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18. *Matsushiro Earthquakes Observed with a Temporary Seismographic Network. Part 1.*

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A prolonged earthquake swarm has been threatening people in Matsushiro, a small town in Nagano Prefecture, since the summer of 1965. The standardized seismograph of USC&GS ($T=1$ sec, $T=1$ sec, $V_{max}=100,000$) which had been installed at the Matsushiro Seismological Observatory of Japan Meteorological Agency (36°32.5′N, 138°12.5′E) on the outskirts of the town began to register very small earthquakes which seemed to occur in close proximity since August 3, 1965. According to an announcement from that observatory, the daily frequency of earthquakes recorded on the seismograms increased day by day and exceeded 100 on August 7. This increased to over 500 on September 28 and at that time people in the town of Matsushiro began to feel sudden shocks with dull earthsounds like distant thunder more than ten times a day. In November, the daily frequency of the recorded earthquakes reached 1,000 and people felt shocks and heard sounds more than 100 times a day in many days of the month. Earthquakes with an intensity of 4 on the JMA intensity scale, which corresponds to the intensity of 6 or 7 on the revised Mercalli intensity scale, began to manifest during this month, two of them being most severe, causing slight damage to houses in the town, as indicated in Table 1. The activity came to a peak on November 22, the daily frequency of recorded earthquakes exceeded 2,000 and people felt more than 200 shocks a day. After this climax the daily frequency of earthquakes decreased but appeared, in general tendency, to remain on the same level showing some fluctuation in activity till March in 1966 when the activity came to the second peak, as shown in Fig. 1.

The Earthquake Research Institute dispatched members to Matsushiro and set up a seismographic network temporarily and the observation was

Table 1. Remarkable shocks among the Matsushiro earthquakes

Date	Hour	M	JMA Intensity	Damage
1965 Nov. 04	23^h45^m	4.6	IV	
05	10 07	4.7	IV	
13	23 17	4.5	IV	
21	03 30	4.7	IV	
22	21 09	4.8	IV	Window-panes of the Matsushiro middle school were broken. Tiles fell from roofs and grave-stones fell down in some part of the town. Cracks were made along a distance of 150 m on the banks of the river (蛭川).
	22 30	4.7	IV	
23	02 57	5.0	IV	
24	14 13	4.4	IV	Cranks were made on the wall, Tiles of roots fell, Window-panes were broken.
Dec. 09	23 11	4.3	IV	
19	13 43	4.0	IV	Rocks of a quarry fell on the outskirts of the town (松代町柴地区). Cracks were made on the walls of the primary school.
1966 Jan. 03	03 59	4.5	IV	Cracks were made on the walls and window-panes were broken at the primary school (東条小学校).
08	22 34	4.7	IV	Wall plaster fell and window-panes and roof tiles were broken at the gymnasium of the primary school.
23	20 16	4.6	V	Cracks were made on the street, walls and roof tiles fell and stone-walls collapsed in a part of the town.
Feb. 07	04 05	4.4	V	Grave-stones fell down. Cracks of the ground, 2-3 cm wide and 2-3 m long, appeared in the town. Cracks of the ground, 10 cm wide, 50 cm deep and 7 m long, were made on the outskirts of the town (加賀井).
12	04 05	4.6	IV	Cracks were made on the walls.
Mar. 08	19 28	4.5	IV	
10	07 03	4.5	IV	Grave-stones fell down. Walls of the gymnasium collapsed at the primary school (西条小学校).

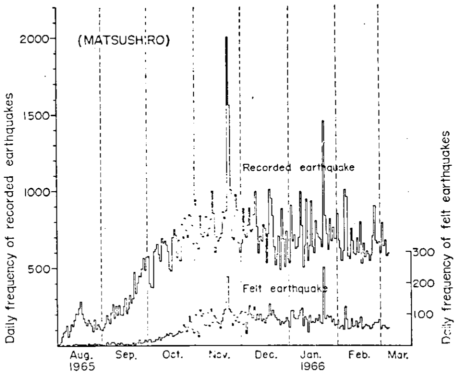


Fig. 1. Daily frequency of earthquakes observed at Matsushiro Seismological Observatory, JMA.

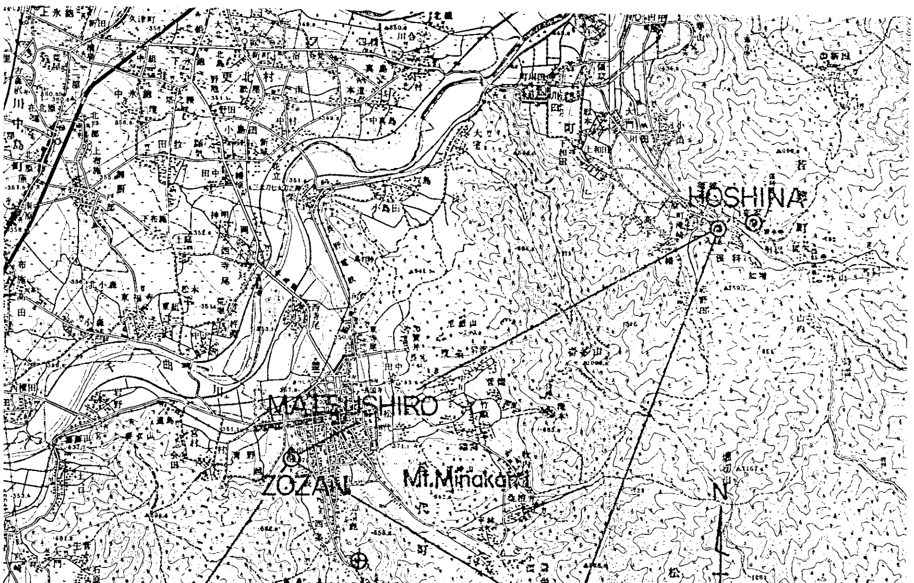


Fig. 2. Location of temporary seismographic stations.

commenced on October 7, 1965. The spots where the seismographs were installed were Hoshina, Akashiba and Zozan, as seen in Fig. 2. The seismographs used at each spot are three components of the portable acceleration seismograph and three components of the electromagnetic seismograph of Type HES-1-0.2. One more set of the electromagnetic seismograph of the same type was installed at Mori later on October 21. The constants of these instruments are shown in Table 2.

Table 2. Constants of Seismographs

Stations	Comp.	Seismographs		
		HES 1-0.2	Acceleration seimograph	
		V max	*V*	*S* (gal/mm)
Hoshina	E	50,000	220	2.3
	N	10,000	210	2.2
	Z	10,000	210	1.9
Zozan	E	50,000	220	2.2
	N	10,000	220	2.1
	Z	10,000	220	1.8
Akashiba	E	10,000	230	2.1
	N	10,000	230	2.3
	Z	10,000	220	1.8
Mori	E	10,000		
	N	10,000		
	Z	10,000		

The members of the Institute who participated in the field observation were

T. Hagiwara, S. Saito, I. Karakama, M. Shibano, M. Watanabe, T. Watanabe, Y. Maeda, T. Takahashi, A. Yoshihara and I. Nakamura,

and the members of the Institute who engaged in interpretation and analysis of seismograms were

T. Hagiwara, T. Iwata, K. Makino, M. Itsui, N. Kamata, M. Kino and Y. Miura.

Matsushiro earthquakes are still continuing and showed no sign of decay even at the end of March 1966, after eight months had passed since the outbreak. Hence, in this paper, we shall compile the result of our observation as a preliminary report for the earthquakes observed in the period from the beginning to the end of February 1966.

1. Seismic activities in the region in historical time.

The epicentral distribution of earthquakes which have brought greater or lesser damage in the past in Nagano Prefecture where Matsushiro is located is shown in Fig. 3. During the period of time from 841 to 1943,

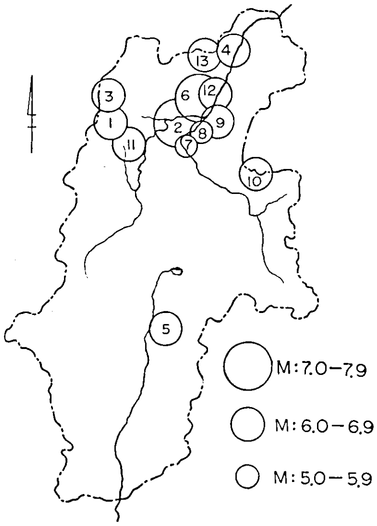


Fig. 3. Disastrous earthquakes that have occurred in Nagano Prefecture in the past.

thirteen disastrous earthquakes have taken place in Nagano Prefecture, most of them originating in the northern part of the prefecture, especially in the neighbourhood of the cities of Nagano and of Omachi. Disastrous earthquakes have seldom occurred in the southern part of the prefecture. Most of these earthquakes were of a magnitude around 6 but two of them which have occurred near the city of Nagano were of a magnitude exceeding 7 and caused tremendous damage of the city and the neighbouring villages, as listed in Table 3.

It is recorded in old documents that two severe earthquakes, the magnitude of which were estimated to be about 6, occurred at Kamitakaigun a few kilometers apart northwards from Matsushiro in January and April in 1897 and small shocks continued during a period of over one year after the first two earthquakes. This earthquake swarm seems to have been of a similar character in some aspects to the present Matsushiro earthquakes but the details are not clear.

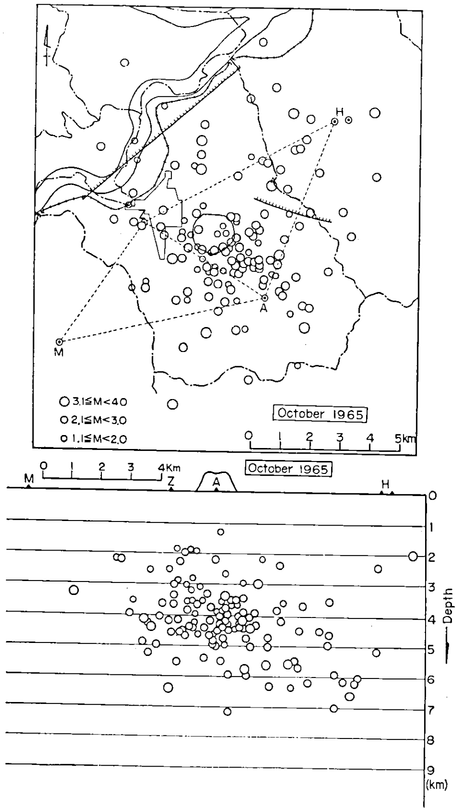
Table 3. Disastrous earthquakes that have occurred in Nagano Prefecture in the past

No.	Dete	Region	$\lambda°$	$\varphi°$	M
1.	841 III 13	Matsumoto	137.8	36.6	6.7
2.	890 VIII 26	North of Nagano	138.1	36.6	7.4
3.	1714 IV 28	Omachi	137.8	36.7	6.4
4.	1718 X 05	Iiyama	138.3	36.8	6.2
5.	1725 VIII 14	Ina	138.1	35.8	6.1
6.	1847 V 08	Zenkoji	138.2	36.7	7.4
7.	1853 I 26	North of Nagano	138.1	36.5	5.9
8.	1858 IV 23	Matsushiro	138.2	36.6	5.9
9.	1897 I 17	Kamitakai	138.2	36.6	6.3
10.	1916 II 22	Asama piedmont	138.4	36.4	6.0
11.	1918 XI 11	Omachi	137.8	36.5	6.1
12.	1941 VII 15	North east of Nagano	138.2	36.7	6.4
13.	1943 X 13	Lake of Nojiri	138.2	36.8	6.0

2. Hypocenters of larger earthquakes in the present case.

We obtained the hypocenters of the earthquakes assuming that the velocity of P and S waves is constant with depth. Assuming this, the hypocentral distance from a station is given by $\Delta = kt$, where Δ is the hypocentral distance, t the difference of arrival time of P and S waves, k a constant. Since the position of hypocenter has three unknown quantities (latitude, longitude and depth) and k is also unknown, there are four unknown quantities. Therefore if we observed the difference of arrival time of P and S waves at four stations, we can determine these four unknown quantities. Once we have determined the value of k, we can determine the position of hypocenter simply by using the values of t at three stations because the hypocentral distance from the three stations are determined from the equation $\Delta = kt$. First we determined the value of k using the observational data of four stations, Hoshina, Zozan, Akashiba and Mori. The number of used data for this purpose was 113 and we obtained $k = 7.39 \pm 0.53$ as a mean value, excepting 32

Fig. 4. Above: Epicentral distribution of felt earthquakes. Below: Vertical distribution of felt earthquakes.



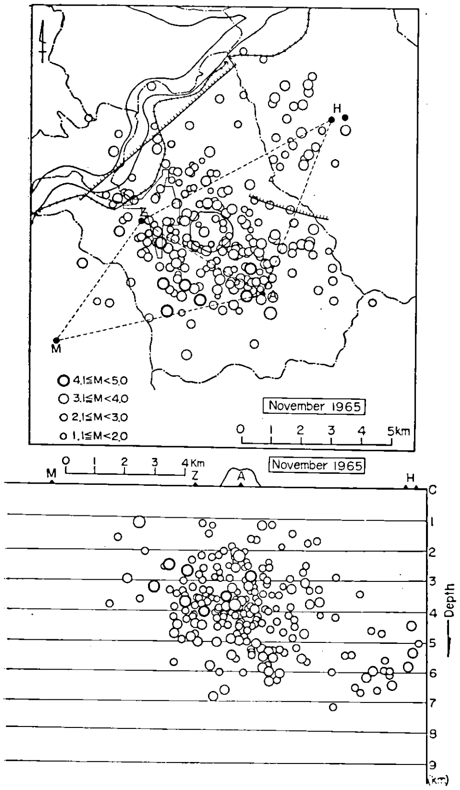


Fig. 5. Above: Epicentral distribution of felt earthquakes. Below: Vertical distribution of felt earthquakes.

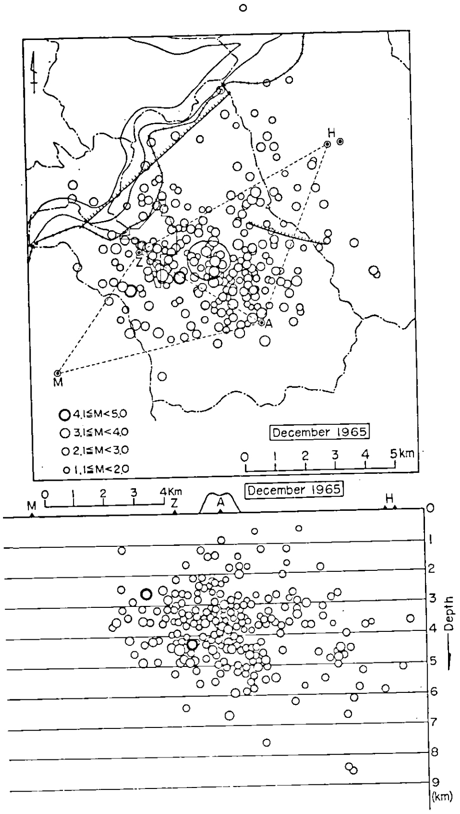


Fig. 6. Above: Epicentral distribution of felt earthquakes. Below: Vertical distribution of felt earthquakes.

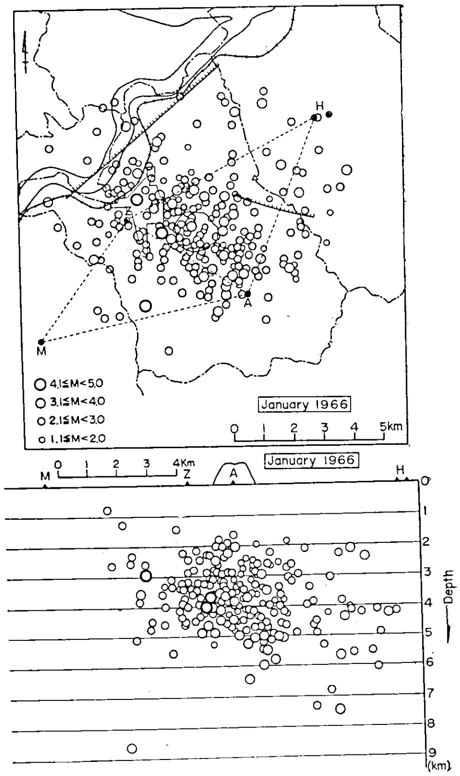


Fig. 7. Above: Epicentral distribution of felt earthquakes. Below: Vertical distribution of felt earthquakes.

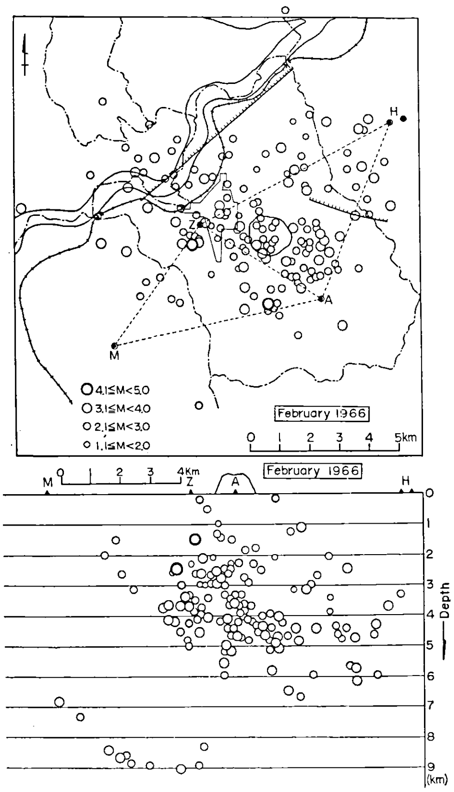


Fig. 8. Above: Epicentral distribution of felt earthquakes.
Below: Vertical distribution of felt earthquakes.

data which gave large deviations from the mean value.

The epicenters of Matsushiro earthquakes which gave a larger intensity observed with the acceleration seismographs were determined by the above mentioned method and they are shown, at an interval of one month, in Figs. 4–8. The vertical distributions of hypocenters which were projected to a vertical plane placed NE–SW wards, are shown in Figs. 4–8.

As seen in these Figures, the epicenters of earthquakes distribute, say roughly, in a circle 4 km in radius and with its center northeast of Minakami-yama, an old volcanic dome created in Pleistocene and now entirely extinct. The depths of the earthquakes are between 2 and 8 km, the depth of 4.0–4.9 km being most frequent in October but becoming 3.0–3.9 km after November (Fig. 9). An interesting fact is that many small earthquakes cluster and the earthquakes with large magnitude

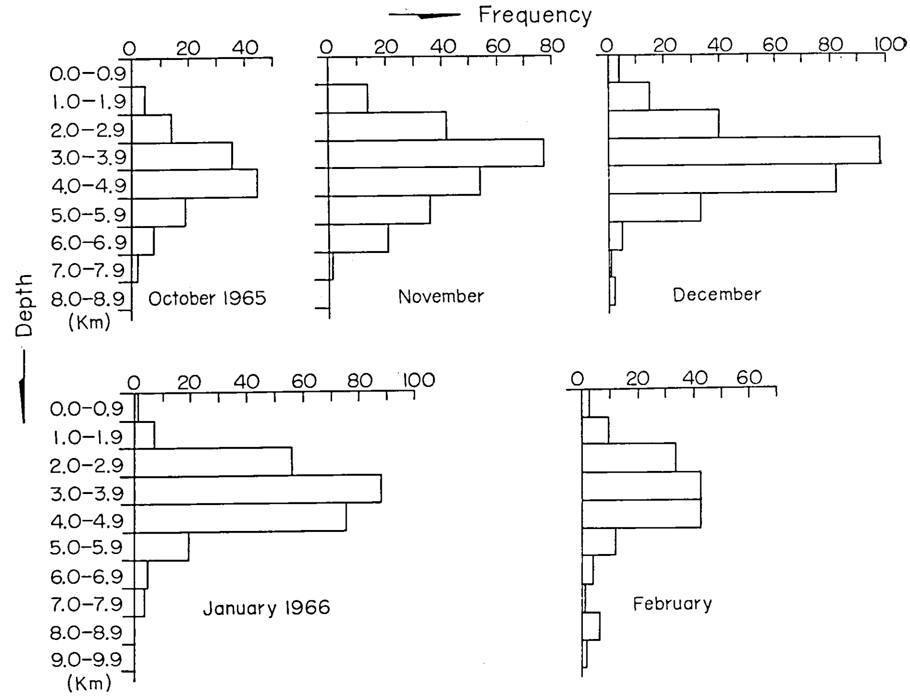


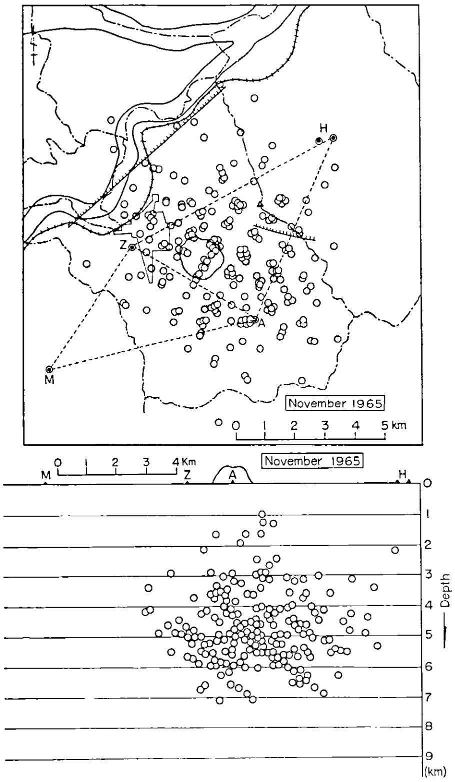
Fig. 9. Frequency distribution of depth of felt earthquakes.

occur outside of the cluster.

3. Hypocenters of smaller earthquakes.

The epicenters and depths of the smaller earthquakes observed with the HES electromagnetic seismographs at four stations Hoshina, Akashiba, Zozan and Mori, during the period of one or two days in October and November 1965 and in January 1966, were determined by the same method and are shown in Figs. 10–12. These smaller earthquakes were densely distributed in depths of 4–6 km in October and November becoming a little shallower in January. It is noted that there was a group of smaller earthquakes which gathered at depths 8–9 km. (Fig. 13) Comparing the distribution of these smaller earthquakes with that of larger ones above described, the larger earthquakes were a little shallower than the smaller ones in October and November 1965 but both the distributions were almost the same in January in 1966.

Fig. 10. Above: Epicentral distribution of recorded earthquakes. Below: Vertical distribution of recorded earthquakes.



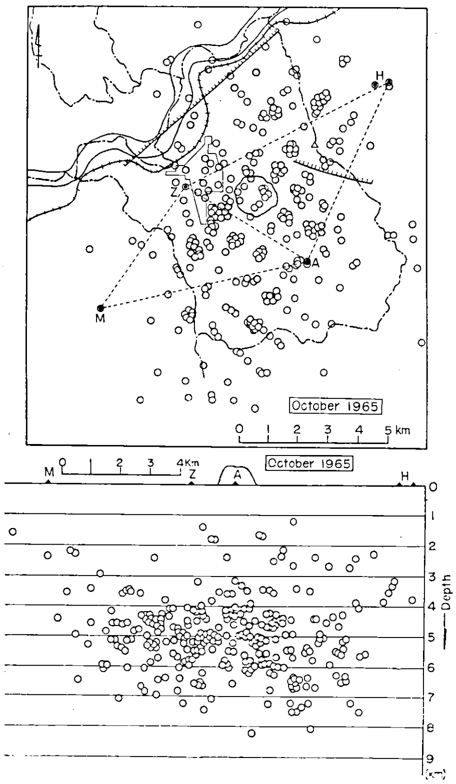


Fig. 11. Above: Epicentral distribution of recorded earthquakes. Below: Vertical distribution of recorded earthquakes.

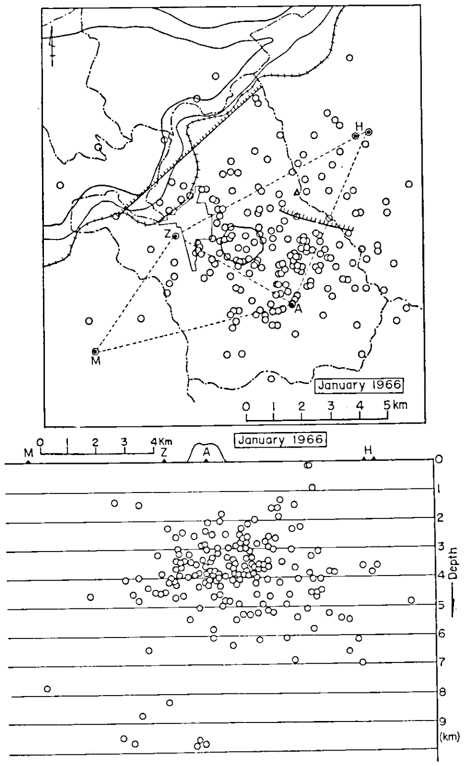


Fig. 12. Above: Epicentral distribution of recorded earthquakes. Below: Vertical distribution of recorded earthquakes.

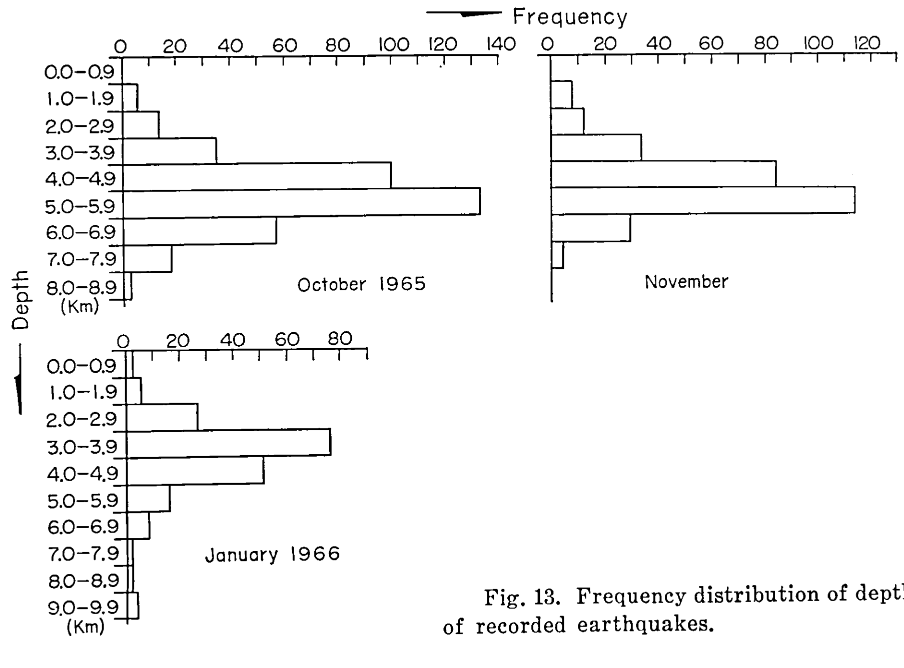


Fig. 13. Frequency distribution of depth of recorded earthquakes.

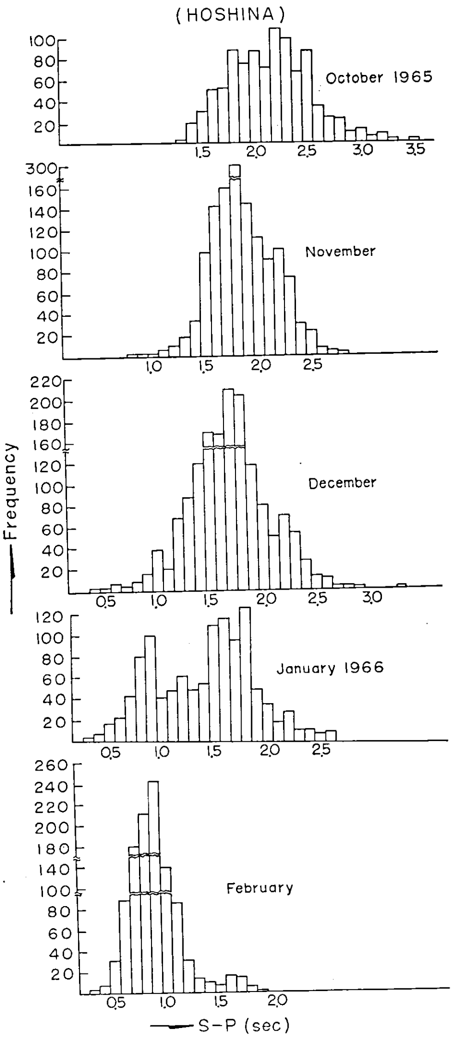


Fig. 14. Frequency distribution of *P-S* time observed at Hoshina.

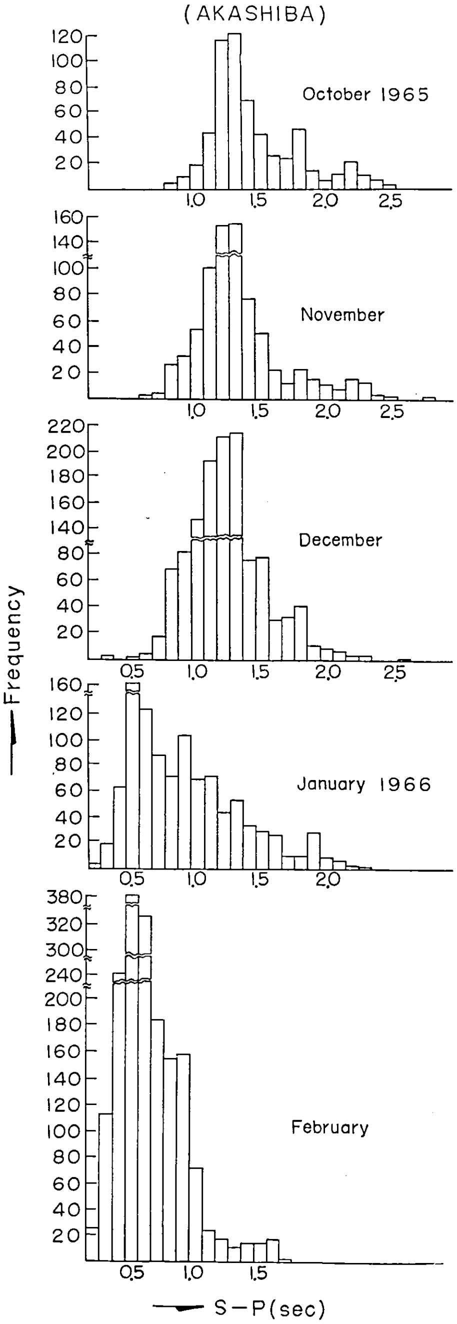


Fig. 15. Frequency distribution of *P-S* time observed at Akashiba.

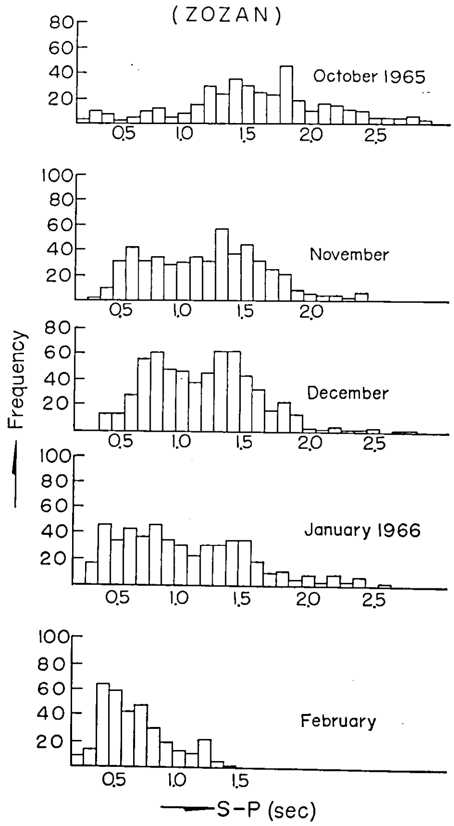


Fig. 16. Frequency distribution of *P–S* time observed at Zozan.

4. *P–S* distribution of larger earthquakes.

The *P–S* times (the differences of arrival time of *P* and *S* waves) of all earthquakes recorded by the acceleration seismographs at three stations, Hoshina, Akashiba and Zozan were read off, their distributions being shown in Figs. 14–16. At Hoshina, the *P–S* times between 1.6–2.5 sec were most frequent in October and November 1965 but *P–S* times shorter than 1 sec began to appear after December in 1965. This means that a small seismic activity began in the neighbourhood of Hoshina in December. At Akashiba, the *P–S* times distributed mostly in the interval between 1.0 and 1.4 sec. At Zozan, the *P–S* times distributed mostly in an interval of 0.6–1.8 sec but there were two peaks at 0.8 sec and 1.3–1.4 sec in December 1965.

5. Daily frequency of earthquakes at each station.

The daily frequency of earthquakes was counted on the seismograms at three stations, Hoshina, Akashiba and Zozan (Figs. 17–19). Such frequencies read off from the acceleration seismograms correspond approximately to those of earthquakes felt by residents, so that these frequencies were indicated as the daily frequency of felt earthquakes in the figures. The frequency recorded by the HES seismographs is indicated simply as the daily frequency of recorded earthquakes in the figures. The daily frequencies of recorded earthquakes and felt earthquakes announced from Matsushiro Seismological Observatory, JMA, are also shown in Fig 1. Comparing the daily frequency at our stations with that of the Matsushiro Seismological Observatory, we can see a large difference between them

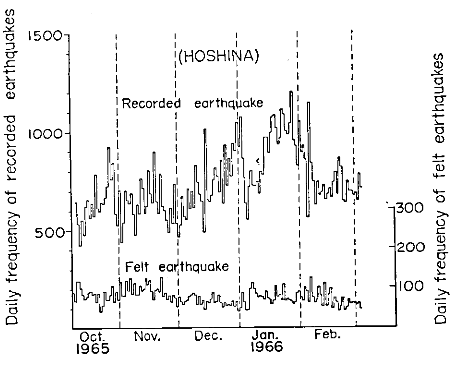


Fig. 17. Daily frequency of earthquakes observed at Hoshina.

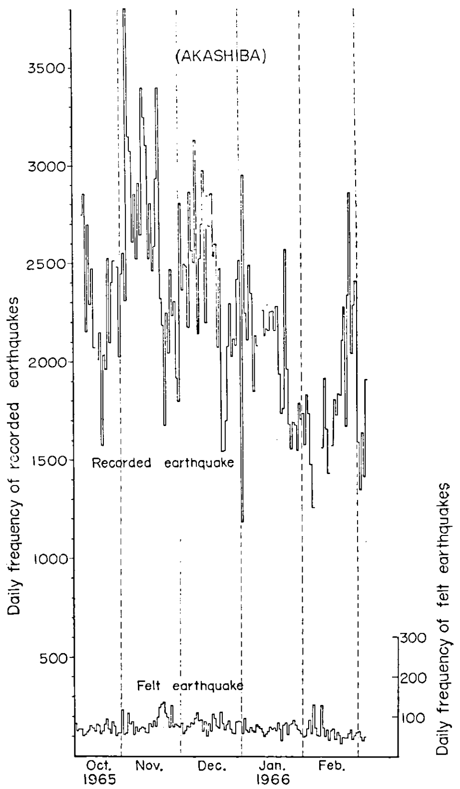


Fig. 18. Daily frequency of earthquakes observed at Akashiba.

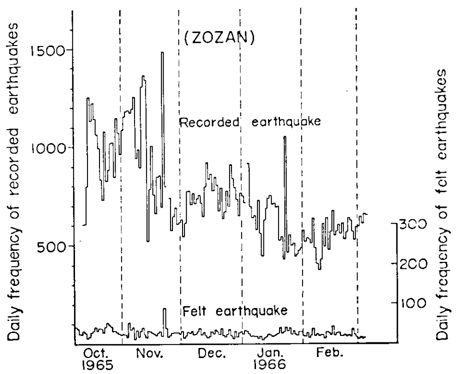


Fig. 19. Daily frequency of earthquakes observed at Zozan.

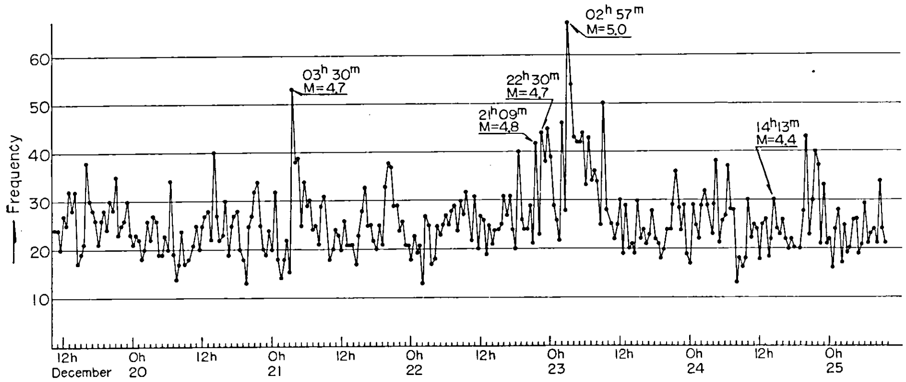


Fig. 20. Frequency of earthquakes at an interval from 0 to 10 minutes and from 30 to 40 minutes of each hour during the period from Nov. 19 to 25, 1965, counted on HES Seismograms of EW component at Hoshina Station.

with respect to recorded earthquakes. Such a difference may be caused by reason of micro-earthquakes recorded with highly sensitive seismograps being of very short period of vibration and having so high an attenuation that earthquakes occurring very near the station are mainly recorded.

Fig. 20 shows the frequency of earthquakes at an interval from 0 to 10 minutes and from 30 to 40 minutes of each hour during the period from November 19 to 25, 1965, counted on the HES seismograms of EW component ($T_1=1$ sec, $T_2=0.2$ sec, $V_{max}=50,000$) at the Hoshina station. The seismic activity reached the first climax, the number of recorded earthquakes increasing considerably with many earthquakes of large magnitude at this interval of time. We can see how the pattern of occurrence of smaller earthquakes changed before and after the occurrence of a larger earthquake.

6. Release of energy.

We obtained the magnitude of Matsushiro earthquakes using maximum amplitudes of all earthquakes recorded on the acceleration seismograms of two stations, Akashiba and Zozan, and adopted the mean of the values of these two stations. For obtaining the magnitude, we used the graph devised by I. Muramatu,[1] who gave the relation between the maximum amplitude and the hypocentral distance taking M as parameter for the wide range of hypocentral distance and magnitude. The magnitude of larger earthquakes obtained by this method was compared with the cor-

1) I. MURAMATU, *Zisin*, [ii], **17** (1964), 215.

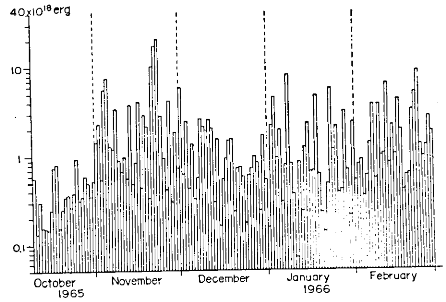


Fig. 21. Daily sum of energy released by Matsushiro earthquakes.

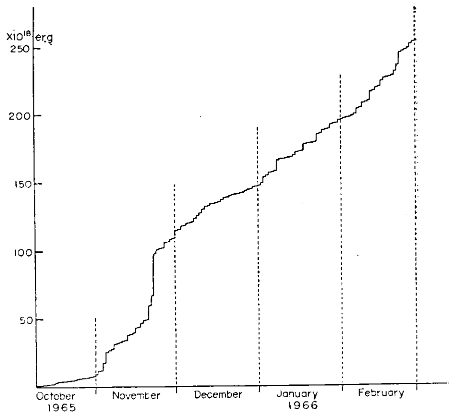


Fig. 22. Cumulative sum of energy released by Matsushiro earthquakes.

responding magnitude obtained by JMA using observational results of an ordinary seismological network. We found that there was a certain systematic difference between them, that is to say, the values obtained by Muramatu's method were always smaller than the JMA magnitude by 0.5. So that we adjusted our magnitude to the JMA magnitude adding 0.5. The daily and cumulative sum of energy released by the Matsushiro earthquakes thus obtained is shown in Figs. 21–22. As figures show, the energy of 0.63×10^{18} erg which corresponds to the energy of a single earthquake of magnitude 4.0 has been released every day except some active days, since the end of October, 1965. The accumulated value of energy released in seven months, from August 1965 to February 1966 was 2.6×10^{20} ergs which corresponds to the energy released by a single earthquake of magnitude 5.8.

7. Relation between the number of occurrence and the maximum trace amplitudes.

First we examined the relation between the number of occurrence and the maximum trace amplitude using acceleration seismograms at three stations, Hoshina, Akashiba and Zozan, for this purpose. There is a well-known statistical relation called Ishimoto-Iida's relation, namely, $N=KA^{-m}$, where N is the number of occurrence of maximum trace amplitude from A to dA recorded on the seismograms at a station and k are constants. According to statistical studies hitherto made, m maintains almost the same value in many cases of ordinary earthquakes, aftershocks and earthquake swarms. On the other hand, it is reported that m gives evidently a smaller value than a normal one in the case of foreshocks of a large earthquake.[1] The fact that m has a smaller value means that the shocks with larger amplitude have a tendency to occur more frequently. This fact must be very important, if it actually exists, from the standpoint of the study of earthquake prediction.

In the present case, we examined the relation between N and A with

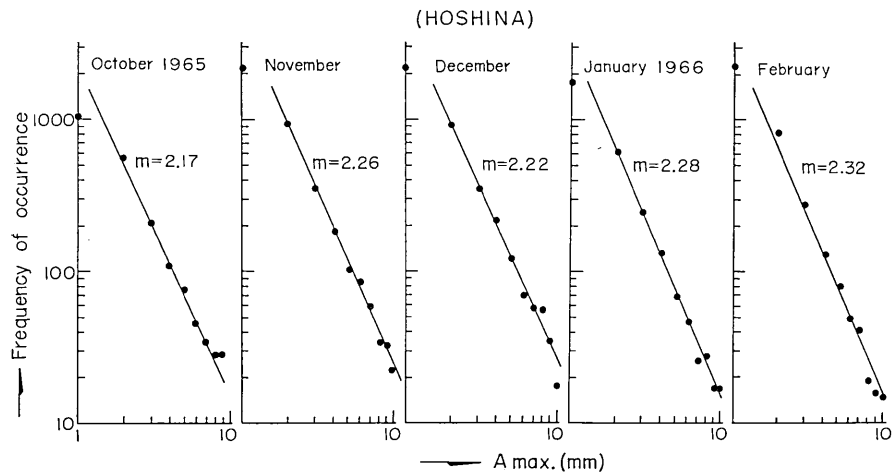


Fig. 23. Relation between the maximum trace amplitudes on the acceleration seismogram and the frequency of occurrence (Hoshina station).

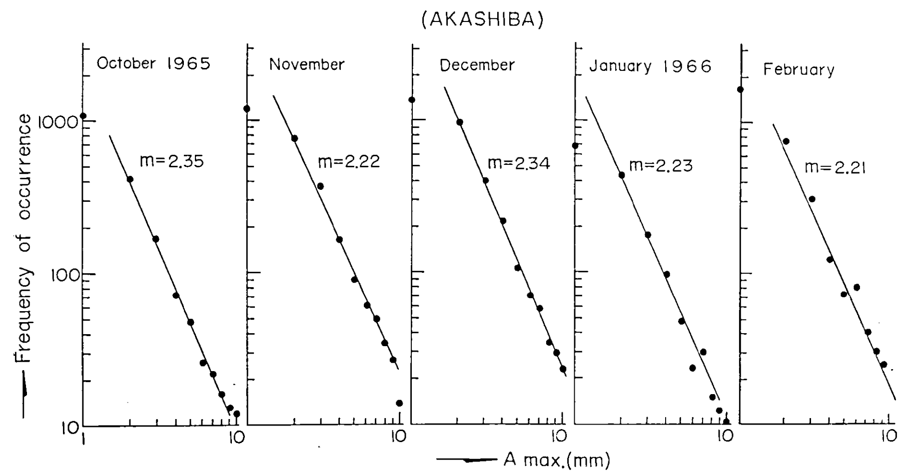


Fig. 24. Relation between the maximum trace apmlitudes on the acceleration seismogram and the frequency of occurrence (Akashiba station).

1) S. SUYEHIRO et al., *Papers in Meteorology and Geophysics*, **15** (1964), 71.

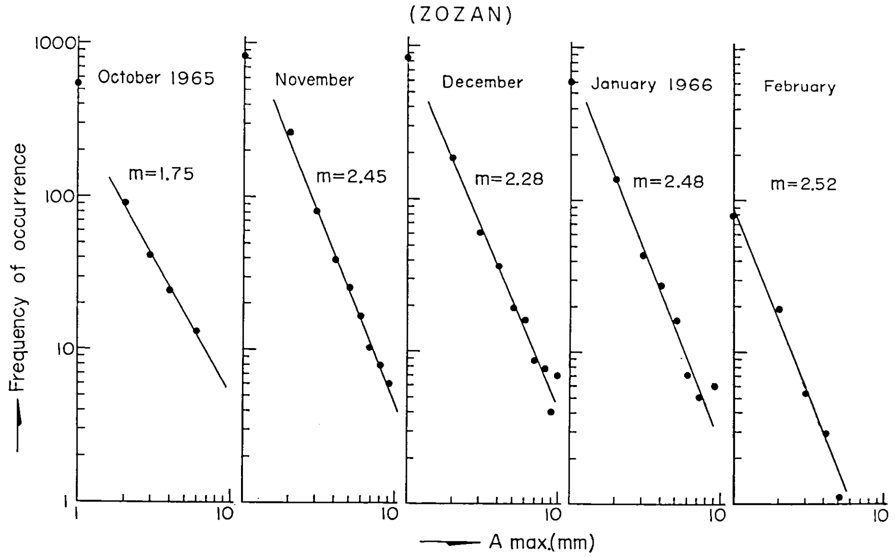


Fig. 25. Relation between the maximum trace amplitudes on the acceleration seismogram and the frequency of occurrence (Zozan station).

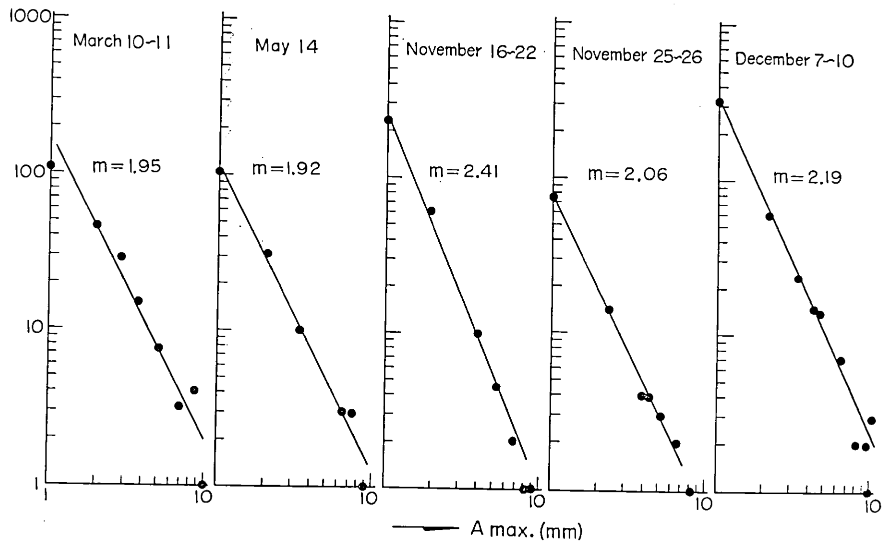


Fig. 26. Frequency distribution of maximum trace amplitudes of the Ito earthquake swarm in March and May 1930 and of the fore and after-shocks of the Izu great earthquake of December 26, 1930.

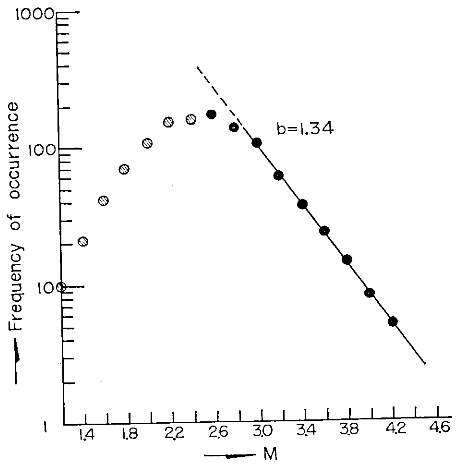


Fig. 27. Frequency distribution of the magnitude of Matsushiro earthquakes.

respect to many different intervals of time, as shown in Figs. 23–25. The earthquakes of larger magnitude occurred on 22nd and 23rd of December, 1965. However, as will be seen from the figures, the values of m maintain almost the same value 2.0–2.4 there being no evident difference between the values of m before and after this activity.

In connection with this problem, we examined the value of m with respect to the earthquakes before and after the destructive earthquake of the northern part of Izu on November 26, 1930, during which event people felt many remarkable foreshocks from the 7th of that month. Fig. 26. shows the relation between N and A in this case. As will be seen from the figures, we could find no evident difference between the values of m before and after the destructive earthquake.

The relation between the number of occurrence N and the magnitude M in the interval from December 1965 to February 1966 is also shown in Fig. 27. According to Gutenberg and Richter, there is a statistical relation, $\log N = a + b(8 - M)$, in which a and b are constants. b is not independent of m in the Ishimota-Iida's relation because M is combined with A by the relation $M \propto \log A$. As will be seen from the figure, the value of b becomes 1.34 in the case of the Matsushiro earthquakes.

8. Push-pull distribution of initial motions.

The push-pull distribution of initial motions of the Matsushiro earth-

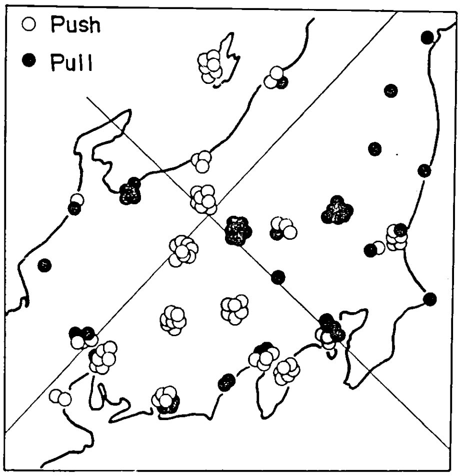


Fig. 28. Push-pull distribution of initial motions of the Matsushiro earthquakes of large magnitude as determined from the ordinary wide seismological network under JMA. (After Ichikawa)

quakes of large magnitude as determined from the ordinary wide seismological network under JMA is shown in Fig. 28.[2] The distribution is of the quadrant type, the nordal line inclining by 45° from merridian. According to Ichikawa, JMA, the type of distribution of initial motions in the present case is the same as that of those remarkable earthquakes which have occurred in this region in the past.

In order to investigate the same matter with respect to smaller earthquakes, we examined the direction of initial motion of the earthquakes observed at our temporary stations, Hoshina, Akashiba and Zozan. For this purpose we used the acceleration seismograms obtained at these stations during the period from October 1965 to January 1966, except December 1965. The push-pull distributions of different earthquakes were superimposed together, putting the epicenter to the common point. If the mechanism of earthquakes is the same for all earthquakes, the push-pull distribution obtained by such a method may give a certain difinite configuration. Fig. 29 shows the push-pull distribution obtained by this method with respect to earthquakes shallower than 3 km.

At a glance over the figure, we may regard distribution of smaller

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2) Report of Matsushiro Earthquakes published by Tokyo District Meteorological Observatory and Nagano Local Meteorological Observatory, January 1966.
(東京管区気象台，長野地方気象台：地震調査報告—1965年8月以降の長野県松代町附近の頻発地震—[昭和41年異常現象調査報告第1号])

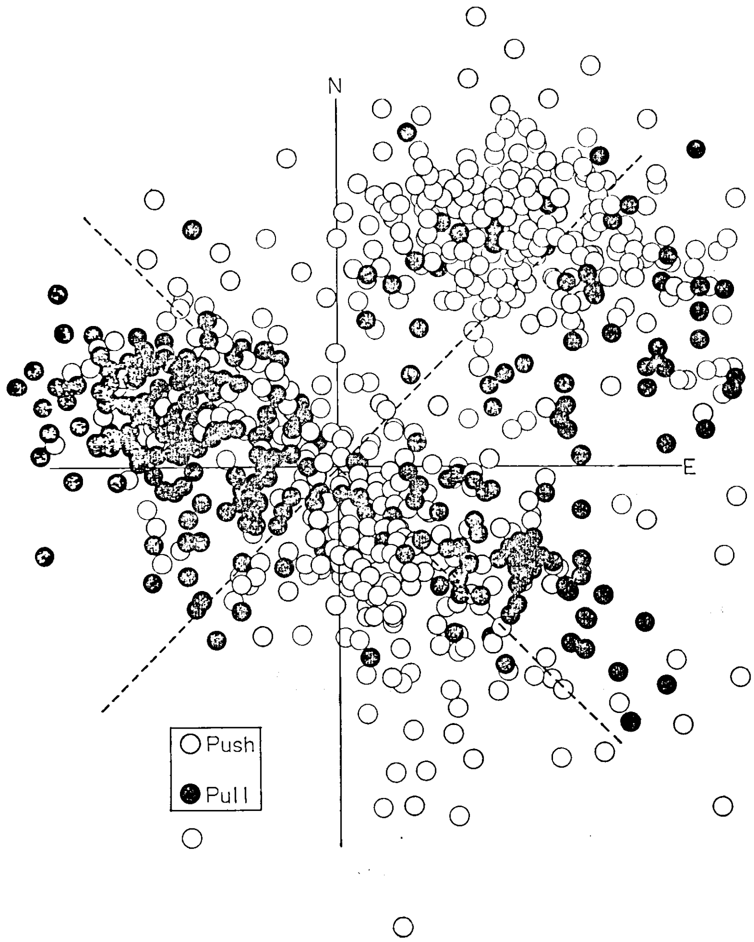

Fig. 29. Push-pull distribution of initial motions of Matsushiro earthquakes.

earthquakes as being of the same type as that of large earthquakes obtained by the JMA network as a whole. We excluded the earthquakes which occurred in the neighbourhood of the Hoshina station in the present case, because those occurring in this region seemed to give a different distribution from others. Clarification of this matter was postponed to a future investigation.

18. 臨時地震観測網による松代地震群の調査結果 (第一報)

地震研究所 {地震観測班 / 地震計測部}

1965 年 8 月 3 日に始まつた長野県松代町附近の地震群は，気象庁松代地震観測所の標準地震計(電磁式最高倍率 10 万) により観測された報告によると，8 月 7 日頃には地震回数が 100 を越し，9 月 28 日になると 500 回以上となつた．11 月に入ると地震活動は顕著となり，地震回数が 1000 回以上にも達する日があり，有感地震は地鳴を伴つて日に 100 回以上を記録する日が多くなつた．ことに 11 月 22～24 日の地震活動は顕著で，震度 IV の地震 3 回を含めて地震回数は 2000 回以上となり，有感地震回数は 223 回と報告されている．さらに震度 IV の地震により松代地域では軽微な被害を生じた (Table 1).

地震研究所では 10 月 7 日から，若穂町保科，松代町赤柴および象山にそれぞれ加速度地震計と HES-1-0.2 型電磁地震計を設け観測体制に入つた．なお，10 月 21 日からは，更埴市森に同じく HES 電磁地震計を設けた．これら地震計の定数を Table 2 に示す．

地震観測に参加した者の氏名は次の通りである．

萩原尊礼，斎藤貞夫，唐鎌郁夫，柴野睦郎，渡辺政雄，渡辺唯夫，前田良弘，高橋辰利，吉原暉雄，中村功．

また，地震記象の読取，解析には次の者が当つた．

萩原尊礼，岩田孝行，牧野和子，佃井満智子，鎌田憲子，木野みさ子，三浦義治，

松代地震は，8 カ月経過した今日も未だその活動は一向に衰えず，なお続行中であるが，とりあえず 1965 年 10 月～1966 年 2 月に至る観測結果を第一報として報告する．

1. 長野県下の過去における被害地震

長野県下の過去における被害地震は，西暦 841 年～1943 年に至る間に 13 回発生している．これらのうち，ほとんどが長野市と大町附近に集中して起つていて，県南部に起ることは極めてまれである (Fig. 3)．これら地震のマグニチュード (以下 M と記す) は 6 程度のものが最も多い．$M=7$ 程度の地震は 2 回あるが，いずれも長野市附近に起り大きな被害を生じた．

古文書によると，1897 年 1 月と 4 月には松代町北方の上高井郡に $M=6$ 程度とみられる地震が別々に起つている．これらの地震の後，1 カ年以上にわたり小地震が続いたといわれる．この地震は，今回の松代地震と類似性があるように思えるが詳細については不明である．

2. 有感地震の震源分布

震源決定には $\Delta=kt$ の，いわゆる大森公式を用いた．ここで Δ は震源から観測点までの距離，t は P と S の到達時刻の差，k は定数である．震源決定には 4 つの未知数 (λ, φ, h, k) があるので最小 4 観測点の P～S 時間が必要である．

保科，赤柴，象山および森の 4 点から得られた資料は合計 113 個で，このうち平均値から 20% 以上のへだたりを持つ k の値 (32 個) を除いて，残りの 81 個の k の値について平均値を求めると $k=7.39\pm0.53$ が得られた．

Fig. 4～8 をみると，震源の分布は主に，皆神山の北東部を中心にした半径数 km の円の範囲に存在し，深さはおよそ 2～8 km である．10 月における深さの頻度は 4.0～4.9 km が最も多い Fig. 9)．しかし 11 月以後の 3 カ月間においては，その深さの最高頻度は 3.0～3.9 km である．Fig. 4～8 から見られるように，比較的 M が大きい地震は小地震群の外側で発生している事実は興味あることである．なお，図中の太い丸は気象庁震度階 IV と V の地震の震源位置である．

3. 比較的小さい地震の震源分布

比較的小さい地震の震源決定は，保科，赤柴，象山および森の HES 電磁地震計 (最高倍率 1～5 万) の記録によつた．小さい地震の回数が非常に多いため，1965 年 10 月，11 月，1966 年 1 月の

それぞれについて1〜2日間の抜取り計測を行つた．これらの震源分布を Fig. 10〜12 に示してある．

震源の深さについては，10月，11月ともに4〜6 km の範囲が大部分であつたものが，1月に入ると若干浅発の傾向を示している．また注目すべきは 8〜9 km のやや深い微小，極微小地震群が存在していることである (Fig. 13)．有感地震の場合には2月に 8〜9 km のものが現われている (Fig. 8)．

有感級の大きな地震と微小地震とを，鉛直分布について比較してみると，10月，11月では微小地震より，有感級の大きな地震がやや浅発性の傾向を示し，1月においては両者同程度の深さで起つている．

4. P〜S 分布

保科，赤柴および象山の加速度地震計記象から P〜S 時間を読取ることができる地震すべてについて集計した．加速度地震計記象の上で読み取り可能の地震は，すべて有感地震とみて大きな過ちはないので，便宜上以下これを有感地震として記載することにした．

それぞれの観測点における P〜S 分布の特徴について述べると

1) 保科： 10月，11月では有感地震の P〜S 時間は，1.6〜2.5 sec の範囲に大部分集中しているが，12月以後では 1 sec より短いものが現われている．
   特に，1月は 0.9 sec と 1.5〜1.8 sec にピークがあり，2月では 0.8〜0.9 sec のピークが一層顕著である (Fig. 14)．
2) 赤柴： 10月〜12月では有感地震の P〜S 時間は，1.1〜1.3 sec が最も多く，1月，2月では 0.5 sec にピークがある (Fig. 15)．
3) 象山： 10月〜1月では有感地震の P〜S 時間は 0.6〜1.8 sec の範囲に集中し割合変化がない．2月には 0.4〜0.5 sec にピークを示している (Fig. 16)．

以上，各観測点とも，2月に入ると P〜S 時間の短いものが顕著に現われており，それぞれの観測点の附近で地震活動が起つていることが推定できる．

5. 各観測点における地震回数

有感地震回数は加速度地震計記象から，それより小さい地震（無感級）は HES 地震計記象から集計を行つた．これらの地震回数 (Fig. 17〜19) を松代地震観測所の資料 (Fig. 1) と比較すると，無感地震について大きな差がみられる．これは，小さい地震は減衰により遠方まで達しないために，地震回数は観測点に非常にごく近い場所の活動によつて左右されることが多いためと思われる．

また，11月19日〜25日には震度 IV の地震を含めて地震活動が盛んであつた．このため震度 IV の地震について前震，余震の有無を調べたのが Fig. 20. である．多少前震的な地震回数増加が，大きい地震の前に見られる．またはつきりした余震と思われる地震回数の増加も見られるが，急速に正規の回数に戻る．

6. 放出エネルギー

赤柴，象山の加速度地震計に記録された地震の最大振巾からそれぞれ M を求め，両者の M を平均してその M とした．

M を決めるために村松の方法（村松郁栄，1964: Magnitude の定義式について．「地震」II 第 *17* 巻第4号 215 頁）を使用した．この方法では最大速度振巾と震源距離から，広い範囲にわたりMが決められるような図表が作られている．このようにして決めた M の値を，気象庁の通常の地震観測網による大きな松代地震の M と比較した結果，規則的な差が見出された．すなわち，村松の方法によつて求めた松代地震の M は常に気象庁の M より 0.5 小さい．このため，われわれの値に 0.5 を加えて気象庁方式の値に修正した．

日別の放出エネルギーは Fig. 21 に示す．10月下旬頃から毎日平均 6.3×10^{17} erg を放出したことになる．これは $M=4.0$ の地震が毎日1発ずつ起つたことに相当する．

8月以後，2月末日までに放出したエネルギーの積算は 2.6×10^{20} erg となり，$M=5.8$ の地震一発分に相当する (Fig. 22)．

7. 最大振巾と地震回数との関係

$N=KA^{-m}$ は石本・飯田の関係式と呼ばれているもので，N は地震回数，A はその観測点におけ

る記録上の最大振巾，m と K は定数である．通常の地震や余震について m は，多くの場合ほぼ同じ値 (2 に近い値) をとることが知られている．しかし，前震の場合は m の値がはなはだしく小さくなるという報告もある．(浅田敏，末広重二，大竹政和，1964: 有感地感地震に伴つた前震と余震について.「気象研究欧文報告」第 *15* 巻第 1 号 84 頁.)

松代地震の月別に求めた m の値は，赤柴，保科および象山いずれも 2.0～2.4 である (Fig. 23～25.).

参考として，1930 年 11 月 26 日北伊豆大地震の前後のある期間の地震記象を調べ m を求めみてたが，大地震の前と後で m に大きな差は認められなかつた (Fig. 26).

また，M とその起る回数 N との関係については，加速度地震計記象の 10 月～2 月までの資料について調べた．

Gutenberg-Richter によれば，$\log N=a+b(8-M)$ なる関係があり，a, b は定数である．

松代地震の場合は，$b=1.34$ という値を得た (Fig. 27).

8. 押し一引き分布

松代地震群のうちの比較的大きな地震について，気象庁管下の観測網で決めた押し引き分布は，節線が子午線から 45° 傾く象限型を示している (Fig. 28). 気象庁の市川によつて調べられた，過去における長野県下の地震についても，その分布は大体同様な傾向が得られている．

われわれは，赤柴，保科および象山の加速度地震計記象から押し引き分布を調べてみた．資料は 10 月～1 月 (12 月を除く) の間の有感地震で，深さ 3 km より浅いものは除いてある．得られた結果は一括して，震央を共通に重ね合せ，押し引きをプロットした (Fig. 29). その結果は，気象庁が比較的大きい地震について得た分布と同型とみてよいようである．

なお，保科附近に起つた地震の押し引き分布は，これと異つているように見られるため，特に除外してあり，これについては将来調査することにする．