Outline of Geophysical Investigations on the Great Earthquake in the South-West Japan on Dec.21, 1946.

By

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I. General Introduction.

In the early morning of Dec.21,1946,a great destructive earthquake occurred in the south-western Japan. According to the seismogram obtained in our university, the earthquake motion began at Tokyo from 4 h 20 m 10.4 s on Dec.21,1946. The maximum amplitude of NS,EW, and up-down components of the earthquake motion at Tokyo was 12.0 mm , 14.0 mm and 3.0 mm respectively, while the initial motion was composed of 80μ south, 67μ west and 20μ down movements.

The elements of seismogram of the earthquake obtained at various seismological stations in Japan[(1)] are tabulated in Table I. From those data the epicentre was determined to be placed at the position 33.0°N in latitude and 135.6°E in longitude.

On the other hand, the distribution of initial motion of seismic wave at various stations are shown in Fig.2, where the directions of the horizontal components of initial motion are shown by arrows, while the full and hollow circles denote respectively the upward and downward motions. It will be clearly shown in the figure that the initial motion was "push" at all points in NW side of the broken line except that at Shionomisaki--the station nearest to the epicentre--, while it was "pull" in the opposit side, and that almost all of those directions of horizontal movement pass through the epicentre. From those data, we can assume a dynamical model of stress distribution[(2)] in the origin of the earthquake such as shown in Fig.2, this model corresponding to the combination of upward and downward motions in NW and SE sides of the hypocentral region respectively.

Table I.

Observatory	Time of Occurence	Maximum Amplitude			Seismic Intensity	Initial Motion			Duration of Preliminary Tremor	Epicentral Distance
		N	E	Z		N	E	Z′		
SHIONOMISAKI	$04^h\ 19^m\ 04.7^s$				5	-17200^{μ}	$+900^{\mu}$	(−)	$^m 04.5^s$	50^{km}
OWASE	25.3	22500^{μ}	17500^{μ}		5	+470	−190.6	+448.7	15.4	128
KASHIWABARA	30.9	>2700	>2000		5	+1026	−43		13.5	162
TOKUSHIMA	32.5	27000>	26000>		5	+850	−1300	+950	15.1	148
KŌBE	34.2	93000	119000	32000	4	+389	−205	+480	12.0	190
KAMEYAMA	36.3			15473	4	+369	+102	+310	28.3	210
ŌSAKA	36.3				4	+2150	+80	+740	18.8	168
SUMOTO	37.0	36000	36000	19333	5	+325	−282	+606	25.9	160
KŌCHI	38.0	47000			5	+56	−375	+178	18.2	192
KYŌTO	38.4	19601	21251		4	+36	−5		29.4	212
HIKONE	41.5				5	+347	+42	+241	29.8	248
TOYOOKA	48.8	24700	31250	600	3	+270	−111	+239	29.9	276
GIFU	49.6				5	+116	+55	+38	15.1	272
TOTTORI	50.0	2000>	2000>		4	+267	−63		30.0	290
IBUKIYAMA	50.2	61800			3	−8	−11		27.0	264
NAGOYA	55.3				4				24.9	260
MISHIMA	57.7	2620	1480	670	3				39.9	372
YONAGO	58.3				4	+44	−30		1^m 02.0	334
TOYAMA	58.8				3				24.7	416
WAJIMA	58.8	26000	20000	7000	3	+28	+21	(+)		476
SHIMONOSEKI	20^m 02.6				3	+10	−30		31.7	426
YOKOHAMA	08.5	34000	20000	2000	3	−13	−12	−18	54.8	438
NAGANO	08.6	>25000	>3150	>2000	3	+11	+13	−0	59.4	450
MIYAZAKI	09.7	16700>	27500>	9250>	4			+43	1^m 04.4	390
KUMAMOTO	11.1	>36000	>71250	>18220	4	−6.9	−56.5	+50.0	36.2	438
ONSENDAKE	12.4				4		−68.0		16.9	476
TOKYŌ	12.5		20000		2	−10	−20	−22	60.0	466
KARUIZAWA	14.6	>2258	>3888		3	+7.5	+10.0	+2.0	52.5	444
MAEBASHI	16.6	285	707	203	3	+3.5	+3.6		1^m 01.7	472
KAGOSHIMA	19.0	>1650	>1650	>1500	3	−11	−31	+11	59.1	478
FUKUOKA	20.2	30000	36000	15000	3	−4.0	−42.0		34.3	470
ONAHAMA	20.8	>731	>644	>878	2	−11	−13	−8	1^m 25.9	622
SENDAI	45.2	2292	5060	2075	1	−312	+273	−538	1^m 36.3	720
MORIOKA	21^m 02.4	12000	9000	8000	1	+5.2	+4.5	+3.0	1^m 32.2	856

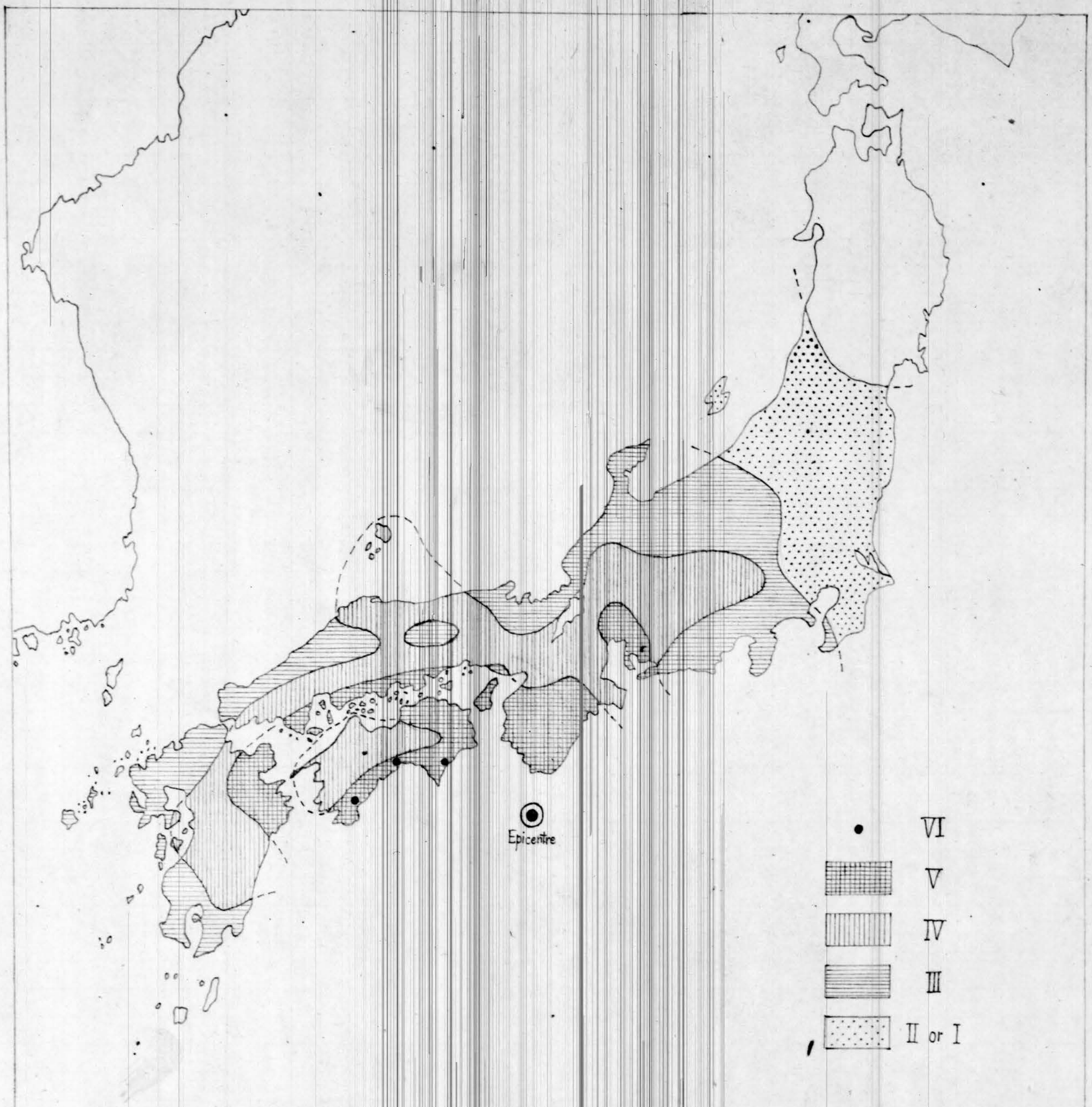
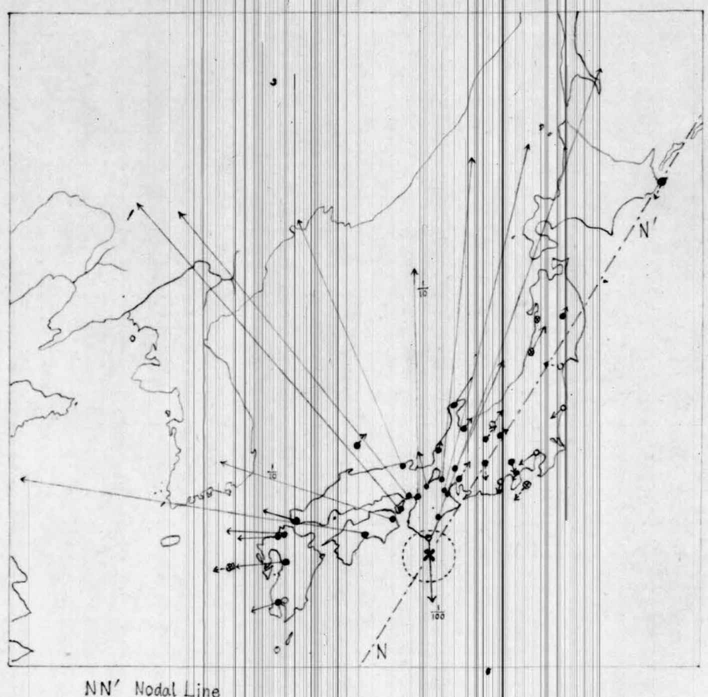


Fig. I Distribution of Intensity of the Earthquake on Dec. 21, 1946.



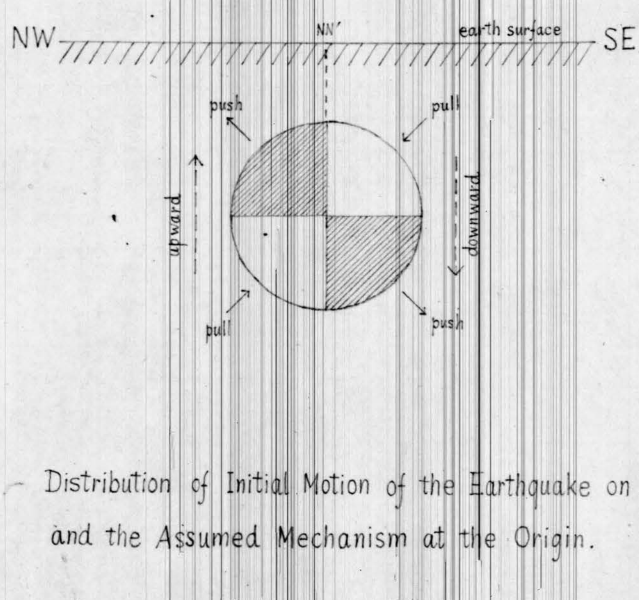


Fig. 2 – Distribution of Initial Motion of the Earthquake on Dec. 21, 1946. and the Assumed Mechanism at the Origin.

In the above-mentioned interpretation, the initial motion at Shionomisaki is omitted from the consideration, since it seems to be rather reasonable to assume that the earthquake motion in the epicentral region is subjected to complicate conditions and does not neccessarily follow the general law which is applicable for observing points fairly distant from the epicentre.

K.Sagisaka[3], however, assumes that there may be a nodal circle surrounding the epicentre as shown by the dotted curve in the figure, where the origin of the earthquake is assumed to be very small. If Sagisaka's model is adopted, the observed fact will be interpreted as that NW side part made downward motion while ES side part upward motion on the contrary.

Since this problem is very important relating to the mechanism of occurrence of the present earthquake, it should be carefully examined in details from various points of view in future. Here, it will only be noted that there occurred a thrust motion in the subterranean crust, its strike being shown by the nodal line in the figure.

Although the earthquake on Dec.21,1946 was large in its intensity --much larger than the earthquake on Sept.1,1923 which destroyed the larger part of Tokyo -, the damages on land was, fortunately not so much large as that in 1923, since the origin of earthquake was fairly far from the sea coast and there scarcely occurred the fire. However, the present earthquake was accompanied by great Tsunami, which destroyed many houses on the sea coast of the south-west Japan. The distribution of seismic intensity is given in Fig.1, while the numbers of casualties and damages of houses in the earthquake area are shown in the following table. (Table II)

On the other hand, according to the old record, the south-west Japan was attacked by great destructive earthquakes a few times in the histrical age of Japan, and they were always accompanied by great Tsunami waves.

They are as follows:

(1) Earthquake on Feb.3, 1605 accompanied by Tsunami.

Total casualties were about 5,000 in killed, and about 3,800 people were killed by Tsunami itself.

(2) Earthquake on Oct.28,1707, accompanied by Tsunami.

Total casualties were about 4,900 in killed, and numbers of destroyed houses were about 29,000.

All of the sea coast of the west Japan - from Kyushu to Izu Peninsula - were attacked by Tsunami wave, its height being about 20m in the southern Shikoku. The east-south part of Shikoku rose up markedly, while the west-south part subsided on the contrary.

Table II.

Prefecture	Casualties			Damages of Houses							
				dwelling houses		non-dwelling houses		work houses		houses washed away by Tsunami	burnt houses
	killed	wounded	lost (by Tsunami)	fully destroyed	half destroyed	fully destroyed	half destroyed	fully destroyed	half destroyed		
GIFU	32	46		340	720	246	232	8	6		
SHIZUOKA		2			1						
AICHI	10	19		75	122	81	69	18	6	1	
MIE	35			65	92	71	18			23	
SHIGA	3	1		9	23						
KYŌTO											
ŌSAKA	32	46		234	194	27	23				
HYŌGO	50	91		330	759	370	242	6			
NARA		13		37	46	106	350	3	6		
WAKAYAMA	195	562	74	969	2442					325	2399
TOTTORI	2	3		16	8	6	5				
SHIMANE	9	16		71	161	202	84				
OKAYAMA	51	187		478	1959	614	798	2	1		
HIROSHIMA		3		19	42	30	32				
YAMAGUCHI					2		1				
TOKUSHIMA	181	665	30	1076	1523	301	456			536	
KAGAWA	52	273		317	1569	291	840	12	28		
EHIME	26	32		155	425	147	118				
KŌCHI	670	1836	9	4834	9041			21	32	566	196
FUKUOKA				1	6	5					
NAGASAKI					2						
KUMAMOTO	2	1		6	6	3					
ŌITA	4	10		36	91	21	18				
MIYAZAKI		1					2				
TOTAL	1354	3807	113	9070	19240	2521	4283	70	79	1451	2598

(9)

(3) Earthquake on Dec.23,1854, accompanied by Tsunami.

The earthquake attacked chiefly the central Japan, about 8,300 houses being destroyed and washed away by Tsunami.

(4) Earthquake on Dec.24,1854 accompanied by Tsunami.

More than 16,000 houses were destroyed by the earthquake and about 15,000 houses in Kii-Peninsula and the southern Shikoku were washed away by great Tsunami. In this case also, the south-east part of Shikoku rose up abruptly and its south-west part was depressed.

Among the above-mentioned four great earthquakes, (1), (2) and (4) occurred in nearly the same position as the present earthquake did. Especially as for the earthquakes (2) and (4), the general aspect has been cleared from seismological point of view. Here, the distribution of seismic intensity and the origin of the earthquake in those two cases will be shown in Fig. 3 for the purpose of comparison with that of the present earthquake.

It must be mentioned here that the earthquake which occurred in the south-west Japan was always extremely large in its intensity, and that the time interval between successive occurrence of earthquake seems to be kept about 100-150 years.

Therefore, it has been frequently said by some Japanese seismologist that there is a possibility of occurrence of great earthquake accompanied by Tsunami in the south-west Japan in coming few tens years, because it has already passed more than 90 years since the last large earthquake. The present earthquake occurred 93 years after the last one.

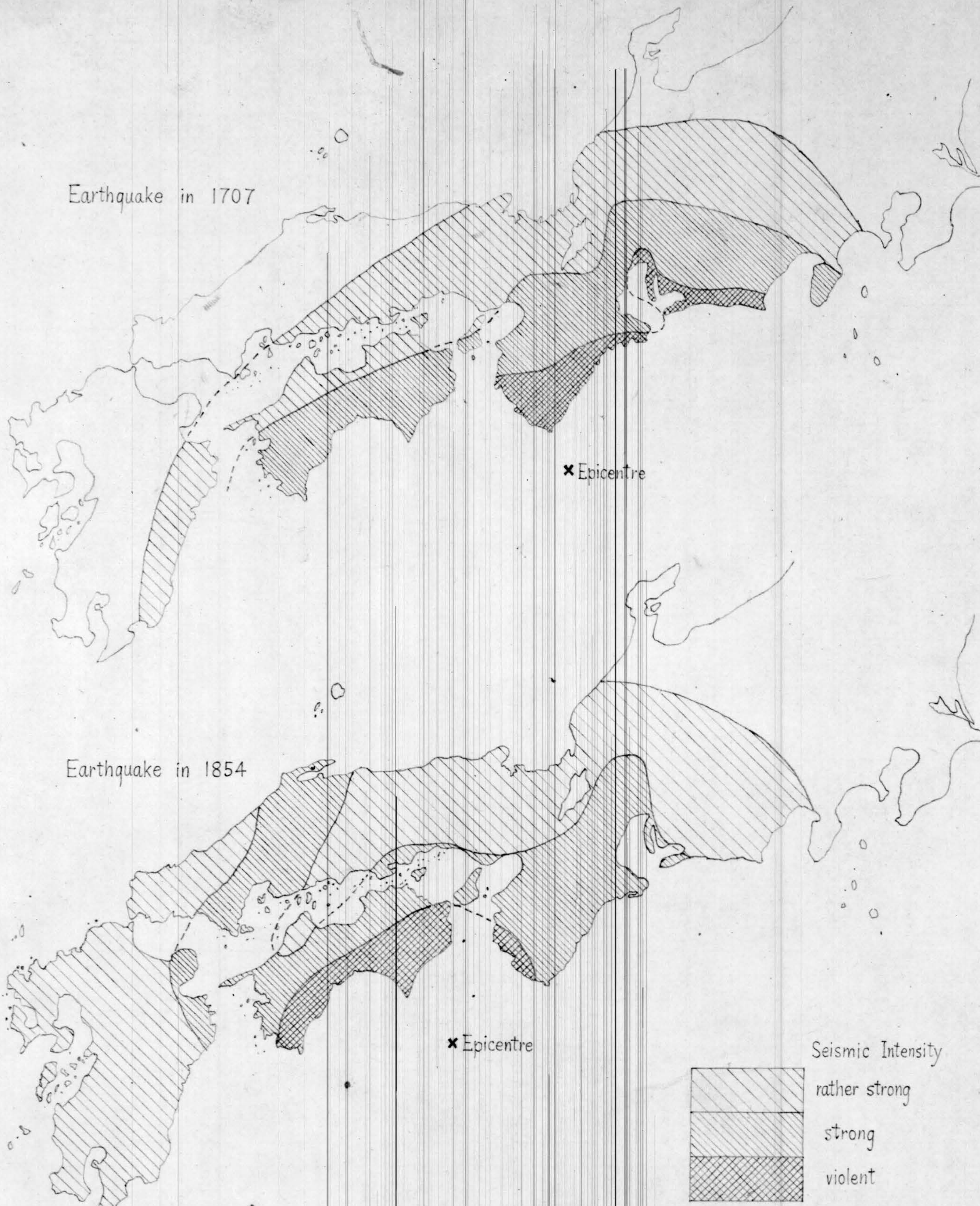


Fig. 3 Earthquakes on Oct. 28, 1707 and Dec. 28, 1854.

The above-mentioned periodicity in occurrence of earthquakes may be not merely apparent one, but rather subjected to some systematic causality in the subtaerranean movement, as will be partly mentioned in §III.

At any rate, the present earthquake was one of the largest ones in Japan during the period after we have had the present scientific seismology, it influencing a wide area of the western Japan.

The magnitude of earthquake itself concluded from the distribution of seismic intensity was designated to be M ≒ 7, (for comparison, M of the Kwanto great earthquake in 1923 was 6). H. Kawasumi[(4)] estimated from the above-mentioned data the seismic energy of the present earthquake to be about 10^{26} ergs, this value being ten times that of the Kwanto great earthquake.

For the purpose of investigating the details of the present earthquake, two expedition parties were sent from Tokyo Imperial University, one from the Geophysical Institute, College of Science, and the other from the Earthquake Research Institute.

The party of the Geophysical Institute was composed of four subparties, the chief aim of them being respectively (1) land deformation accompanying the earthquake and change in tilt, (2) seismometric observation of after shocks, (3) earth-current measurement and the other electric phenomenon relating to the earthquake, and (4) investigation on distribution of Tsunami waves.

While the Earthquake Research Institute Party also included (1) seismological observation, (2) investigation on damages of structures, (3) investigation on damages due to Tsunami, (4) investigation on distribution of intensity of the main earthquake, and others.

Those two parties always have been co-operating with each other. Since, however, the present writer himself conducted directly the members of the Geophysical Institute Party, the writer will chiefly deal with the results of that party and with a little of E.R.I. Party so far important. (Therefore, we shall deal here very little with damages of houses, buildings, and other structures, which are under the chief purpose of investigation of E.R.I.)

II. After Shocks.

Systematic observation of after-shocks by means of portable seismometers was carried out at four places surrounding the origin of the main earthquake. The position of the temporary seismological stations and seismometers used there are as follows:

(i) Tanabe in Wakayama Prefecture.

(1) Tanabe Middle School situated on aluvial layer.

Seismometer; horizontal one componet (N - S direction)

Inverted pendulum type, Period T. = 5 sec.

Magnification V.= 35.

(ii) A hill of Tertiary on the southern margin of Tanabe City.

Seismometer; Horizontal two components (NS and EW)

horizontal pendulum type, period T. = 4 sec.
V. = 50

in both components.

(iii) Shirahama Primary School on Tertiary hill.

Seismometer; horizontal two components, (NS and ES)

horizontal pendulum type, T. = 1.0 sec.

V. = 40

in both components.

(2) Muroto Misaki in Kochi Prefecture, (on Paleozoic).

Seismometer; horizontal two components, (NS and EW)

horizontal pendulum type, T. = 4 sec

V. = 50

in both components.

(Above two stations were operated by members of Geophysical Institute.)

(3) Tomioka in Tokushima Prefecture.

Seismometer; horizontal one component,

inverted pendulum type, T. = 5 sec.

V. = 35.

(4) Gobo in Wakayama Prefecture.

Seismometer; horizontal two components,

inverted pendulum type, T. = 1.0 sec and V=150

and T. = 5 sec and V. = 35.

(Above two stations were operated by members of Earthquake Research Institute)

The positions of those four stations are marked in Fig.4.

It must be mentioned here that there are also a few permanent seismological stations (connected to meteorological stations) in the earthquake area. They are placed in Kochi, Tokushima and Shionomisaki. Our temporary stations were placed in the earthquake area for the purpose of getting perfect and comprehensive data of distribution of the after shocks following the present great earthquake with co-operation of those permanent stations.

(a) Daily numbers of After-shocks.

Daily numbers of after-shocks observed at Tanabe, Shirahama, Muroto and Kochi are shown in Fig.6, where it will be noted that numbers of after shocks rapidly decreased with time during about a week from Dec. 21, 1946. After then, however, after shocks do not seem to decrease gradually, but rather seem to make quasi-periodic change in numbers of occurrence, sometime occurring as a group earthquake.

In a short word, the tendency of decreasing of after-shocks in the present case seems to fairly differ from that of usual one, which follows generally a hyperbolic curve with some fluctuations.[5]

(b) Distribution of origin of after-shocks.

In Fig. 7, the frequency curve of duration of preliminart tremor (P-S) of earthquake obtained at our seismological stations are given. As will be seen in this figure, there occurred many near earthquakes of less than 5 sec. in their duration of P-S at Tanabe, Shirahama and Kochi, while on the contrary few near earthquakes (less than 5 sec. in P-S) occurred at Muroto during the same period.

The distribution of epicentres of after-shocks, which were observed, at least, at three stations, are plotted in Fig. 4 , where we can see that those after-shocks were distributed in a wide area. The largest parts of origins of after-shocks given in the figure correspond to those earthquakes having longer P-S in each station.

While on the other hand, there were many cases that the after-shocks which were very near one station could not be observed at the other stations. It goes without saying that they wer local earthquakes. For the purpose of examining the local earthquake, we set especially a seismological net around the Tanabe Bay, it being composed of three stations mentioned in the foregoings.

The epicentres of earthquakes of less than 5 sec. in their P-S observed at Tanabe are plotted in Fig. 5, where we can see that many earthquakes occurred as a group just under Tanabe Bay. Quite the same phenomenon occurred in the neighborhood of Kochi and also in that of

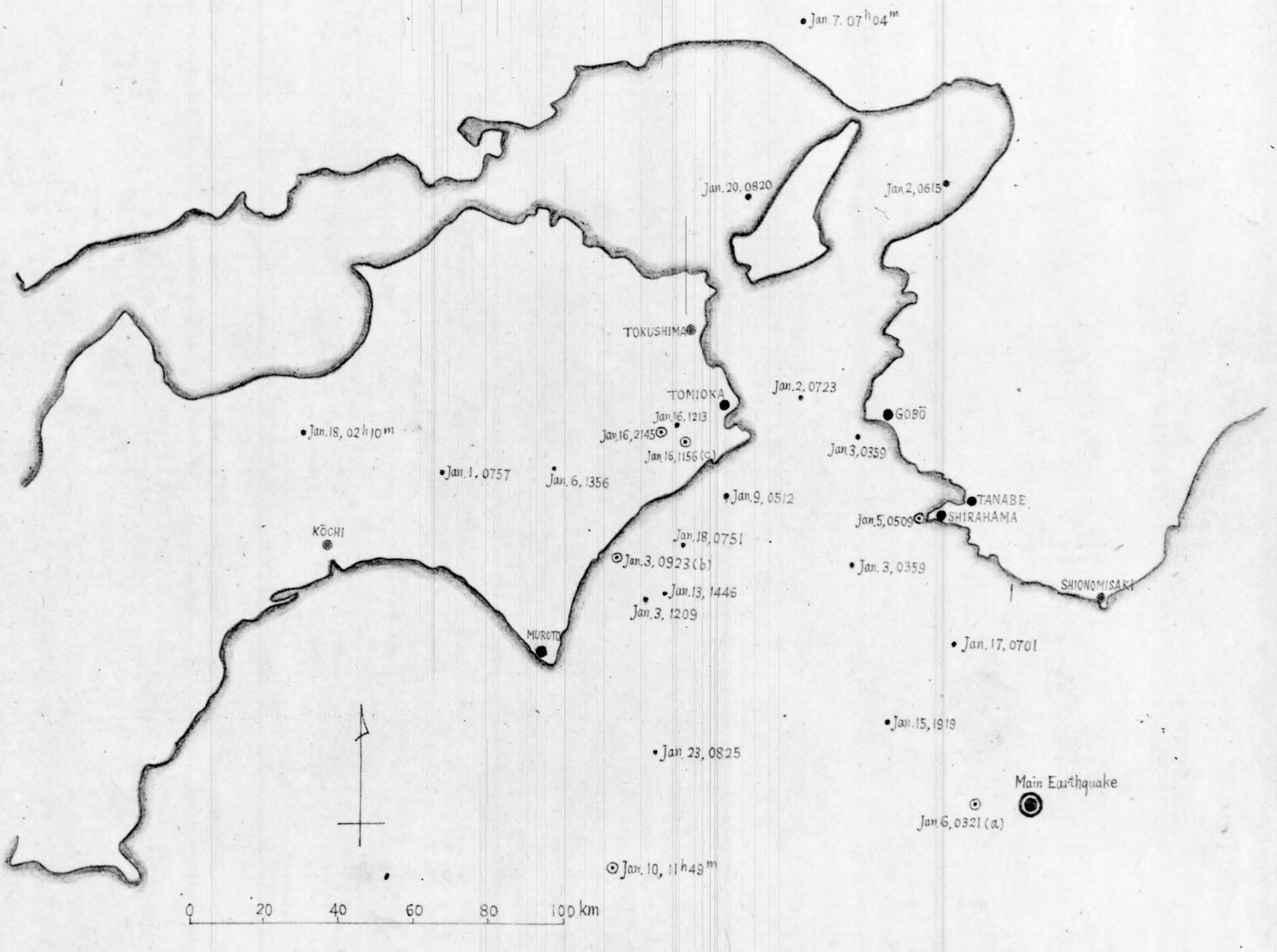


Fig. 4 Seismological Stations & Epicentre of Main After-Shocks.

Red Circles ; Stations of Tokyo Imperial University.

Violet Circles ; Stations of Meteorological Observatory.

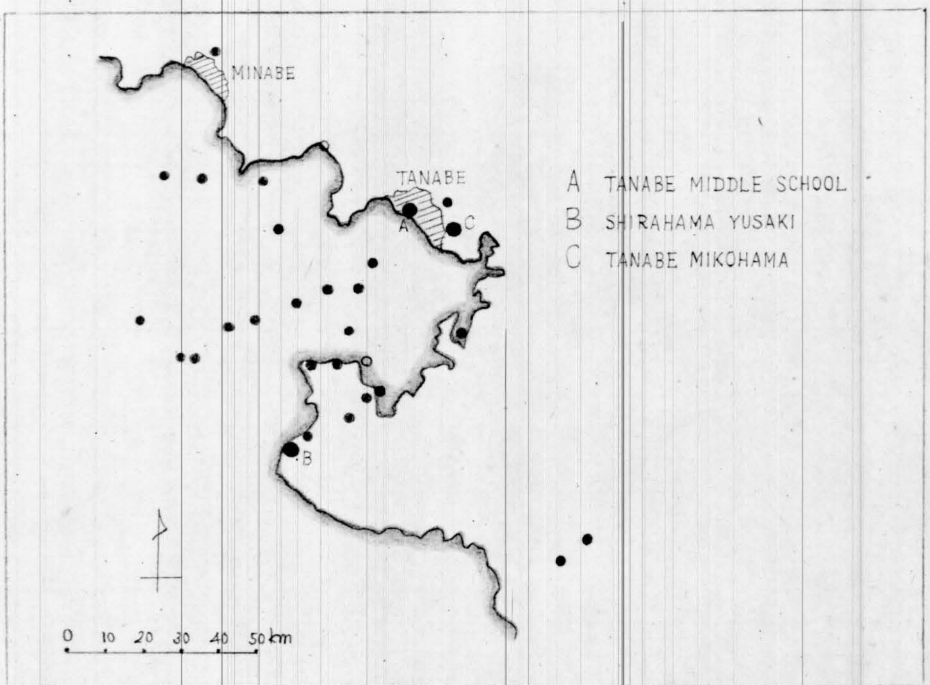


Fig. 5 Epicentres of Local Earthquakes in Bay of Tanabe.

Red Circles show Seismological Stations.

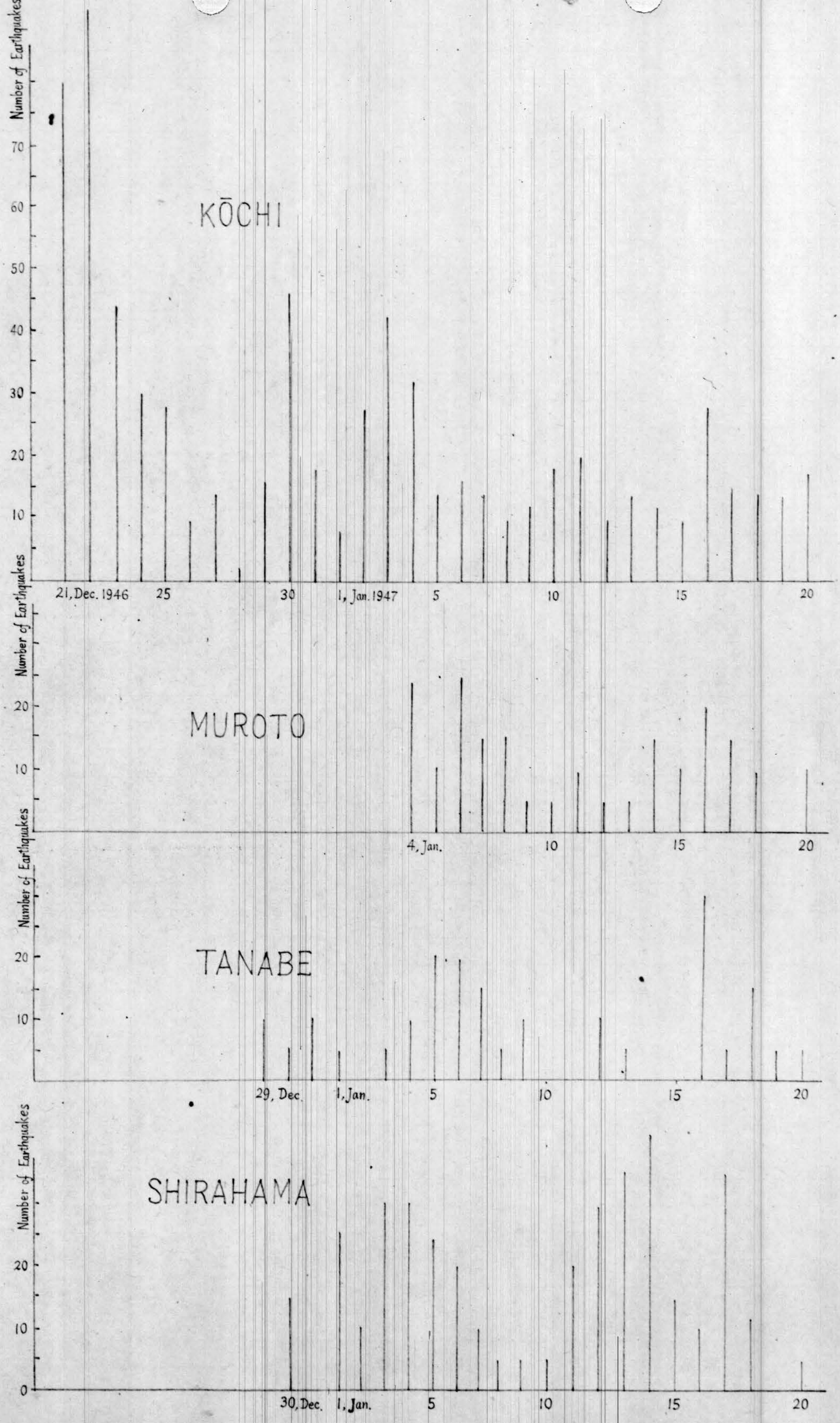


Fig. 6 Daily Number of After-Shocks at Kōchi, Muroto, Tanabe and Shirahama.

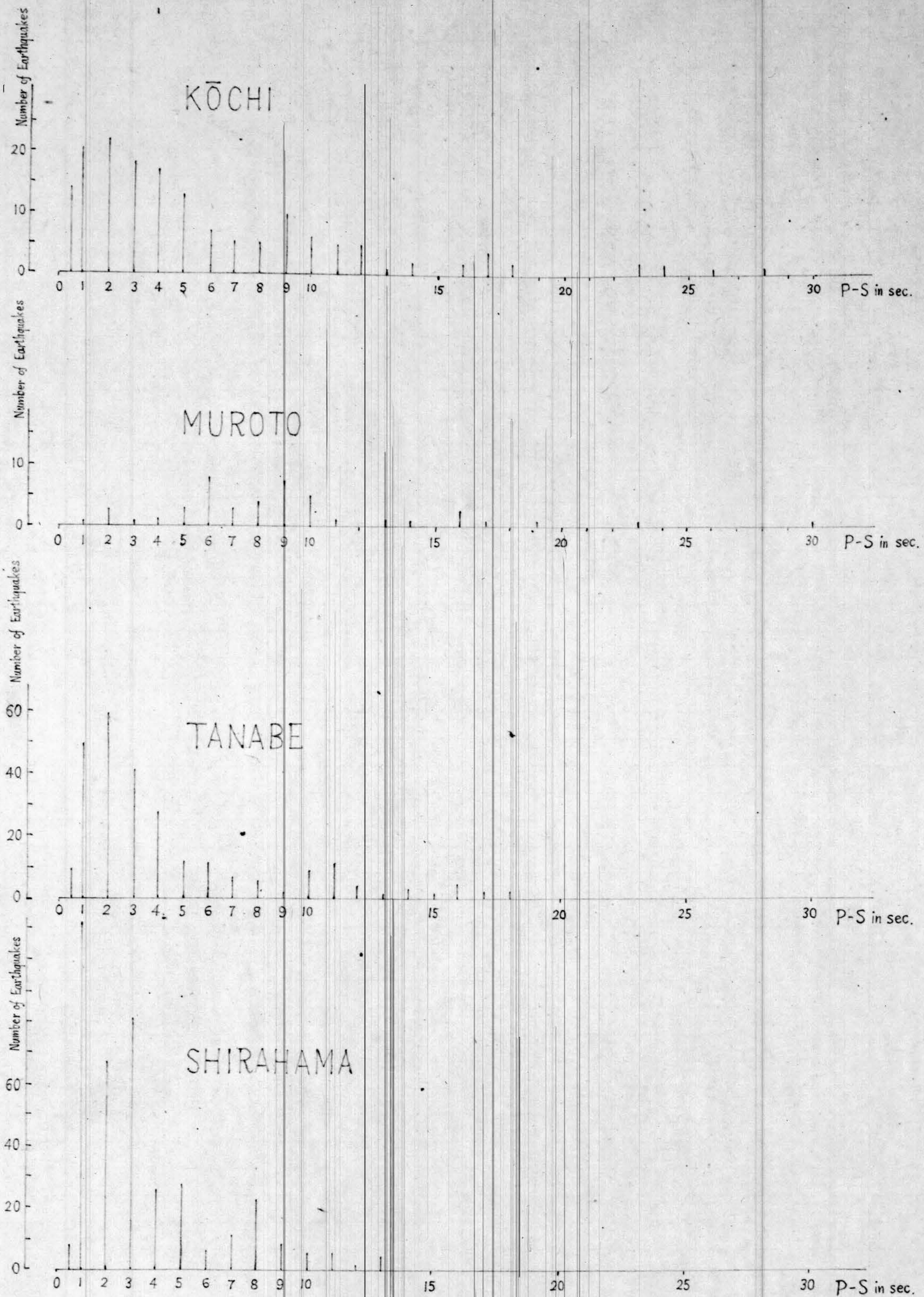


Fig. 7 Frequency of Time of Duration of Preliminary Tremors of After-Shocks observed at Kōchi, Muroto, Tanabe and Shirahama.

Tomioka. Although local earthquakes had scarecely occurred in the vicinity of Muroto until the end of January, there also the similar phenomenon began to take place from the middle of February.

Summarizing the above-mentioned facts, we can say that the present great earthquake was followed by groups of local minor earthquakes in various regions as well as those distributed generally in a wide area.

(c) Wave form of earthquake motions.

The wave form of earthquake motion has been especially studied with carefuly attention at Tanabe in the present opportunity. It has been generally said[6] that total duration of earthquake becomes larger and the shorter period vibration in earthquake is more attenuated according as the epicentral distance becomes larger.[7]

The above stated rule is, however, general one, and actual phenomenon seems to be subjected to more complicated conditions. A few typical examples of actual seismogram obtained by the same seismometer at the same point in Tanabe are shown in Fig.8. In this figure we can notice the following facts.

ex. 1. Earthquakes (B) and (E) are nearly the same with each other in their maximum amplitude as well as in their time of duration of preliminary trmor (P-S). While on the other hand, the time of total duration of (B) much differs from that of (E).

ex. 2. Although P-S time and maximum amplitude of earthquake (G) are nearly equal to those of (F), the latter contains short periods vibration much more than the former.

ex. 3 (H) is a example of near earthquake, short period vibration being predominant in its wave form. While, (C), (B), and (A) are rather distant earthquakes, in which the larger parts of short period vibration vanished.

ex. 4. Although P-S of (B) and (E) takes the nearly same value, the composition of (E) is much simpler than that of (B).

The above-mentioned discrepancy in the constitution of seismic wave will be first caused by difference in mechanism of occurrence of earthquake, and secondly by that in geological structure along the path of propagation. Although a definite explanation for the above-mentioned facts has not yet been obtained, it is believed at present that seismic wane passing through very simple stratum has a simple wave form and its time of total duration is comparatively short, while if it passes through multiple stratified strata, its form and duration become complicated and longer respectively, though seismic wave just emitted from its origin would also have different forms in different directions, as already pointed out by many seismologists.

Thus it can be concluded that the form of seismic wave observed at one place is generally much different owing to thoseconditions that (1) an-isotropic behaviour of emission at origin, (2) geological structure along the path of propagation[8], and (3) vibrational characteristics of the ground of the observing point.

(d) Statistical test for the mode of occurrence of after-shocks.

Whether or not there are persistency and periodicity in the mode of occurrence of after-shocks was examined, the result showing that there was a clear persistency but no definite periodicity, so far dealing with the data obtained until the present.

Next, statistical examination was made for relations between maximum amplitude of after-shocks and their frequency of occurrence and others, the result showing that the conclusions in (b) is satisfactory.

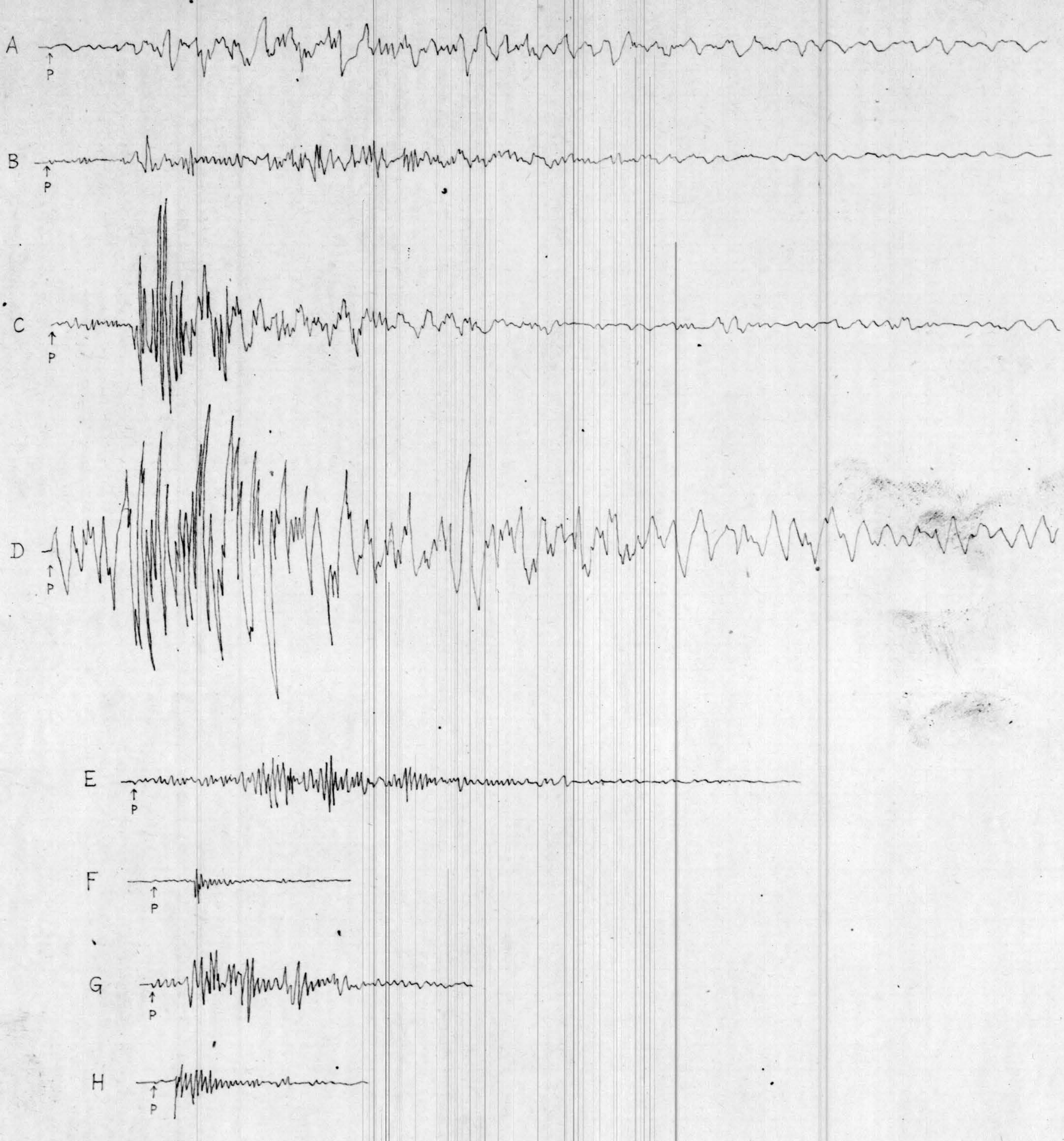


Fig. 8 Examples of Seismogram Obtained at Tanabe.

III. Crustal Deformation relating to the Earthquake.

Accompanying the occurrence of earthquake, the earth's crust in the neighbourhood of its origin is always more or less deformed. This is the conclusion[9] obtained from a lot of actual data of geodetic surveys which were carried out many times in the earthquake areas in Japan. On the other hand, according to the old records of past great earthquake in the south-west Japan, remarkable land deformation took place in the southern part of Shikoku in both cases of 1707 and 1854 earthquakes, that is, the neighbourhood of Kochi City subsided 1 or 1.5 meters, while the Cape of Muroto Peninsula rose up about 1.5 - 2.0 meters in both cases. Furthermore, the topography of the sea coast of Muroto Peninsula forms very typical marine-terrace, which is composed of many minute terraces 1 or 2 meters in height.

This fact may suggest that Muroto Peninsula has continued an upheaval movement, not continuously but probably stepwisely in occasions of occurrence of earthquakes.

While on the other hand, we can clearly see the mode of land deformation of the southern Shikoku and Kii Peninsula from the results of precise levelling survey carried out two or three times in those regions. In Figs. 9 and 10, the change in height along the levelling route during the period from 1895 to 1928-1930 is graphically shown.

As will be seen in Fig. 9, Muroto Peninsula subsided while Kochi Plain rose up during the period of 1895 - 1929. In 1935, the levelling route from Kochi City to the Cape Muroto was again re-surveyed, the result showing that the tendency of land deformation given in Fig. 9 still continued.

In Fig. 9 also, the southern part of Kii Peninsula subsided, while the mountain region in the central and northern parts of Kii Peninsula rose up during 35 years from 1895. A part of levelling route was again re-surveyed in 1937, the result showing that the above-mentioned movement still continued until 1937.

Since the amount of land deformation in the south-east Shikoku and Kii Peninsula during recent 40 years was markedly large, we had paid special attention to this phenomenon, it probably suggesting that the strain energy was accumulating into the earth's crust in the vicinity of the above-mentioned two districts.

For instance, A. Imamura, the former Professor of Seismology in our University, constructed three-special seismological stations at Tanabe in Kii Peninsula, Tomioka and Muroto in S-E Shikoku, where observations of earthquake and change in tilt of land had been carried out continuously until 1943. The aim of observations was, of-course, to keep watch for the earthquake expected to ccur in that district. Unfortunately however, the observation had been interupted from the beginning the War until the present, those stations being closed.

From the standpoints of view both empirical and theoretical, we could expect that the present great earthquake accompanied a fairly large land deformation in the districts mentioned above. Hence, we have planned to investigate especially in details the problem of curstal deformation in the earthquake area, the works being now carried out. Here, we shall deal with the results of work obtained until the present time.

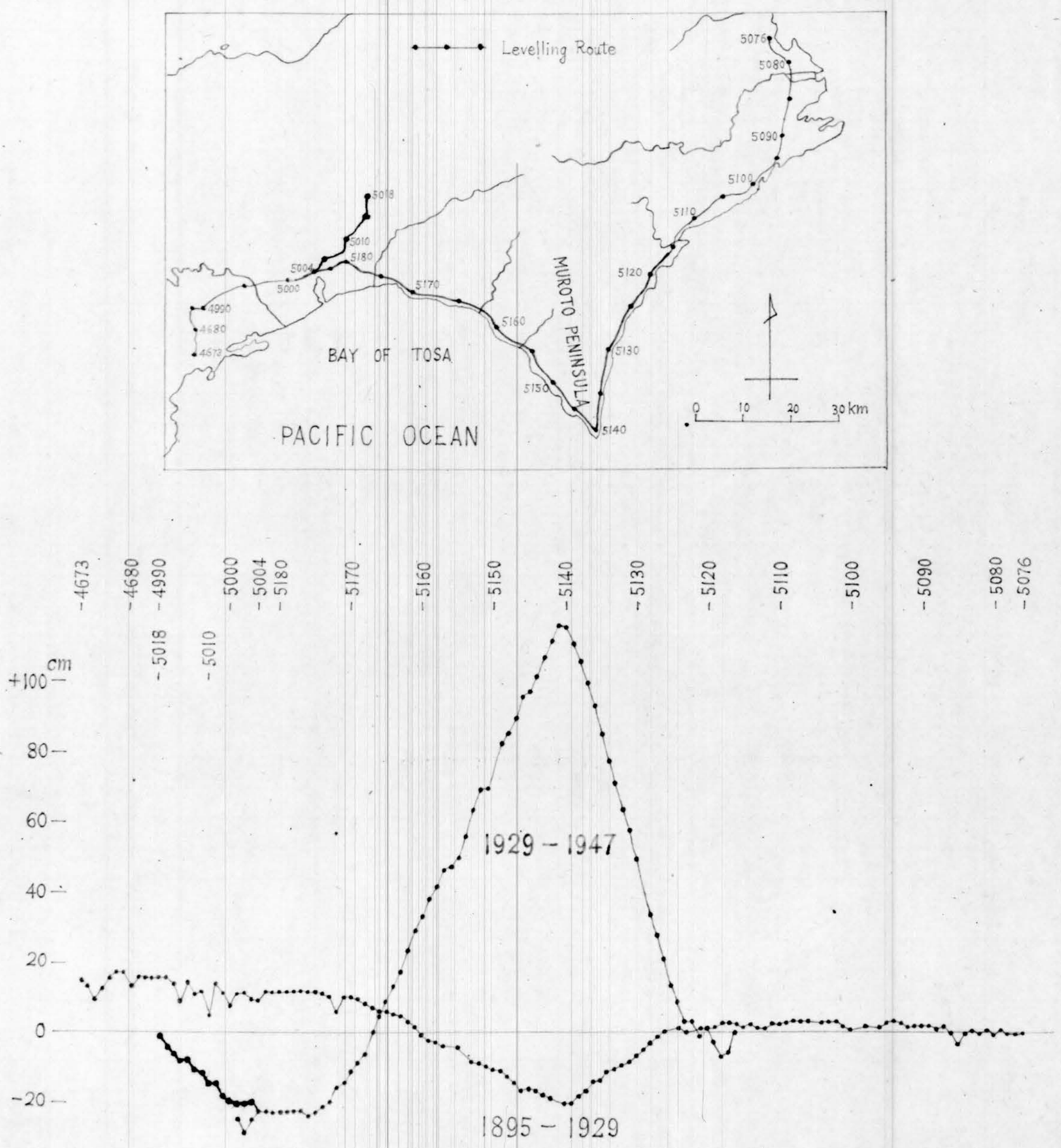


Fig. 9 Comparison of the Change accompanying the Earthquake with that before the Earthquake.
(Shikoku)

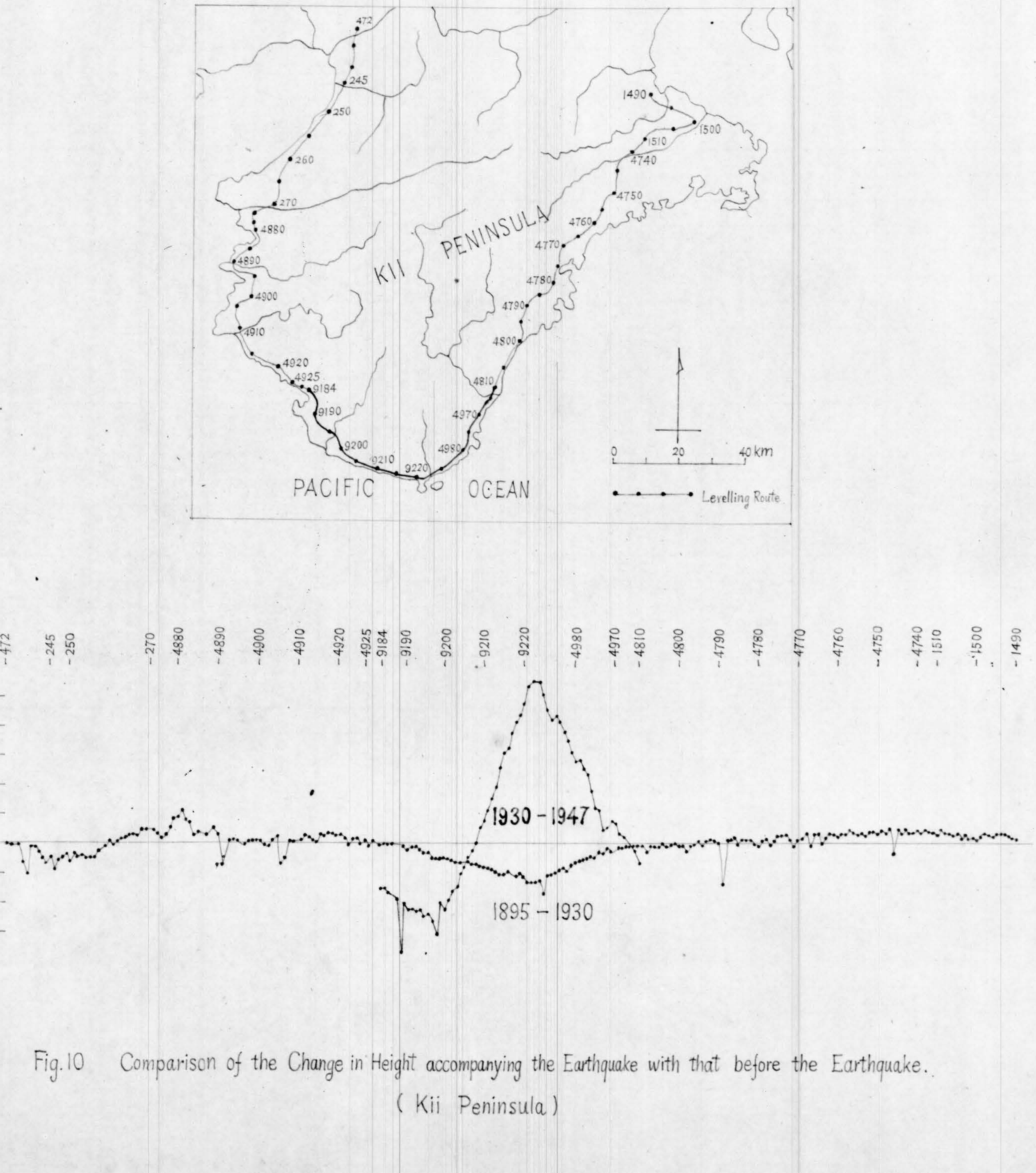


Fig. 10 Comparison of the Change in Height accompanying the Earthquake with that before the Earthquake.
(Kii Peninsula)

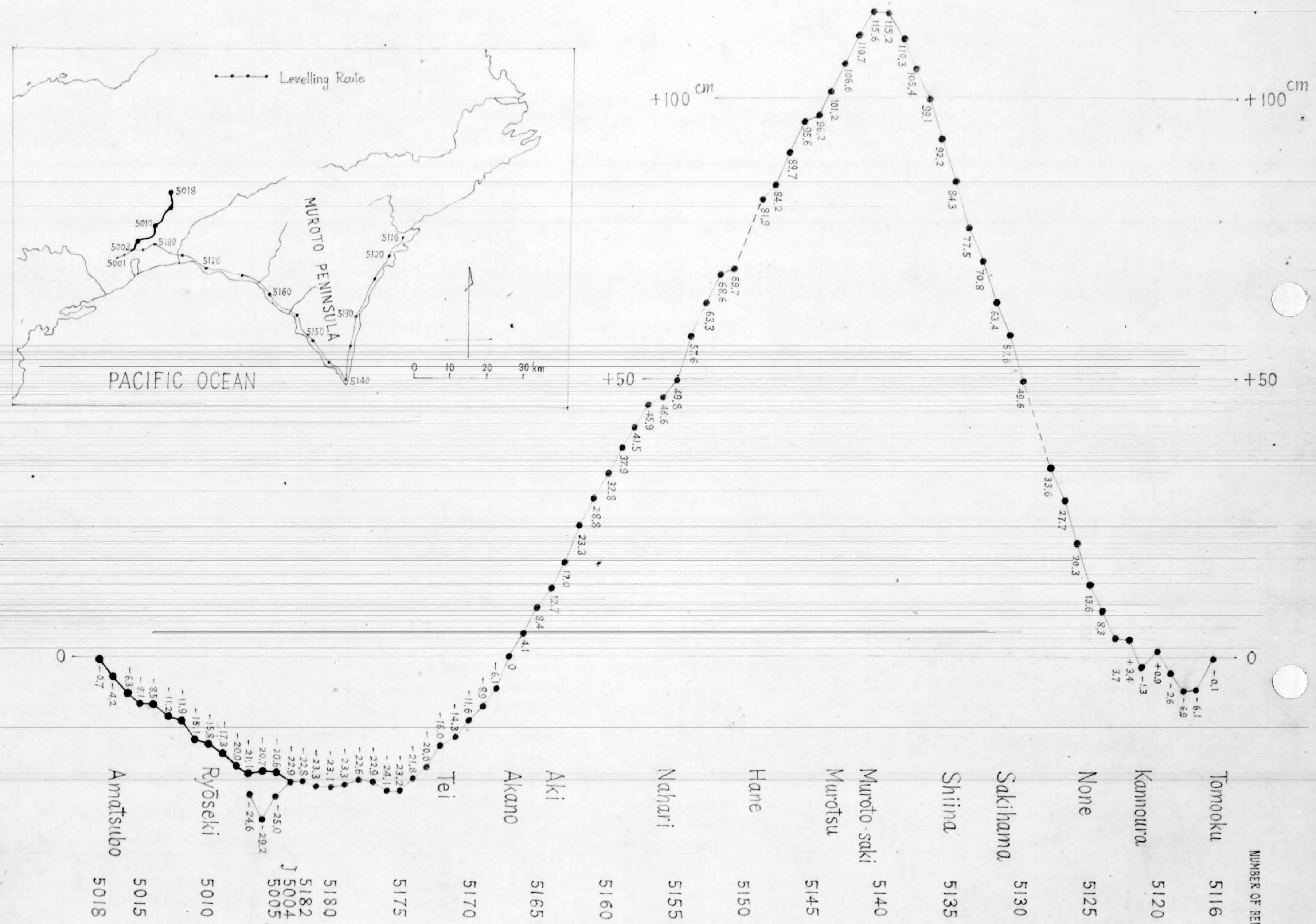


Fig. 11 Change in Height of Bench Marks in the South-Eastern Part of Shikoku during 1929 — 1947.

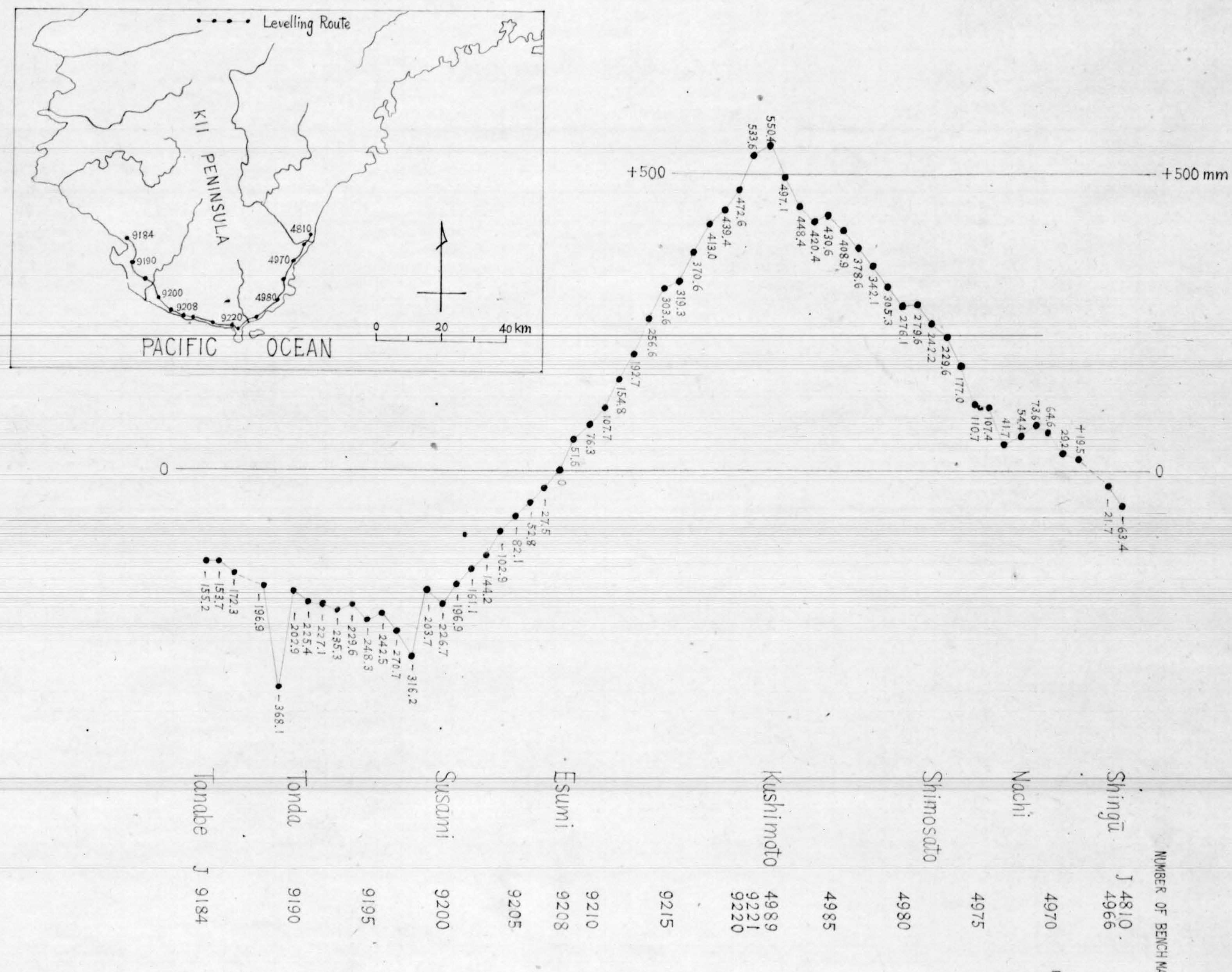


Fig. 12 Change in Height of Bench Marks in the Southern Part of Kii Peninsula during 1930 – 1947.

(i) Upheaval and Subsidence of the Sea Coast.

Amounts of upheaval or subsidence of the sea coast of the southern part of Shikoku and that of Kii Peninsula, which accompanied the present earthquake, were measured in various places referred to the average sea level, the result being given in Fig. 13.

As shown in Fig. 13, Muroto Peninsula rose up remarkably, the magnitude of upheaval of Cape Muroto amounting to 1.25 m, while on the contrary Kochi Plain and the eastern coast of Shikoku fairly subsided.

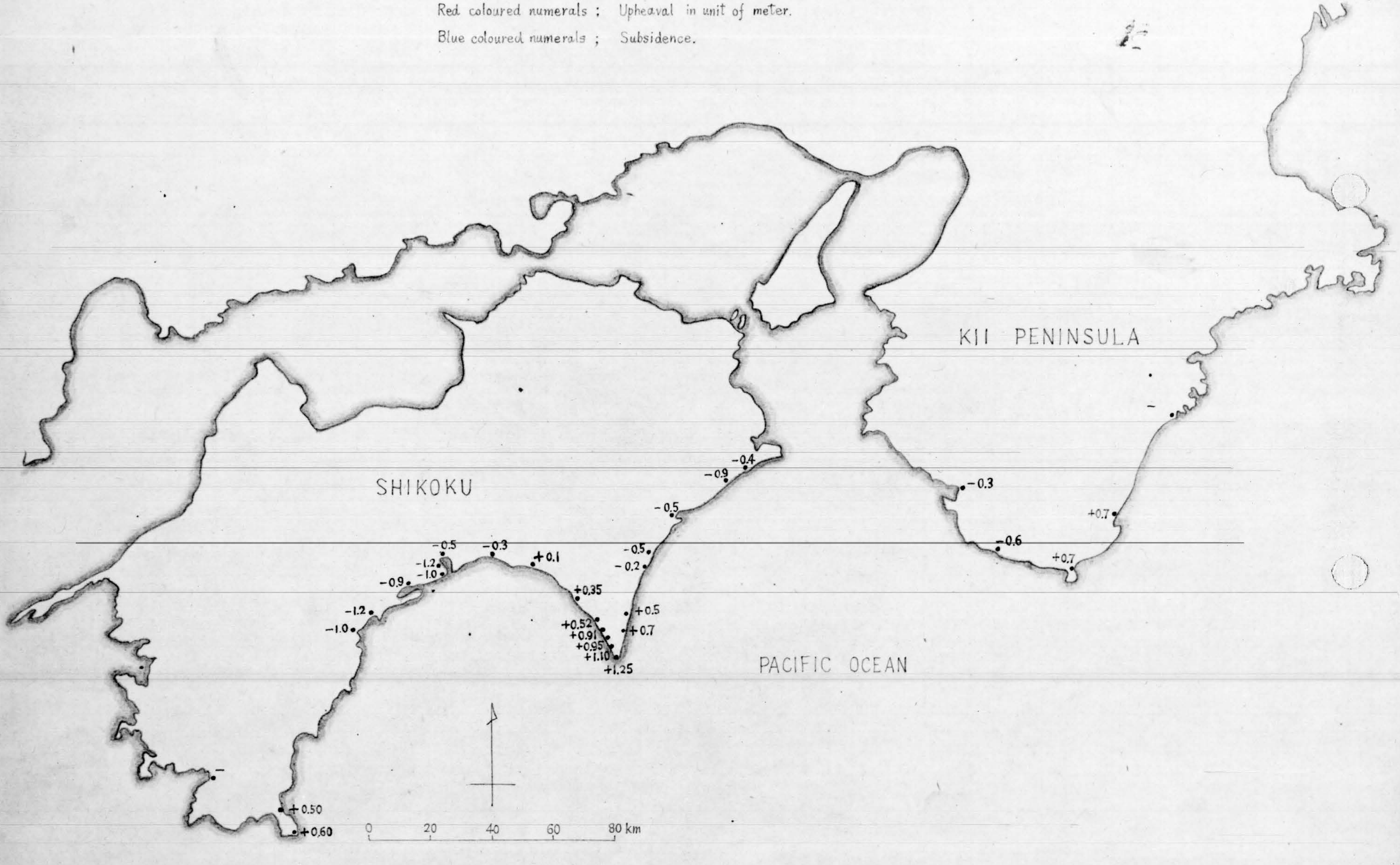
In Kii Peninsula also, the southern cape also rose up about 0.7 m, while the northern parts were rather depressed. Comparing Fig. 13 with Figs. 9 and 10, we may say that the mode of deformation of sea coast accompanying the present earthquake was just in the opposite sence against that of deformation continued gradually during, at least, a few tens years before the occurrence of the present earthquake.

(ii) Result of Precise Levelling.

In order to make clear the above-mentioned land deformation, we carried out the re-survey of precise levelling along the routes on the sea coasts of Kii Peninsula and the South-East part of Shikoku with the co-operation by the members of Geographical Survey Bureau.

Fig.11shows the change in height of bench marks in the South Eastern part of Shikoku during the period of 1929-1947, while Fig12 shows that in the Southern Kii Peninsula during 1930-1947. Here, it must be mentioned that those numberical values of height change are, strictly speaking, not absolute ones.
Since the deformed area was so wide that we could not extend our levelling route to a bench mark, which is considered to be quite safe from the land deformation, being possible to be taken as the base-point of no-change. Hence we arbitrarily assumed that Bench Mark No.5107 and No.9208 did not change during the period mentioned above in Shikoku and Kii Peninsula respectively. Since, however, the assumption is derived from the fact that the beach lines just near those base bench marks scarecely changed accompanying the earthquake, the curves given in Figs.11 and12 will express approximately the true change in height. Strictly speaking, however, those curves mean the sum of the true change and a small constant value which is common for all bench marks among one continuous route.

Fig. 13 Change in Height of Sea Coast due to the Land Deformation accompanying the Present Earthquake.



It is believed here that, almost all parts of the change shown in Figs.11and12 took place rather abruptly accompanying the earthquake on Dec. 21, 1946.

In Fig.11,it is clearly seen that Muroto Peninsula upheaved accompanying the earthquake and the amount of upheaval becomes larger in the more southward place, it exceeding one meter at the cape of the South end, while on the contrary the plain area in the vicinity of Kochi City fairly subsided.

In Fig12, the most southern part of Kii Peninsula upheaved about 55 cm, while the amount of upheaval gradually decreases in proportioh as the bench mark becomes the more northward point ___both in the Western and Eastern coarsts of Kii Peninsula ____, and the Northern part of the surveyed area subsided in 20 - 30 cm on the contrary.

Generally speaking, the Southern regions of both of Shikoku and Kii Peninsula were inclined northwards accompanying the present earthquake, it resulting the land sinking in the Northern part and rising in the Southern part.

In Figs. 9 and 10, the changes in height of the same levelling routes during the period of 1895-1929 for Shikoku and during 1895-1930 for Kii Penonsula are shown together with those during 1929-1947 and 1930-1947 respectively. Comparing the change during 1929-1947 __which mostly accompanied the present earthquake __with that during 1895-1929 in Fig. 9, we can find out that the mode of the former is almost opposit to the latter in the sence of their change.

On the other hand, examining in details the old historical records about the great earthquakes in 1707 and 1854, we can find out that the mode of land deformation in Muroto and its vicinity accompanying those great earthquakes was just the same as that in the present case, so far concerning with data which the old record dealt with. Thus, we may presume that, during the recent historical ages, the Southern Shikoku repeated intermittently such a marked land deformation as occurred at the occasion of present great earthquake.

We must take into consideration further that the topography of Muroto Peninsula is characterized by the regularly arranged marine terraces, the old beach lines becoming higher in proportion as the observing point comes to the more ~~nor~~ sou thward place. For example, from the result of his detailed ~~topographic~~ geomorphological survey, A. Watanabe[10] has concluded that Muroto Peninsula and its vicinity have made such a land deformation during ~~the later Quaternary~~ Pleistocene as shown in Fig.14(a), where the areas marked by (+) and (-) denote respectively the upheaving and subsiding areas, while the line between (+) and (-) areas means the nodal line where is no change. Comparing Fig.14(a) with Fig.14(b), which shows the deformation during 1895-1929, and Fig.14(c) showing the deformation accompanying the present earthquake, we may conclude that Fig.14(a) and Fig.14(c) agree with each other in their tendency, while Fig.14(b) is opposit to the former two.

This conclusion will lead us to find out that the land deformation accompanying the great earthquakes __including the cases of past earthquakes __agrees with the general tendency of land deformation in this

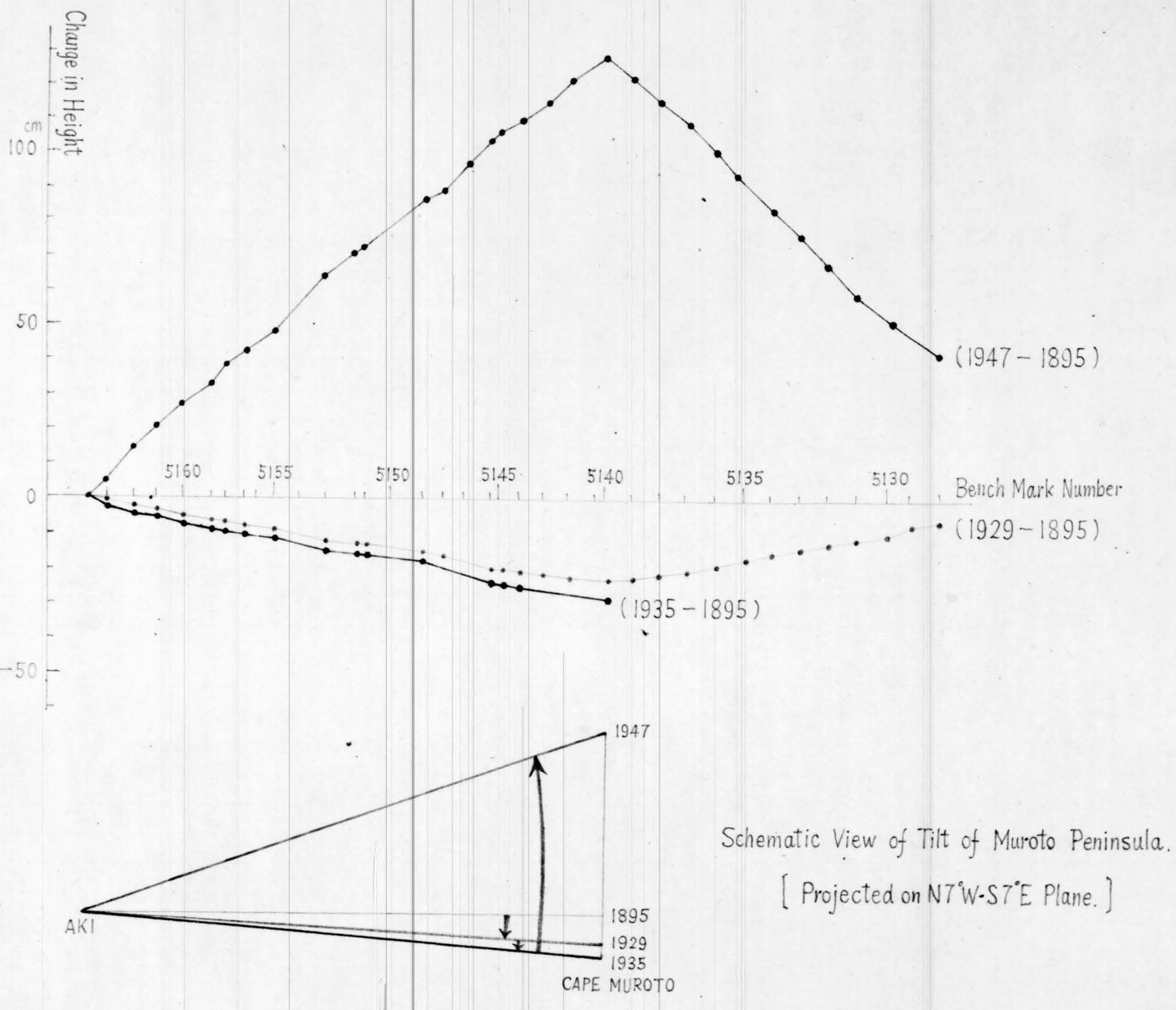


Fig. 15 Change in Height of Bench Marks along the Route in Muroto

district during the later Quaternary, and that the deformation continuing more than 40 years before the present earthquake is opposit to the general tendency mentioned above.

In the case of Kii Peninsula shown in Fig.10, the general behaviour seems to be nearly same as that in the case of Shikoku; that is, the mode of change during 1930-1947 is nearly opposit to that during 1895-1930. Since, however, there occurred a great earthquake in 1944 at the sea bottom just east of Kii Peninsula, the land of Kii should be affected by this earthquake. Therefore, it will be rather resasonable to presume that the obtained land deformation of Kii Peninsula, at least in its Eastern half, during 1930-1947 includes the effect of 1944 earthquake and that of the present one.

(iii) Special Investigation on Tilting Motion in the Neighbourhood of Cape Muroto.

For the purpose of examining the tilting motion of Muroto Peninsula in details, we planned to carry out the levelling survey frequently along a short route at Cape Muroto about 14km long. After the earthquake, the survey work was carried out three times, the dates of survey being as follows:

1947(I) , Jan.7 - Jan.13,1947,
1947(II) ,Jan.30 - Feb.3,1947,
1947(III),Mar.3 - Mar.5, 1947.

The change in height of bench marks during the periods of 1895-1929, (before the earthquake), 1929-1947(I) (including the time of occurrence of the earthquake), 1947(I)-1947(II), and 1947(II)-1947(III), (both after the earthquake), are shown in Fig.6, where the change of bench mark No.5144 is assumed to be always zero.

Hence, the amount of change given in Fig.16 being the relative one compared with the base bench mark No.5144, the results shown in this figure are considered to show the tilt of land.

The deformation during 1895-1929 shows that Muroto Peninsula had been inclined into the direction of S10°E, i.e. the S10°E side had subsided compared with N10°W side, the magnitude of tilt during 34 years amounting to 1.2".

In 1935, the levelling re-survey was again carried out along the route from Cape Muroto to Aki on the west-side coast of Muroto Peninsula. Although that survey did not cover the whole area which we are now examining, we can find out, at least, that the change during 1929-1935 was an extension of the change during 1895-1929 not only in its mode but in its rate of change also, the total magnitude of tilt during 40 years of 1895-1935 amounting to about 1.4".

Next, the change accompanying the present earthquake, shown in Fig.16(b), was exactly opposit in its sence of change to that during 1895-1929, i.e. Muroto Misaki was inclined into the direction of N10°W, the magnitude of change during this period amounting to about 6.6". For the purpose of showing more clearly the above-mentioned regular change, the relative values of change of each bench mark projected on a vertical plane of N10°W - S10°E in direction are shown in Fig.17.

While, as will be seen in Fig.16(c) and (d), the changes during the periods of 1947(I)-(II) and (II) -(III) were not so monotonous as those during 1895-1929 and 1929-1947(I). However, as shown in Fig.17 where the changes during 1947(I)-(II) and (II)-(III) are also projected on the N10°W–S10°E plane, Muroto Misaki after the earthquake is, generally speaking, inclining again into the southward direction, and moreover the time-rate of the southward tilt has been decreasing with time. The general tendency of tilt of Muroto Misaki before, accompanying and after the present earthquake, projected on the N10°W–S10°E plane, is tabulated in the following table and graphically shown in Fig.18.

Time	Amount of Tilt	Change in Tilt	Rate of Change
1895	0 (assumed)		
1929	- 1.2"	-1.2"	-10×10^{-5} "/day
1935	- 1.4"	-0.2"	-9×10^{-5} "
1947(I)	+ 5.2"	+6.6"	
1947(II	+ 4.6"	-0.6"	-3×10^{-2} "
1947(III)	+ 4.1"	-0.5"	-1.7×10^{-2} "

From those results, we can conclude that Muroto Peninsula had been inclined southwards with almost constant rate during more than 40 years before the present earthquake, it rebounding abruptly at the time of occurrence of the earthquake, and then the deformation in excess at that occasion is now settling.

The levelling surveys are still continued at present. After those works are completed, the general aspect of the land deformation relating to the present great earthquake will be much more cleared.

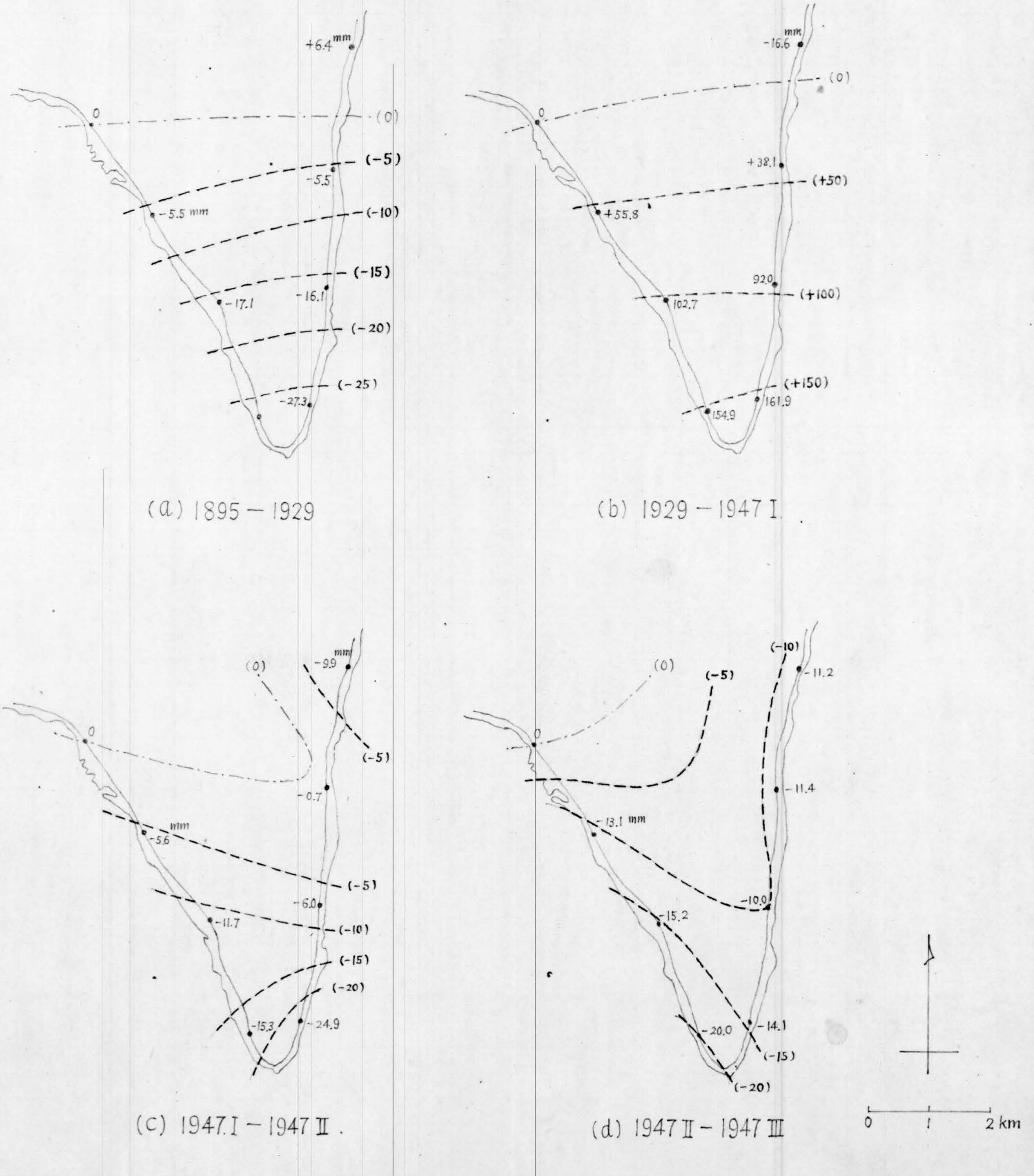


Fig. 16 Land Deformation in the Vicinity of Cape Muroto before, accompanying and after the Earthquake.

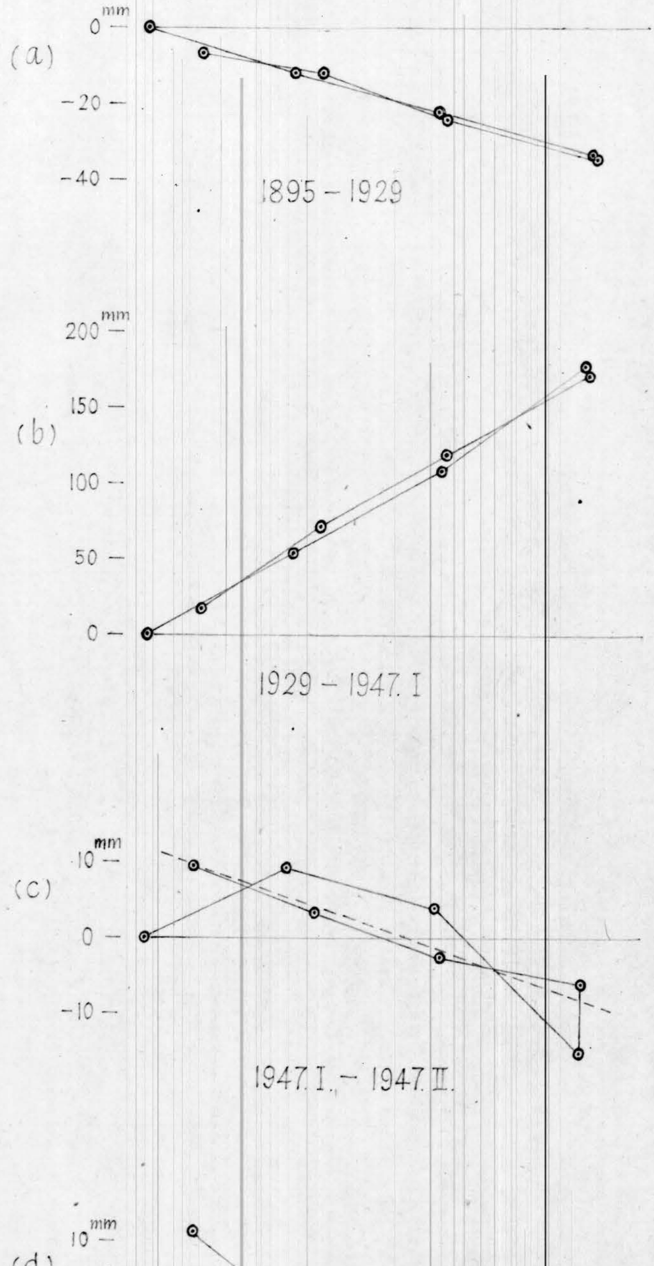


Fig. 17 Tilt of the Land in the Vicinity of Cape Muroto Projected on N 10°W – S 10°E Plane.

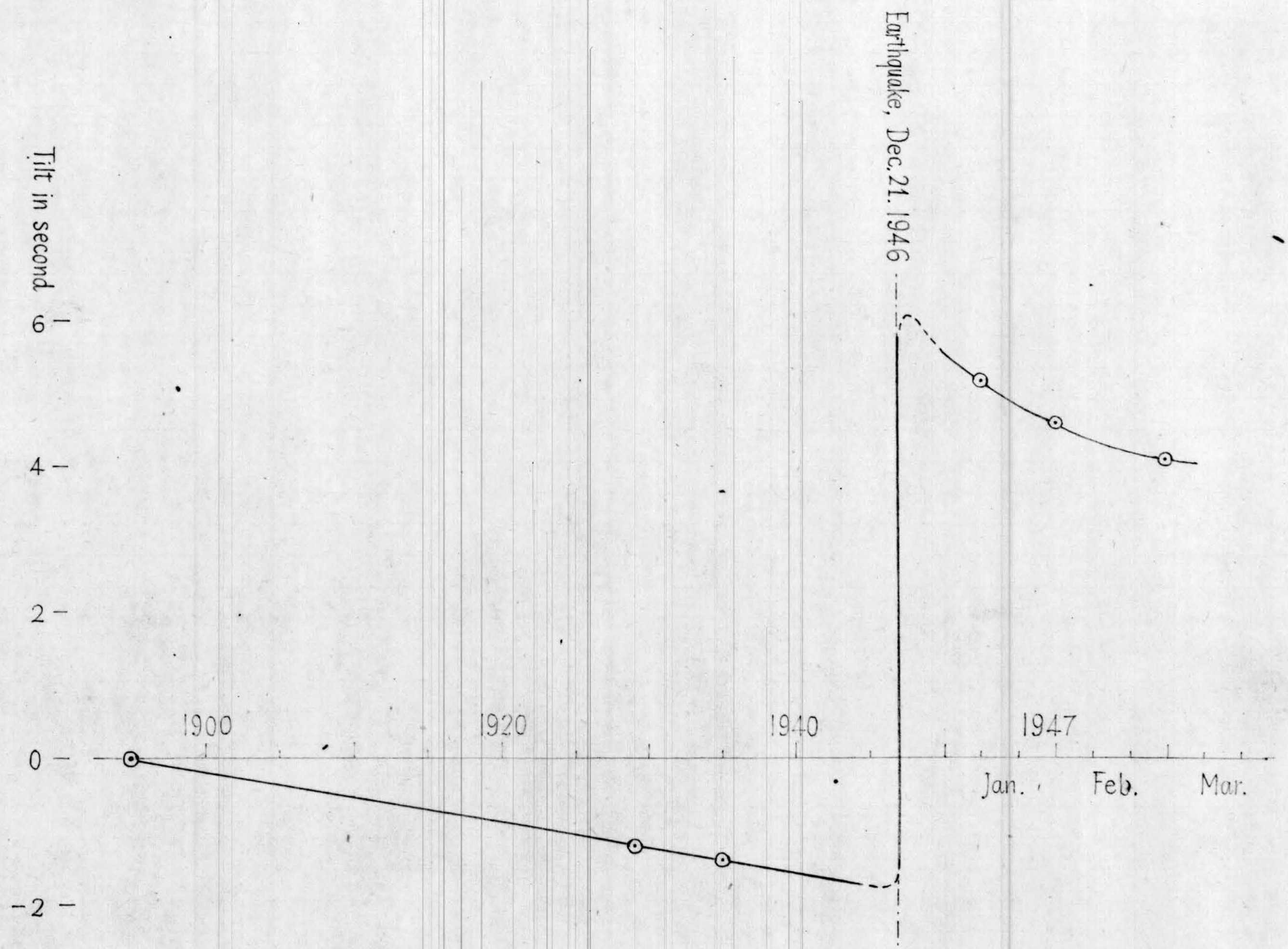


Fig. 18 The General Tendency of Tilting Motion of Muroto Peninsula during the Period of 1895 – 1947 March.

(iv) General Remark on the Land Deformation.

Judging from the foregoing data, we can presume the following schematic mechanism of occurrence of the present earthquake. The earth's crust of the south-west Japan had been deformed gradually owing to some strong force in the subterranean structure, it resulting gradual progress of tilt in Muroto Peninsula as well as in other nieghbour districts. When the strain of the crust reached its breaking strain (about 1/10000), the energy accumulated in the crust was released, a part of energy being propagated as the seismic wave, while the other became the potential energy for land deformation. At the same time, the earth's crust broken down rebounded, this phenomenon resulting Tsunami in the sea and observed tilt on the land. And it is presumed that it will need about 100 years for the earth's crust to reach its breaking strain.

It will need, however, more comprehensive measurement of land deformation to prove the hypothesis mentioned above completely. Fortunately, the levelling survey on Shikoku and the southern part of Kii Peninsula is now carried out by the members of the Geographical Survey Bureau, Department of Home Affairs, at our disposal, and moreover triangulation surveys will also be made in near future. After those works are completed, we shall be able to get more rigorous view of land deformation due to the present earthquake.

(42)

IV. Tsunami (Sea Wave due to Earthquake).

Accompanying the present great earthquake, there occurred great Tsunami wave (large sea wave due to earthquake) in the sea surrounding the epicentre, and many towns and villages along the sea coast of Shikoku and Kii Peninsula were covered and destroyed by the waves.

The distribution of height of Tsunami in various ways were investigated, the results being shown in Fig. 19(1) -(13). As well known, the height of Tsunami in a bay is first subjected to the power of primary Tsunami arriving at the mouth of the bay from its origin, and secondly to the shape and slope of the bottom of the bay. The relation between the mode of distribution of Tsunami and topography of bay can be seen in many actual examples given in Fig.19.

For examples, the records of Tsunami wave observed at Sakai in Osaka Prefecture and at Shimotsu in Wakayama Prefecture are shown in Fig. 20, where we can find that the initial phase of Tsunami at those two stations was pull, i.e. decrease of sea level, and then extreme increase of sea level repeated, at least, a few times.

Next, we shall deal here with time (τ) from the occurrence of earthquake to the arrival of Tsunami. The distribution of τ along the sea coasts are shown in Fig.19. Time means the difference of time of travel of Tsunami (from its origin to the observing point) from that of seismic wave. Since we can estimate the velocities of propagation of both of Tsunami and Seismic wave, we can calculate the distance of the origin of Tsunami from the observing point. Here, the velocity v of propagation of Tsunami is given by that of long wave $v = \sqrt{gh}$, where h denotes the depth of the sea.

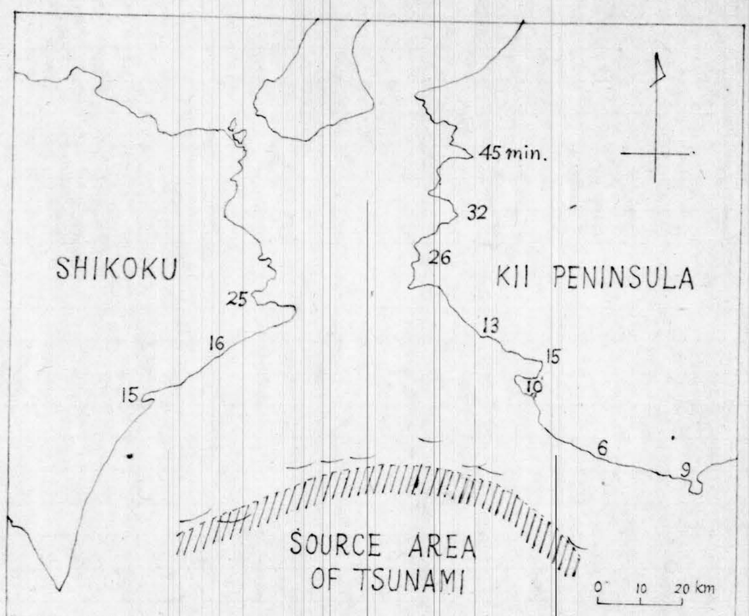


Fig. 9. The Source Area of Tsunami Accompanying the Earthquake on Dec. 21. 1946.

Numerals denote the difference between the arrival time of Tsunami from that of earthquake at respective observing points.

(43)

By means of numerical integration, we could determine the possible locus of position of origin of Tsunami corresponding to each observing point. The results of actual estimation are shown in Fig.21, where it will be clearly seen that those locus curves do not converge to a special point. This fact may show that the origin of Tsunami was not a small area, but it should have rather wide area. Then, we can interplet that the envelope for the group of those locus curves corresponds to the margin of source-region of Tsunami.

As shown in the figure, the area of source of Tsunami was fairly large, surrounding the epicentre of the earthquake itself. Comparing the above-mentioned conclusion with the fact that the land deformation took place in the wide area including Shikoku and Kii Peninsula, we can presume that the crustal movement in the sea bottom, which caused the Tsunami wave, had also a wide area and probably connected closely to the deformation on the lands.

As mentioned in the introduction , the damages due to Tsunami was the largest one in the presne earthquake, hence a few actual examples of the damages are shown in Photos.

INDEX MAP

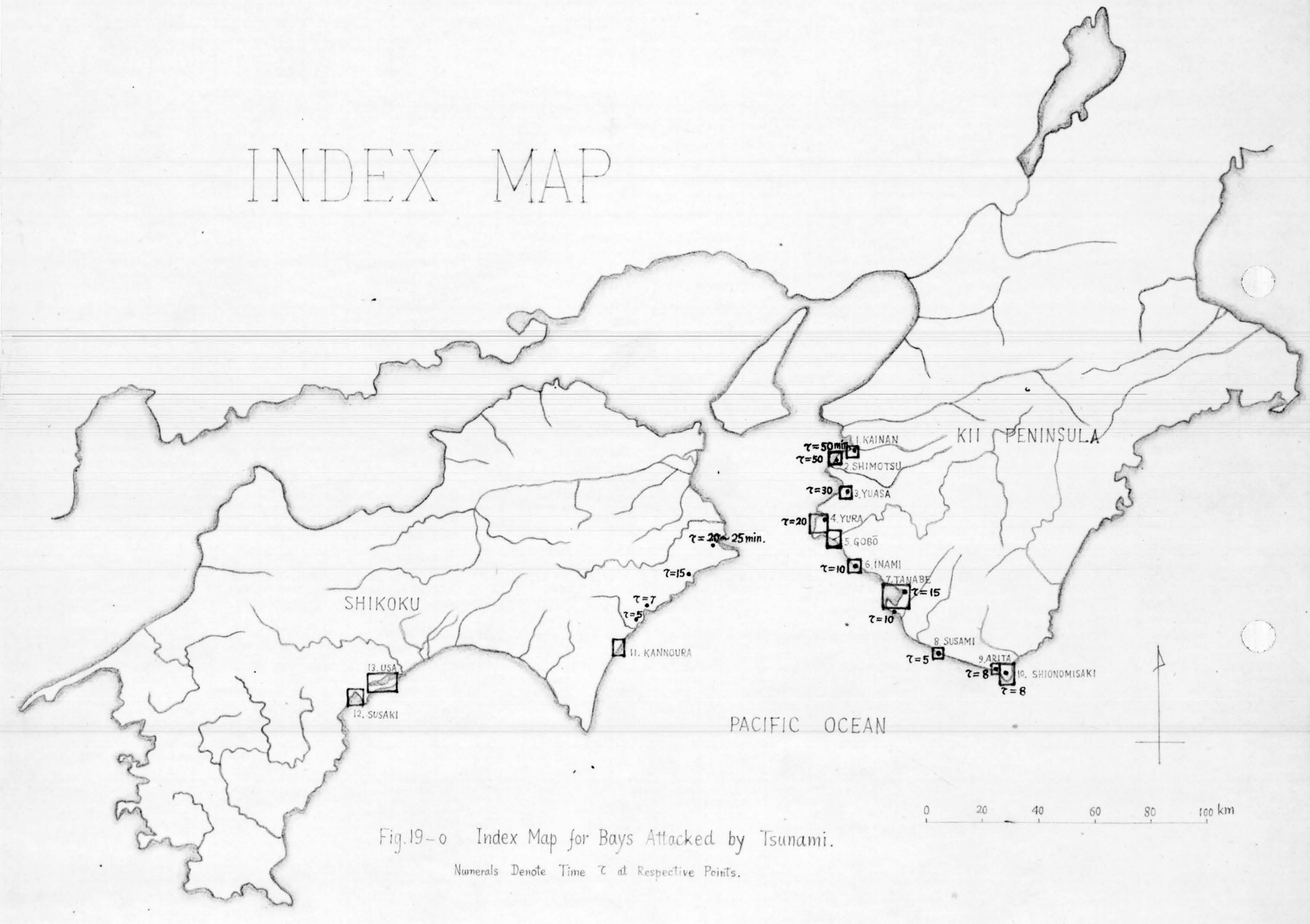


Fig. 19-0 Index Map for Bays Attacked by Tsunami.

Numerals Denote Time τ at Respective Points.

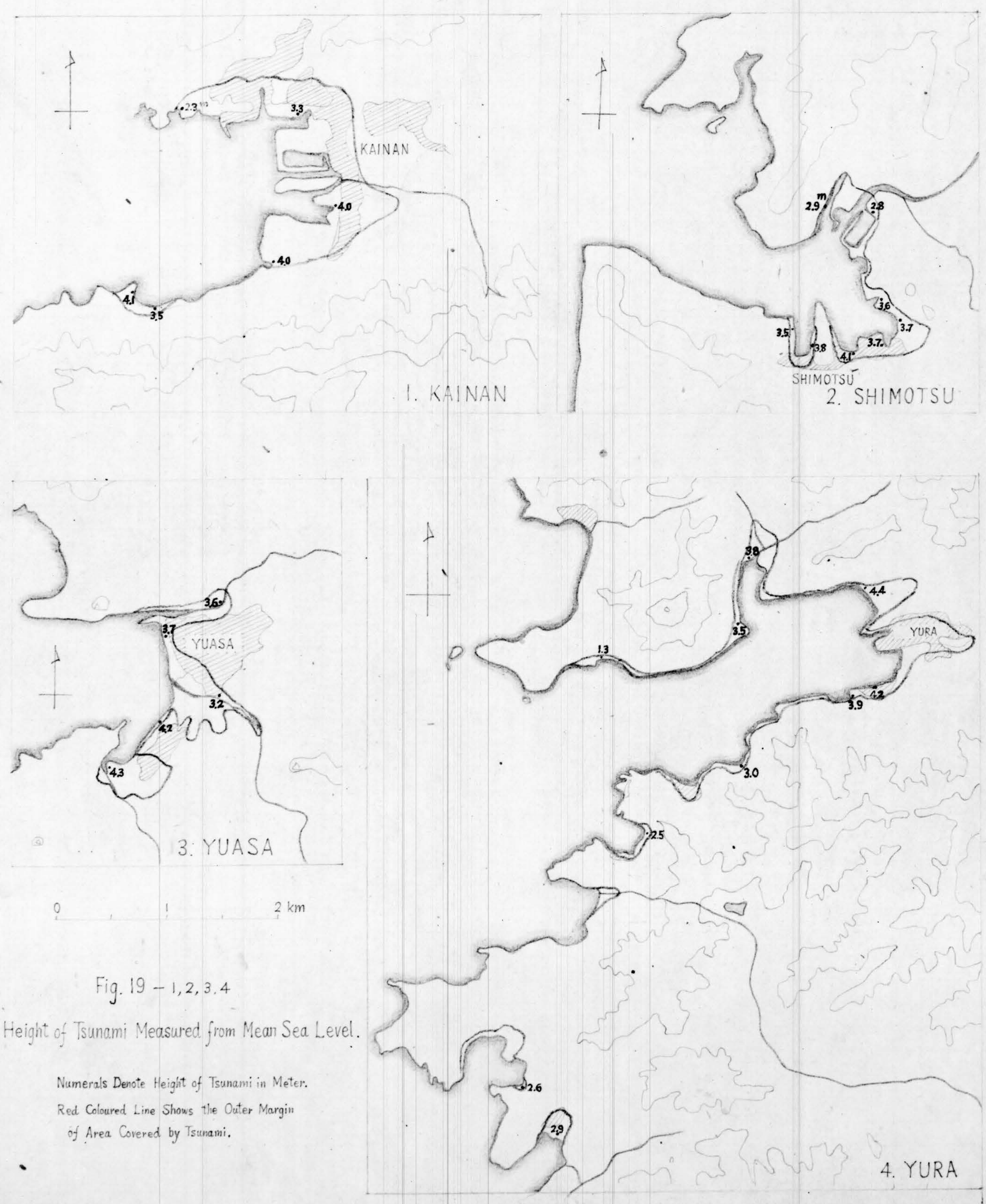
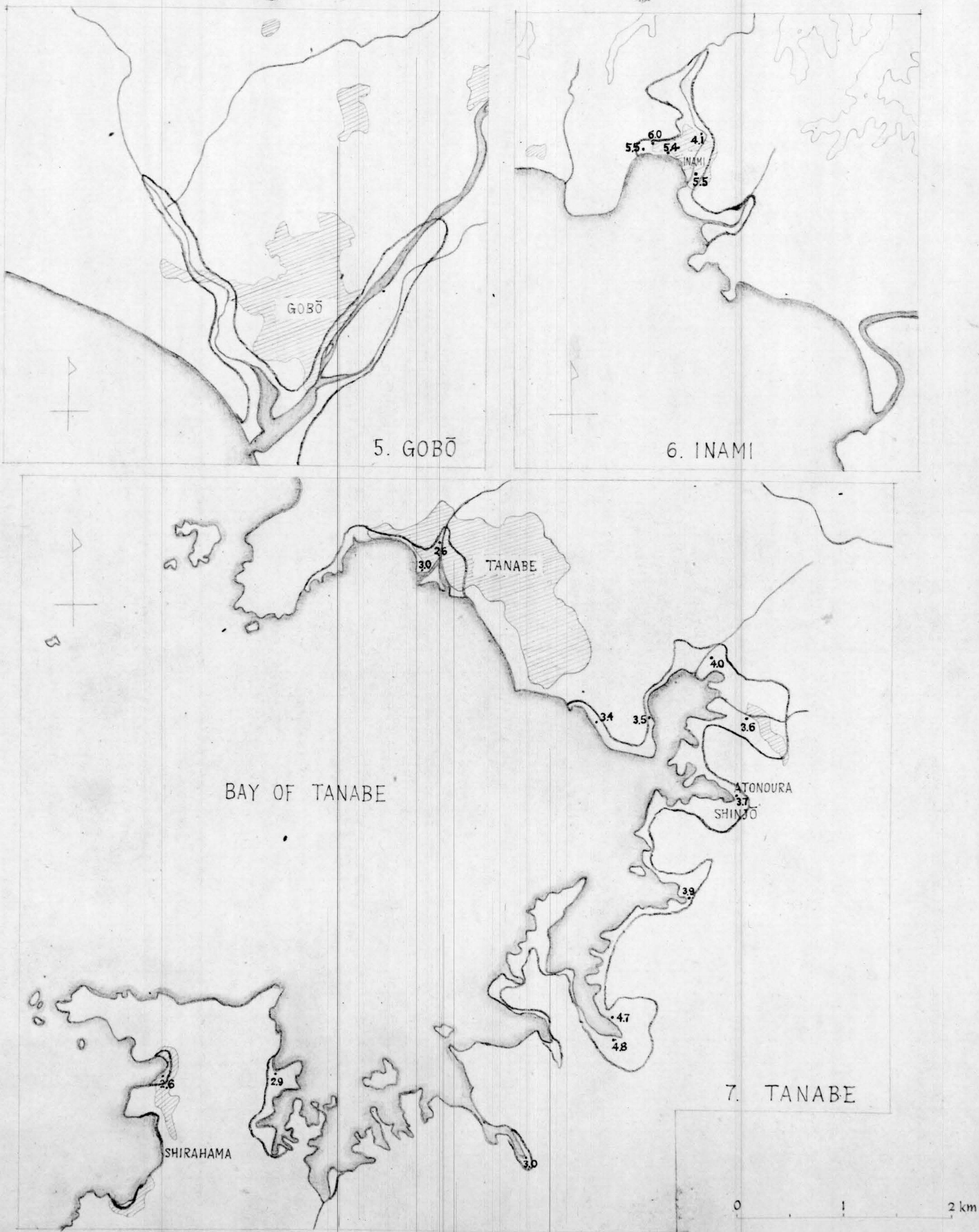


Fig. 19 – 1, 2, 3. 4

Height of Tsunami Measured from Mean Sea Level.

Numerals Denote Height of Tsunami in Meter.
Red Coloured Line Shows the Outer Margin of Area Covered by Tsunami.



GOBŌ
5. GOBŌ
6.0
5.5
5.4
4.1
INAMI
5.5
6. INAMI
2.6
3.0
TANABE
4.0
3.4
3.5
3.6
ATONOURA
3.7
SHINJŌ
BAY OF TANABE
3.9
4.7
4.8
2.9
2.6
SHIRAHAMA
3.0
7. TANABE
0
1
2 km

Fig. 19 — 5, 6, 7

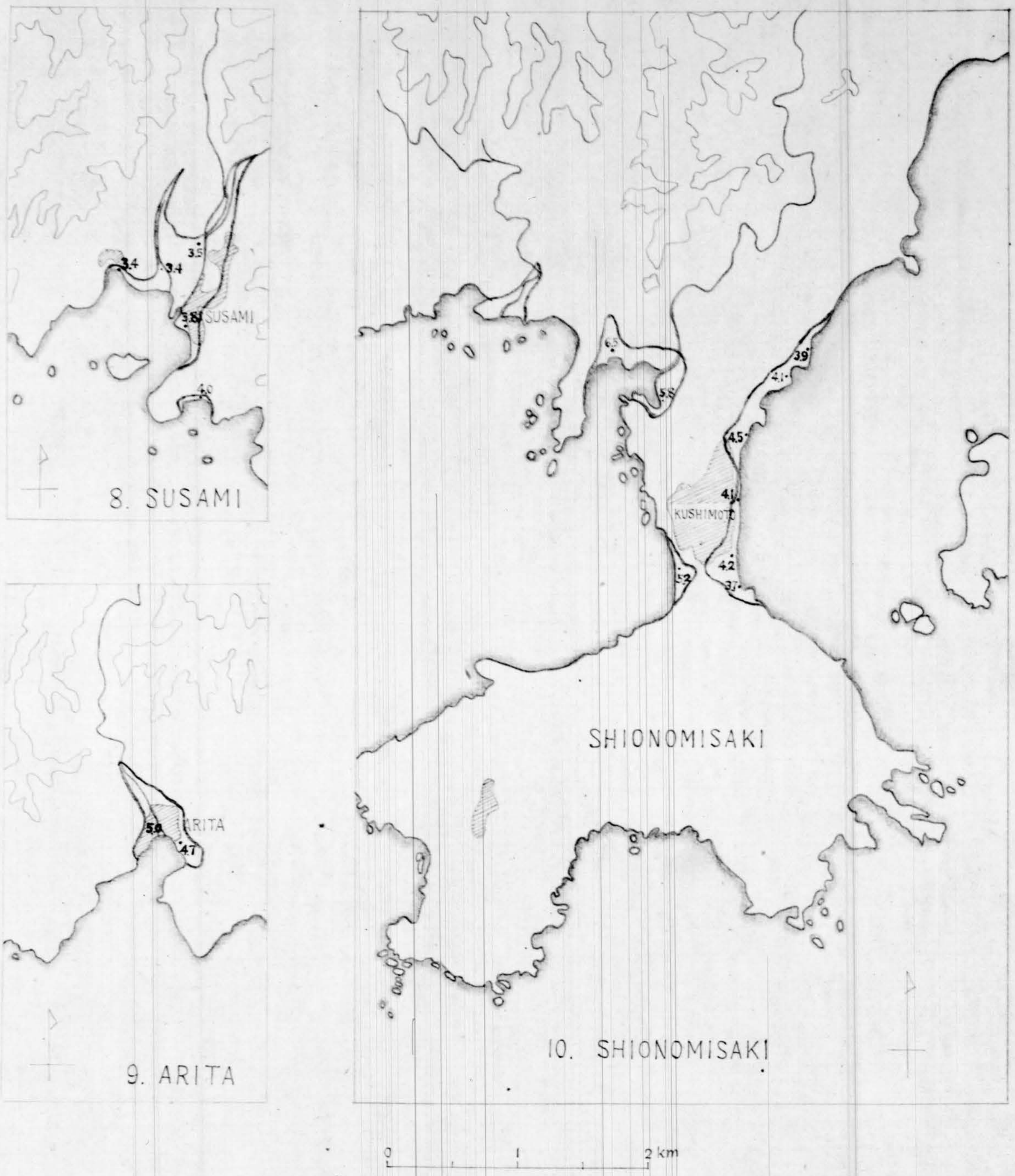

SUSAMI
8. SUSAMI
ARITA
9. ARITA
KUSHIMOTO
SHIONOMISAKI
10. SHIONOMISAKI
0
1
2 km

Fig. 19 — 8, 9, 10

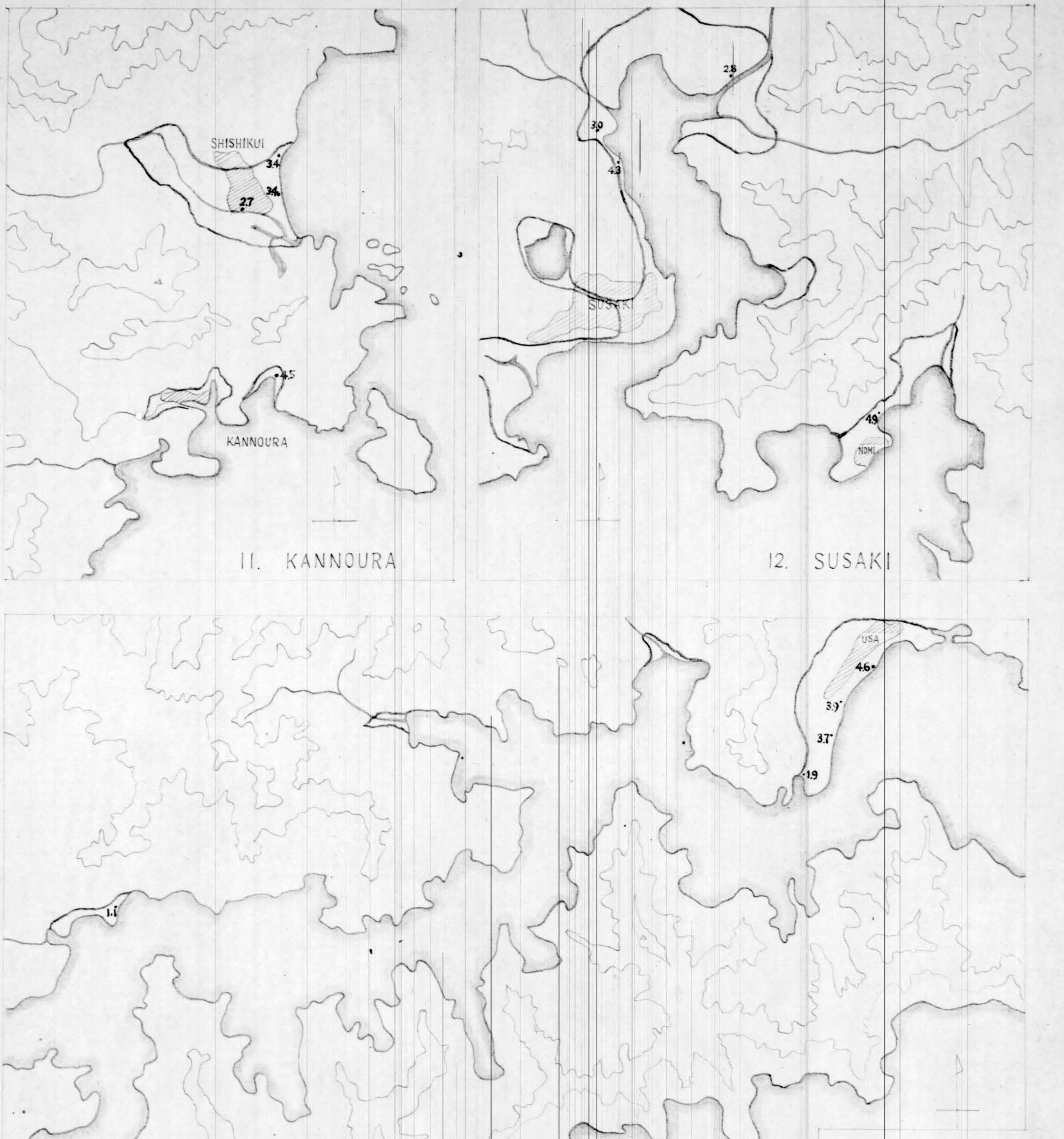
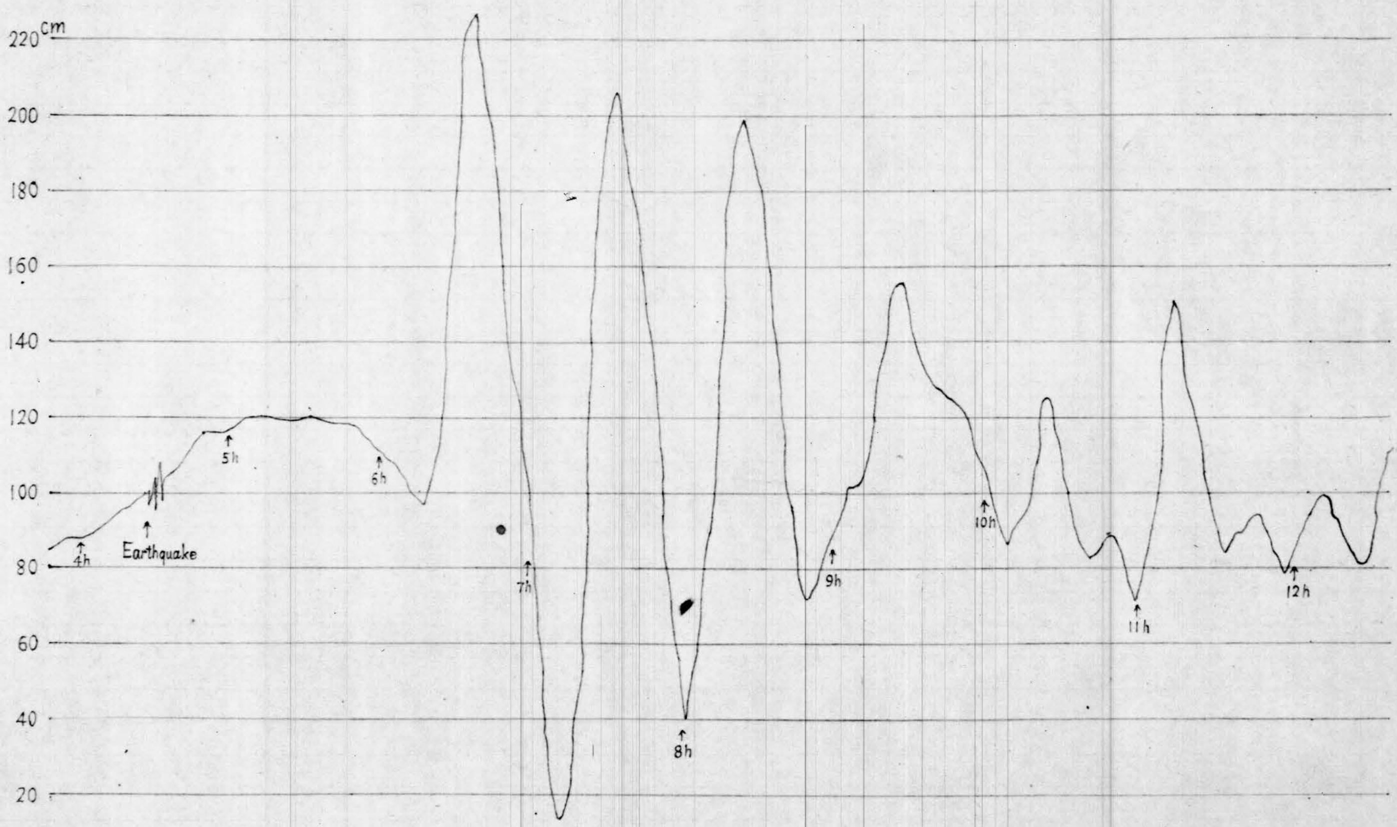


Fig. 19 — 11, 12, 13



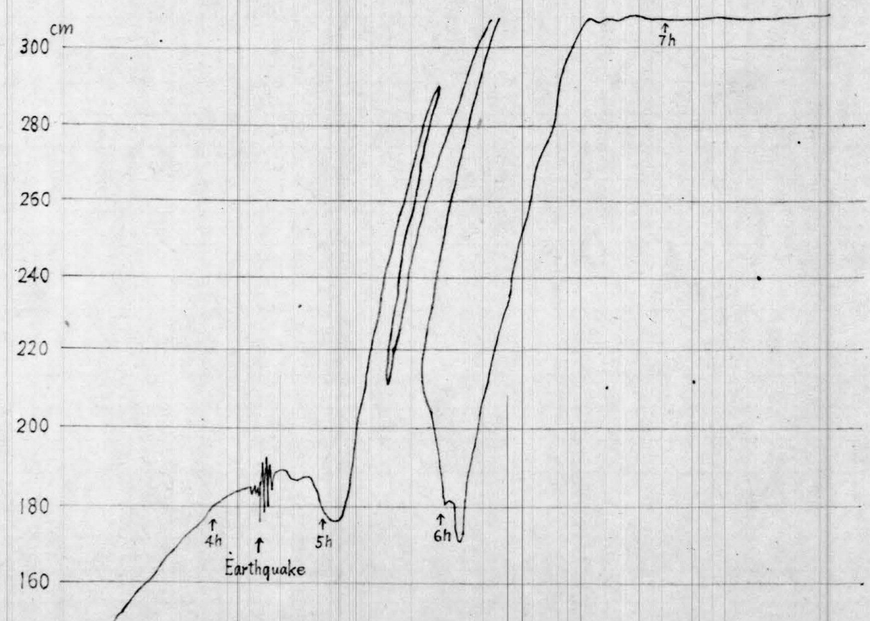


Fig. 20 Record of Tide Guage for Tsunami. (Sakai in Osaka Pref. & Shimotsu in Wakayama Pref.)

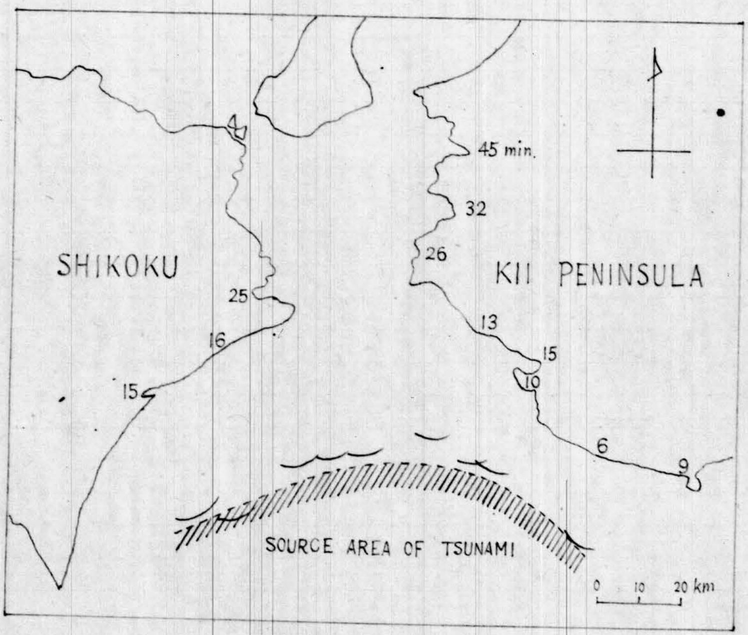


Fig. 21 The Source Area of Tsunami Accompanying the Earthquake on Dec. 21. 1946.

Numerals denote the difference between the arrival time of Tsunami from that of earthquake at respective observing points.

V. Earth-Current Measurement.

It has been frequently reported in Japan that an anomalous change in the so-called earth-current preceeded the occurrence of earthquake. Since the change in earth-current is chiefly subjected to the geomagnetic vatiations, it is rather difficlut to abstract the anomalous change purely owing to the subterranean causes.

The results obtained until the present time seem to show that the earth-current in the place just near the origin of subterranean activity sometimes changes anomalously a few hours before the occurrence of the activity.[11] In order to promote the above-mentioned study, we carried out the earth-current measurement in the present earthquake area. The earth-current apparatus were set at three places, i.e. Tanabe in Wakayama Pref., Tomioka in Tokushima Pref. and Muroto in Kochi Pref., the appartus set at each station being quite similar ones, composed of two components, N-S and E-W span about 100 m long.

Throughout the whole data obtained at those three stations, however, it is difficlut to find out the remarkable change in the earth-current corresponding to occurrence of after-shocks. Since the active period of after-shocks agreed with that of the geomagnetic activity, the anomalous change in earth-current, if it were, may be masked by the induced current due to the geomagnetic changes.

On the other hand, it has been well known that the earth's crust is, generally speaking, electrically anisotropic, it resulting that the variation in earth-current generalted into the earth by the geomagnetic variation predominates in a special direction. The grounds of Muroto, Tomioka and Tanabe have also such anisotropic electric con-

conductivity as mentioned above, the ratio of maximum to minimum of conductivity amounting to 3-4. Although the predominant direction at Tanabe and Tomioka was kept almost constant during the whole period of our observation, that at Muroto changed markedly during the same period. as will be shown in Fig.22. It seems in the figure that the predominant direction rather sharply changed during a few days about Jan.20, the average direction before Jan.20 being E35.1°N±15°, while it was E17.2°N±0.4° after that date. Furthermore, the change in the above-mentioned direction seems to be fairly well correlated with tilting motion at Muroto, the correlation coefficient between the former and the latter amounting to 0.65.

Hence, taking into consideration the experimental fact that the electric conducitivity of soil is directly subjected to the mechanical stress, we may presume that the electric conductivity of the ground of Muroto Peninsula was affected by the crustal movement which was still going on during our observing period.

Although the result of the present work is not enough to clear the electric behaviour of the earth's crust, it seems to have a possibility of becomimg a useful method for solving the problem about the possible relation between earth-current and earthquakes.

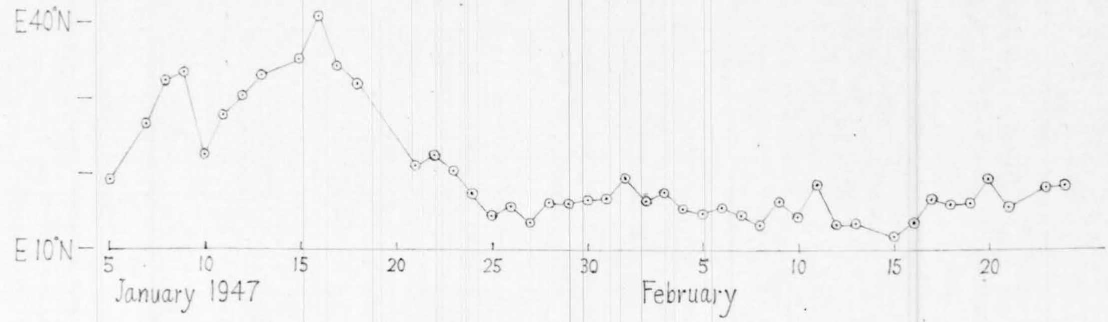


Fig.22 The Change in Predominant Direction of the Earth-Current at Muroto.

VI. Luminous Phenomena Accompanying the Earthquake.

Anomalous lightning in the sky has been frequently observed at the occasions of great earthquake, while it has been also observed that some blue or green coloured luminosity accompanies Tsunami wave.

In the present case also, there are many people who observed the so-called earthquake lightning. Judging from the data reported by many observers, we can conclude that, although a part of observed lightning is ascertained to be due to the spark lightning of electric cable, there were the other kind natural luminosity in the sky, generally red coloured, which was observed ~~eu~~even on the sea.

On the other hand, the blue or green coloured luminosity was observed along the head of Tsunami wave. This phenomenon was ascertained to be the light of "Noctiluca", which were excited by strong motion of Tsunami, just as pointed out by late Prof. T. Terada[12] in the case of Tsunami in 1933.

Although the origin of red coloured lightning in the sky observed by many people has not yet been ascertained, this phenomenon should be, the writer believes, related to some electric discharge between the ground and sky. In order to examine practically this question, we have continued the self-recording of point-discharge current from the ground at Muroto station. Since, however, there has been no luminous lightning accompanying after shocks during our observation period, our trial will be rather unsuccessful in the present case.

VII. Other Miscellaneous Works.

(i) Tilt on land after the earthquake*.

Change in tilt after the earthquake has been observed by means of tiltmeters at Tanabe and Muroto stations. The purpose of this observation is to measure directly the general change in tilt after the occurrence of great earthquake and also to examine whether or not there is also anomalous change in tilt corresponding to fairly large after shocks.

Generally it is rather difficult to observe very small change in tilt by means of tiltmeters set on the earth's surface, because the surface of land is always affected by artificial and meteorological disturbances. However, it was found in the result of observation at Muroto that Cape Muroto has been inclining into the southward direction with the speed of about 0.05 "/day after the earthquake, this result agreeing with that obtained from precise levelling survey men-

* The observation of tilt at Muroto was carried out chiefly by T. Hagiwara of E.R.I.

tioned in III.

(ii) Problem of Subsidence of the Earth's Surface in the Neighbourhood of Kochi City.

Accompanying the present earthquake, the land in the neighbourhood of Kochi City subsided about 1.0 - 1.2 meters, it resulting that a wide area in that region has been covered by the sea water. Since this phenomenon was one of main damages owing to the present earthquake, we shall deal shortly with the result of our investigation on this problem.

Kochi City is placed on a layer of aluvial deposit, though its northern margin is bounded by mountain range of Mesozoic rocks with fault. According to our levelling survey, the centre of the place where amount of depression is the largest subsided about 29 cm more compared with above-mentioned Mesozoic region. This result may show that the amount of subsidence corresponding to contraction of aluvial layer itself caused by earthquake motion, is only about 30 cm, the remaining depression ~~of about 30 cm~~ being probably owing to subsidence of base rock layer as a result of crustal movement in large scale. Details of this phenomenon, however, will be cleared after all survey are finished.

 (56)

VIII. Concluding Remark .

As discussed from various points of view in the foregoing chapters, the earthquake on Dec.21,1946 was one of the extensive scale, accompanying the remarkable land deformation, Tsunami wave as well as many after-shocks. It must be noted further that there was a systematic relation among the land deformation before and accompanying the earthquake, the distribution of origin of Tsunami , and the mechanism of earthquakemotion deduced from the distribution of the initial motion.

Although the general view of the process of occurrence of the present great earthquake was already dealt with in each chapter, the final definite conclusion should be obtained after all data concerning with the earthquake are fully analyzed. Since the geological structures in the present earthquake area is comparatively simple and they have been examined by various authors, it seems to be possible in future to explain the present earthquake as a line or a page in the book of geological history of this district. The writer's special interest is concerning with the physical mechanism of causation of the present earthquake viewed from the background of geological and geomorphological knowledges. If it were established, it will become a useful key for a prediction of occurrence of great earthquakes.

Each phenomenon relating to the present earthquake will be discussed in details by the respective specialists. Here, the writer describes only an outline of the results of our investigations chiefly from the standpoint as mentioned above.

In conclusion, the writer wishes to express his cordial thanks to Mr.R.Y.Grant of Natural Resources Section,GHQ,SCAP for his helpful encouragement throughout our expedition and investigation.
Our expedition party was composed of many younger seismologists and gephysicists, and they always assisted the writer in his all investigations. The writer wishes to express his sincere thanks for their hearty help to Messers.A.Okada,Y.Harada and Y.Obayashi in the levelling survey, to Messers T.Asada.J.Suzuki and T.Tajime in the seismometric works. to Messers K.Hirao.T.Rikitake and T.Hatakeyama in the electric works, and Mr. K.Yoshida and others in the field investigation of Tsunami. He is also indebted especially to Mr.N.Fukushima for his continuous assistance throughout the field works and studies of the obtained data, to whom his hearty thanks are also due.

(58)

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SUPPLIMENTARY NOTES

TO

OUTLINE OF GEOPHYSICAL INVESTIGATION ON THE GREAT EARTHQUAKE IN THE SOUTH-WEST JAPAN ON DEC.21,1946.

By

Takesi NAGATA

Geophysical Institute, Faculty of Science,
Tokyo Imperial University.

June 1947

SUPPLIMENTARY NOTES FOR (III) CRUSTAL MOVEMENT RELATING THE EARTHQUAKE.

(i) The works of precise levelling survey were continued until the end of March in both of Shikoku and Kii Peninsula. The observed results are shown in Figs.1 and 2. Fig.1 shows the change in height of bench marks in the South Eastern part of Shikoku during the period of 1929-1947, while Fig.2 shows that in the Southern Kii Peninsula during 1930-1947. Here, it must be mentioned that those numerical values of height change are, strictly speaking, not absolute ones.
Since the deformed area was so wide that we could not extend our levelling route to a bench mark, which is considered to be quite safe from the land deformation, being possible to be taken as the base-point of no-change. Hence we arbitrarily assumed that Bench Mark No.5107 and No.9208 did not change during the period mentioned above in Shikoku and Kii Peninsula respectively. Since, however, the assumption is derived from the fact that the beach lines just near those base bench marks scarecely changed accompanying the earthquake, the curves given in Figs. 1 and 2 will express approximately the true change in height. Strictly speaking, however, those curves mean the sum of the true change and a small constant value which is common for all bench marks among one continuous route.

As already mentioned in the foregoing report, almost all parts of the change shown in Figs.1 and 2 took place rather abruptly accompanying the earthquake on Dec.21,1946.

In Fig.1, it is clearly seen that Muroto Peninsula upheaved accompanying the earthquake and the amount of upheaval becomes larger in the more southward place, it exceeding one meter at the cape of the South end, while on the contrary the plain area in the vicinity of Kôchi City fairly subsided.

In Fig.2, the most southern part of Kii Peninsula upheaved about 55 cm , while the amount of upheaval gradually decreases in proportion as the bench mark becomes the more northward point — both in the Western and Eastern coarsts of Kii Peninsula —, and the Northern part of the surveyed area subsided in 20 - 30 cm on the contrary.

Generally speaking, the Southern regions of both of Shikoku and Kii Peninsula were inclined northwards accompanying the present earthquake, it resulting the land sinking in the Northern part and rising in the Southern part.

In Figs.3 and 4, the changes in height of the same levelling routes during the period of 1895-1929 for~~m~~ Shikoku and during 1895-1930 for Kii Peninsula are shown together with those during 1929-1947 and 1930 -1947 respectively. Comparing the change during 1929-1947 — which mostly accompanied the present earthquake — with that during 1895-1929 in Fig.3 , we can find out that the mode of the former is almost opposit to the latter in the sence of their change,

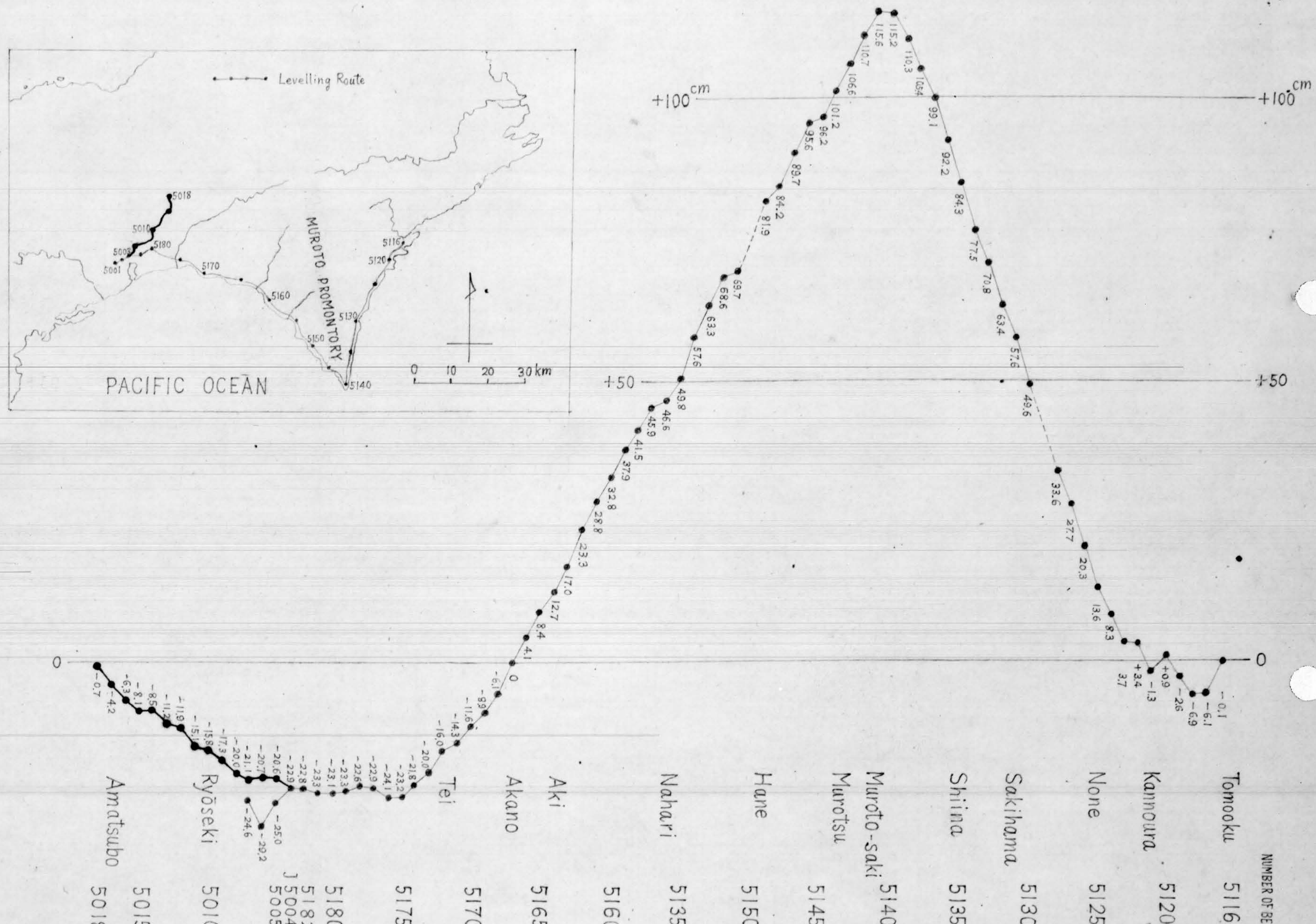


Fig 1. Change in Height of Bench Marks in the South-Eastern Part of Shikoku during 1929 – 1947.

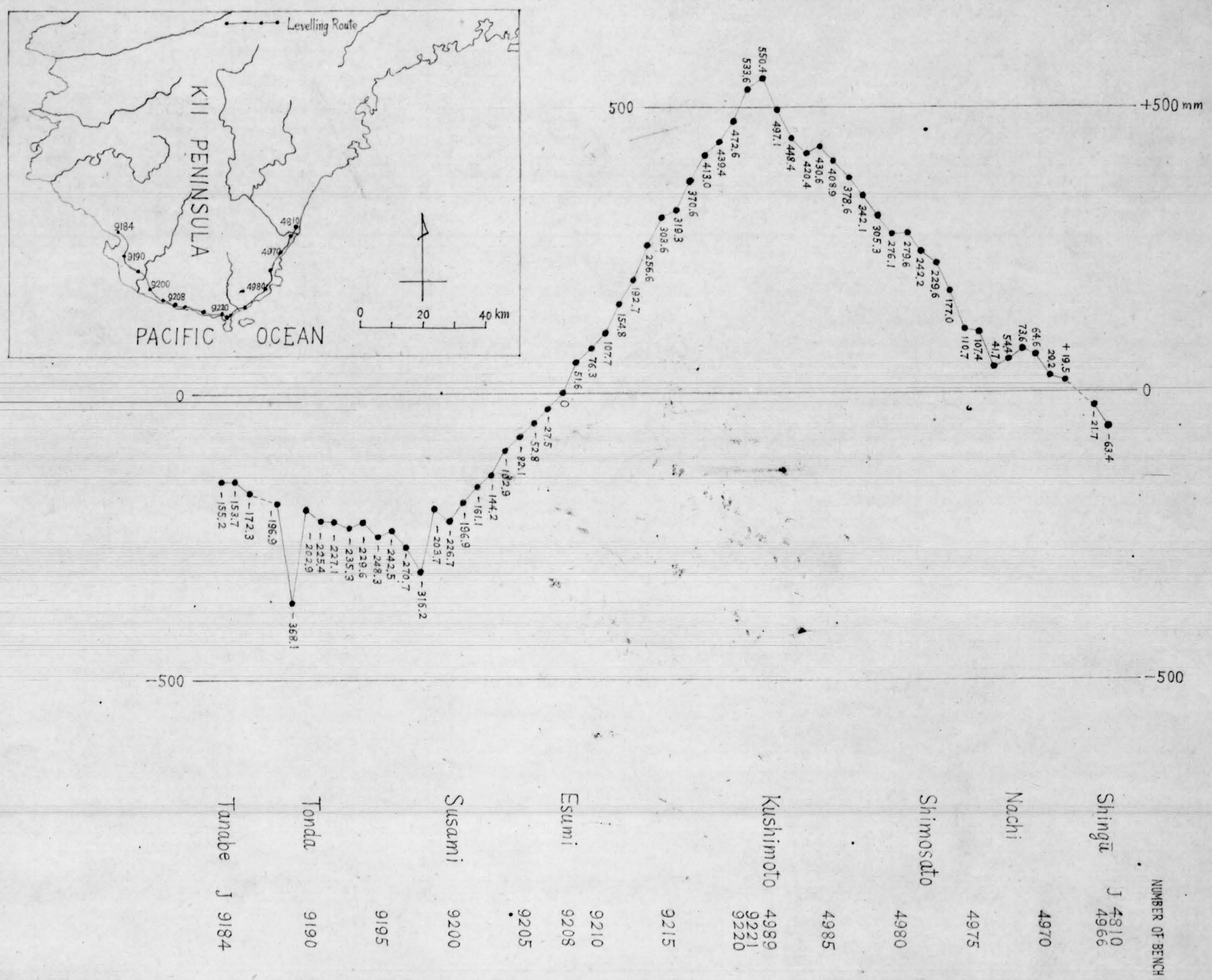


Fig. 2. Change in Height of Bench Marks in the Southern Part of Kii Peninsula during 1930 – 1947.

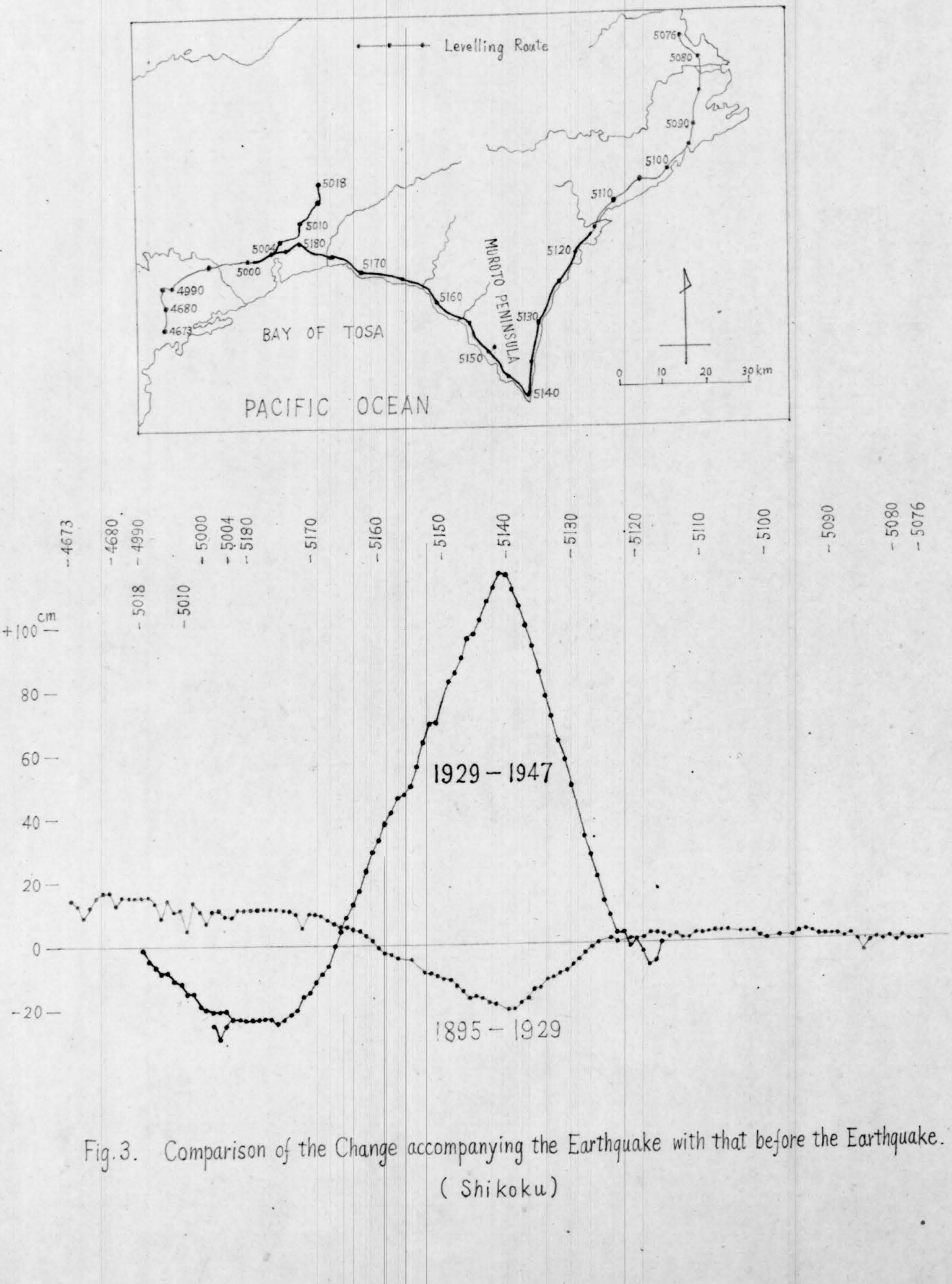
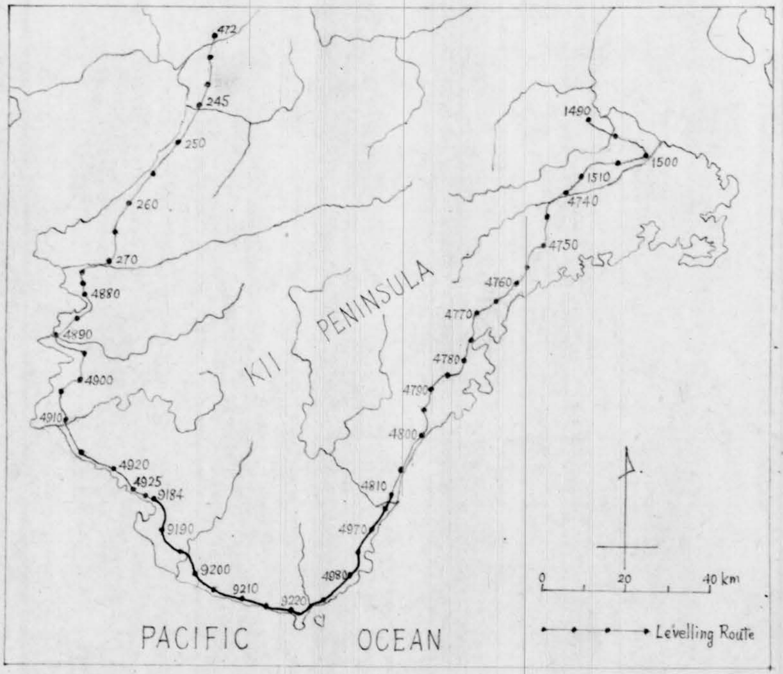


Fig. 3. Comparison of the Change accompanying the Earthquake with that before the Earthquake.
(Shikoku)



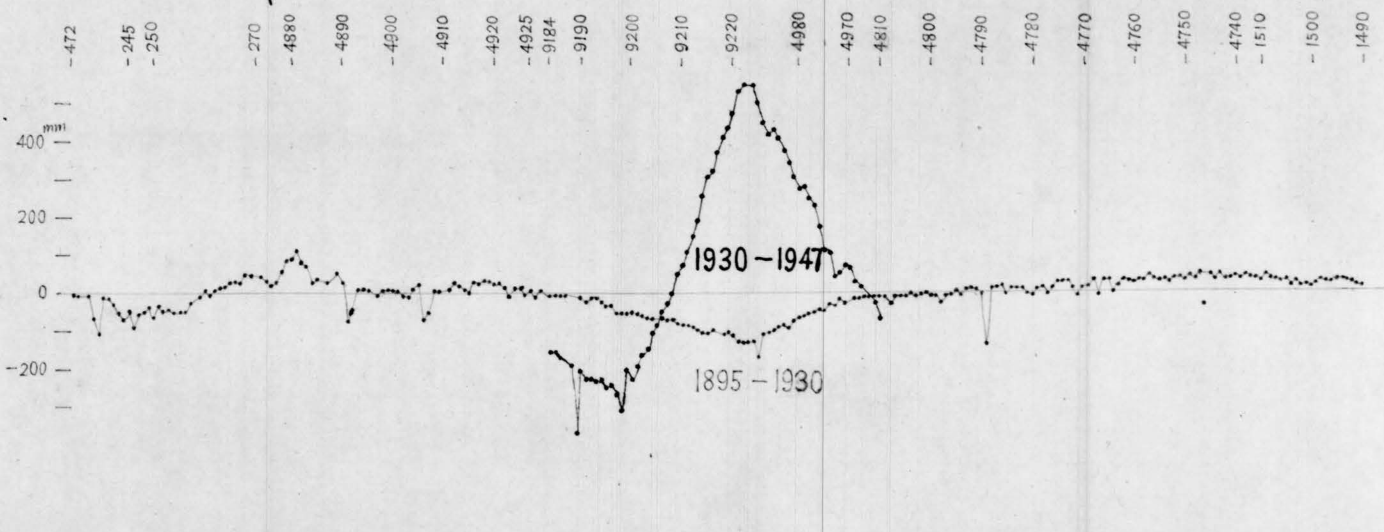
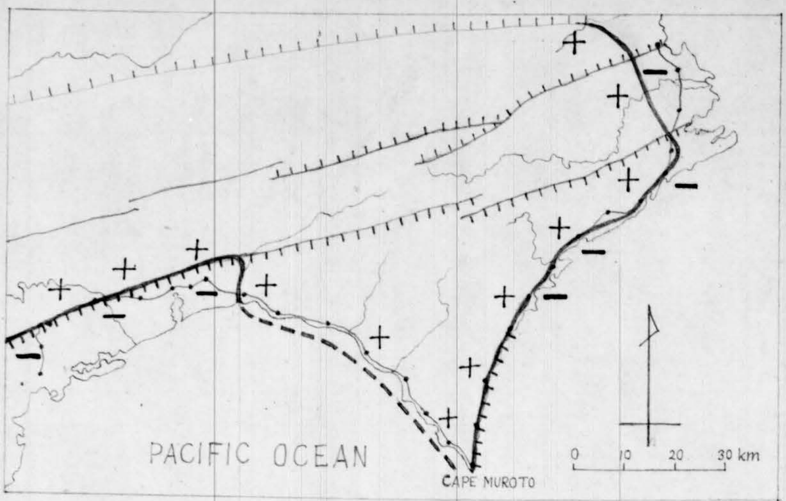
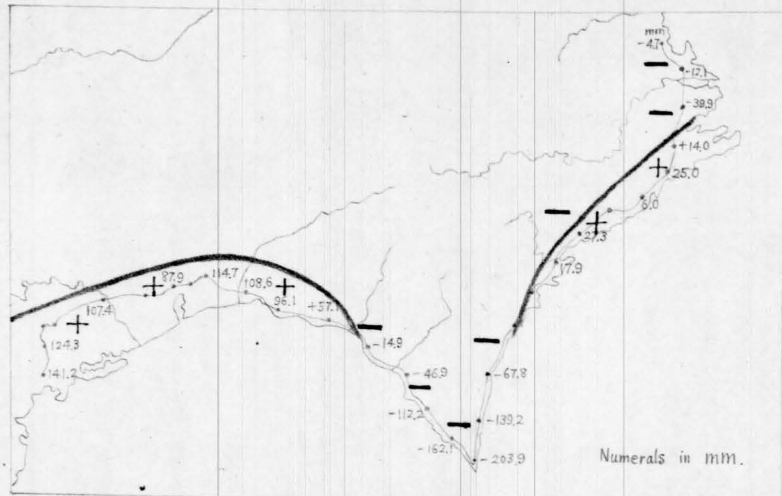


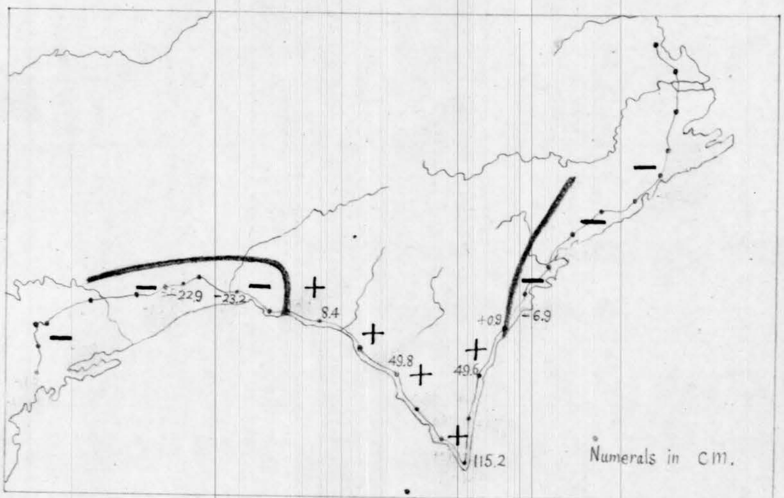
Fig. 4. Comparison of the Change accompanying the Earthquake with that before the Earthquake.
(Kii Peninsula)



(a) The General Tendency of Land Deformation during the Later Quarternary.



(b) Land Deformation before the Earthquake. (1895 – 1929)



(c) Land Deformation accompanying the Earthquake. (1929 – 1947)

Fig. 5.

district during the later Quaternary, and that the deformation continuing more than 40 years before the present earthquake is opposit to the general tendency mentioned above.

In the case of Kii Peninsula shown in Fig.4, the general behaviour seems to be nearly same as that in the case of Shikoku; that is, the mode of change during 1930-1947 is nearly opposit to that during 1895-1930. Since, however, there occurred a great earthquake in 1944 at the sea bottom just east of Kii Peninsula , the land of Kii should be affected by this earthquake. Therefore, it will be rather reasonable to presume that the obtained land deformation of Kii Peninsula, at least in its Eastern half, during 1930-1947 includes the effect of 1944 earthquake and that of the present one.

(ii) As already dealt with in the foregoing report, we planned to carry out the levelling survey frequently along a short route at Cape Muroto about 14 km long. After the earthquake, the survey work was carried out three times, the dates of survey being as follows:

1947(I) , Jan.7 - Jan.13 ,1947,
1947(II) , Jan.30 - Feb.3,1947,
1947(III), Mar.3 - Mar.5 ,1947.

The change in height of bench marks during the periods of 1895-1929, (before the earthquake),1929-1947(I) (including the time of occurrence of the earthquake),1947(I)-1947(II), and 1947(II)-1947(III),(both after the earthquake), are shown in Fig.6, where the change of bench mark No.5144 is assumed to be always zero.

Hence, the amount of change given in Fig.6 being the relative one compared with the base bench mark No.5144, the results shown in this figure are considered to show the tilt of land.

The deformation during 1895-1929 shows that Muroto Peninsula had been inclined into the direction of S10°E ,i.e. the S10°E side had subsided compared with N10°W side, the magnitude of tilt during 34 years amounting to 1.2".

In 1935, the levelling re-survey was again carried out along the route from Cape Muroto to Aki on the ~~xxxxxxxxxx~~ west-side coarst of Muroto Peninsula. Although that survey did not cover the whole area which we are now examining, we can find out , at least, that the change during 1929-1935 was an extension of the change during 1895-1929 not only in its mode but in its rate of change also, the total magnitude of tilt during 40 years of 1895-1935 amounting to about 1.4".

Next, the change accompanying the present earthquake, shown in Fig.6(b), was exactly opposit in its sence of change to that during 1895-1929, i.e. Muroto Misaki was inclined into the direction of N10°W, the magnitude of change during this period amounting to about 6.6". For the purpose of showing more clearly the above-mentioned regular change, the relative values of change of each bench mark projected on a vertical plane of N10°W - S10°E in direction are shown in Fig.7.

While, as will be seen in Fig.6(c) and (d), the changes during the periods of 1947(I)-(II) and (II) -(III) were not so monotonous as those during 1895-1929 and 1929-1947(I). However, as shown in Fig.7 where the changes during 1947(I)-(II) and (II)-(III) are also

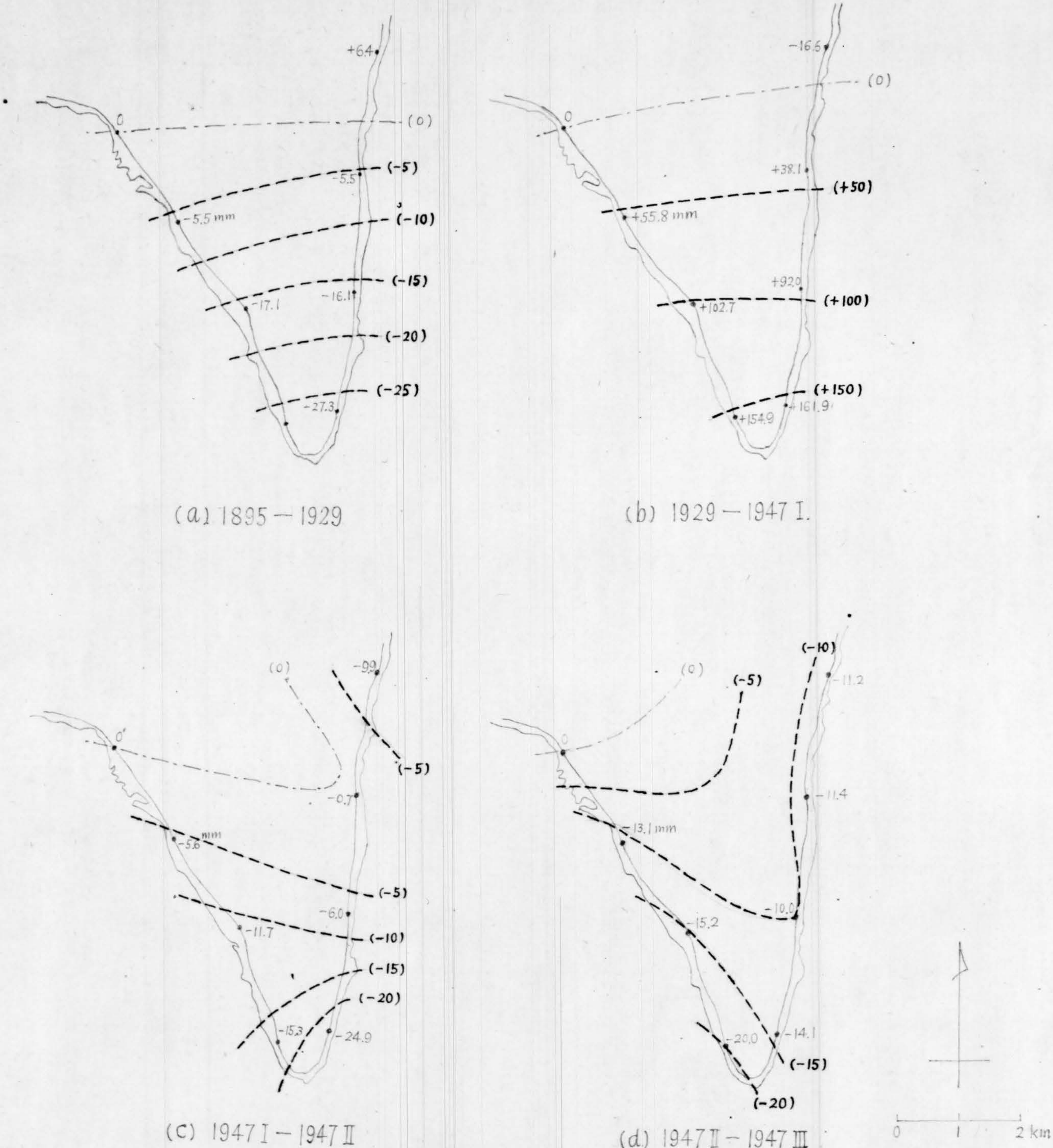


Fig. 6. Land Deformation in the Vicinity of Cape Muroto before, accompanying and after the Earthquake.

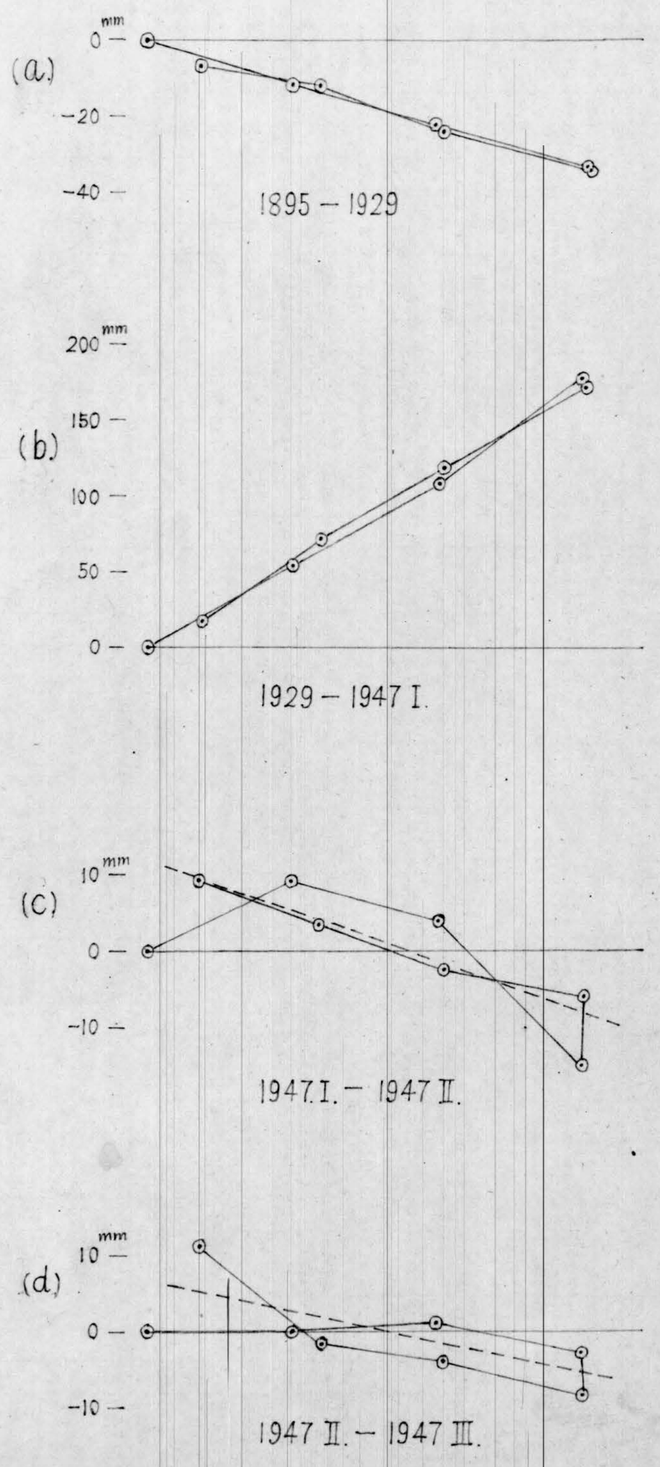


Fig. 7. Tilt of the Land in the Vicinity of Cape Muroto Projected on N 10°W – S 10°E Plane.

projected on the N10°W-S10°E plane, Muroto Misaki after the earthquake is, generally speaking, inclining again into the southward direction, and moreover the time-rate of the southward tilt has been decreasing with time. The general tendency of tilt of Muroto Misaki before, accompanying and after the present earthquake, projected on the N10°W-S10°E plane, is tabulated in the following table and graphically shown in Fig.8.

Time	Amount of Tilt	Change in Tilt	Rate of Change
1895	0 (assumed)		
		- 1.2"	-10×10^{-5} "/day
1929	- 1.2"		
		- 0.2"	$- 9 \times 10^{-5}$ "
1935	- 1.4"		
		+ 6,6"	
1947(I)	+ 5.2"		
		- 0.6"	$- 3 \times 10^{-2}$ "
1947(II)	+ 4.6" (+) denotes the rise of S10°E side against the N10°W side.		
		- 0.5"	$- 1.7 \times 10^{-2}$ "
1947(III)	+ 4.1"		

From those results, we can conclude that Muroto Peninsula had been inclined southwards with almost constant rate during more than 40 years before the present earthquake, it rebounding abruptly at the time of occurrence of the earthquake, and then the deformation in excess at that occasion is now settling.'

The levelling surveys are still continued at present. After those works are completed, the general aspect of the land deformation relating to the present great earthquake will be much more cleared.

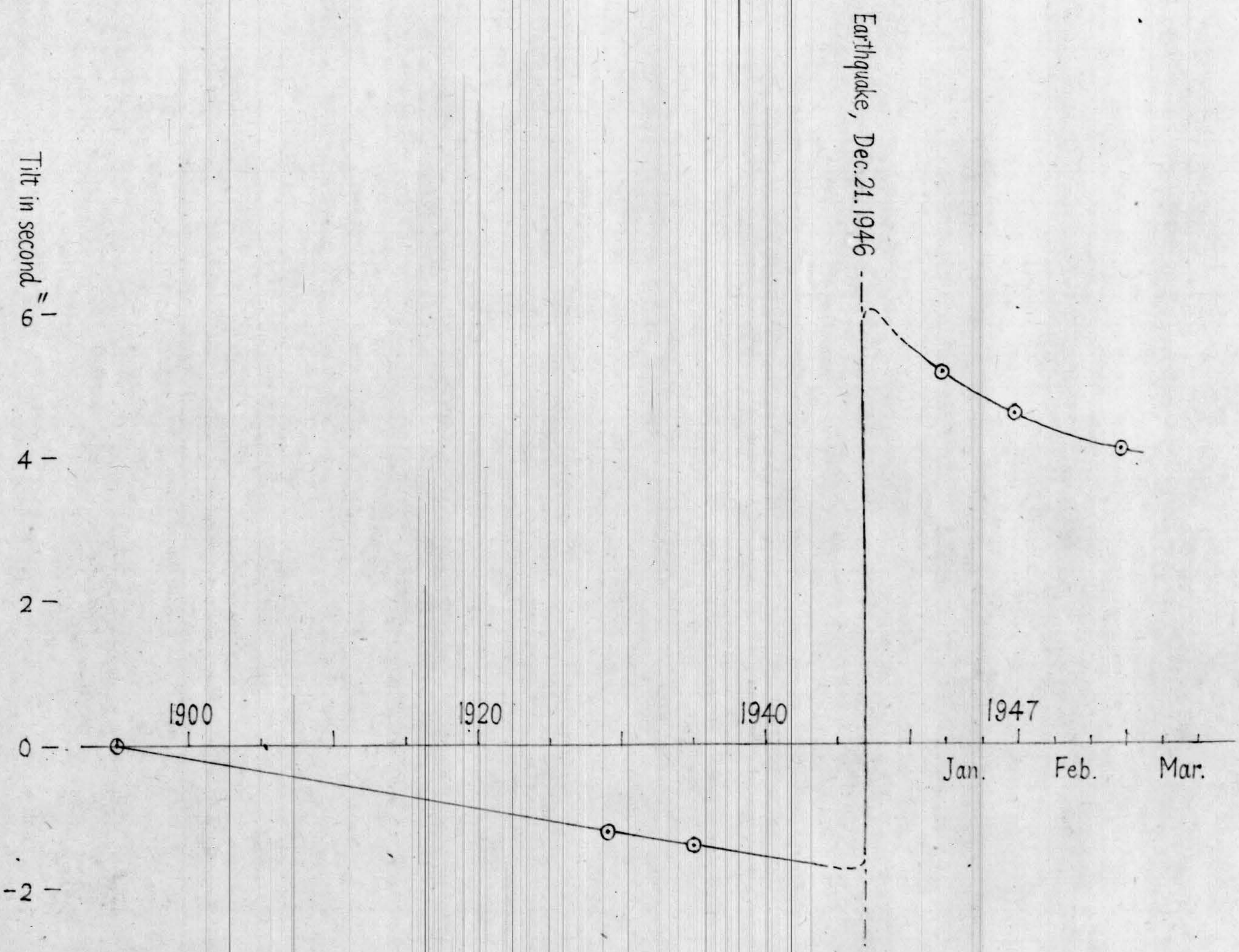


Fig. 8 The General Tendency of Tilting Motion of Muroto Peninsula during the Period of 1895 – 1947 March.

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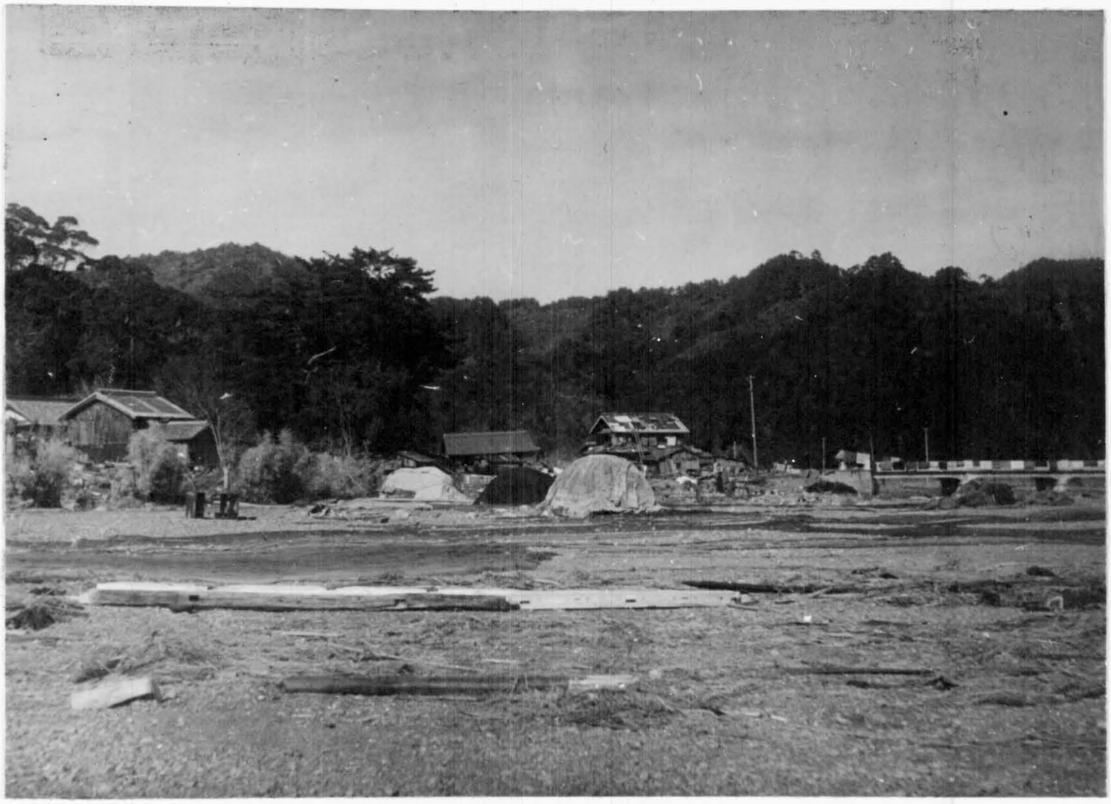
SUPPLIMENTARY NOTES TO (IV) TSUNAMI .

From the observed data about the difference of arrival time of Tsunami from that of earthquake, we could determine the distance of the origin of Tsunami wave from the observing points. Here, the velocity v of propagation of Tsunami was assumed to be given by $v = \sqrt{gh}$, where g and h denote the accerelation of gravity and the depth of the sea respectively.

By means of numerical integration, we could determine the possible locus of position of origin of Tsunami corresponding to each observing point. The results of actual estimation are shown in Fig.9, where it will be clearly seen that those locus curves do not converge to a special point. This fact may show that the origin of Tsunami was not a small area, but it should have rather wide area. Then, we can interplete that the envelope for the group of those locus curves corresponds to the margin of source-region of Tsunami.

As shown in the figure, the area of source of Tsunami was fairly large, surrounding the epicentre of the earthquake itself. Comparing the above-mentioned conclusion with the fact that the land deformation took place in the wide area including Shikoku and Kii Peninsula, we can presume that the crustal movement in the sea bottom, which caused the Tsunami wave, had also a wide area and probably connected closely to the deformation on the lands.



Damages due to Tsunami.

About 30 houses were perfectly washed away by Tsunami.

Asakawa, Tokushima Prefecture.

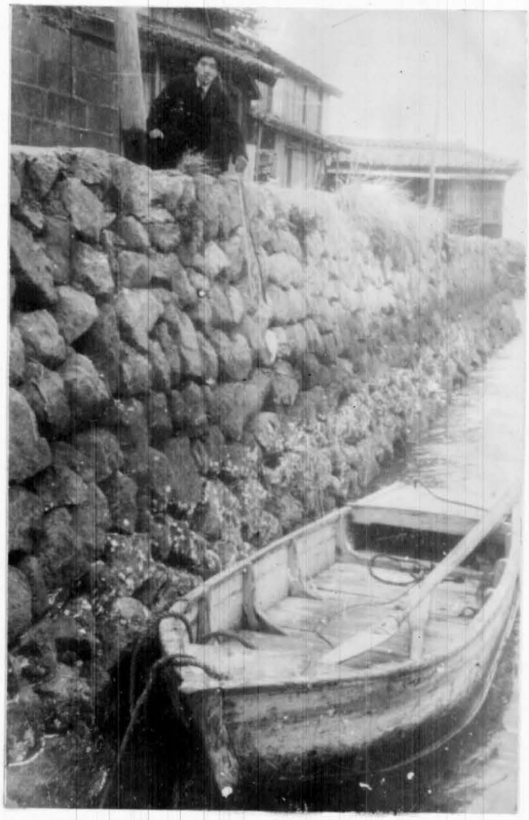
Damages due to Tsunami.

Susami, Wakayama Prefecture.

Upheaval of Land.

Muroto, Kōchi Prefecture.

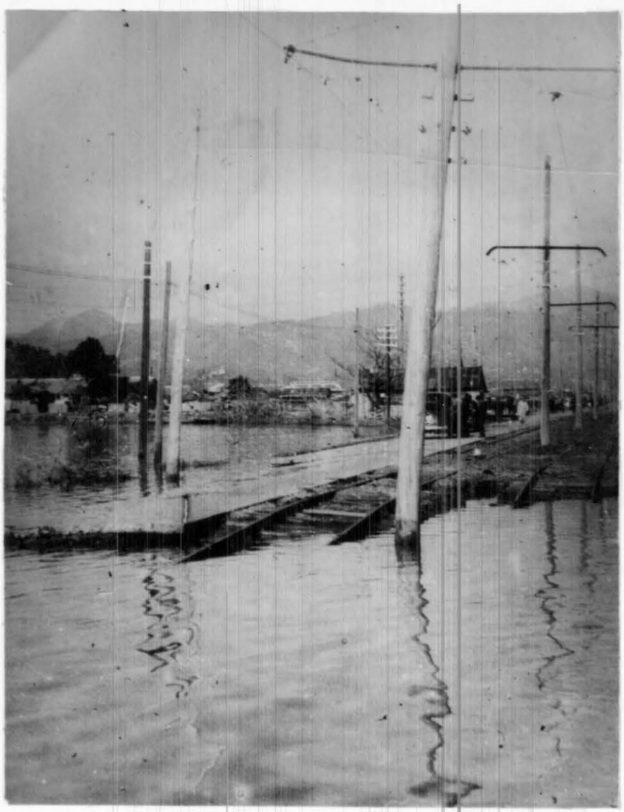
The upper and lower lines of black coloured zone show the maximum and minimum sealevels before the earthquake respectively.

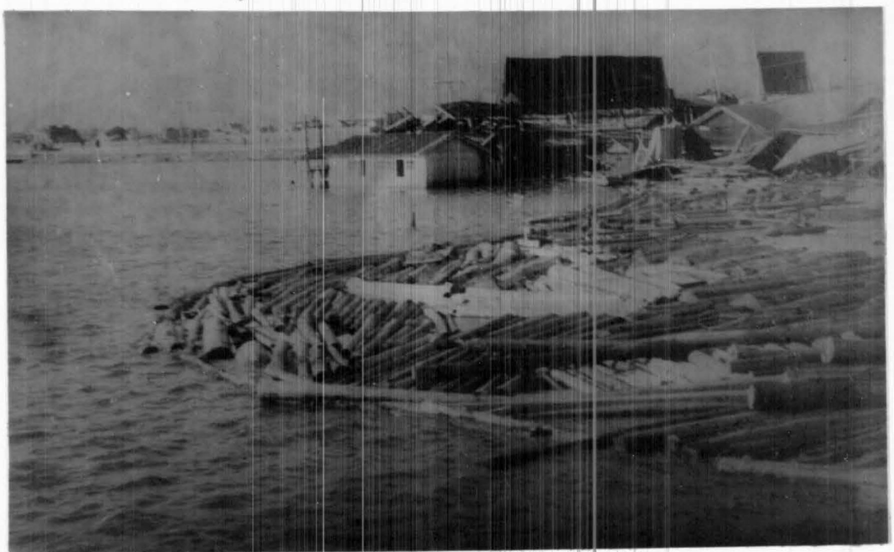


Upheaval of Land.

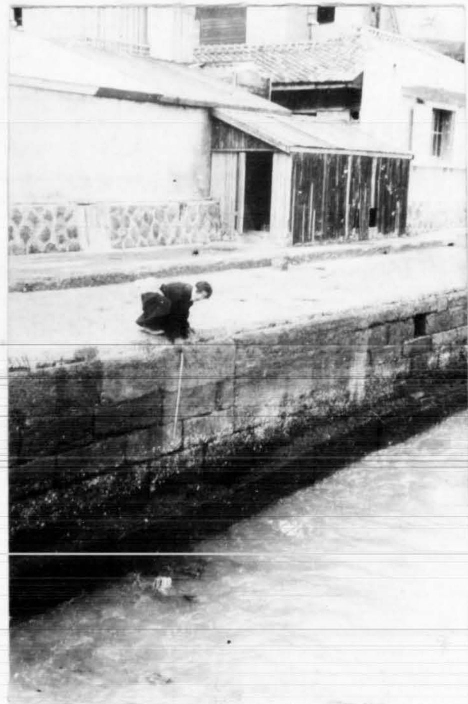
Shionomisaki, Wakayama Prefecture.

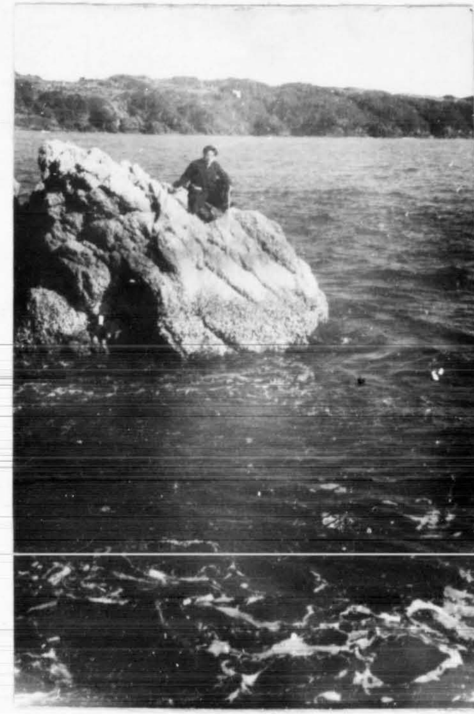
The upper line of black coloured zone shows the maximum sea-level before the earthquake. (Jan. 24, 14h43m photo.)





Subsidence of the Ground of Kōchi City.





Upheaval of the Land at Shionomisaki

Horizontal Line, Which is Pointed to, Shows the Beach Line before the Earthquake.

1. Damage due to Tsunami Wave
at Shirahama Town in Wakayama Prefecture.

2. Damage due to Tsunami Wave at Asakawa Village in Tokushima Prefecture.