49. *The Tunami that accompanied the Oga Earthquake of May 1, 1939.*

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On May 1, 1939, at 14 h 58 m, a violent earthquake occurred in the Oga Peninsula, Akita prefecture. Villages around the extinct volcano, Kanpūzan, the highest mountain in the peninsula, were considerably damaged: 27 persons were killed, 53 persons wounded, 476 houses were thrown down, and 926 houses badly damaged.[1] Besides, land-slides and earth-fissures occurred in a number of places in the peninsula, and a small tunami was recorded by some tide-gauges, although unnoticed by anyone. Seismic tunamis rarely occur in the Japan Sea. The tunami that accompanied the Tango earthquake of 1927, and recorded at Tuiyama harbour,[2] is the only record of a tunami caused by earthquake on the Japan Sea coast before the one mentioned in this paper. In order to study this tunami, the writers collected mareograms from various places on the northern coast of the Japan Sea, such as Azigasawa, Nosiro, Tutizaki, and Sakata, and attempted to ascertain the propagation of the tunami and the position of its origin.

The main earthquake was followed about 100 seconds later by another one of nearly the same intensity. This twin earthquake aroused considerable interest at places near its epicentre, such as Oga, Akita, Nosiro, etc. They were identified also on seismograms at Akita and on

1) See papers on this earthquake: F. KISHINOUYE and others, *Disin*, **11** (1939), 265, (in Japanese).
A. IMAMURA, *do*, 372, (in Japanese).
Y. KATO, *do*, 319, (in Japanese).
T. HAGIWARA, *Bull. Earthq. Res. Inst.*, **17** (1939), 627, (in Japanese).
N. MIYABE and R. TAKEI, *do*, 638, (in Japanese).
Y. OTUKA, *do*, 650, (in Japanese).

2) A. IMAMURA, *Bull. Earthq. Res. Inst.*, **4** (1928), 191, (in Japanese), and Fig. 7.

the tidal record at Tutizaki, which latter is shown in Fig. 1 c. At the same time, Dr. Imamura identified the two earthquakes on seismograms from Sendai, Tōkyō, and Wakayama. It seems impossible, however, to say which earthquake caused the tunami, because the recording speed of the tide-gauge were too slow to distinguish the disturbances with so short an interval between them, so that in order to simplify matters, it was assumed that the tunami was generated by the first earthquake.

The tidal records used in the investigation are shown in Fig. 1, and the instrumental constants of the tide-gauges are as shown in Table I.

Table I.

Place	Recording ratio of reduction	Speed of recording paper	Place	Recording ratio of reduction	Speed of recording paper
Azigasawa	1/10	11 mm/hour	Tutizaki	1/25·7	13 mm/hour
Nosiro	1/32·3	0·17 〃	Sakata	1/26·4	13·5 〃

The indicators of all the tide-gauges were first disturbed by the earthquake vibrations, and later by the tunami. The difference of the

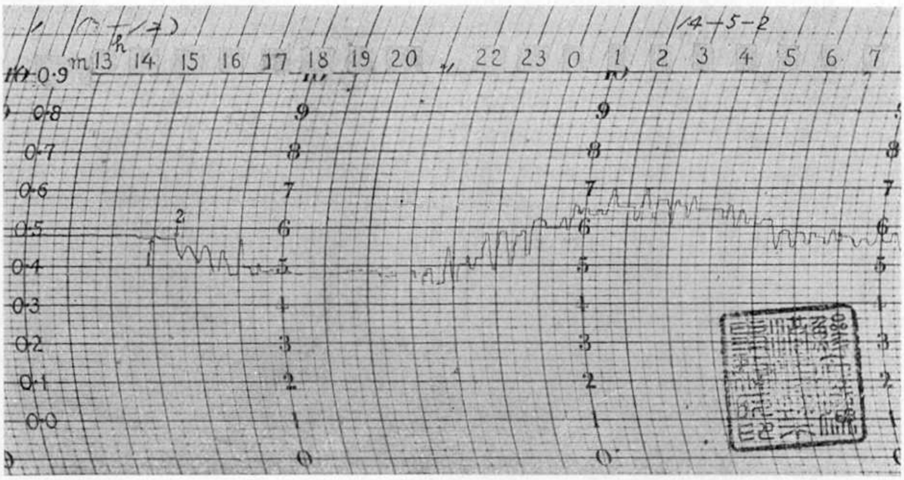

Fig. 1 a.

times of arrival of the seismic wave and the tunami may be regarded as the travel-time of the tidal waves from the origin to the tidal stations, for, as shown in Table II, it is clear that the travel-times of the seismic waves t_s were negligible compared with the travel-times of the

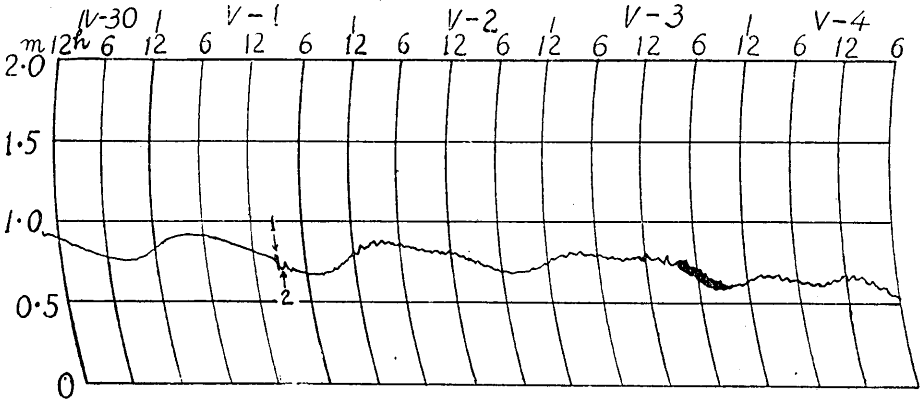

Fig. 1 b.

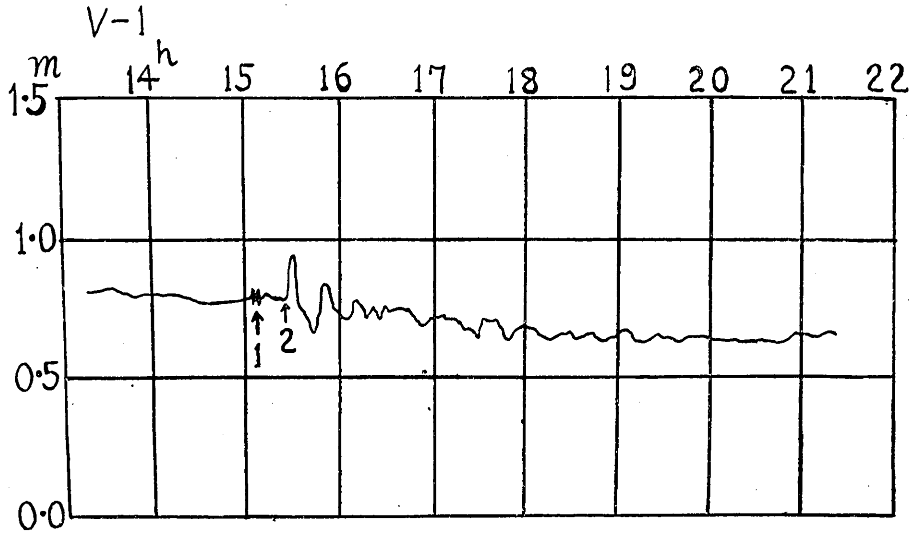

Fig. 1 c.

tidal waves t. The errors in time observation on the records may, moreover, exceed the travel-time of the seismic waves themselves, owing to the slow recording speed of the tide-gauges.

With the observed data in Table II, it is possible to determine the position of the origin of the tunami. The method of determination adopted by us was similar to that used by N. Miyabe in his study of

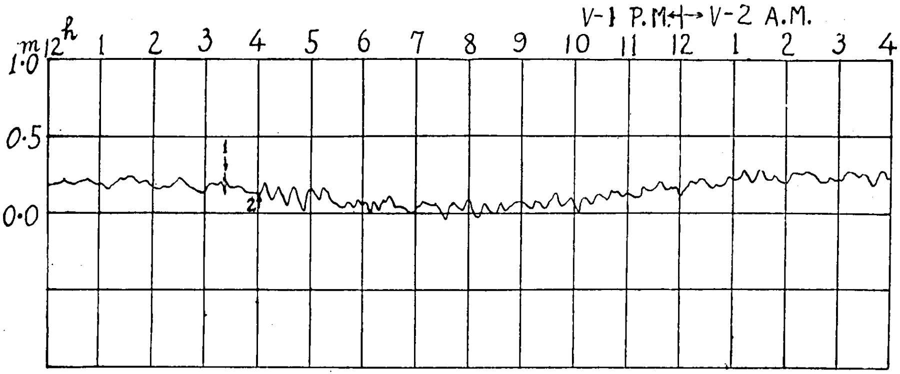

Fig. 1 d.

Fig. 1. Mareogram of various stations.

a Azigasawa. b Nosiro.
c Tutizaki. d Sakata.

Arrow 1: Disturbance due to earthquake motion.
" 2: Time of commencement of tunami.

Table II.

Place	t	d	The first tidal wave		Δ	t_s
			a	T		
Azigasawa	32 min	1·0 mm	− 5 cm	24∼26 min	100 km	13 sec
Nosiro	32	3·0	+ 5	60?	40	5
Tutizaki	19	1·6	+17	9∼12	30	4
Sakata	40	4·5	+10	17∼20	110	14

t=difference in the arrival times of seismic waves and tidal waves.
d=displacement of indicator by seismic vibrations.
a=maximum double amplitude of tidal wave; the negative sign indicates that the sense of the first movement at the station was downward, and the positive sign that it was upward.
T=period of the tidal wave.
Δ=distance of station from the Oga Peninsula in round numbers.
t_s=travel-time of seismic wave calculated approximately.

the Sanriku tunami of 1933.[3] By calculating the velocity of propagation of the tunami by means of the formula

$$v=\sqrt{gh},$$

where h is the depth of the sea and g the acceleration due to gravity,

3) N. MIYABE, *Bull. Earthq. Res. Inst. Suppl.*, 1 (1934), 112∼126.

we can get the travel-time t and the travel distance s during the time interval t by the formulae,

$$t=\int_0^s \frac{ds}{v}=\int_0^s \frac{ds}{\sqrt{gh}},$$

$$s=\int_0^t v\ dt=\int_0^t \sqrt{gh}\ dt.$$

In order to find the origin of the tunami, we purposely start from the direction opposite that of the actual propagation, namely, by taking the imaginary source of the waves at the nearest point on the seashore to the stations, and drawing imaginary wave-fronts for every 100 seconds. We may find on these curves the locus of the place where the origin should be. But before determining the origin with the data given above, corrections to the travel-times should be made. These corrections will be given here for each station.

The Azigasawa tide-gauge is installed at the end of the breakwater that projects about 300 m NE at the western corner of the fishing harbour, facing north. This harbour is on the Japan Sea. The depth of the water near the gauge is about 7 m. The time required for the wave to pass round the breakwater was deduced to be about 40 sec—a value too small to be used as a correction of the travel-time. As to the distance of the wave path, no correction is required either, because the velocity of propagation is only about 8 m/sec. Therefore no correction seems necessary. But owing to the unsatisfactory condition of the gauge, the wave was not recorded well. The somewhat large friction of the instrument caused the indicator to move in jerks. We determined the arrival time of the seismic waves to be 14 h 59 m, which value we accepted on the assurance of the observer of the instrument that the time-keeping was good. The first tidal wave on the record goes smoothly downward; apparently the indicator was not affected by friction of the instrument. But it is a question whether, as seen in Table II, the sense of the first wave was really contrary to that as recorded at all the other stations. If we take the upward wave that succeeded the one just mentioned as the first wave, its travel-time becomes 41 min, which value would place the origin at a point south of the peninsula. We therefore took the value of 32 min obtained above, and assumed the travel-time at Azigasawa to be 32 min less 40 sec.

The Nosiro station is about 1700 m up the course of the Yonesiro River. The depth of this river near the town of Nosiro, being 3·6 m, to simplify the calculation it was assumed to be 3·0 m. The travel-time of the tunami from the mouth of the river to the station has to be corrected. The propagation velocity of tidal wave in the river was calculated by Airy's formula,[4]

$$v=\sqrt{gh}\left(1+\frac{3}{2}\frac{\eta}{h}\right),$$

where η is the height of water from the equilibrium surface, h the depth, and g the acceleration due to gravity. The travel-time in the river worked out to about 5 min. The condition of the instrument here being no better than that at Azigasawa, the record there was not clear. As already stated, the speed of the recording drum here was so slow that it was not possible to say whether the first motion was that of the earthquake or that of the tidal wave. Judging from the damage elsewhere, we presumed it to be the earthquake. The tide-gauges at Azigasawa and Sakata, both far from the epicentre, clearly recorded the earthquake motion, although these places suffered no damage. We therefore took the first disturbance on the record of Nosiro as being the earthquake and the second as the tidal wave.

The tide-gauge at Tutizaki is installed about 1300 m up the Omono River, where the depth of the river is about 3 m. Applying Airy's formula again, the travel-time between the mouth of the river and the station came out as 3 min 40 sec. By subtracting this value from t in Table II, we found that the origin of the tunami was probably nearer Tutizaki than any other place.

As the tidal station at Sakata is at the mouth of the Mogami River, no correction for travel-time was necessary.

Fig. 2 shows the wave-fronts at every 100 sec of the waves that were propagated, imaginarily, from the coast near the stations. The depth of the sea was taken from chart 'No. 144 of the Imp. Japanese Navy", consulting also chart No. 145. After correcting the travel-times from the above-mentioned data, we found the origin on the 1800 sec wave-fronts from Azigasawa, on those of 1620 sec from Nosiro, those of 920 sec from Tutizaki, and on those of 2400 sec from Sakata. Although the times are given in seconds, it is merely for convenience in comparing the above values with the times in Fig. 2, which are given in seconds. The wave-fronts corresponding to the foregoing times are shown in thick lines in Fig. 2.

From the thick lines around the Oga Peninsula, we may conclude that the origin of the tunami had an area as large as that of the peninsula. From theory, it is in order to regard the dimensions of the

4) H. LAMB, *Hydrodynamics*, *Cambridge*, (1932), 262.

origin as being comparable with that of the wave-length, which was estimated in this case at 10∼100 km by multiplying the period of the waves by the mean wave velocity. Since, in his study of the Sanriku

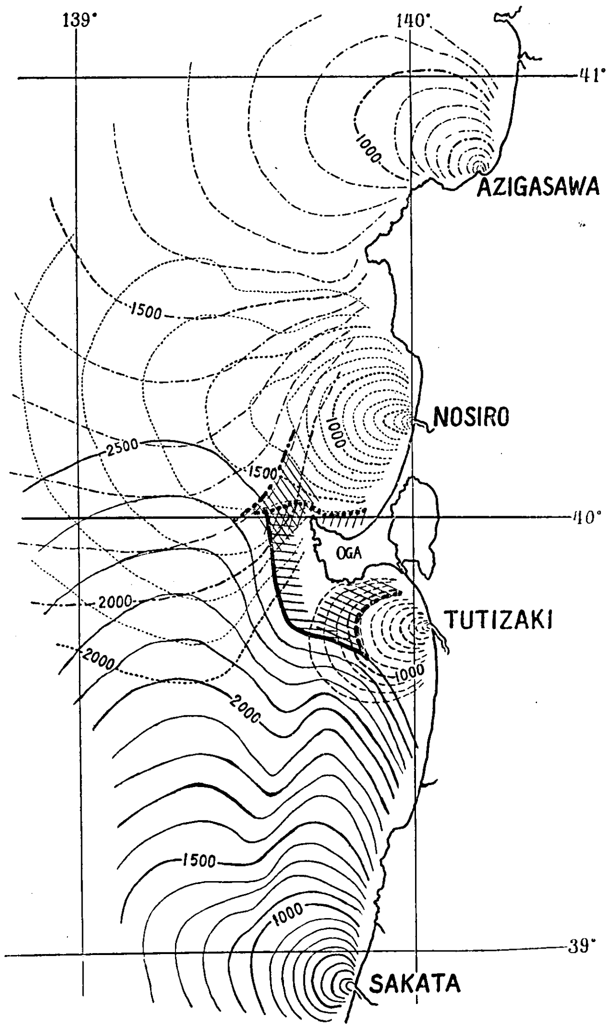

Fig. 2. Map showing the position of the origin of tunami.

tunami of 1933, N. Miyabe[5] obtained a wave-length of about 400 km, and about 600 km for the diameter of the origin, there is nothing irrational in his values being larger than those obtained by us, as the earthquake in his case was very severe.

In our case, on the other hand, the origin of the earthquake was

5) N. MIYABE, *loc. cit.*, 3)

determined by seismometrical methods as being near the northern shore of the Oga Peninsula. To explain the inconsistency in the place for the origin in that as deduced from the seismic waves and that from the tidal waves, certain hypotheses are invoked. First, at the time of the earthquake many land-slides occurred near Kitaura on the northern coast of the peninsula and near Hunakawa on the southern coast, where land-slide debris fell into the sea and disturbed the sea water. Second, the peninsula was shaken by the earthquake, and by a certain mechanism, tidal waves were generated by the vibration. Third, tunamis would be caused by land deformations at the bottom of the sea around the peninsula. Although nothing positive is known about these land deformations, from theory[6] we may expect them as the result of the generation of a number of earthquakes following the first violent shock.

In conclusion, the authors' thanks are due to the Chief-engineers of the Bureau of Public Works, Mr. Takimoto and Mr. Sinoda, and the Chief of the Azigasawa Harbour Improvement Office, who kindly allowed us the use of their records in the present study.

49. 昭和14年5月1日の男鹿地震の津浪に就て

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昭和14年5月1日午後2時58分頃に秋田縣男鹿半島に大きな地震が發生し相當の被害を生じた．尙此の地震には驗潮儀の記錄によつて知り得る程度の小津浪が伴つたのである．

筆者等は日本海に面せる鯵ケ澤，能代，土崎，酒田等の港にある驗潮儀の記錄を調査する事が出來たので此の地震津浪の發生に關して檢べる事とした．日本海に於いて地震に伴つた津浪が驗潮儀によつて記錄報告されたのは昭和2年の丹後地震の際のものが恐らく始めてであつて，今回は第2回目であらう．本報告には此の得難き資料を基として津浪の傳播の狀態から推定されたる其の發生箇所に就いて述べた．

要するに求められた津浪の發生箇所は男鹿半島の周圍にあつて可なり廣範圍を占めてゐる事は注目される事である．從つて此の津浪が如何にして發生したかを考究する事は興味ある事であらう．筆者等は此れを此の地震の際に半島の各地で大小多數の山崩れがあり海中に崩れ込み海水に擾亂を與へた事，或ひは半島全體が振動體として作用し，其の結果半島の周圍から浪を起したのであらう事，又主な地震以後多數の地震が半島の各地に發生した事や山崩れが多數あつた事等から地殼變形が推定されるのであるが此の海底の變形により津浪が起されたのではあるまいかと種々の原因を考へたのである．

6) F. KISHINOUYE, *Disin*, 8 (1936), 590, (*in Japanese*). *Bull. Earthq. Res. Inst.*, 15 (1937), 805.
M. ISHIMOTO, *Disin*, 9 (1937), 110, (*in Japanese*).