

(a) The First Crater, taken at the northeastern rim of the crater.

(b) The Second Crater, taken at the eastern crater rim.

(c) The Third Crater, taken at the eastern rim of the Second Crater.

(d) The Fourth Crater, taken at the eastern crater rim.

(Photo. Ueno)

Corresponding to the seven principal groups of the described eruptions in this period, there were seven principal fluctuations of amplitude of the micro-tremors of the first and the second kind as shown in Fig. 11, and the relation between the micro-tremors and the volcanic activity observed in these cases is exactly similar to that observed in the most simple case of eruption of the Fourth Crater on Sept. 5–8, 1930, already described in one of the preceding paragraphs; this was as already expected from our previous considerations on the mechanism of the volcanic activity. Speaking in somewhat greater detail, the amplitude of the micro-tremors of the second kind increases at first, and keeps its maximum value for several days with rises and falls over a considerable range, and then begins to decrease rapidly, and soon after this the first eruption of the group takes place suddenly. As long as the eruption is repeated, the amplitude of the tremors generally keeps its lower value. The variation of amplitude of the micro-tremors of the first kind is nearly similar to that of the tremors of the second kind described above, but speaking more accurately, the amplitude of the former tremors generally keeps its maximum value, or rather increases even after the amplitude of the latter tremors has begun to decrease, and begins to decrease only a short time before the occurrence of the first eruption. In the case of the small eruptions of Nov. 1–2, 1933 the variations of amplitudes of the tremors of the first and second kinds were on a very small scale but behaved similarly to the other cases.

The amplitude of the tremors of the first kind observed in a rainy season was abnormally great as compared with that of the tremors of the second kind, and the activity of the volcano also increased slightly in the same season. These facts are to be considered as due to the effect of water poured or sunk into the magmatic reservoir from the crater or its neighbourhood, exciting the internal eruptions generating the tremors to greater frequency and intensity. Ashes and dusts taken together with water into the vent will produce the same effect, inducing a certain load on gases and vapours not free to escape. The micro-tremors of the third kind changed, as shown in Fig. 11, in almost a similar way to those of the first kind did. The amplitude of the micro-tremors of the three kinds, especially those of the second kind, changed in a period of, roughly, 27 days, the synodic period of the sun's rotation, and this is probably due to the effects of certain meteorological conditions upon the volcano. The daily mean values of atmospheric pressure observed in the whole active period of the volcano were as shown in Fig. 11. The relations of eruptions of the volcano to the variation in atmospheric pressure are not apparent from the daily mean values of the latter, but there seems some tendency for the first eruption of an eruptions-group to occur more frequently at the time of low pressure than at the time of high pressure. This observed result seems to be due to a relief of load owing to the low atmospheric pressure.

17. Micro-tremors and minor fluctuations of the eruptions-activity

Observations of the micro-tremors at our summit station of Hondô were made three times during the last active period of the volcano, and two typical examples worthy of notice, showing the relation between the variation of the amplitudes of the micro-tremors and that of the volcanic activity in a short interval of less than an hour, will be described below. The observed amplitudes of the tremors of the third kind, the eruption-earthquakes, and the barometric disturbances during 17^{h}–20^{h} on March 4, 1933, on the evening of which day the violent eruptions of the Second Crater took place, were as shown in Fig. 23. At that time the micro-tremors of the third kind were most

Fig. 23

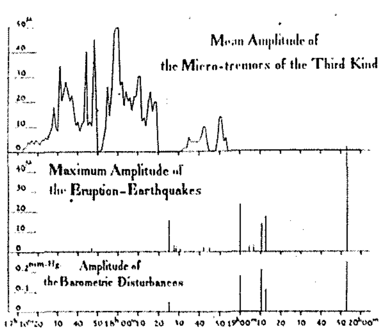
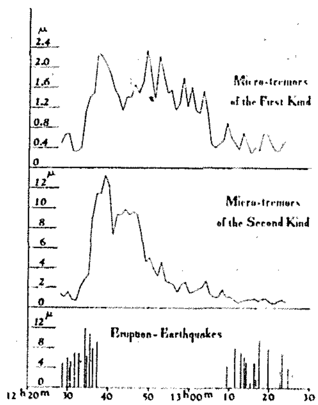


Fig. 24



predominantly recorded, those of the other two kinds being utterly masked by them. After a strong eruption of the First Crater at $17^{h}01^{m}42^{s}$, the same crater ceased to erupt, only emitting black smoke, and the Second Crater was also in repose, emitting only slight vapour at times. The micro-tremors of the third kind began to be recorded at $17^{h}13^{m}$, and increasing rapidly in amplitude, soon attained a maximum value of ca. 30 microns about 20 minutes after their first appearance on the record, as shown in Fig. 23. At $17^{h}45^{m}17^{s}$ they rapidly decreased in amplitude to only ca. 5μ, and it was at $17^{h}47^{m}30^{s}$ that slight fragments of rock began to mingle with the black smoke emitted from the First Crater. The amplitude of the tremors again increased to ca. 50μ at $17^{h}59^{m}$ and soon decreased to 20μ, keeping the lower value for about 20 minutes. At $18^{h}19^{m}$ it suddenly decreased to such a small value that it completely disappeared from the record, and about 6 minutes after that a strong eruption of the Second Crater suddenly occurred, large lava blocks being ejected to a horizontal distance of ca. 300 m., and several sight-seers standing near were injured by the ejectamenta. After the eruption the same crater very frequently, or rather continuously, ejected small fragments of rock to a height of ca. 100 m. till $18^h30^m30^s$, after which time both craters again became quiet. At 18^h33^m the micro-tremors reappeared on the record, their amplitude sometimes reaching ca. 7μ, but they soon went out of sight again from the record at 18^h54^m. About 6 minutes later a violent eruption of the Second Crater took place with loud detonations and after this eruptions of the same crater were frequently repeated. Of these, the eruption at $19^h52^m40^s$ was the most severe, many large lava blocks being ejected to a horizontal distance of ca. 700 m. Fig. 24 shows recorded amplitudes of the micro-tremors of the first and the second kind and those of the eruption-earthquakes observed at the Hondô Observing Room during 12^h28^m–13^h24^m on Aug. 17, 1933, on which day the eruptions of the First Crater were frequently repeated at intervals of about one or half an hour, fragments of rock being ejected to a height of ca. 150 m. above the mouth of the vent. As shown in Fig. 24 the eruptions occurred at $12^h28^m43^s$ lasted till $12^h37^m14^s$, and then ceased. The amplitude of the micro-tremors of the first kind began to increase rapidly from 12^h34^m and after keeping nearly the same value of ca. 1.5μ for half an hour, again rapidly decreased to a value of ca. 0.5μ at 13^h05^m, while those of the tremors of the second kind increased from 10.6μ at 12^h32^m to 11μ at 12^h37^m, soon decreasing to 9μ at 12^h41^m and after keeping the lower value for 7 minutes, they began to decrease rapidly. At $13^h09^m37^s$ the first eruption of the next group suddenly took place and then eruptions were frequently repeated for 15 minutes. Thus in a stage of surface eruptions of an active period, there are cases in which amplitudes of the tremors of the first and second kinds have already decreased and eruptions occur, not in a continuous series but intermittently, 2 or 3 groups per hour. The above examples show that, in such cases, the changes in amplitude of tremors of the first and the second kind, corresponding to the succession of groups of eruptions, occur in a manner very similar to their occurrence in cases where the factors of time and magnitude are on a much larger scale, as frequently described in the previous paragraphs, and that, when eruptions are on a small enough scale to be considered as having their origin at a shallower place in the magmatic reservoir or somewhere in the vent, the tremors of the third kind that come into play have to be considered in place of the tremors of the first kind considered in the case of eruption on a larger scale. The above result is a very interest, and may be summarized in the form: Whatever may be the nature of the eruption, whether continuous or intermittent, and whatever the scale of time or magnitude, the fluctuations in amplitude of the micro-tremors corresponding to the fluctuations in volcanic activity occur in quite similar ways; the micro-tremors begin to increase in amplitude, reach a maximum, and begin to decrease, and then eruptions take place, the meanings of the terms 'micro-tremors' and 'eruptions' must be properly interpreted according to the particular nature of the case.

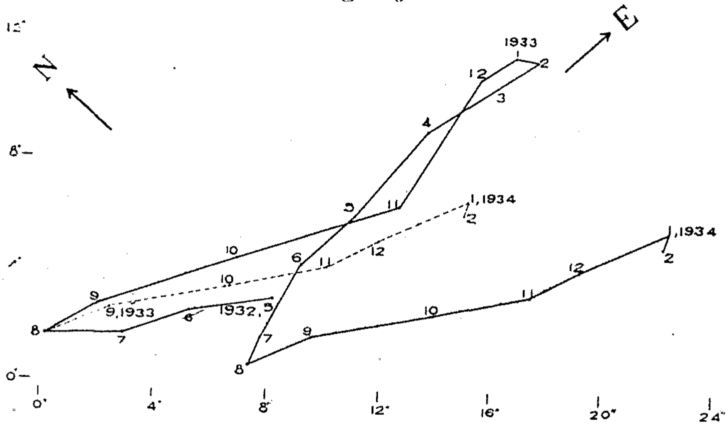
18. Tilt of the earth's crust observed in the active period of the volcano

The horizontal pendulum apparatus of Rebeur's type made by Repsold, which was used by Prof. T. Shida to observe the change of plumb line at our Kamigamo Geophysical Observatory in 1910–1911, was provisionally set up in an underground room of our Aso Volcanological Laboratory in May 1932, at which place the daily tilts due to the complicated effects of solar radiation were proved to be minimum; for the specially constructed underground observing room of ca. 40 m. depth in volcanic rock was not yet finished at that time. The pendulum No. 1, the SE comp., records the variation of the direction of plumb line in azimuth E42°S–W42°N and the other one, No. 2, the NE comp., that in azimuth N42°E–S42°W.

The daily variation of temperature of the pendulum room was not small though not exceeding 0.1°C, and the daily variation of zero-point displacement calculated as tilt was 0.″7 for the SE component and 0.″3 for the NE component; the annual variation of tilt in the same meaning was ca. 12″ for the SE component and ca. 5″ for the NE component. The changes of the daily mean position of zero-point, calculated as tilt of the ground in the period under consideration, are as shown in Fig. 11 together with the observed results of the volcanic micro-tremors, volcanic earthquakes, atmospheric pressure, air temperature, and amounts of precipitation. All the eruption-groups, 20 in all, started in the periods of rapid increase of the east-downward tilt of the earth's crust, or speaking more accurately, the east-upward tilt attained a maximum a few days before the eruption and then the sense of tilt was reversed down towards the east, and at this latter time the first eruption took place. So long as the eruption continued, the east-downward tilt increased, and when the eruption ceased the earth's crust returned gradually to its mean position. For the case of the great eruption-group of Feb. 24—March 4, 1933, a more detailed study has already been given as a typical example in the preceding pages (see Fig. 15). The apparent variation of tilt due to the variation in meteorological conditions is generally very great when observed near the surface of the ground, but the above described variations of tilt cannot be considered as mainly due to a change in the meteorological conditions, for the former nearly always took the same direction in all 20 cases, while the latter did not, as shown in Fig. 11. Accordingly the variation of tilt of the earth's crust observed at the times of eruptions above described should be considered as being mainly due to the variation of internal conditions of the volcano, as is to be expected from the observation of micro-tremors; the above result may be interpreted as follows :—

During the stage of gradual accumulation of mass and energy in the vicinity below the vent, the earth's crust in the neighbourhood of the vent is gradually upheaved, but when the rate of drilling a way to eruption increases, the effect will be the same as occurred in yielding, and the rate of upheaval of the ground will decrease, and then reach a maximum, and the ground will begin to be depressed before the eruption is ready to start. During the time of repeated eruptions the earth's crust under consideration will be more and more depressed owing to the escape of mass and energy from the vent, and will finally come to its mean position when the volcano is in repose. Proceeding a step further and considering things from a broader aspect, the mass and energy *accumulating in the vicinity* beneath the crater during the entire active period of the volcano, should have caused an upheaval of the earth's crust in the neighbourhood of the crater from the position of the period of repose, the only differences being of time scale and the amount of tilt. The monthly mean values of the ground observed are vectorially shown in Fig. 25, in which the positive sense of the vector corresponds to the upward tilt of the ground. As will be seen from the figure the tilt of the ground observed turned rapidly to east-upward in Dec. 1932, deviating greatly from its path of annual variation, and attained a maximum in Jan. and Feb. of the following

Fig. 25



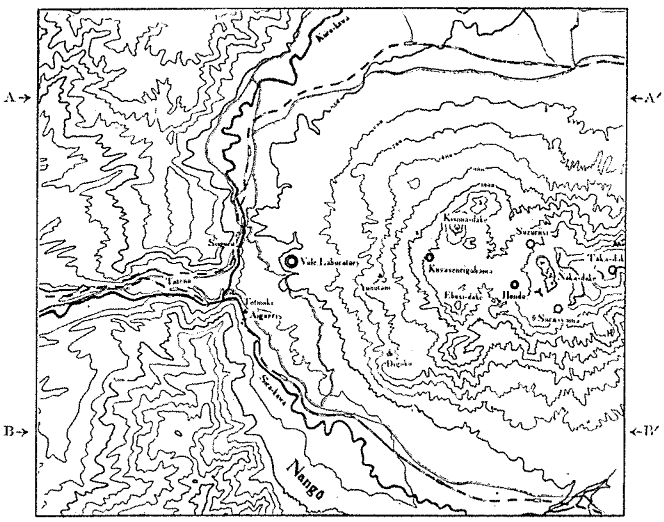
year, corresponding to the increase in the activity of the valcano in Dec. 1932. In January and the beginning of February of the following year great numbers of volcanic earthquakes occurred in the neighbourhood of the crater as already described, while the surface eruptions of the volcano were relatively quiet, the maximum eruptive activity being from the end of Feb. to the beginning of March of the same year. Soon after the volcano went into the declining stage of its activity in March, the tilt of the ground was reversed to west-upwards, and in the summer of the same year the amount due to volcanic activity was virtually nothing, a permanent zero-displacement of ca. $7''$ of the pendulum for the SE component being due to other causes.

19. Volcanic earthquakes

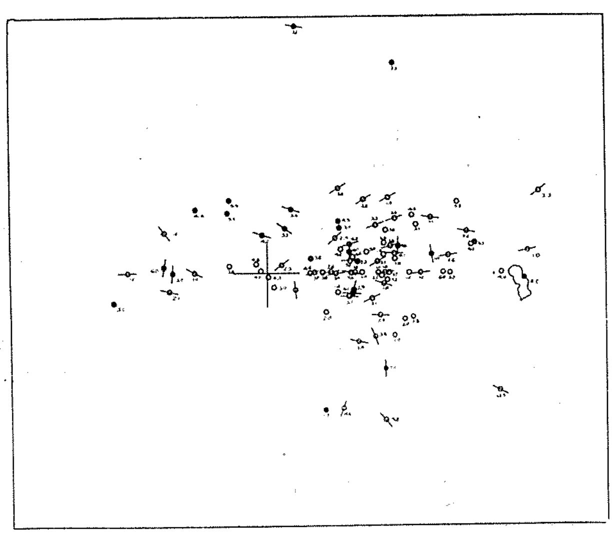
The volcanic earthquakes observed at our Volcanological Laboratory during the last mentioned active period of the volcano were about 1,500 in number, and those with the initial motions undoubtedly read from the Wiechert seismograms will be studied in this paragraph. The positions of their epicentres and depths of origin were roughly determined are shown in Figs. 26 and 27 respectively. The epicentral distance $\triangle$ was calculated from the formula, $\triangle$ km. $=4.5\times$(duration of preliminary tremors), obtained from the observed velocities of propagation of the P (1.25 km./sec.) and the S (0.98 km./sec.) waves in the district excluding the immediate vicinity within about 1 km. of the crater. The real emergent angles observed at the Laboratory were almost always greater than 40°, being independent of the durations of preliminary tremors, and moreover those of the earthquakes occurring in the immediate vicinity of the crater were about 50°, in spite of their shallow origins determined to be about 1 km. from the observations made at the Hondô Observing Room, using the results of observations of eruption-earthquakes. To satisfy these observed facts a discontinuous surface at a depth of 1 km. is assumed, the uniform velocity of propagation of the P wave (V_1) in the upper layer being smaller than that (V_2) in the lower medium, so to make $V_1/V_2=\sin 40°=0.64$, and on this assumption the positions of epicentres and depths of origins were roughly determined from the observed azimuths, emergent angles and durations of the preliminary tremors at our

Fig. 26. Map of a part of the Volcano Aso, showing region of earthquakes (a) and distribution of the epicentres and the directions of the cracks in the period of (b) Dec. 28, 1932—Jan. 28, 1933, (c) Jan. 29-Feb. 28, 1933, and (d) March 1—Dec. 31, 1933. (○ : Pull, ● : Push, Annexed figures: Depth in km., Cross: Position of the Laboratory).

(a)

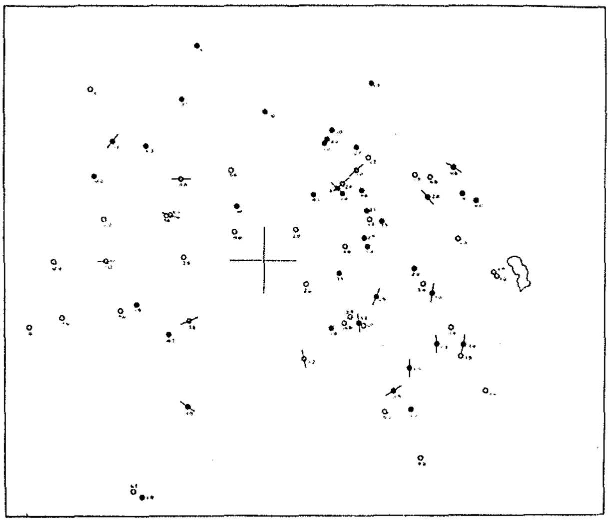


(b)

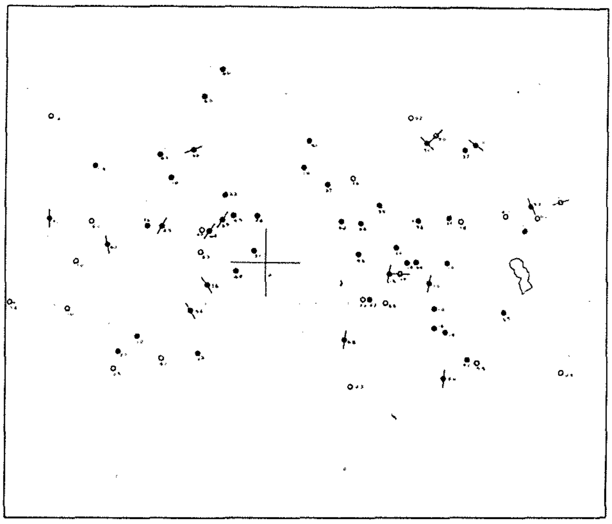


Figs. 26

(c)



(d)



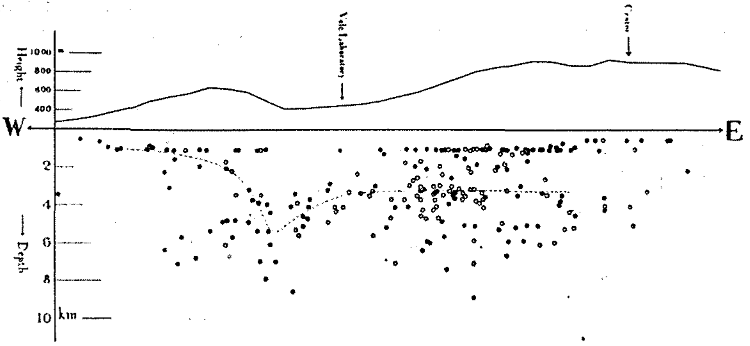
Laboratory. As will be seen in Fig. 26 (b) the greater number of volcanic earthquakes observed for one month from Dec. 28, 1932 to Jan. 28, 1933, during which period a gradual upheaval of the earth's crust in the neighbourhood of the crater occurred, took place in the western slopes of Kisimadake, Kusasenrigahama, Ebosi-dake and along the Tateno barranco, and the number of the earthquakes (○) with initial motions in pull-phase was about twice as many as that of the earthquakes (●) having initial motions in the push-phase. But, as shown in Fig. 26 (c), the origins of earthquakes observed for one month, e. g. Jan. 29—Feb. 28, 1933, in which period the described upheaval of the crust remained at its maximum value, were distributed sporadically in the district extending over to the west of the crater, and the earthquakes (○) with initial motions in pull-phase were nearly the same in number as those

(●) with initial motions in push-phase, while earthquakes observed during 10 months of subsidence from March 1—Dec. 31, 1933 took place mainly in the western and northern slopes of Naka-dake, Kisima-dake, and Ebosi-dake and along the internal side of the western part of the old great caldera as shown in Fig. 26 (d). In this latter period the number of earthquakes (○) having initial motions in pull-phase was about half that of the earthquakes (●) with initial motion in push-phase. As described above, almost all these volcanic earthquakes occurred in the district west but not east of the crater, and when their intensities are considered, this cannot simply be attributed to errors in position of epicentres calculated from the observations at a single station, the Laboratory, 7.5 km. west of the craters. A certain number of these earthquakes was recorded by Wiechert instruments even at Beppu, ca. 60 km. NE of the volcano. Accordingly the above fact makes us consider that the active magma of the volcano lies at present mainly in the district west of the present active craters, which is in harmony with the result of considerations of the district from the geological and topographical points of view. There are two main rupture lines running in the E–W and the N–S directions and crossing each other somewhere near the explosion crater of Kusasenriga-hama. They were probably formed after the formation of the great caldera as a result of subsidence. In the E–W line, the four cones of Neko-dake, Taka-dake, Naka-dake, and Ebosi-dake, counted from the east, stand in a row, and the Tateno barranco together with the hot springs Yunotani, Totinoki lie in the western extension of the line, while in the N–S line, there stand Okamado-yama, Ebosi-dake, Kisima-dake, and Ôzyô-dake in order from the south. The hot springs, Digoku, Tarutama, Yunotani, Utinomaki, and the beautiful tiny parasitic cone of Komeduka lie along the western side of this line. The two cones of Neko-dake and Taka-dake, standing in the east of the present active craters of Naka-dake were formed and probably ceased to be active in an earlier age than the three cones of Kisima-dake, Ôzyô-dake, and Komeduka, standing to the west of Naka-dake. The above fact together with the fact that the hot springs are only in the western district of Naka-dake makes us consider that the active energy of the volcano had its seat in the district extending over to the west of Naka-dake from early times.

Mechanisms of occurrence of earthquakes are generally difficult to determine from observations at a single observatory. But if it is assumed that the mechanism of occurrence of an earthquake is something like Shida's crack type in a vertical plane, as was observed to be the case for eruption-earthquakes at the volcano as well as almost all earthquakes of shallow origin in Japan, we can roughly determine the direction of crack of an earthquake from the observed initial motions of the P and the S waves at a single station, taking into consideration the effect on their amplitudes of refraction and reflection of seismic waves at the free and the internal discontinuous surfaces. On this assumption the directions of crack of the volcanic earthquakes under consideration were calculated for those cases in which the initial motions of the P and S waves had been accurately recorded, and they are shown in Figs. 26 (b, c, d). As will be seen in the figures the cracks of volcanic earthquakes observed during the period of upheaval of the crust near the crater were mainly in the E–W direction, and those of the earthquakes observed during the time of subsidence mainly in the N–S direction, while for the time of transition from the former to the latter their directions were mixed, both of the E–W and the N–S directions being nearly the same in number. These facts, when considered with the tilting of the upper crust during the period under consideration, make us consider that the direction of the crack caused by the upward mass movement or the upheaval of the upper crust due to increasing pressure, is at right angles to that of the crack caused by the downward mass movement or the subsidence of the earth's crust due to relief of pressure.

The significance of the frequent occurrence of the volcanic earthquakes with repect to the volcanic activity has already been discussed in the preceding pages, and it is in satisfactory agreement with the distribution of the directions of crack of earthquakes with respect to time and space as described above. The calculated depths of the observed earthquakes are shown in Figs. 26 (b, c, d) and Fig. 27, in which they are projected on a vertical plane in the E–W direction. In mountain regions both outside and inside the great caldera the distribution of the depths of earthquakes was almost uniform within a range from 0.5 to ca. 6 km., but in valleys, or speaking more accurately, along the internal cliff of the western part of the old caldera, they were about 3 km. deeper in mean than those in the former regions. This fact together with the fact that only a few earthquakes occurred in the valleys of Aso and Nangô are very interesting in connection with the formation of the great caldera.

Fig. 27 Depths of the volcanic earthquakes and mean height above sea-level of the region AA′BB′ of Fig. 26 (a), projected on a vertical plane in the E-W direction.



From the results of the above described studies on the eruptions of the volcano, we may conclude that volcanic eruption in general may be a single eruption of any degree of violence or a series of eruptions repeated over any period of time taken as a whole and is always foretold by micro-tremors, and sometimes by earthquakes in addition, and the tilting of the ground near the volcano gives some indications of eruptions also, which is quite in harmony with the conceptions which guided our present study; and it is not difficult to give a forecast of the commencement of an active period of the volcano as well as of its intensity, and even for the commencement of an eruption-group in an active period, if it is constantly observed with micro-seismometers and tiltmeters. There are some other interesting problems concerning the mechanism of volcanic activity, not conclusively studied in the present paper, which is only micro-seismometric and rather preliminary, and to come to any further conclusion the study must be extended to other branches of geophysics.

Hoping that this study may be undertaken, I conclude the present paper with my best thanks to Prof. Toshi Shida for his kind suggestions and encouragement in the work and to Mr. H. Hayashi, the Assistant, to whose diligence the success of this and other observatory work is largely due.

Errata

In the preceding paper "Volcanic Micro-Tremors and Eruption-Earthquakes" (These Memoirs A. 18 pp. 255–293).

p. 255, line 10, *for* "have not been" *read* "have been."

p. 255, line 28, *for* "Mathematico-Physical" *read* "Physico-Mathematical."

p. 256, line 19, *for* "vetical" *read* "vertical."

p. 257, line 24, *for* "Cardan springs" *read* "springs."

p. 267, line 3, *for* "α" *read* "$1/\alpha$."

p. 258, line 27, *after* "instead" *introduce* "of."

p. 275, line 3, *after* "1 min" *introduce* ".".

p. 288, line 6, *for* "is" *read* "are".

Plate II, line 5, *for* "1933" *read* "1932".

Notations in the following tables;

A_1, A_2, A_3: Mean amplitude of the tremors of the first, the second and the third kind respectively.

T_1, T_2: Mean period of the tremors of the first and the second kind respectively.

F_2: Frequency of occurrence per hour of the tremors of the second kind.

A: Ashy smoke emission. B: Brown smoke emission.

C: Black smoke emission. V: Vapour emission.

R: Rumblings were heard. D: Ash-fall.

E: Explosive eruptions occurred, red-hot fragments of rock being ejected.

P: New vent formed. $E_{(I),\ (II)}$: Eruptions of the First and Second Crater respectively. w: weakly or feebly. s: strongly or heavily. t: intermittently.

Example; sC_{1000}. $E_{(I)}{}^{0.2}_{100d}$, 9^h. Rt. means that" Large quantities of black smoke were continuously emitted to a height of ca. 1000 m. above the crater rim and explosive eruptions of the First Crater occurred at about 9^h, red-hot fragments of rock of about 0.2kg. weight being ejected to a horizontal distance of ca. 100 m. Rumblings were heard at times."

Table 1

1929	June		July		August		September		October		November	
Date	A_1	Remarks	A_1	Remarks	A_1	Remarks	A_1	Remarks	A_1	Remarks	A_1	Remarks
	μ		μ		μ		μ		μ		μ	
1	4.8	wA	2.8	sD	3.5	wC	3.8	A.R	1.5	A.wD	1.9	wVt
2	3.8	wA	2.8		4.0	sC.D	4.2		1.6	A.wD	1.7	wA
3	3.5	A.R	2.1	A	3.9	C.D.Rt. $E^{0.2}$	4.5	wA	1.7	A	1.9	wA
4	3.6	sA	2.1		4.9	C.D	3.9	wA	1.6	A	2.1	wC-sC
5	4.3	A	2.8		3.7	C.D.Rt	3.5	wA	1.3	A	1.6	sC.R
6	3.5		2.8		4.7	R	3.9	wA	1.6	sA.D	2.3	sC. $E^{4.0}_{300d}$
7	3.4	A	2.2		4.0	C.D	3.4	A.R	1.8	wA	1.6	wE
8	3.8	A	2.0	sC_{800}	4.0	C.D.R	3.6	sA.R	1.7	sA.D	0.8	wV
9	3.0	V.R	2.3	At	4.0	C.D.R	3.6		1.6	A	0.6	wV
10	4.6	V	2.3	sC.sD	3.1	C.D.R	4.7		1.9	A.R	1.1	
11	3.1		2.3	sC.sD	2.4	C.D.R	3.8	C.D	1.8	A.R	0.9	wV
12	3.4		2.3	sC.sD	2.6	C.sR	3.3	C.D	1.8	sA.D.R	0.6	wV
13	3.6	sB	2.9	sC.sD	2.2	V.R	3.8	sC.D	1.1	wA	0.6	wVt
14	2.9	sB.D	2.8	sC.D	2.4	V.R	4.3	$E^{0.2}$,9^h	1.3	A	0.6	wVt
15	2.9	sB	3.4	C.D	2.3		3.5	V	1.7	A	0.7	Vt
16	3.1	sB	3.2	C.D	2.7	V	2.7	wV	1.3	A	0.6	wV
17	3.0	sB	3.2	C.D	2.4	V	3.0	sA.D	1.5	A	0.5	wV
18	3.0		2.8	C.D	2.9		2.9	A	1.6	sA.D	0.7	wV
19	2.6	sB	3.7	C.D	4.5		3.6	C	1.2	sA.D	0.6	wV
20	3.4	A.D	4.4		2.6		3.4	C	1.2	sA.D	0.5	wV
21	2.8		3.5		2.7		3.6	C	1.4	sA.D	0.5	wV
22	2.3	wA-sC	3.4	wB	2.6		2.8	sC.D	1.3	C.D	0.8	wV
23	2.3	sD.$E^{0.2}$	3.8	wC	2.9	sA.R	2.1	sC.D	1.6	C.sD-wC	0.8	wV
24	1.5	wA	3.2	C.D	2.6	wA.R	1.2	C.R	2.1		0.5	wV
25	1.6		3.3	sC.sD	2.0	V	1.0	C	1.7	D	0.7	wV
26	2.6	A	3.0	C.sD	2.8		1.8			D	0.7	wV
27	2.0		3.3		2.3		1.3	wC		wV	0.8	wVt
28	1.8	A	3.4	wC	2.4	wA.wR	1.1	wC	1.2	sC.D	0.7	wVt
29	2.6	A.D	3.2	sC_{1800}.sD	2.3	wA.wR	1.3		1.2	wV	0.6	
30	1.8	R	3.6	sC.sD.E	3.0	wA.wR	1.4	C.D	1.3	wV	0.4	
31			4.1	C.D	2.6				1.6			

Table 2

Aug. 30, 1930

Hour	A_1	T_1	A_2	T_2	F_2
h	μ	sec.	μ	sec.	
0	0.01	1.3			0
1	.02	1.2			0
2	.13	1.2			0
3	.13	1.1			0
4	.06	1.1			0
5	.05	1.2			0
6	.07	1.1			0
7	.08	1.2			0
8	.01				0
9	.03				0
10	.16	1.2			0
11	.10	1.3			0
12	.13	1.2			0
13	.16	1.2			0
14	.10	1.2			0
15	.05	1.2			0
16	.47	1.2	3.3	4.0	6
17	.43	1.2	4.7	3.7	4
18	.28	1.2	4.9	3.9	5
19	.34	1.1	4.3	4.2	6
20	.65	1.1	4.3	4.0	4
21	.37	1.1	4.6	3.9	2
22	.58	1.2			
23	.37	1.2			

Sept. 1.

Hour	A_1	T_1	A_2	T_2	F_2
h	μ	sec.	μ	sec.	
0	0.93	1.3	5.8	3.5	9
1	.34	1.3	5.8	3.8	12
2	.51	1.3	6.7	3.7	
3	.49	1.3			
4	.44	1.4			
5	.64	1.4			
6	.48	1.4			
7			5.0		9
8			5.3	3.8	6
9			5.5		8
10			5.9	3.5	12
11			6.0	3.7	16
12			5.8	3.6	16
13	.71	1.3	6.1	3.6	12
14					
15					
16					
17	.83	1.2	8.3	4.0	6
18	.96	1.2	7.3	3.6	16
19	.86	1.2	5.6	3.6	12
20	.63	1.2	5.1	3.7	12
21	.92	1.2	4.7	3.6	12
22	.91	1.3	4.6	3.5	11
23	.59	1.3	4.4	3.6	9

Sept. 3.

Hour	A_1	T_1	A_2	T_2	F_2
h	μ	sec.	μ	sec.	
0	1.80	1.0	5.3	3.8	13
1	0.88	1.0	4.9	3.7	12
2	1.45	1.0	4.7	3.8	10
3	1.23	1.0	4.5	3.7	13
4	1.45	1.0	4.9	3.7	10
5	1.85	1.1	5.0	3.6	13
6	1.43	1.1	5.0		
7	1.58	1.1	5.0		
8	1.30	1.1	5.2	3.7	16
9	1.90	1.1	5.0	3.6	12
10	1.93	1.1	4.9	3.4	11
11	2.25	1.1	5.1	3.5	9
12	2.75	1.1	5.6		
13	2.65	1.0	5.8	3.8	13
14	1.53	1.1	6.1	3.8	12
15	1.68	1.1	6.5	3.8	8
16	2.00	1.1	6.4	4.0	11
17	2.80	1.1	6.3	3.7	9
18	3.00	1.2	5.9		
19	3.00	1.2	5.6	3.8	13
20	2.55	1.1	6.0	3.9	6
21	3.30	1.1	5.5	3.8	13
22	2.35	1.0	5.7	3.9	8
23	4.08	1.0	5.7	3.9	12

Aug. 31.

Hour	A_2	T_1	A_2	T_2	F_2
h	μ	sec.	μ	sec.	
0	0.17	1.2			
1	.93	1.3			
2	.58	1.3			
3	.64	1.3			
4	.48	1.3			
5	.60	1.3			
6	.69	1.3			
7	.30	1.3	3.9	4.0	14
8	.91	1.3	3.7	3.7	16
9	.53	1.3	3.6	3.7	15
10	.62	1.4	3.4	3.9	11
11	.63	1.4	3.2	3.8	16
12	.47	1.4	3.6	3.9	15
13	.81	1.4	4.1	3.9	11
14	.66	1.4	4.3	3.9	9
15	.96	1.4	4.3	3.9	11
16	.71	1.5	4.8	3.8	17
17	.70	1.5	5.1	3.7	13
18	.80	1.4	5.4	3.8	15
19	.52	1.4	5.6	3.8	9
20	.34	1.4	5.4	3.8	5
21	.63	1.3	5.1	3.8	12
22	.31	1.3	4.6	3.9	15
23	.53	1.3	4.5	3.5	15

Sept. 2.

Hour	A_1	T_1	A_2	T_2	F_2
h	μ	sec.	μ	sec.	
0	0.61	1.2	5.0	3.4	15
1	1.05	1.2	5.3		
2	1.02	1.2	5.6	3.7	15
3	1.01	1.2	6.4	3.2	8
4	0.78	1.2	6.3	3.7	8
5	0.98	1.2	5.4	3.7	8
6	0.98	1.2	4.7	3.5	12
7	1.27	1.2	4.7	3.6	14
8	0.93	1.2	5.5	3.7	19
9	0.98	1.2	5.4	3.7	11
10	1.07	1.2	5.1	3.6	17
11	0.73	1.2	4.8	3.6	17
12	0.79	1.2	4.9		
13	0.88	1.2	5.4	3.6	12
14	0.98	1.1	5.1	3.7	11
15	1.15	1.1	4.8	3.5	14
16	1.00	1.1	4.7	3.8	13
17	1.07	1.1	5.1	3.7	13
18	1.33	1.1	5.7	3.6	12
19	1.33	1.1	5.9	3.8	10
20	1.20	1.1	6.1	3.6	11
21	1.00	1.0	5.6	3.6	13
22	1.25	1.1	5.4	3.6	13
23	1.03	1.0	5.2	3.6	14

Sept. 4.

Hour	A_1	T_1	A_2	T_2	F_2
h	μ	sec.	μ	sec.	
0	4.05	1.0	6.0	4.0	10
1	2.53	1.0	5.9	3.7	6
2	3.30	1.0	5.1	4.0	4
3	3.80	1.0	4.9	3.4	7
4	3.05	1.0	5.1	4.0	3
5	2.90	1.0	5.0	3.9	4
6	2.48	1.0	4.4	4.0	6
7	3.40	1.0	3.7		4
8	2.95	1.0	3.7	4.0	6
9	3.30	1.0	3.6		
10	3.25	1.0	3.4	3.8	8
11	3.05	1.0	3.6	4.0	14
12	3.25	1.0	3.5		
13	3.05	1.0	3.6		
14	3.35	1.0	3.5	4.0	14
15	3.40	1.0	3.6	3.9	16
16	3.00	1.0	3.6	3.9	15
17	3.10	1.0	3.5	3.9	18
18	3.30	1.0	3.3	3.9	17
19	2.50	1.0	3.4	4.0	11
20	2.60	1.0	3.2	4.0	13
21	1.95	1.0	3.4		11
22	2.55	1.0	3.3		7
23	2.10	1.0	3.6		14

	Sept. 5th.				6th.				7th.	8th.	9th.	10th.	11th.
Hour	A_1	T_1	A_2	F_2	A_1	T_1	A_2	F_2	A_1	A_1	A_1	A_1	A_1
h	μ	sec.	μ		μ	sec.	μ		μ	μ	μ	μ	μ
0	2.25	1.0	3.5	12	1.95	1.0	2.9	18	1.15	1.15	0.90	0.42	0.39
1	2.55	1.0	3.5	9	2.10	1.0	3.2	6	1.55	1.25	.80	.45	.30
2	2.03	1.0	3.7	8	1.90	1.0	3.2	4	1.55	1.30	.90	.67	.34
3	2.35	1.0	3.5	11	1.95	1.0	3.3	6	1.55	1.10	.90	.58	.27
4	2.35	1.0	3.6	3	1.40	1.1	3.0	6	1.35	1.05	.75	.56	.27
5	2.20	1.0	3.5	9	1.75	1.0	2.7	6	1.15	1.10	.80	.54	.25
6	2.00	1.0	4.0	11	1.55	1.0	2.4	5	1.10	1.20	.95	.57	.24
7			3.8	7	1.30	1.0	2.0	4	1.30	0.95	.85	.44	.26
8	2.18	1.0	3.9	8	1.30	0.9	1.8	1	1.40	1.15	.85	.43	.28
9			3.7		1.45	0.9	1.4	2	1.20	1.05	.75	.39	.33
10			3.8	6			1.1	4	1.25	1.00	.70	.45	.27
11			3.6	11			1.4	1		0.80	.80	.35	.23
12			3.6	4			1.4	1	1.25	0.85	.85	.41	.25
13			3.6	7			2.4	2		0.90	.70	.32	.23
14	1.95	1.0	3.5	3	1.60	1.0	1.8	2	1.25	1.05	.54	.38	.29
15	1.95	1.0	4.1	7	1.80	1.0		0	1.30	0.95	.54	.42	.33
16	2.38	1.0	4.1	4	1.40	1.0	0.9	1	1.23	0.78	.56	.42	.33
17	2.25	1.0	4.4	6	1.80	1.0		0	1.65	1.03	.53	.42	.41
18	2.35	1.0	3.6	5	1.40	1.0		0	1.35	1.15	.56	.43	.28
19	1.90	1.0	3.6	5	1.55	1.0	0.3	1	1.25	1.25	.51	.37	.35
20	2.40	1.0	3.5	3	1.60	1.0		0	1.35	0.90	.43	.36	.38
21	2.10	1.0	2.9	3	1.50	1.0		0	1.25	1.20	.57	.41	.29
22	2.45	1.1	2.5	1	1.55	1.0		0	1.30	1.25	.62	.38	.35
23	2.30	1.1	2.5	3	1.60	1.0		0	1.15	0.90	.52	.36	.25

Table 4 (A)

1932 September

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	0.05			0.025	0	wV
2	.05				2	wV
3	.05				0	wV
4	.00				0	P, 11^h.wC.
5	.05	1.25	4.4	.082	0	C.D, 17^h.
6	.10	1.00	4.8	.056	0	wD
7	.10	1.61	5.0	.051	1	wD.R
8	.10			.041	1	D
9	.05	2.32	4.0	.057	0	
10	.15	1.43	4.0	.100	0	D
11	.15	1.61	4.8	.098	0	C
12	.05			.025	0	
13	.05			.015	0	
14	.05			.015	0	V
15	.05			.015	0	V
16	.05			.010	0	wV
17	.05			.030	0	V
18	.10			.030	0	
19	.10			.035	0	C_{1000}
20	.10	1.07	6.0	.030	0	
21	.05	1.43	5.0	.035	0	A
22	.05	1.79	6.5		0	
23	.00				0	
24	.05	1.61	4.2		0	A
25	.05	1.64	4.3		0	
26	.20	1.43	5.0	.020	0	wA
27	.10	1.89	4.4	.015	0	V
28	.15	1.78	5.9	.020	0	
29	.20	1.50	4.9	.015	0	A
30	.05	1.43	4.2		0	V

1932 October

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	0.20			0.015	0	A.wD
2	.10	1.07	5.0	.010	0	wV
3	.05				1	wA
4	.05			.010	0	wA
5	.25				1	wA
6	.00			.010	0	wV
7	.10				0	wV
8	.10			.010	0	wV
9	.10			.015	0	wA
10	.05			.010	0	wA
11	.05	1.43	4.3	.010	2	
12	.15	2.14	5.2	.010	1	A–C
13	.15	1.61	4.8	.010	0	wA
14	.10			.010	1	
15	.05			.010	0	
16	.05				0	
17	.05				4	V
18	.05				2	
19	.10				0	wA
20	.10	2.14	6.0		0	wA
21	.10	1.66	6.3		0	
22	.05	1.96	6.1		1	V
23	.15	2.18	6.3		0	A
24	.05	1.69	5.9		0	wA
25	.05	1.98	5.9		0	wA
26	.05	2.82	6.0		0	wC.wD
27	.15				0	A
28	.05				0	wA
29	.05				0	sA
30	.20				0	A
31	.20				0	V

1932 November

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	0.18				2	A
2	.14	2.43	5.9		0	wC
3	.14	2.61	5.9	0.010	0	wC
4	.17			.010	1	A
5	.11	3.00	5.9		0	A
6	.13	3.86	6.0		0	
7	.01			.020	0	
8	.05				0	A.P
9	.07	2.75	5.4		0	V
10	.16	4.07	6.2	.020	0	A
11	.13	3.64	6.2		0	wA
12	.12				0	wA
13	.08			.025	0	A
14	.03				1	
15	.08				0	A
16	.03			.040	0	
17	.42				0	A
18	.40	4.30	6.0		0	sV
19	.28	5.30	5.5	.040	0	sC.wE^{100}
20	.32	4.57	5.5		0	
21	.17	5.80	5.8		0	A
22	.26	4.92	5.7	.040	0	A
23	.19	4.92	5.6		0	A.E^{100}
24	.28	5.82	5.5		0	wA.E^{100}
25	.22	5.65	5.6	.065	0	P, 7^h.sR.E^{200}
26	.15	4.92	5.5		0	sR.E^{200}
27	.41	5.30	5.6		0	sC.sR
28	.42	5.82	5.7	.062	0	A.sR
29	.31	5.63	5.7		0	A.sR
30	.30	5.13	5.6		0	sA.sR

1932 December

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	0.35	5.30	5.8		0	A.sR
2	.31	5.48	5.7		0	Do.
3	.56	5.11	5.6	0.060	0	sC
4	.66	4.82	5.8		0	sC.sD
5	.72	5.57	5.5		0	
6	.78	5.90	5.4	.125	0	
7	.64	6.60			0	sC.E_{300}, 14^h.E_{100}
8	.80	7.20			0	
9	.90	6.12		.115	0	C.E_{100}
10	1.00	6.49		.145	0	sC.E_{100}
11	1.17	5.70		.131	0	sC.R.E_{150}
12	1.67	6.25			0	Do.
13	1.54			.168	1	Do.
14	1.30	5.70		.173	0	Do.
15	1.76	5.70		.173	0	sC.sR.E_{300}
16	1.61	6.08		.178	0	Do.
17	1.76	6.13		.172	0	s$E^{2000}{}_{300d}$
18	1.43	6.90		.211	0	Do.
19	2.04	7.49		.215	0	Do.
20	1.84	7.64		.243	0	E_{200d}
21	1.77	6.71		.217	0	sR.E
22	1.87	6.83			0	Do.
23	1.74	7.11		.223	0	Do.
24	1.61	7.62			0	
25	1.86	7.92		.238	5	Do.
26	2.14	7.22			3	sRt.E
27	1.55	6.39		.250	0	wR.E
28	1.91	6.12			1	
29	1.66	5.11		.257	23	Rt.E
30	1.72	4.45	4.0		3	
31	1.64	4.21	4.2	.307	3	

1933 January

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	1.68	4.00	4.2		2	C.sR.wEt.
2	1.22	3.55	4.6		1	Do.
3	1.72	4.05	4.1		2	Do.
4	1.25	2.85	4.0	0.234	12	
5	1.16	3.00	4.0		9	sC.R
6	1.42	3.15	4.0	.165	8	sC
7	1.19	2.85	4.0	.182	19	Do.
8	1.19	2.75	4.0	.175	25	
9	1.16	3.55	4.0	.171	21	C
10	0.63	3.05	4.3	.143	17	Do.
11	.69	3.15	4.2	.141	49	Do.
12	.86	3.85	4.3		12	
13	.96	3.25	4.3	.121	16	
14	1.58	3.75	4.2		$89+x$	
15	0.71	2.65	4.5		15	A
16	0.71	2.45	4.3		11	Do.
17	1.86	5.00	4.6		17	Do.
18	0.55	5.35	4.2	.115	24	sA
19	1.52	6.20	4.8		10	Do.
20	1.26	6.40	4.2	.179	10	sV.wR
21	0.43	4.15	4.3		14	A
22	.67	2.70	4.2	.094	17	A
23	.79	6.70	4.4	.132	10	sA
24	.98	5.75	4.0	.092	21	
25	.63	5.15	4.2		15	
26	.71				24	
27	.37	3.00	4.5		25	E, 14^h
28	.40	4.05	4.5	.088	12	C.E^{500}
29	.58	4.20	4.4	.091	15	Do.
30	1.03	3.40	4.2	.130	6	Do.
31	2.57	7.45	4.8	.502	31	Do.

1933 February

Date	A_1	A_2	T_2	A_3	No of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	2.85	10.75	4.8	0.595	11	
2	2.75	11.85	4.7	.520	31	
3	3.25	11.95	4.2	.510	34	
4	3.20	12.05	4.2	.507	32	C.EsR
5	3.15	12.50	4.4	.650	19	Do.
6	3.10	12.05	4.2		41	Do.
7	2.75	13.80	4.2	.480	49	
8	3.05	12.85	4.4	.497	11	wC.wR
9	2.70	12.85	4.3		33	Do.
10	2.50	9.80	4.2		20	Do.
11	2.24	8.35	4.2	.452	14	$P_{(II)}$.sV.wR
12	2.40	8.05	4.6	.385	36	
13	2.30	7.85	4.5	.400	14	sR
14	3.55	11.20	4.4	.685	4	C
15	4.25	15.00	4.8	.645	11	$P_{(II)}$, 19^h.sC
16	3.25	14.90	4.2	.615	5	A
17	3.31	13.35	4.6	.620	11	V
18	3.28	10.05	4.4	.720	13	
19	3.42	10.40	5.0	.820	4	V.R
20	3.74	12.40	4.7	.807	13	sA.sR
21	3.50	9.10	4.8	.630	13	
22	2.71	8.60	4.5	.630	17	
23	3.00	7.55	5.0	.600	9	E_{100}
24	30.00	48.55	4.7	3.750	3	$E_{(II)}$, 6^h–s$E_{(II)}$
25	32.50	37.50	5.0	5.550	6	$E_{(I),(II)}$. ${}^{3000}_{1000d}$
26	27.50	35.05	4.9	4.320	1	Do.
27	17.40	29.25	5.0	3.450	2	Do.
28	13.00	21.05	4.8	3.150	2	Do.

1933 March

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	19.50	19.05	5.0	3.570	2	s$E_{(I),(II)}$, ${}^{1000}_{800d}$
2	17.00	22.90	4.6	1.980	2	Do.
3	5.30	14.40	4.5	1.230	2	Do.
4	3.95	10.60	4.4	1.425	4	s$E_{(I),(II)}$, ${}^{1000}_{800d}$
5	2.25	7.05	4.0	.460	5	V
6	3.05	7.30	4.0	.520	1	V
7	1.80	7.75	4.3	.475	5	V
8	2.30	7.45	4.0	.525	2	V.wR
9	3.10	9.20	4.0	.625	4	V.s$E_{(II)}$, 16^h
10	2.40	11.30	4.0	.610	17	R
11	2.65	9.20	4.2	.525	8	V.R
12	2.20	8.85	4.2	.470	9	V.wEt
13	2.75	8.75	4.0	.410	5	
14	2.15	7.35	4.0	.475	9	V.R
15	2.00	8.15	4.0	.415	8	
16	2.20	9.55	4.0	.405	11	
17	2.55	10.15	3.9		1	
18	1.25	8.10	4.0	.345	3	V
19	2.05	7.35	3.8	.475	3	
20	1.75	8.10	4.0	.455	2	V
21	2.50	8.50	4.0	.390	4	
22	2.05	6.50	4.0	.350	32	
23	2.55	7.70	4.4	.510	19	
24	2.15	8.05	4.4	.480	8	D
25	2.30	7.35	4.0	.520	20	
26	2.85	8.20	4.0	.430	35	A.sR
27	1.75	4.55	4.0	.295	26	A
28	1.75	4.95	4.0	.210	8	A.R
29	1.20	4.75	4.0	.215	4	
30	1.20	5.05	4.0	.150	5	
31	1.80	8.40	4.0	.525	16	V.R

1933 April

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	1.86	8.35	4.2	0.220	9	
2	1.51	4.70	4.0	.210	12	A.sR
3	1.25	2.40	3.8	.125	5	
4	1.00			.250	7	V
5	1.00			.200	5	E.sE, 20^h
6	1.20			.280	6	C.Et
7	1.50	3.40	3.7	.265	13	
8	1.50	3.40	3.7	.345	8	C.R
9	4.50	9.30	3.8	1.650	5	C.E
10	3.40	15.40	4.3	.470	8	C.sR
11	2.65	10.70	4.0	.450	5	
12	2.60	10.10	4.0	.595	0	B.R
13	2.30	8.55	4.0	.595	15	Do.
14	3.50	9.45	4.0	.480	7	Do.
15	1.95	8.10	4.0	.405	10	
16	3.20	6.50	4.0	.310	12	Do.
17	1.80	8.25	4.2	.540	2	A.R
18	3.10	11.30	4.2	.540	2	Do.
19	2.15	9.50	4.0	.310	4	Do.
20	1.75	4.30	4.0	.195	4	Do.
21	1.75	5.90	4.0	.390	6	
22	2.65	5.90	4.0	.545	2	sA.R
23	2.20	9.15	4.0	.360	6	
24	1.80	8.25	4.0	.390	1	C
25	1.95	6.25	4.0	.305	12	Do.
26	1.90	3.75	4.0	.225	2	Do.
27	1.40	3.85	4.0	.145	1	sC.R
28	1.50	3.75	4.0	.120	12	Do.
29	1.10	3.65	4.0	.155	7	
30	1.00	4.30	4.0	.185	5	A

Table 4 (B)

1933 May

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	1.35	1.70	3.6	0.194	2	A
2	1.80	2.65	3.8	.152	2	
3	2.65	3.40	3.6	.160	2	
4	1.45	2.25	3.9	.115	2	B.wEt
5	1.55	4.20	3.7	.159	24	
6	1.70	6.05	4.1	.139	12	E
7	1.20	4.10	4.1	.139	5	$E_{(I)}$
8	2.10	6.40	4.1	.133	4	$E_{(I)}^{300}$,$E_{(II)}^{100}$
9	1.95	5.00	4.1	.137	5	
10	2.05	5.30	4.1	.147	1	B.sR
11	1.90	4.80	4.2	.156	2	B.R.
12	1.85	4.40	4.4	.134	6	B.R.w$E_{(I)}$
13	1.65	3.80	4.2	.162	8	B
14	1.25	3.40	4.3	.122	2	wB.wR
15	2.90	4.60	4.2	.117	4	wA
16	2.50	5.00	4.2	.209	3	
17	2.15	3.20	4.7	.254	1	wA
18	2.50	5.20	4.2	.668	0	R.wE
19	4.00	4.35	4.4	.219	1	wA.R
20	3.15	8.75	4.5	.239	0	wA
21	2.20	5.85	4.1	.253	2	B.w$Et_{(II)}$
22	3.45	1.30	4.0	.369	3	Ct.R.$E_{(II)}$
23	2.75	1.85	3.7	.253	2	C.$E_{(II)}$, 16^h
24	2.65	2.75	3.9	.253	1	
25	3.05	2.10	4.1	.238	6	sA.wR
26	3.40	2.60	3.9	.238	4	sA.Rt.
27	3.10	3.20	3.8	.293	2	sA.R
28	3.50	2.65	4.1	.443	3	Do.
29	3.90	3.05	3.9	.392	1	sA.$E_{(I)200d}$
30	3.40	2.15	3,9	.313	0	A.R.wEt
31	2.95	3.10	4.1	.358	3	A

1933 June

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	3.65	4.10	4.0	0.675	3	A.R
2	3.35	3.45	4.1	.309	1	A.Rt
3	3.66	2.55	4.0	.439	2	Do.
4	4.95	7.40	3.9	.339	2	Do.
5	4.95	7.35	3.5	.449	0	B.Rt.wEt
6	3.85	2.65	3.5	.327	1	
7	4.05	4.40	3.4	.400	0	
8	4.70	8.00	3.5	.330	1	wE.R
9	4.95	2.95	3.4	.314	0	A.wR
10	3.60	2.45	3.4	.424	0	Do.
11	3.55	3.60	3.7	.316	2	Do.
12	4.55	2.55	3.6	.331	3	Do.
13	3.90	4.10	3.4	.322	1	sA
14	2.85	1.65	3.4	.301	1	A
15	2.95	1.60	3.4	.365	0	Do.
16	3.35	1.40	3.4	.359	0	Do.
17	2.80	0.80	3.5	.322	0	Do.
18	2.95	1.75	3.3	.250	0	wA
19	2.90	1.35	3.4	.242	7	
20	2.90	1.90	3.4	.169	2	wA.wR
21	1.95	1.60	3.4	.233	1	
22	2.55	0.35	3.6	.393	0	
23	2.25	1.30	3.8	.186	0	
24	3.50	1.70	3.6	.210	0	A
25	2.95	1.00	3.2	.226	5	Do.
26	3,20	2.60	3.4	.279	3	V
27	3.10	1.80	3.4	.250	1	E(?)
28	3.50	3.50	3.7	.252	0	
29	3.55	4.05	3.7	.277	1	E(?)
30	2.90	3.15	3.6	.174	6	wA

1933 July

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	2.80	3.90	3.7	0.222	5	A
2	2.95	1.10	3.6	.185	2	
3	3.45	3.60	3.9	.222	1	A.Rt
4	3.55	2.80	4.1	.168	0	sA
5	5.05	1.30	4.0	.248	0	Do.
6	2.55	1.20	4.2	.164	0	wA
7	1.35	0.10	3.9	.090	2	A
8	2.05	0.60	3.8	.246	5	wA
9	2.60	1.90	3.8	.216	1	
10	2.65	2.05	3.6	.229	5	B.wEt
11	2.25	1.90	3.8	.124	0	B.D
12	2.20	0.85	3.3	.080	0	C
13	1.30	0.40	3.7	.120	1	sC.D.Et
14	2.05	0.55	3.2	.100	1	sC
15	1.80	0.00		.065	1	Do.
16	1.70	0.00		.099	1	C
17	1.25	0.00		.066	3	B
18	1.45	0.25		.078	3	
19	1.45	0.00		.097	1	wB
20	1.75	0.00		.129	0	Do.
21	2.60	0.85		.085	0	wA
22	1.55	0.00		.124	1	wA
23	1.50	0.00		.127	1	
24	1.60	0.00		.145	1	V
25	2.55	0.75		.178	1	
26	2.30	0.75		.165	0	
27	2.40	0.25	3.9	.166	1	wA
28	2.40	1.60	4.7	.213	0	Do.
29	2.25	2.95	4.4		0	sB
30	2.30	2.65	4.4	.196	1	B.R
31	2.30	0.90	4.3	.214	0	Do.

1933 August

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	2.60	1.50	4.2	0.118	1	wB
2	2.10	1.75		.171	2	wEt
3	2.35	1.90			1	R
4	1.85	3.10		.239	0	R
5	2.70	1.30	3.8		0	sR.wE
6	2.25	1.35	4.3	.213	1	
7	1.55	0.00			1	D
8	1.45	0.00			5	D
9	1.15	0.00			1	$E_{(I)200}$
10	0.60	.00			1	A
11	.60	.00			2	wB
12	.65	.00			0	Do.
13	1.15	.00			0	sB
14	.90	.00			0	
15	1.10	.00			1	Rt.Et
16	.80	.00			3	B.$E_{(I)200}$
17	1.75	.00			3	sC.w$Et_{(I)}$
18	1.50	.00			0	C.$E_{(I)200}$
19	1.35	.00			1	sC
20	1.10	.00			1	
21	1.45	.00			0	
22	1.85	.00			3	
23	1.45	.00			0	wEt
24	1.80	.00			1	B
25	1.70	.00			2	wB.wEt
26	1.85	0.60	3.7		3	
27	1.30	.10	3.6		3	
28	1.45	.00			1	wA
29	1.40	.00			3	Do.
30	1.65	.70			0	B.wEt
31	1.90	.15			2	wB

1933 September

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	1.65	0.65	4.4		1	
2	1.95	.90			0	wB.w$E_{(I)30}$
3					0	Do.
4					0	Do.
5					1	wB.w$E_{(I)60}$
6	1.95	.00			0	wB
7	2.10	1.25	3.9	0.111	2	Do.
8	2.20	0.80	4.0		0	Do.
9	1.95	1.05	3.7	0.71	0	wB.wEt
10	2.10	0.95	3.4		2	wB
11	2.20	2.30	3 8		0	Do.
12	2.45	0.70	3.6		0	wB.R
13	2.55	2.30	3.7		2	
14	2.20	1.40	3.8		2	A
15	1.95	0.90	4.2	.151	0	A
16	1.85	0.25	4.3		1	wA
17	2.00	0.10	4.3	.181	0	Do.
18	2.55	0.65	4.2		1	
19					2	
20					2	
21	2.25			.157	1	wA
22	2.10	1.10	4.1		1	
23	3.20	1.45	4.3	.332	0	
24	0.95	0.65	4.5		0	Ct
25	0.85	0.00		.044	0	C.$E_{(I)200}$
26	1.15	0.00			1	B
27	0.75	0.00		.044	3	C
28	0.60	0.00			0	Ct.$E_{(I)300}$,14^h
29	1.05	0.00		.074	2	wC
30	0.55	0.00			1	

1933 October

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	0.85	0.00			0	
2	.55	0		0.023	3	wB
3	.95	0			2	wA
4	.95	0		.085	3	wB
5	1.15	0			2	B
6	1.20	0		.058	3	
7		0			0	
8	0.95	0		.043	0	
9	1.10	0			0	wA
10	1.10	0			0	wC
11	1.70	0		.043	0	wA
12	1.05	0			1	Do.
13	1.30	0		.042	1	Do.
14	1.30	0			0	B.Rt
15	1.20	0		.063	2	
16	1.10	0			1	
17	1.15	0		.029	1	B.Rt
18	1.00	0			1	
19		0		.047	0	
20		0			0	
21	1.65	0		.054	0	wA
22	1.15	0			3	wV
23	1.15	0		.035	0	
24	1.85	0			0	wA
25	2.05	0		.073	0	Do.
26	1.65	0			0	Do.
27	1.40	0			1	Do.
28	1.30	0			0	
29	0.95	0			0	wA
30	1.55	0		.050	1	Do.
31	1.10	0.25	4.0		1	Do.

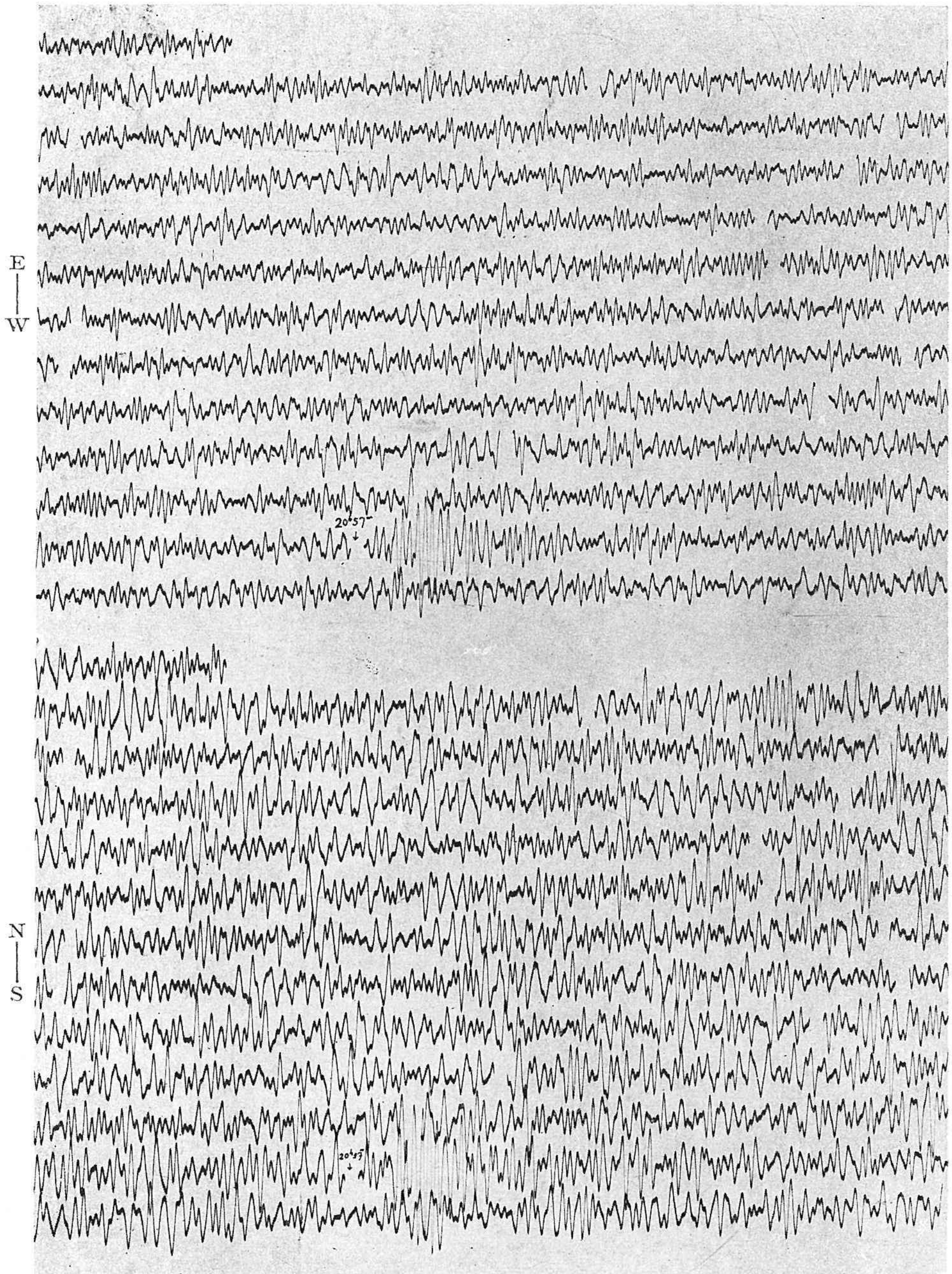
1933 November

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	1.35	0.25	3.3	0.054	4	
2	1.70	.15			0	A.w$E_{(I)100}$
3	1.35	.00		.037	0	Do.
4	1.45	.25	3.8		1	wA
5	1.25	.50		.034	1	
6	1.50	.50	4.3		0	
7	1.30	1.25	3.6	.045	0	wA
8	1.55	.30	3.5		0	Do.
9	1.50	.35	3.8	.047	1	wB.wR
10	1.35	.20	3.3		6	Do.
11	1.45	.35	3.5	.042	0	A
12	1.50	.45	3.3		0	wB
13	1.55	.90		.052	0	Do.
14	1.80	.15	3.4		1	sA
15	1.75	.75	3.5	.040	0	wA
16	1.35	.00			0	
17	1.85	.00		.035	0	wV
18	1.45	.00			0	A
19	1.75	.00		.034	2	wA
20	1.35	.00			1	Do.
21	1.90	.00		.038	0	
22	1.35	.00			1	wB
23	1.50	.00		.034	0	wC
24	1.70	.00			0	wV
25	1.35	.40	3.5	.051	0	
26	1.10	.00			0	
27	1.35	.00		.044	1	
28	1.15	.00			0	
29	1.30	.50	3.3		0	A
30	1.30	.00		.053	0	Do.

1933 December

Date	A_1	A_2	T_2	A_3	No. of Eqkes.	Remarks
	μ	μ	sec.	μ		
1	1.60	0			0	V
2	1.80	0		0.045	1	A.R
3	2.00	0			0	B.w$E_{(I)70}$
4	1.65	0		.053	0	Do.
5	1.85	0			0	Do.
6	2.00	0		.039	2	B
7	1.80	0			1	wB
8	1.90	0		.031	3	
9	1.85	0			1	
10	1.75	0			0	
11	1.85	0		.029	0	
12	2.30	0			2	sA
13	1.40	0			2	sB.$E_{(I)}^{300}$$_{150d}$
14	1.60	0		.015	0	wA
15	1.25	0			3	V
16	1.25	0		.022	1	
17		0			3	
18	1.30	0		.021	2	
19	1.60	0			0	
20	1.50	0		.049	1	
21	1.75	0			2	
22	1.35	0		.027	1	
23	1.10	0			1	
24	1.15	0		.016	0	
25	1.10	0			0	
26	1.00	0		.011	0	V
27	1.30	0			0	
28	1.20	0		.011	1	
29	0.95	0			0	wB
30	1.35	0		.014	0	V
31	1.15	0		.020	0	Do.

Plate I

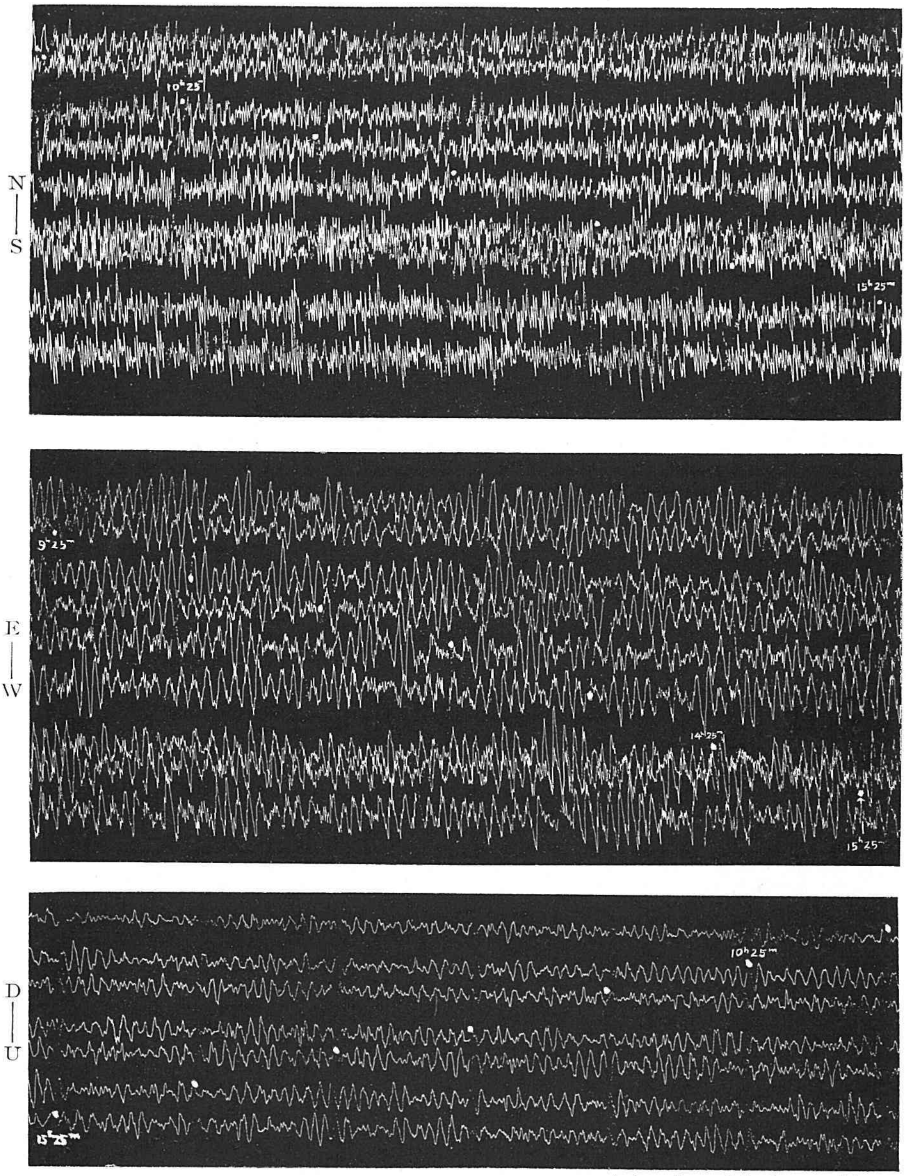


(2/3× the original record)

Fig. 9. A portion of a record of the micro-tremors of the third kind obtained by the short period micro-seismographs, S_B at the Volcanological Laboratory on May 7, 1933. (Time between two consecutive marks = 1 min.).

	T_0	μ^2	T_1	μ_1^2	k	V
Instrumental constants:	$0.55^{sec.}$	0	0.55	0	25,600	19.300

Plate II

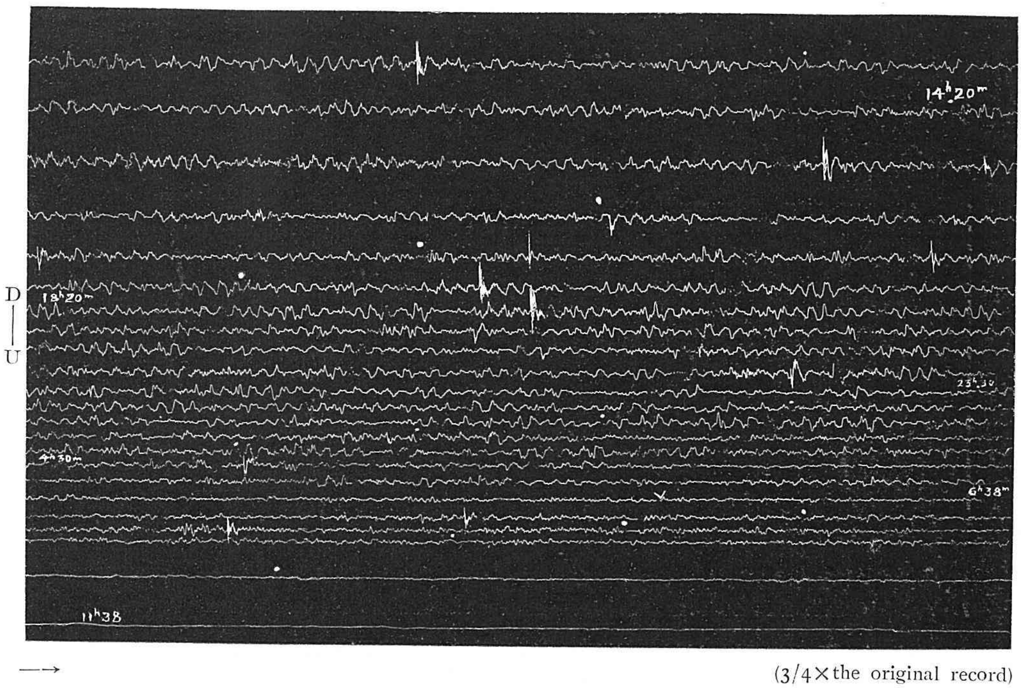


⟶ (3/5 × the original records)

Fig. 10. Portions of records obtained from the Wiechert seismographs on Feb. 25, 1933. On this day the amplitudes of the volcanic micro-tremors were the greatest ever observed at our Volcanological Laboratory. (Time between two consecutive marks = 1 min.).

		T_0	v	V
Instrumental constants:	Horizontal comp.	10.0$^{sec.}$	4 : 1	200
	Vertical comp.	4.6	4 : 1	150

Plate III



(3/4×the original record)

Fig. 19. A portion of a record obtained from the Wiechert vertical component seismograph at the Volcanological Laboratory on Feb. 27–28, 1933. The quick vibrations are the sound shocks caused by the eruptions and the slow vibrations tremors of the second kind. (Time between two consecutive marks =1 min.).

	T_0	v	V
Instrumental constants:	$4.6^{sec.}$	4 : 1	150