On the Mechanism of the Great Sagami Bay Earthquake on September 1, 1923.

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大正十二年相模灘大地震の機巧に就いて

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摘　要

相模灘大地震卽關東大地震の原因に就ては諸說紛々たり、著者等は先づ是等諸說を列擧し、次に批判の材料となるべき事實を擧げ．自說の概要を述べて、之を事實に徵し、其毫も事實と矛盾するなきのみならず、土地の渦動的水平移動等は本說に依りてのみ說明し得る所以を明にしたり。次に進んで自說の根據となるべき諸項目を吟味し、又他諸家の說との比較に於て根本的相違なきを確めたり。次に更に事實の確實性の吟味をなし、相模灣方面に於ける渦卷的水平移動の實在せるを確かめ、之に依つて又房州瀧山斷層の主貌を推論し、之を事實に徵して推論の如くなるを確かめたり。かくて

關東大地震は北太平洋方面よりの一般的地流に原因を有し、相模灣及附近に於ける渦卷的逆地流の爲に蓄積せられたる勢力の發露なるを推定したり。

CONTENTS

SYNOPSIS

A theory of the earth vortical formation is proposed for the explanation of the mechanism of the great Sagami Bay Earthquake, 1923, based on the observed facts and results of survey, making use of model experiments.

Introduction.

§1. In August of 1925 one of the present authors summarised many theories published in Japan on the cause of the great Sagami Bay earthquake on September 1, 1923, giving at the same time his own theory from the vortical point of view.(1) Since this was written in Japanese, Professor B. Koto persuaded him to translate it in English. Three years have since elapsed without doing so during which the triangulation over the shaken area was made by the Land Survey Department of the Japanese Army and now two maps (Reproduced and put together in Fig. 1.) have been completed showing the relative horizontal and vertical displacement of trianguration stations in the area concerned. The results of this survey stand in a good accordance with the inferred motion from the vortical theory. Hence in this opportunity it will be of some interest to recapiturate the former theory in more universal language and in fuller scope.

Sketch of the Former Theories.

§2. *Theories already proposed.* There are many theories and hypotheses proposed by many seismologists, geologists and geophysisists in Japan on the cause of that earthquake. These are tabulated as follows:—

	Theory	Author	Reference
No. 1.	Upthrust	T. Kato	Rep. Imp. Earthq. Inv. Comm. 100, B (1925) p. 9.
2.	Block movement	N. Yamasaki	ditto p. 51.
3.	Submarine fault	A. Imamura	ditto A, p. 54.
4.	Underground fault	Saem. Nakamura	ditto p. 118–119.
5.	T-shape fissure	T. Shida	The next paper by T. Ogawa
6.	Plutonic origin	T. Ogawa	Chikyu (The Globe) Vol. 1, (1924) No. 1–5.

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(1) S. Fujiwhara, On the mechanism of Sagami Bay earthquake, Kensin Ziho, (Japanese seismological magazine, issued from the Central Meteorological Observatory) **1**, p. 161–170.

7.	Linear rebound	M. Matsuyama	Conceil Intern. Rech., Soc. Seismology, Bureau Centr. Seism. Strasbourg, Travaux Scientifique. Fasc. 2 (1925) p. 23.
8.	Local horizontal folding due to emigration of continent	T. Terada	Rep. Imp. Earthq. Inv. Comm. 100, B, (1925) p. 66–72. Proc. Imp. Acad. Vol. 4, (1928) p. 55.
9.	Vortical rebound	K. Suda.	Memoirs Imp. Marine Obs. Kobe, Vol. 1, (1924) pp. 200–205.
10.	Sudden yield to stress of vortical nature	S. Fujiwhara	Journ. Met. Soc. Japan, (1924) p. 32–36.
11.	Vortical recoil due to the Pacific movement	S. Fujiwhara	Kensin Ziho, Vol. 1 (1925) p. 165–170.

Very recently Professor H. Nagaoka has proposed a hypothesis based on a magma theory, but it is not yet in press.(1)

At first sight these theories seem to contradict to each other, but by careful studies they are found to be in harmony to some degree. We shall come later on this point.

§3. *Historical note,* No. 10 in the above table, which was issued three months after the great earthquake, gives only a suggestion that the earthquake might be caused by an elastic release of stress accumulated by a *torsional* or *vortical strain* of the earth's crust in the vicinity, of Sagami Bay. He has pointed out that by giving shear to a flexible plate or to a sheet of paper, an elevation of horse-shoe shape and depression in side it can easily be produced, resembling the form of uplifted and subsided area actually occurred on the occasion of the great earthquake. This theory was seconded by K. Suda in his big paper—No. 9. in the above table—on the same subject.

From the analysis of Japanese volcanic ranges by using the law of échelon cracks, Fujiwhara has proved that Japanese Islands are subject to

(1) H. Nagaoka, Lectures delivered at the meeting of the Earthq. Res. Inst. Feb. 21, Mar. 20, April 24, May 28, June 19, 1928.

a compressional shearing stress acting from NE to SW along the north-eastern coast facing to Pacific Ocean.(1)

This gives another support to the above theory, so that in the note No. 11 in the above table the shearing force which caused the vortical strain is considered to originate from the general Pacific movement, being impeded by Volcanoes such as Osima, Amagisan, Hakone and Huzi (Fuji).

FACTS TO BE EXPLAINED.

§4. *Four main facts.* In order to criticize the raised theories, the facts must first be grasped exactly. The facts of primary importance are:—

(1) An earthquake of first-class intensity occurred over Sagami Bay and its surrounding districts at 11h 58 m., Sept. 1, 1923.(2)

(2) The coast of the Bay from Manazuru to the southern end of Bosyu was suddenly uplifted by the amount at least from one to two meters as shown in Fig. 1. Along the west coast of the Bay the elevation was rather small, at Atami it was 0.1 to 0.7 m. and at Hasima it was 0.9 m., while the level of Osima remained without change.(3)

(3) The bottom of Sagami Bay subsided by the amount up to 210 m. during years from 1912 to 1923. Surrounding the subsided area there is uplifted area in a horse-shoe shape opening to SE.(4)

(4) A *tsunami*—earthquake sea bore—took place and was observed along the whole coast of the Bay.(5)

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(1) S. Fujiwhara, 地理學評論 Geographical Review of Japan. 1 (1925) p. 735. Also see Gerland Beitr. Bd. 16. p. 1–14.

(2) K. Suda, On the great Japanese Earthquake on Sept. 1, 1923. Mem. Imp. Mar. Obs. 1, p. 139. Jan. 1924. Saem. Nakamura, Report on the great Kwanto earthquake (Japanese) issued from the Centr. Met. Obs. Sept. 1924. A. Imamura,, The great Kwanto earthquake on Sept. 1, 1923. Rep. Imp. Earthq. Inv. Comm. No. 100-A (1925), p. 21.

(3) The fact was first observed on the level mark on beach by all authorities in the field. Later it was accurately measured by the leveling by the Land Survey Department. Rep. Imp. Earthq. Im. Comm. No. 100, B. p. 55. Also See Seiji Nakamura, ditto p. 73.

(4) Result of the sounding by the Fishery Institute and more acculately by the Hydrographic Department of the Navy. Bull. Hydro. Depart. 5, Pl. 11. Also see Rep. Imp. Earthq. Inv. Comm. No. 100, B, p. 61.

(5) Reports of K. Suda, A. Imamura, Saem. Nakamura and others loc cit. Especially T. Terada and S. Yamaguti, on Tsunami etc. (Japanese) Rep. Earthq. Inv. Comm. No. 100, B. p. 113.

(5) The regions round Sagami Bay were subject to a vortical displacement during years between 1884 and 1924. In Fig. 1 the motion relative to Teruisiyama as origin and to the initial direction connecting this with Tukubasan is represented by arrows.[1]

§5. *Subordinate facts.* Beside these facts of primary importance, there were also a number of facts of primary importance, but accompanying some ambiguity, and those of secondary importance. They are:—

(6) From the record of tide gauge at Aburatubo in Miura Peninsula, it was likely that the land at this place was continuously sinking these 20 years since the gauge was first installed in 1900. The sinking amounted to 10 cm. relative to the mean sea level. The inhabitants of the district noticed the fact on the gradual landward retrogradation of beach line. [2]

(7) The coast round Sagami Bay especially the part from Boso Peninsula to Odawara has been subject to upheaval as well in geological as historical ages.[3]

(8) A tiltometer installed by the Late Prof. F. Omori at Tokyo is said to have recorded 1″.7 of integrated tilting of the earth towards west from July 30th to Aug. 17th, 1923, which is free from temperature effect.[4]

(9) Four small faults and one big crack system were formed, as shown in Fig. 2[5]

(10) The isoseismic curves were very irregular on this occasion, having long

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(1) Land Survey Department, Provisory Map showing the Horizontal Displacement of the Primary Triangulation Points in Kwanto Districts, observed after the Great Earthquake of Sept. 1, 1923. Bull. Earthq. Res. Inst. 4, Pl. 65.

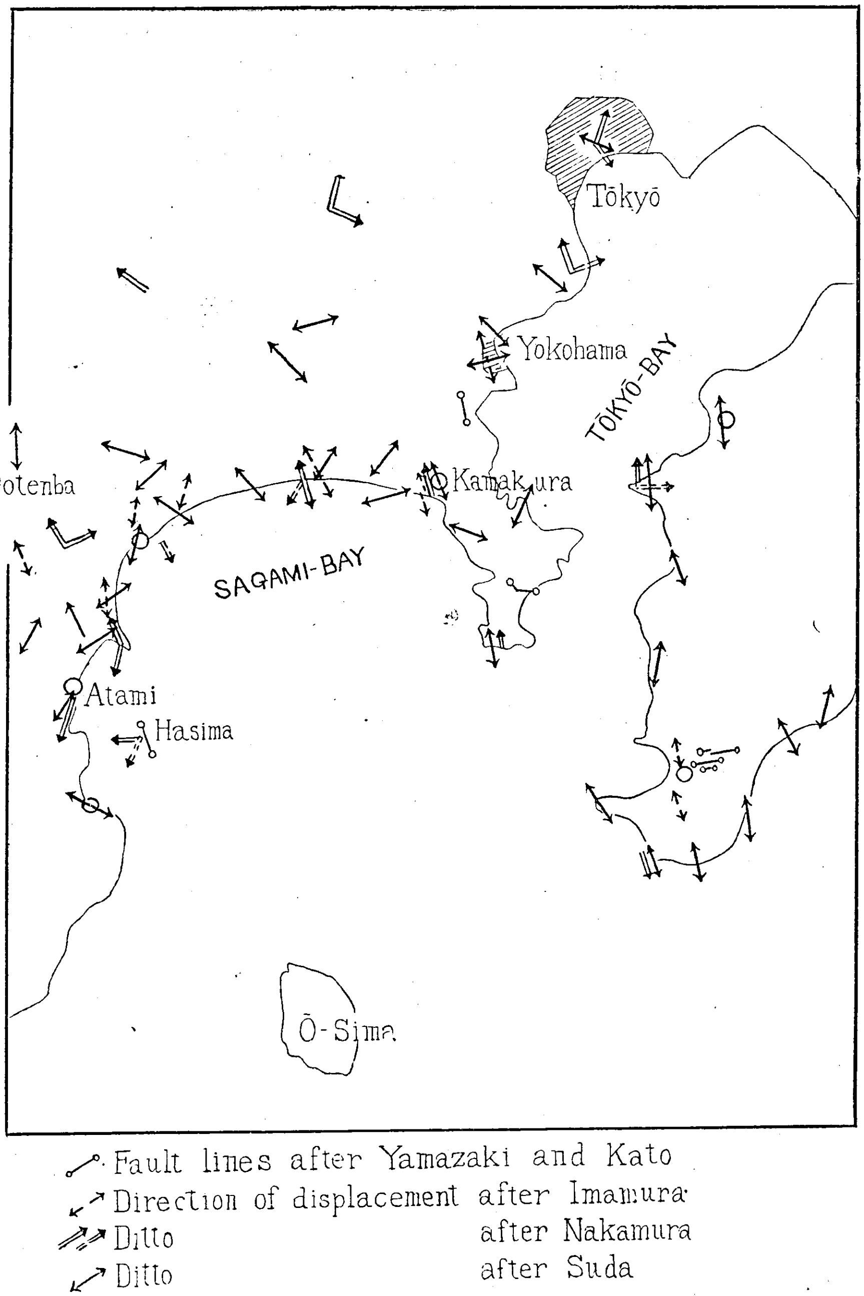
(2) N. Kawakami, On the Secular Upheaval and Subsidence of Land in Some Districts of Japan. Memoirs Imp. Marine Obs. Kobe, 2, No. 1, p. 71. The fact was first noticed by F. Omori, then later by St. Nakamura, K. Suda, H. Nagaoka, A. Imamura, H. Tanakadate, etc.

(3) D. Kikuchi, 1891, J. Milne, Seismology p. 3. H. Tujimura, Text book of Geomorphology (地形學) p. 456, 1923. A Imamura Rep. Imp. Earthq. Inv. Comm. No. 100, B, p. 91. H. Tanakadate, Rising and sinking of the Coast in connection with the great Kwanto Earthquake (Japanese). Journal of Geogr. Soc. Japan, 38 year No. 445, 446, 448, and 449. The last is most elaborate.

(4) A. Imamura, Proc. Imp. Acad. Japan. 4, No. 4, p. 149.

(5) T. Kato, Rep. Imp. Earthq. Inv. Comm. No. 100, B, p. 1. N. Yamasaki, Ditto p. 11.

Fig. 2.
Directions of Shocks judged from fallen or dislocated Bodies.



extension towards NW. This is most clearly seen from the percentage distribution of wooden houses which were crushed by the earthquake.[1] The form of isoseisms are not zonal but radiant.

(11) The distribution of the direction of the earthquake motion judged from the direction of the fallen stone monuments, crushed or displaced houses etc. was irregular, but rather vortical. See Fig. 2.[2]

(12) Submarine telegraphic cables were snapped by the earthquake at the mouths of Sagami Bay and Tokyo Bay.[3] See Fig. 1.

(13) On the 2nd Sept. 1923, deep sea fishes are said to have been found floating dead at the mouth of Sagami Bay.[4]

(14) Landslips are most intense on the mountain slopes along the west coast of the Bay. Then next in the mountainous region to NW of the Bay.[5] A curious fact is that in Hakone volcanic region land slided more remarkably on the base or middle slopes than on the upper part.[6]

(15) Change in the temperature, amount of issue, colour, mineral contents etc. of hot or mineral springs and also the changes of levels of lakes and wells are said to have occurred before and after the great earthquake.[7]

(16) The distribution of after shocks are not uniform as pointed out by K. Suda,[8] K. Shiratori,[9] T. Hirano[10] and A. Imamura.[11] After shocks were repeated having their epicenters in two or three district zones. Some intermittent activity between these zones was observed.[12]

(17) The law of exponential decrement of the frequency of aftershocks was

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(1) T. Matuzawa, Rep. Imp. Eartthq. Inv. Comm. No. 100, A, p. 163.
(2) S. Fujiwhara, Kensin Ziho, **1** p. 165.
(3) loc. cit. Bull Hydro. Depart., **5**, Pl. 11.
(4) K. Suda, loc. cit. also see Bull. Hydro. Depart., **5**, Pl. 11.
(5) Saem. Nakamura, loc. cit. p. 32. T. Matuzawa, A. Imamura, etc. Rep. Earthq. Inv. Comm. No. 100, B, p. 81, 85. K. Suda, loc. cit. p. 159.
(6) Eye observation of the present author.
(7) Saem. Nakamura, loc. cit. p. 18–23, etc. K. Suda, loc. cit. p. 171.
(8) K. Suda, loc. cit. p. 186.
(9) K. Shiratori, Jap. Journ. Astr. Geophys. **2**, No. 4, (1925) p. 173.
(10) T. Hirano, Journ. Met. Soc. Jap. 2nd Ser. **2**, (1924) No. 3. p. 77.
(11) A. Imamura, Rep. Imp. Earthq. Inv. Comm. No. 100, A. p. 58.
(12) T. Hirano, loc. cit. p. 78.

not simple and unique in this case as pointed out by K. Suda, who gave general warning on the residual seismic activity still stored up in dangerous degree in the crust of these districts,(1) which was answered by the heavy shock on the morning of Jan. 15, 1924 with much damage.

(18) Any definite point could not be determined as the exact position of the epicenter by analysing seismographic records obtained at more than 10 stations within 150 km. of distance from Sagami Bay. So many authorities proposed so many positions and at last K. Suda and T. Hirano(2) arrived at the conception of the 'seismic domain' or the epicentral region in order to avoid the infinite velocity of propagation of seismic waves as existed.

(19) The distribution of the initial motions recorded by seismographs at many stations near by also led seismologists to some confusion. Seam. Nakamura(3) concluded that the first motion was emitted from a point near Hadano on the north west coast of the Bay at the depth of about 60 km, where a fault plane with inclination of 77° from the vertical plane to west(4) was formed and along this plane, its east part slides upward and west part down. There is, however, still some anbiguity on the way of reasoning. Very recently S. Kunitomi attacked the same phenomena with fuller data than those of Nakamura taking the earth's discontinuity and phases of P, $\overline{P}$ etc. into consideration. He concluded that the first motion must have started from a point near Atuki at the depth of 28 km. The plane of invisible slip was inclined 47° toward W 16° S from the vertical plane and western lower part of the crust has slided up and eastern upper part down. Epicenters by Nakamura and Kunitomi are entered in Fig. 5. Those by Matuzawa and Matuyama also converge to this vicinity. Hence the epicenter of the first motion of this great earthquake is safely concluded to have been on land between Hadano and Atuki.

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(1) K. Suda, loc. cit. p. 181–185.

(2) T. Hirano, Journ. Met. Soc. Japan, 43 y. (1924) p. 16. K. Suda, loc. cit.

(3) Saem. Nakamura, loc. cit. pp. 44, 45.

(4) S. Kunitomi, Read before the monthly meeting of Met. Soc. Japan, Nov. 1928. but not yet printed.

THE OUTLINE OF THE PROPOSED THEORY.

§6. *The vortical formation at the earth-discontinuity.* The vortical displacement is explained as the effect of the rotational motion caused by the shearing stress at the line of discontinuity, i.e. the intersect of the surface of discontinuity in the earth's crust with the earth's surface. The most important discontinuity in the vicinity of Japan is one marking the boundary of the northwest Pacific Ocean and well known as one part of Circum Pacific zone of orogenic and seismic activities. As proved elsewhere(1) this part of the crust is making southwesterly shift in general and the relative motion at the boundary is SW-ly on the ocean side and NE-ly on the land side. Under such circumstances shearing stress must be accumulated with consequent shear. As the result, a rotational or vortical displacement of the crust must take place along the line of discontinuity or the line of shear, so far as the material is rather safe against shearing stress but weak against compressional, and most weak against tensile stress ——the earth and rock materials have such nature——, the material has tendency to break in crossed echelons along the line of shear and consequently presents a block structure. The effect of the elementary rotation of each block can produce a big vortical deformation in the general aspect. Such a mechanism of the earth vortices was explained already from actual facts as well as from model experiments.(2)

§7. *Volcanic hindrance.* Heiskanen,(3) on the basis of gravitational survey of M. Matsuyama and others,,(4) has shown that in this part of Japan the isostatic compensation is not yet complete. Consequently, the vertical motion of land masses and horizontal flow of magma must be going on in the present days. Indeed the volcanic ranges seem to be the result of the excess of compressive force as inferred in the author's former paper.(5)

(1) S. Fujiwhara, Gerland Beiträge f. Geophys. **16** (1926) S. 1–14. Also see Jap. Journ. Astro. Geophys. **3**, p. 113.

(2) S. Fujiwhara, Journ. Met. Soc. Japan, year 43, p. 32–36.

(3) Heiskanen, Zeitschrift f. Geophys. III (1927) H. 5.

(4) M. Matsuyama, T. Yamamoto, S. Hirayama, K. Sotome, T. Matukawa, etc. Rep. Imp. Jap. Geod. Comm. Vol. 1–5.

(5) S. Fujiwhara, loc. cit. Gerland Beitr. f. Geophys. Bd. 16 (1926) p. 4.

No excess of compression can exist without a local support or resistance against the general pressure, hence we must conceive some resisting action, whatever its original mechanism may be, existing in the neighbourhood of volcanoes against the general flow of magma and accompanying crust movement. Thus it may now be admitted that a volcano can be looked upon as a visible mark on the earth's surface of invisible resistance against the underground slow but steady flow.

§8. *Formation of an earth vortex by the back current behind Osima Volcano.* Let us now suppose that Osima with other companion volcanoes exerts resistance against the general Pacific movement of the crust towards W or SW, which perhaps is associated with magma flow underneath. Then the general movement must change its direction towards SSW or S by Osima and in the area to north of the volcano, there must exist a back current of the earth-motion in clockwise sense of rotation as usually seen on the flow of water by a hindrance at any bank of river. Though this back current flows very slowly in the earth crust, it will be sufficient to make up a vortical formation in the lapse of sufficiently long time.

§9. *Horse-shoe distribution of stress.* As already explained, such vortical formation accompanies elevation and depression of horse-shoe shape, which fact is also shown by an experiment in the next paragraph. From this view Sagami Bay corresponds to the central depression of the horse-shoe, and has been formed throughout the present and past geological ages and the process is still going on. Professor Terada has already pointed out this fact from the observation of radial and concentric semicircular tectonic lines round the bay.(1) To accomplish this formation the stress distribution in the earth's crust must also be of the horse-shoe type.

§10. *Sudden yield of crust.* The crustal movement may be continuous to some extent so far as its rigidity gradually yields to stress. But in the case when there is some hindrance choking the general motion locally, then the stress must accumulate and indeed up to the critical stage. Prof. Naga-

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(1) T. Terada, Romazi Sekai, (1924).

oka[1] got success to give solution to the equation for asymmetric free vibration

$$\frac{d^2\xi}{dt^2}=-f\xi+g\xi^2.$$

So far as $f>g\xi$, the motion is stable, while when $f<g\xi$, ξ tends to ∞, that means the break down of the material.

In the actual case there act some external forces, and also from the boundary condition the matter becomes complicate. But, at any rate, the state of unstable motion must taken into consideration.

Hence we can divide three stages of yielding.

1. $f>g\xi$ the yielding is slow and oscilatory
2. $f<g\xi$ the yielding becomes somewhat rapid and astatic, but still continuous
3. $\xi=\infty$ the break down or discontinuity

Applying this to the actual case we can also imagine that the so called bradyseisms[2] correspond to the stage 1. The period, during which some symptoms are occuring corresponds to the stage 2 and the earthquake or the final rupture corresponds to the stage 3.

Thus in the region of Sagami Bay the motion of and stress in the crust and the increase and decrease of pressure in magma underneath must have been distributed in horse-shoe shape all through ages and the stress in this sense had been as ever accumulated since the last release of stress or in the other words the last great earthquakes in 1853 and 1854. This belongs to stage 1. Then comes a period of symptoms, the stage 2, and at last the time came for the stage 3, when the crust made a discontinuous yielding again on Sept. 1, 1923, as to pace one more step on its destined course or as to repeate its cycles of about 70 years interval. It was effected in a sudden bending (warping) in horse-shoe shape, by which action the land and the water were tossed so violently that brought such a huge disaster as ever recorded.

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(1) H. Nagaoka, Asymmetric vibration of finite amplitude Proc. Imp. Acad. Japan. 3, No. 2. p. 61.

(2) The thought that the slow motion of the earth's crust is the cause or antecident of the sudden motion was initiated by Milne (Seismology p. 33, 34) and cultivated by Omori, Kusakabe, etc.

EXPLANATION OF FACTS FROM THE PROPOSED THEORY.

§11. *The scheme of explanation.* The fact (1) in §3, i.e. the time and place of the present earthquake could be explained as above. As to the exact time of occurence, we can only do it when the earthquake-forecast will have become possible and it belongs to some future.

As already remarked, there are so many theories on the cause of this earthquake,(1) but only one which can explain the fact (5), i.e. the vortical displacement of land, is the theory of vortical formation due to the general crustal movement in the Pacific region. Therefore, if the remaining facts be explicable from this theory or at least be not in contradiction with it, then the theory must be admitted for the time being.

§12. *The explanation of the main facts from model experiments.* The fact (2) and (3) i.e. the upheaval and depression of the land and sea bottom are very clearly shown by a model experiment with vortical displacement as shown in Fig. 3 and 4.

The first experiment (Fig. 3.) was made with a circular rubber plate of 10 cm. radius, 1.5 mm. thickness laid horizontally on a bed of cotton wool of uniform thickness of about 2 cm., and nailed at two points on a wooden desk underlying the cotton bed. On the surface of the plate a rough chart of Sagami Bay and its vicinity was drawn. One of the nails passed just through the position of Osima Volcano and the other just south of it. This second nail was used only for nothing but to hinder the rotation of the plate slidingly round the first nail. On the points corresponding Amagi, Hakone and Fuji Volcanoes three metal pieces were mounted in order to exert some pressure on these points.(2) A piece of wooden plate was attached on the part of eastern ocean. All these are shown in Fig. 3. a. With a string attached at the southern end of the wooden piece, this was pulled toward south and distorsion, upheaval and depression of the surface of the rubber plate were produced, whose aspect is shown in Fig. 3. b.

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(1) Some one calls this as Kwanto-Earthquake and some other as Japan-Earthquake, all the same as the great Sagami-Bay Earthquake of 1923.

(2) These are proved imperfect. These volcanoes must have been fixed more firmly.

White arcs in the Figure show the rotational displacement, which is of nearly the same nature with the actual one as shown in Fig. 1. Only difference is that the rubber plate wants plasticity, while the earth's crust has it, and as its consequence the rotational or better the vertical motion relative to Teruisiyama, the actual case as shown in Fig. 1, is conspicuous only round Sagami Bay and not remarkable in the northern part of the map, while in Fig. 3. b, the fixed point or reference point is selected at Osima and nearly the same rotation is imposed over the northern part.

Dark shadowy part in Fig. 3, b is the part sloping against light which came from the north of the map at the time of photographing it. The white part is the slope facing north and hence the boundary of white and dark parts is either depressed valley—south white, north dark—or uplifted ridge—north white, south dark. Thus as shown in this figure the bottom of Sagami Bay is depressed as in the experiment as in the actual case, and the arcuate part along the north coast of Sagami Bay is uplifted equally well in the fact and in the experiment. In Fig. 3. c the contour lines on the face of the rubber plate in Fig. 3. b is shown in remarkable coincidence with actual contours.(1) A few number of nearly the same experiment, were done which gave the same results. It is noteworthy that in the experiment with the rubber plate the sense to rise or to sink is indeterminate and just reversed figure can be produced. Even a very slight depression (or elevation) existing before the experiment at the part to be deformed can serve to lead the further deformation to depression (or to elevation). But the general aspect cannot be altered by such initial slight deformations.

§13. *Explanation of faults formation by the model experiment.* Next we improved the experiment by covering the surface of the rubber plate with paste—mixture of powder of zink oxide and wheat, half amount each —with uniform thickness of about 2 mm. We attached one more string at the top of the wooden piece, and pulled along this during the experi-

(1) Figures entered indicate elevation as positive and depression as negative. The measurement of depth from a given standard plane, was made twice, before and after the experiment and the differences are reckoned as the bearing of elevation and depression.

ment in order to keep these part without E-W displacement. The result of the experiment is shown in Fig. 4. a, b and c, in which a is the state before the displacement, b the state of successive displacement and c the final state. The light comes from SW direction and hence the slope facing NE is shown dark. The general feature of the depression and elevation was nearly the same as the former experiments. Th rotational displacement appeared but very little in this case being checked by the upper string.(1) The most remarkable feature in Fig. 4. c is that surface cracks are formed across Bôsô and Miura Peninsulae just as was in the actual case shown in Fig. 2. We see some cracks between Hudi (Fuji) and Hakone Volcanoes in the experiment but not in the actual case. This perhaps due to that, the volcanoes were more immovable in the actual case than in the imitated experiment. Any how the fact 9—the formation of faults—turns out to be a good support of the theory.

§14. *Explanation of tsunami, snapped cables and dead deep sea fishes.* So far as the experiments show, the orographic change must be most intense from the mouth to the central part of Sagami Bay, which servves to explain the fact (4), (12) and (13) in §. i.e. tsunami or seismic bore, break of submarine cables and dead deep sea fishes.

§15. *Explanation of bradyseisms.* The pressure and traction from Pacific side upon Kwanto and Sagami Bay districts are supposed to be ever continuous since at least young geological ages with some fractuations —the cyclic nature of vortex—in intensity, so that the repeated upheavals of coastal districts round Sagami Bay were brought in geological as well as in historical ages. Thus the fact (7) can also stand in a good harmony with the proposed theory.

§16. *Explanation of the tilting of the earth and changes in under ground water.* The fact(8), the tilting of earth before the great earthquake and the fact (15), changes of under ground water or hot springs before and after the earthquake depend on the nature of the superficial

(1) If we can use some material more plastic than a rubber plate, then the rotational displacement round Sagami Bay will be exhibited satisfactory with the same process as above.

crust in the vicinity. Acted by the partial pressure and traction from the ocean side and by the reaction from the volcanic masses on the west, the crust in this site may yield, first very slowly then rather quickly but still continuously as explained after Nagaoka's theory. In its second stage the tilting must have started first and then the chang in the underground water. Hence these two facts also present no discordance with the proposed theory.

§17. *The explanation of the aftershocks-anomaly.* Among the remaining facts, (16) and (17), the anomaly of aftershocks in space and in time, are of local character giving suggestions on the structure and on the stress distribution in the earthcrust under the Kwanto district. The zonal character may be compared to the wave formation marging a vortex area as is usually observable with cloud or water vortices. The experimental result of T. Terada and N. Miyabe is also very suggestive on this point, in which zonal activity is very clearly observable.

If the general stress of fractuating nature superpose with the local stress round the newly broken area, where gradient of the local stress is still very steep, such phenomenon as intermittent zonal activity can take place. We shall however, left this problem to other places.[2]

In all respects these facts are also favourably explained in the view of the present theory.

§18. *Explanation of the irregular isoseisms.* The fact (10) that is the irregular distribution of crushed wooden houses can not be explained by the linear dislocation theory so good as by the vortical theory. There are 5 points to be considered, they are:—

1). The distance from Sagami Bay, nearer to it, greater the number.

2). The softness of soil and hardness of rocks.

3). The block structure of the crust. Along the boundaries of blocks the damage must be great.

4). The existence of the third and forth arms of discontinuity.

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(1) T. Terada and N. Miyabe, This report Vol.

(2) A lecture on this point was already given by the present author at the colloquium of the Eartthq. Research Inst. July 3, 1928, but not yet printed.

5). Asymmetry of vortex in its developing stage.
Those vortices taking rise at discontinuity have normally two principal arms of discontinuity. The third arm is also very common with earth. vortices, for example, the third arm of Celebes vortex extends north to Philippin Islands. As is clearly seen, the zone of damage extends very far toward NW covering Kôhu, Matumoto and Nagano districts, while no damage was reported from Titibu district in nearer position to Sagami Bay. West shadow of Huzi volcano, southern part of Idu province are also districts of less damage. Osima in the very proximity also experienced rather small damage. The NW extension must be due to a conspicuous geotectonic line which was noticed by K. Suda[(1)] and also by H. Yabe and R. Aoki,[(2)] and corresponds to the third arm of Sagami Bay vortex in our sense. Asymmetry of the vortex is always remarkable in such cases, so that the less damage in Osima and Idu and great damage in Tanzawa district is explained. This fact is thus in favour of the theory.

§19. *Explanation of the abundant landslips on the W and NW sides of the Bay.* The fact (14) may be explained as that, if the volcanic range between Hakone and Amagi volcanoes is comparatively immovable, then the zone of superficial fracture shown in Fig. 4. c must bend southward along the eastern slope of the range. Then naturally land slides more abundantly in these regions. Hence this fact can also stands in accordance with our theory.

§20. *Explanation of the diffused epicenters.* The fact (18) may be understood as such that the earthquake occurred in virtue of a horse-shoe deformation of the crust over a great area. Hence it is naturally difficult to determine the so called epicenter as a point.

§21. *Explanation of long range subsidence of the shore at Aburatubo.* The fact (6) may be explained in various ways:—

1). During the first stage of the continuous yielding of the crust in horse-shoe shape as explained before, the depression of the sea bottom may

(1) K. Suda, loc. cit. Pl. IV, Fig. 4. Kofu-Matsumoto line.
(2) H. Yabe and R. Aoki, Relation between Kwanto earthquake and geological structure etc. Saito-Ho-on-Kwai, Nenpo, No. 1 (1925).

be easier than the upheaval of land. The great difference in the character of the crust of the ocean and continent was noticed by Knot, Wegener, Gutenberg, Joly, and many others. T. Terada(1) in his recent researches attributes much plasticity to the bed crust of the ocean and also to that of Sagami Bay, which deeper than 3000 m. and is believed to have more oceanic character than the continental shelf. Hence the easier deformation of the Sagami Bay bottom is not groundless. If so, then the shore land at Aburatubo must have depressed by 10 cm. during 20 years subsiding with the Bay bed. In the second stage of yielding, however, the choking agency against the land motion would gradually be taken away and uplifting set in for two years before the great earthquake.(2) At the third stage in Nagaoka's sense, the sudden rupture might have brought the upheaval of 100 to 200 cm. to the effect. This is nearly the same as to consider the sudden elevation of the coastal land as the effect of rebound.

2). We may also suppose that after the former rupture in 1854, the superficial part of the crust was kept in a state of continuous down settling independent of underlying increase of uplifting stress.

3). A small hindrance against the general flow of magma or westward shift of the crust existed somewhere east of Sagami Bay before the earthquake and by the motion outside of this hindrance, the material under the bottom of the Bay was sacked gradually out through the mouth part of the Bay during these 70 years since the great earthquake in 1854. Shortly before the resent earthquake, the hindrance was gradually taken away and then gradual upheaval of the coast started so that sufficient compression was stored up under the land mass until the great rupture had taken place effecting the upheaval of the coast land.

4). Fractuating flooding in magma flow.

5). The amount 10 cm. is comparatively small and can be explained

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(1) T. Terada and N. Miyabe, Proc. Imp. Acad. 4 (1928) p. 55.

(2) There must be a number of corresponding second stages as the scales of the phenomena concerned. During the third stage of the phenomenon of the greater scale there may be conceived first and second stages of the phenomena of the smaller scale forming members of the family of the greater phonomenon.

otherwise, for example by some meteorological effect on tide.[1] In no way, however, this fact is not against our theory.

§22. *Explanation of the distribution of the first motion of the great earthquake.* As explained in Fig. 4. c the part of land around Hadano or Atuki correspond to the zone of fracture, hence, the first break may started one of such places.

The surface of dislocasion shown by Nakamura or Kunitomi was invisible on the earth surface, hence, if true, this must have been a trigger dislocation, but not the main. Hence the fact (19), does not contradict with the proposed theory.[2]

§23. *A conclusion.* Thus by the proposed theory five main facts (1)–(5), and seven subordinate ones (7), (9), (10), (11), (12), (13) and (14) were explained and the facts (8), (15), (16) and (18) stand rather in favour of the theory, while the remaining facts (6), (17) and (19) do not contradict with the theory.

Hence the proposed theory may be admitted for the present.

DISCUSSION ON THE PROPOSED THEORY.

§24. *Shearing stress and vortical formation.* In the proposed theory in §4, the shearing stress at the eartth discontinuity is assumed. On such shearing stress Kosmat had clear idea and used it in his theory of Alps.[3] A. Wegener also noticed the vortical form in the vicinity of Celebes etc. in his famous researches on the emigration of continents.[4] Hence the idea of vortical formation in the earthcrust or on the earth's surface is by no means extravagant. On the discontinuity in the vicinity of Japan,

(1) T. Terada and S. Yamaguti, Jap. Journ. of Astro. and Geoph. 4, 1, p. 35.

(2) According to Nakamura the fault is overthrust and hence the region of Hadano must be compressional. After Kunitomi the fault is a normal fault and hence the region of Atuki must be under tensile stress. Both are the case as shown in Fig. 5, so that we cannot discriminate these two inferences from this. But Kunitomi's inference taking Mohorovičić wave into consideration is fuller and this may be looked upon as standard for the present.

(3) F. Kosmat, Die Beziehung des Sudosteuropäischen Gebirgsbanes zur Alpentektonik. Geolog. Rundschau, Bd. 15 H. 3, S. 275.

(4) A. Wegener, Die Entstehung der Kontinente und Ozeane, SS. 46, 97, etc.

there are very many researches, among which Gutenberg's work,[1] pointing out the discontinuity in the physical nature between the earth crusts of Eurasian Continent and Pacific bed is worth mentioning.

§25. *Block structure.* On the block structure of the earthcrust in the vicinity of Kwanto, Yamasaki's investigation is most important.[2] He has pointed out the block structure of the earth on the northern coast of Sagami Bay and in Bôso peninsula, and it was newly proved that each of them is making its own tilting, after the survey by the Landsurvey Department.[3]

The vortical formation in the blocked area is not yet investigated. But if we use a model as illustrated in Hobbs's book,[4] only enlarging the area, and make up a big vortex underneath the floating blocks which are now of uniform thickness, then. So far as the vortex is young, or asymmetrical, the blocks may present horse-shoe elevation and depression; after becoming symmetrical, then they will present a circular central depression.

At all events, the blocked earthcrust will exhibit the similar effect as increasing plasticity of the earth material, because elastic reaction is slacked at the boundary of blocks. Hence the vortical formation will be easier by the block structure than by a uniform elastic sheet.

§26. *Stress acting on Japanese arc.* As to the general shift of North Western Pacific earthmass, the readers are referred to the author's former paper,[5] in which the evidences of the anticlockwise rotation of the area are pointed out.

There is a famous theory of Suess on the stress acting on the crust

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(1) B. Gutenberg, Dispersion und Extinktion von seismischen Oberflächenwellen und der Aufbau der obersten Erdschichten. Pys. Zeitscher. 25 J. 1924, S. 377–381.

(2) N. Yamasaki, Physiographical Studies of the Great Earthquake of the Kwanto District, 1923, Journ. Faculty of Science, Tokyo University, **2**, Part 2.

(3) This fact was reported by K. Muto at the meeting of the Earthq. Res. Inst. on May 22, 1928, but is not yet in print.

(4) Hobbs, Seismology Pl. III.

(5) S. Fujiwhara, On the Echélon Structure of Japanese Volcanic Ranges etc. Gerland Beiträge, Bd. 16. S. 1–14. Also the same author Torsional form on the Face of Earth. Nagaoka anniversary Vol. p. 333, also Jap. Journ. Astro. Geoph. **3**, p. 103.

of Japanese region. In this theory the origine of compression is supposed due to the side pressure directed outwardly caused by the gravitational action on the Asiatic continental mass. But this idea evidently contradicts with the theory of isostacy. Under isostatic balance such a side pressure cannot be exist. Moreover Japan Sea which lies between Japan and the Continent is sufficiently deep, and if such side pressure actually existed, it must have exhibited more markedly along the inner margin i.e. the coast of China, Korea and Siberia than in Japan. But in actual case, the seismic and volcanic activity is much stronger in Japan, than in the continental coast. Hence the above theory is quite groundless. Moreover, if Wegener's theory of the west drift of continents is true, then the stress in this site must be traction from the continental side instead of pressure. After Richthofen, the sense of traction is from Oceanic side.(1) The present author, however, does not know which one of these theories is true.

Be what it may be, but the fact is an east-west compression—in rough sense—is acting along the Japanese arc. This can be proved from various points. S. Kunitomi's recent research on the anisotropic propagation of seismic waves(2) give certain bearing upon this point. K. Suda's analysis of the sense of stresses in Japan from the distribution of the first motion also reveals the similar fact.(3) The present author also has proved the fact from the analysis of the échelon faults formed on the occasions of some great earthquakes.(4)

§27. *Sense of horizontal stress.* As to the sense of horizontal stress acting in the earthcrust, no perfect determination is yet established. It is well known that Hobbs(5) considered the landward compression from the Ocean side, against the theory of continental creep of Suess. In the case

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(1) Richthofen, Geomorphologische Studien aus Astasien. 1903.

(2) S. Kunitomi, Propagation of Seismic waves in Japan etc. (Japanese) Journ. Met. Soc. Japan. **3**, Nos. 3, 7, 11, **4**, Nos. 5, 9, **6**, No. 3. Also see Gerland Beitr. Bd. 17, S. 36.

(3) K. Suda, Umito Sora, 5, p. 85.

(4) Read before the annual meeting of Physico-mathematical Soc. of Japan on April 3rd 1928, but not yet printed.

(5) W. H. Hobbs, Mechanics of Formation or Arcuate Mountains. Journ. Geol. **22**, 1914.

of elastic deformation there is no difference if pushed from land or from Ocean, only actor is the compressional stress in both cases. But in the case of plastic deformation and especially when there exist some local hindrances against the general push, we can determine the sense of push. Very recently T. Terada and N. Miyabe[1] made experiments with sandy material and found the asymmetrical deformation caused on the sand surfaee. MacCarthy's experiments in underthrusting show also nearly the same fact.[2] These will serve to determine the sense of push or pull in the actual case in future.

§28. *Origine of stress.* As to the origine of the horizontal stress there are many theories.

W. Inoue proposed a hypothesis that a very slow cylindrical rotation in the earth about an axis penetrating Africa to Pacific was and is going on.[3]

In the well known theory by J. Joly based on the radio activity of rocks the compensational exchange of material between continent and ocean is assumed[4] as usually done in harmony with the theory of isostacy.[5]

A. Daly proposed a theory of horizontal slide of the crust in its full thickness due to chilled tension.[6]

J. W. Evans pointed out the E-W contraction in the equatorial zone of the earth, taking into consideration the effect of cooling and the change of the rotation-period of the earth after the calculation of Stoneley. Evans noticed in this respect the region of compression around Pacific Ocean. On this point, perhaps nearly all geophysists may have their own theories and the current thought of the day seems to recognize the horizontal shift

(1) T. Terada and N. Miyabe, this Bul. **4**, p. 33 (1928); **6**, p. 109 (1929).

(2) G. R. MacCarthy, Amer. Journ. Sci., **16**, 51, (1928).

(3) W. Inoue, Gerland Beitr. **19**, s. 231 (1928).

(4) J. Joly, The surface history of the earth 1924 and other papers appearing later.

(5) The works of Hayford, Helmelt, Hicker etc. discribed in any text book, e.g. Jeffreys: The earth.

(6) A. Daly, Relation of Mountain-Building to igneous action. Proc. Amer. Phil. Soc. **64**, No. 2, 1925, p. 296.

(7) J. W. Evans, Regions of Compression, Nature, 1927, Jan. p. 15–17, etc.

and accompanying compression at the boundary of the ocean and continent.

It is note worthy here that, as Saemont. Nakamura(1) has already noticed, Hawaiian volcano, situating at the central part of North Pacific, had experienced a sudden subsidence of the lava surface on the occasion of the concerning Japanese earthquake.(2) This might be explained as chance, but the simultaneous occurrence of a great earthquare with the eruption of a distant volcano is by no means seldom, and hence wants future investigation.

§29. *Reaction of Volcanoes.* One of important assumptions in our theory is the impedance of volcanoes against the general crustal or magma movement. As reported by Prof. Seiji Nakamura(3) and also by the Land Survey Department.(4) Osima actually did not rise nor sink. Volcano Huzi (Fuji) got no effect from the earthquake in a remarkable contrast with Kohu (Kofu) which, situating in a greater distance from Sagami Bay than Mt. Huzi, was shaken very violently and rents and cracks were formed abanduntly in the vicinity.(5) If the immovability of volcanoes be true, its reason is not yet very clear. Tentatively it may be that the volcanic rocks, newly solidified, are very strong and volcanic neck or tube which already consolidated exerts resistance against the general motion as if a nail or pin prevents a board or sheet paper to remove.

§30. *Horse-shoe bending.* To solve the horse-shoe bending mathematically is very difficult. But the possibility of it can be imagined from the analogy of St. Venent's problem. In the vortex of water or air the horse-shoe shape happens most commonly.(6) A characteristic feature is

(1) There are Many S. Nakamuras in Japan. Seidan Nakamura=Kiyoo Nakamura, Academician, Meteorologist, former director of the Central Meteorological Obs.
Seiji Nakamura, Dean of the Faculty of Science, Tokyo Imperial Univresity, Physisist with some researches on Oceanology and Volcanology.
Saemontaro Nakamura, Prof. of Geophysics, Tôhoku Imperial University, Seismologist.
Sintaro Nakamura, Prof. of Geology, Kyoto Imperial University, Geologist.

(2) Jugger, Volcanological Bulletin, 1923.

(3) Seiji Nakamura, Rep. Imp. Earthq. Inv. Comm. No. 100, B. p. 73.

(4) loc. cit.

(5) H. Obata, Rep. Imp. Earthq. Inv. Comm. No. 100, A p. 141.

(6) S. Fujiwhara, The natural tendency towards symmetry of motion etc., Quart. Journ. Roy. Met. Soc. 47, p. 387, 1921.

that the vortical horse-shoe is usually not symmetrical with its axis. We can see this character also in Fig. 1. in which the elevation to the west of Osima is very thin, while that covering northern and eastern regions of Sagami Bay is very eminent, resembling the rain area of Bjerknes's cyclone.(1)

Comparison with other Theories.

§31. *Theories of Suda and Fujiwhara.* Among theories summarised in §2, No. 9 by Mr. K. Suda is nearly the same as the present one, though he touched rather slightly on the vortical nature. In No. 11 by the present author, the sudden upheaval of the coastal region is considered due to vortical rebound. But since this point cannot be proved exactly from the fact, the vortical displacement and consequent bending are only treated in the present note.

§32. *Terada's Theory.* The theory No. 8 of Prof. Terada is very suggestive one. A model which recoils in the direction of stress—ordinary one recoils oppositly—and another model of floating continent on viscous solid are offered. His final conclusion is the local horizontal fold and this is nearly the same as our horse-shoe bending. There is no contradiction between his and our present one.

§33. *Linear rebound* was actually proved on the occasion of San Fransisco Earthquake in 1906.(2) The slow horizontal displacement on the east and west sides of the great San Andrews fault was northwesterly before the great earthquake and the sudden displacement on the occasion of the earthquake was still NWly on the west side, while SEly on the east side. This is the most evident proof of the linear rebound. In our case, however, no such relation was observed. Only fact supporting the rebound hypothesis is the fact (6) in §3, which alone is not sufficient to prove either vortical nor lenear rebound.

§34. *Lenear dislocation.* The most remarkable feature of the lenear

(1) J. Bjerknes, On the structure of moving cyclones. Geophysik Publicationer, 1, No. 1, 1919.

(2) A. C. Lawson and others No. 1, H. F. Reid No. 2, Publ. No. 87, Carn. Inst. Washington.

dislocation i.e. fault formation in straight line is the zonal distribution of the inner isoseismic lines as was the case in the San Francisco earthquake or in the Tango earthquake. In the case of Sagami Bay earthquake this condition was not fulfilled as proved by a very accurate method by T. Matsuzawa(1) and also by others.(2) There is no rigorous proof for the linear dislocation at the bottom of Sagami Bay. The investigation by T. Terada and N. Miyabe stands in favour of the vortical theory,(3) because the curves of equal displacement plotted by them are round but not zonal. The investigation of A. Imamura and F. Kishinouye contributes as well to the theory of the horse-shoe bending as to that of the lenear dislocasion.(4) Indeed the axis of our horse-shoe coincide with the supposed line of dislocasion by others, and these two theories come together to the same insistence that the horizontal motion of the NE side of Sagami Bay relative to its SW side was SE-ward. Hence those theories No. 1, 2, 3, 4 and 7 are all correct so far as the first approximation is concerned. Of course, in our theory too, some subordinate fissurs in the slope and bottom of Sagami Bay may be admitted.

§35. *Plutonic Theory.* As to the theory No. 6 in §2 i.e. a plutonic hypothesis stands also in accordance with our theory so far as the slow magma motion is concerned. It is more natural to suppose the yield of crust to the accumulated pressure both in lithoral and in magma layer than to imagine a sudden removal of such great amount of magma through considerable distance and over tremendous area as Sagami Bay and its environment in such a short duration as a few minutes during which the upheaval of two or three meters of the Sagami Bay coast was perfected. Hence plutonic hypothesis is not true in this case so far as insisting the sudden magma motion as the direct cause of the great earthquake. But

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(1) T. Matuzawa, Rep. Earthq. Inv. Comp. No. 100, A, plate facing to p. 260.

(2) Saem. Nakamura, K. Suda etc. loc cit.

(3) T. Terada and N. Miyabe, On the Horizontal Displacements of etc. Proc. Imp. Acad. 4, (1928) p. 49.

(4) A. Imamura and F. Kishinouye, On the horizontal shift etc. Bul. Earthq. Research Inst. 5, (1928), p. 40.

slow magma motion is necessary in the course of the isostatic compensation, which supposed true in the vortical theory.

Thus by close investigations, all theories based on the same facts turn out to be only different expressions of neary the same thing.

DISCUSSIONS ON THE RECOGNIZED FACTS.

§36. *Vertical displacement of the Sagami Bay bed.* The two most important facts upon which our theory rests are the upheaval and subsidence of land and sea bottom and the horizontal displacement in the shaken area. The enormous subsidence of the bottom of Sagami Bay was the subject most doubted. By an elaborate investigation by T. Terada,(1) it was, however, proved to be correct, at least, as far as the main figures concerned. T. Ogawa pointed out that the horizontal motion of mad is very easy at the bottom of Sea when tossed by violent shocks. This is quite true, and by this action mady material originally was on the submarine hill or in the upper slope must settle down and occupie the lowest part of the bottom. By closer examination of the original chart of Fig. 1 we find that the parts marked 1, 2, 6, 7, 18, 19, 20, 22, 23 and 25 in Fig. 1. were surely elevated in spite of their original higher positions, and the parts 3, 15 and 30 originally of maximum depths were subsided. The parts 5, 4, 17 etc. might be due to the land slips according to Ogawa's principle. This fact that even deepest part has subsided is a powerful support to the present theory.

The question that whether the subsidence and the horizontal displacement were performed whether gradually or suddenly is one not yet answered. But it is very probable, as Prof. T. Terada and others also remarked, that some fractions of these displacements were due to the momentary motion. The horizontal displacement of the land area is also subject to similar question. Very recently Land Survey Department published the result of the measurement of the base line in Mitakamura in shaken area and

(1) T. Terada, On the Vertical Displacement of the Sea Bottom etc. Proc. Imp. Acad. IV (1928) No. 2, p. 45.

(2) T. Ogawa, chikyu, the Globe, **1**, p. 405, (1924).

the result is that the base line elongated suddenly at the time of the great earthquake and recontracted a little after the quake. Then again it continue the elongation in a greater rate than before the earthquake. This is a favourable fact to our theory.

§37. *Convergence and Vorticity.* On the vorticity apparently shown by the horizontal displacement, suspection was also casted, because such idea as vortical motion in the earth's crust is quite new and was hardly accepted by, excepting a very few geophysicists. First of all, it was doubted that this might be the result of the choice of the reference point at Teruisiyama. To make clear of this question the author calculated the specific convergence C and specific rotation R of each area in squares as shown in Fig. 5. The formulæ are

$$KC=\frac{1}{l^2}\int_s V_n ds=\frac{1}{l^2}\int(vdl_1-vdl_3+udl_4-udl_2)$$

$$=\frac{1}{l}(\bar{v}_1-\bar{v}_3+\bar{u}_4-\bar{u}_2),$$

$$KR=\frac{1}{l^2}\int_l V_t dl=\frac{1}{l^2}\int(udl_1-udl_3+vdl_2-vdl_4)$$

$$=\frac{1}{l}(\bar{u}_1-\bar{u}_3+\bar{v}_2-\bar{v}_4),$$

where K is the magnification factor of the linear scale, l the length of the side, ds the side element, V_n and V_t the normal and tangential component displacements on the side, dl_1, dl_2, dl_3, dl_4 are elements of respective 4 sides round the square in the sense of anticlockwise rotation as positive, $\bar{u}_1$, $\bar{u}_2$, $\bar{u}_3$ and $\bar{u}_4$ are the average component displacements on the respective 4 sides, parallel to dl_1, $\bar{v}_1$, $\bar{v}_2$, $\bar{v}_3$ and $\bar{v}_4$ are the average component displacements on the respective 4 sides perpendicular to dl_1, or parallel to dl_2. The squares are taken proper in order that $\bar{u}$ and $\bar{v}$ are calculable by inter- or exterpolation within the least amount of errors. Though this choice of squares is somewhat arbitrary, it is certain that the main feature obtained is not altered by another plausible choice.

In the next table are shown the values of mean components displacements along and normal to four sides of twelve squares thus chosen.

These mean values are determined by interpolation or exterporation, and owing to the want of sufficient number of measurements, they are relyable only to the first figures.

TABLE I.

Components displacements along and normal to the sides of 12 squares.

Components / No. of Squares	$\bar{u}_1$	$\bar{v}_1$	$\bar{u}_2$	$\bar{v}_2$	$\bar{u}_3$	$\bar{v}_3$	$\bar{u}_4$	$\bar{v}_4$	L (c.m.)	KC	KR
1	53	272	99	−106	199	− 78	80	194	10	31	− 46
2	70	− 25	80	0	145	−180	112	−150	5	37	15
3	78	− 27	34	2	44	7	85	− 55	6	3	15
4	145	−180	85	− 55	76	− 37	140	−170	5	− 19	37
5	91	243	115	100	120	140	119	177	6	18	− 18
6	118	150	148	58	96	29	122	193	7	12	− 19
7	123	38	120	78	130	85	127	115	5	− 8	− 9
8	106	− 4	50	10	36	19	120	78	7	7	0
9	240	0	124	− 58	106	− 4	148	58	6	5	0
10	193	−184	140	−170	104	− 63	150	− 94	4	− 28	3
11	127	− 70	63	− 63	67	− 50	100	− 58	2	8	28
12	92	− 46	− 4	20	27	0	60	− 31	7	2	16

Substituting these values into the above formulae for KR and KC we get the values of KC and KR, which are entered in Fig. 5. They are correct at least to the first figures. The curves of equal rotation and equal contraction are drawn. These curves are now free from the choice of the reference point at Teruisiyama and can be looked upon as indicating bare fact.

We can see on this chart that Sagami Bay was subject to the greatest rotation in the clockwise sense, while there exists a zone of the counter rotation round the area of the primary vortex. Such is one of the characteristics of natural vortices in air or in water.

The area of greatest contraction, situating a little east of the primary vortex, just as already shown by T. Terada by different method,(1) indicates that the phenomenon is not the simple result of lenear dislocation.

As the small Takikawa faults near Hozyo—Fig. 2— are formed in the area of contraction i.e. of compressive stress and anticlockwise rotation or negative shear, the sense of echelon must be negative.(2) This is satisfactory the case as evidently shown in Fig. 12, p. 112 of Yamasaki's reports.(3) The sense of rotation also coinsides well with fact exhibited by the same faults as illustrated in Fig. 13, Plate 27 in the same report.(4)

Such coinsidences of the theory with facts strongly indicate the validity of the theory of vortical formation on the face of the earth and the vortical generation of some of earthquakes.

Oct. 6th, 1928.

IN THE EARTHQUAKE RESEARCH INSTITUTE, TOKYO.

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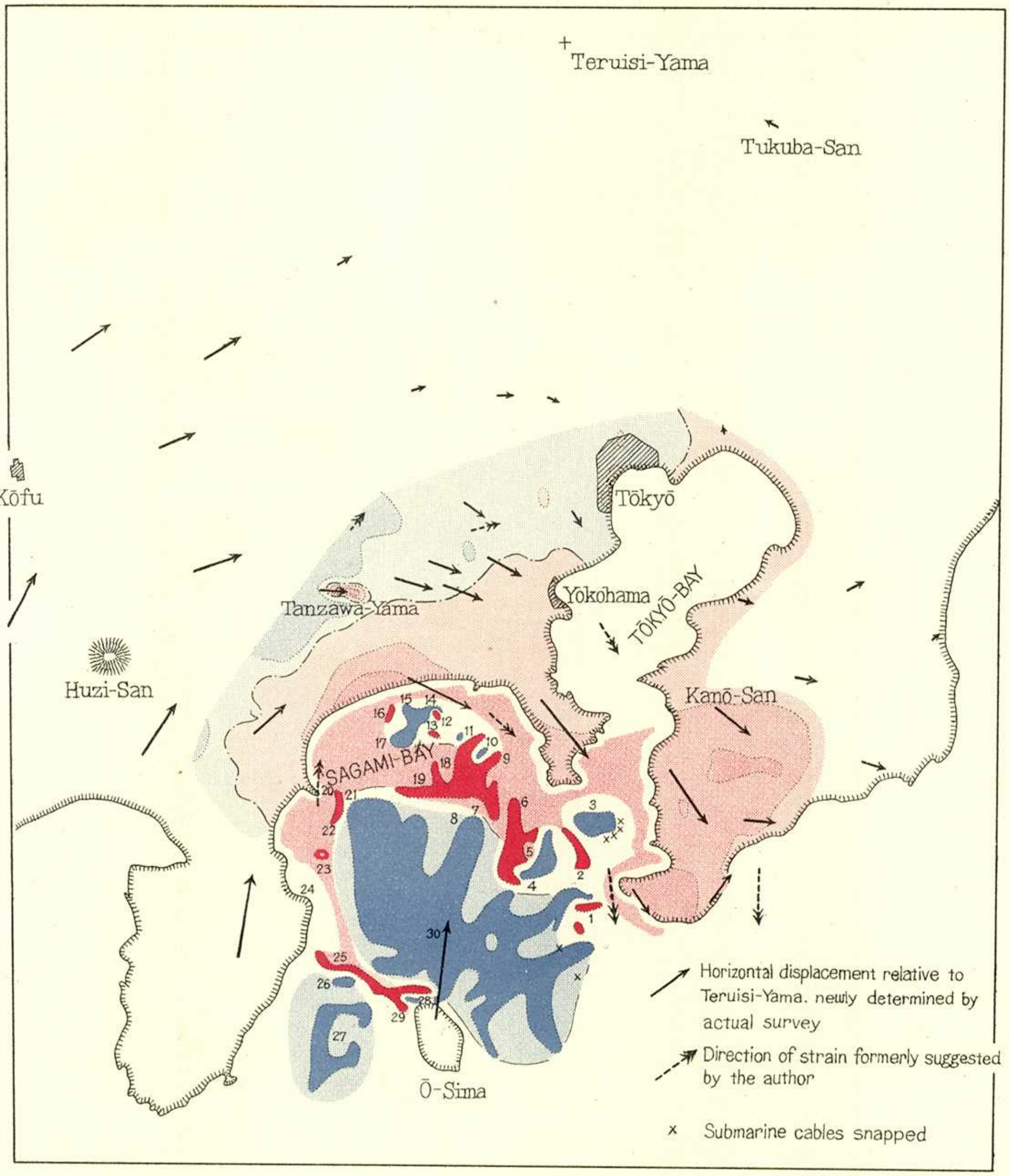
(1) T. Terada and N. Miyabe, loc. cit. Proc. Imp. Acad. **4**, (1928) pp. 49–52.
(2) See S. Fujiwhara, Gerland Beitr. Bd. 16. S. 2.
(3) N. Yamasaki, loc. cit. Journ. Fac. Sci. Imp. Univ. Tokyo, Sect. 2, **2**, part 2.
(4) As to the Sinkawa and Sitaura faults there is no description on the echélon aspect.



(震研彙報、第六號、圖版、藤原、高山)

Fig. 1.
Horizontal and Vertical Displacement, as revealed by Actual Survey.

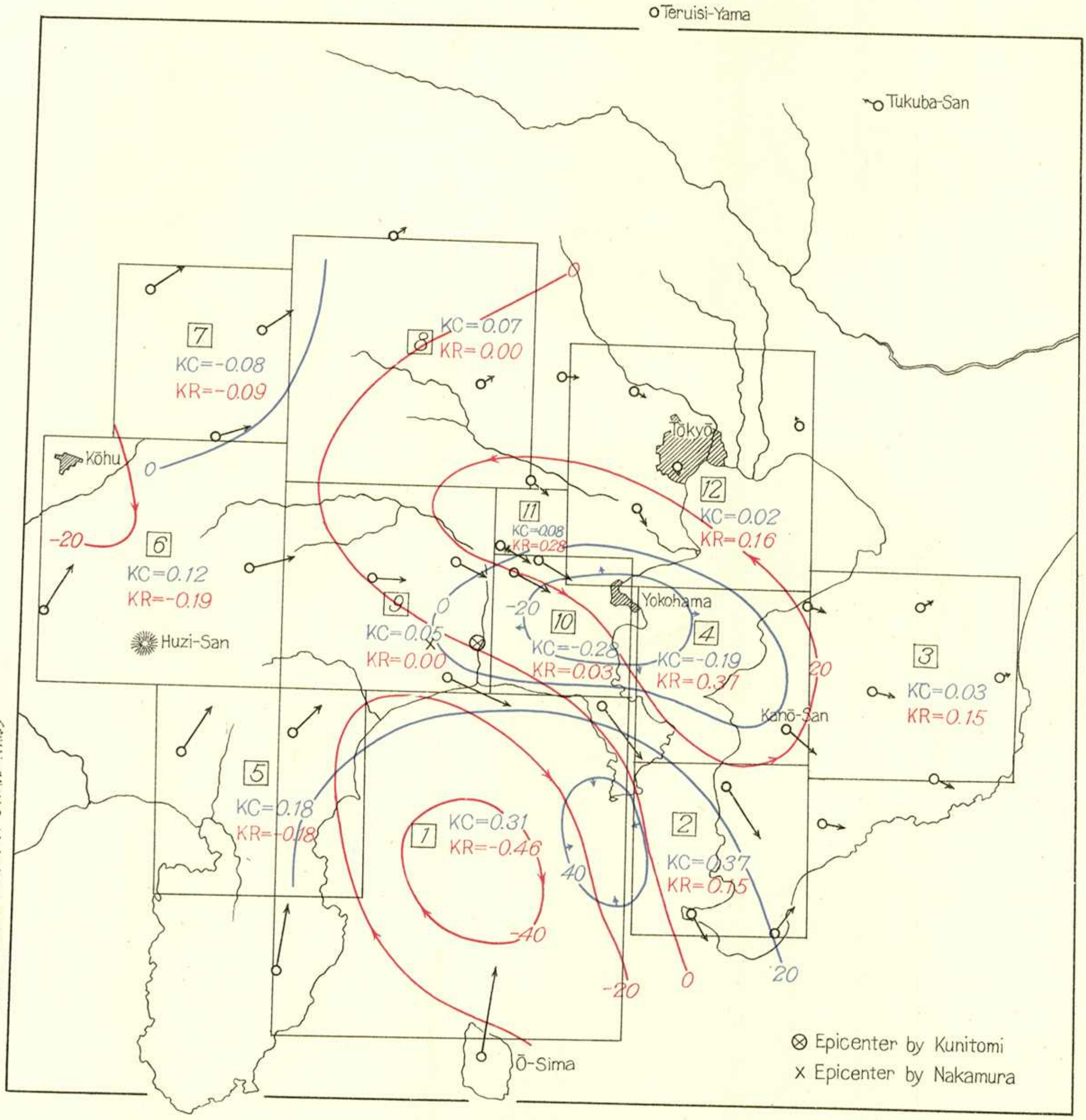


Fig. 5.

Convergence (in blue) and Rotation (in red) in the Shaken Area.

（震研彙報、第六號、圖版、藤原、高山）

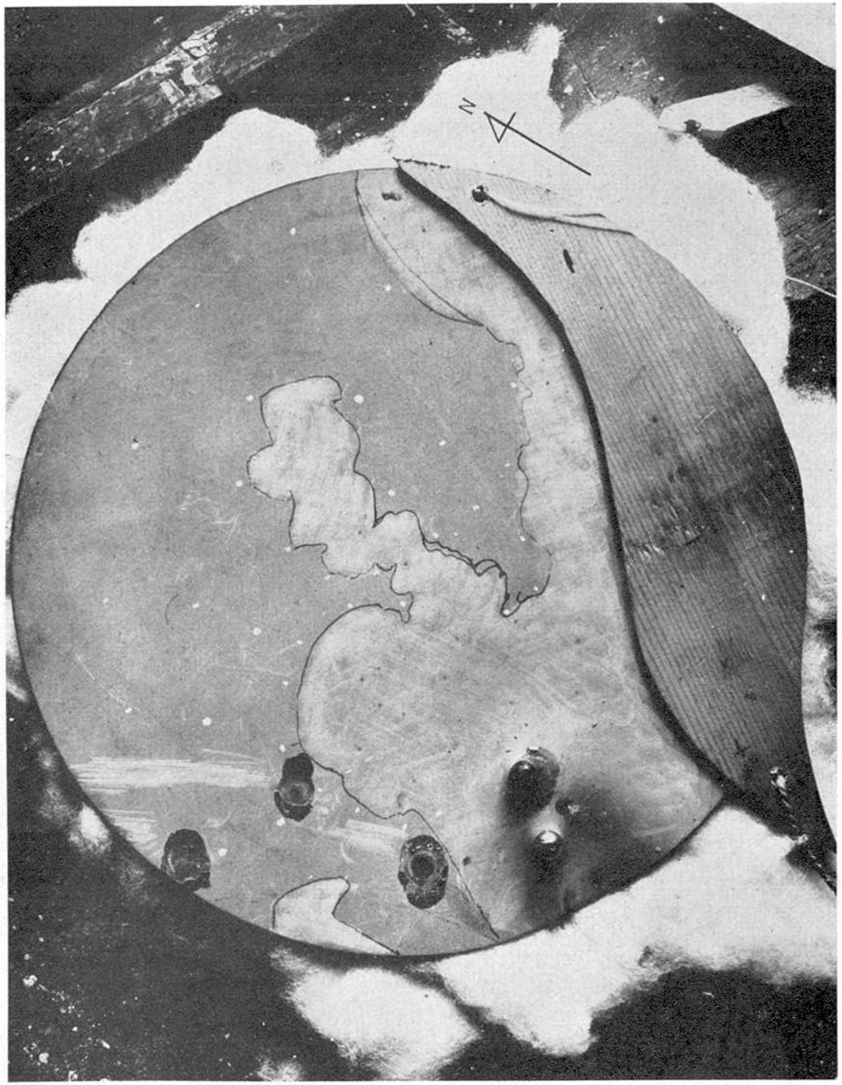


Fig. 3 a.

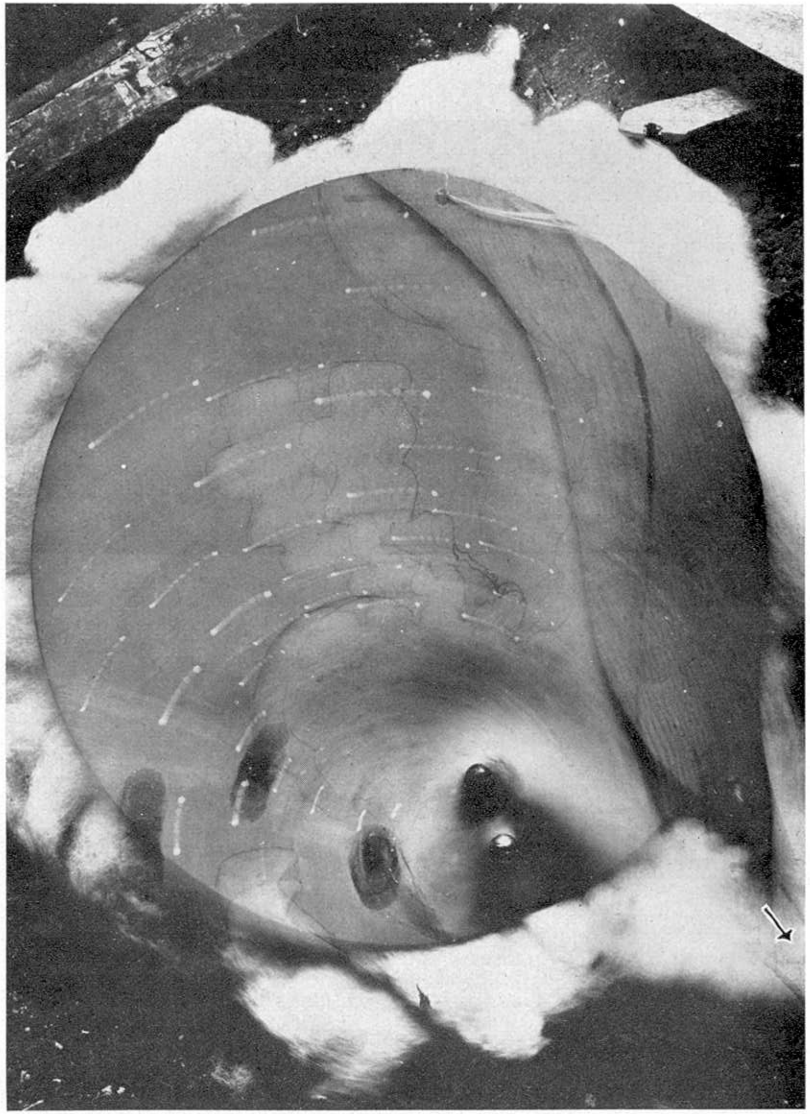


Fig. 3 b.

Fig. 4 c.

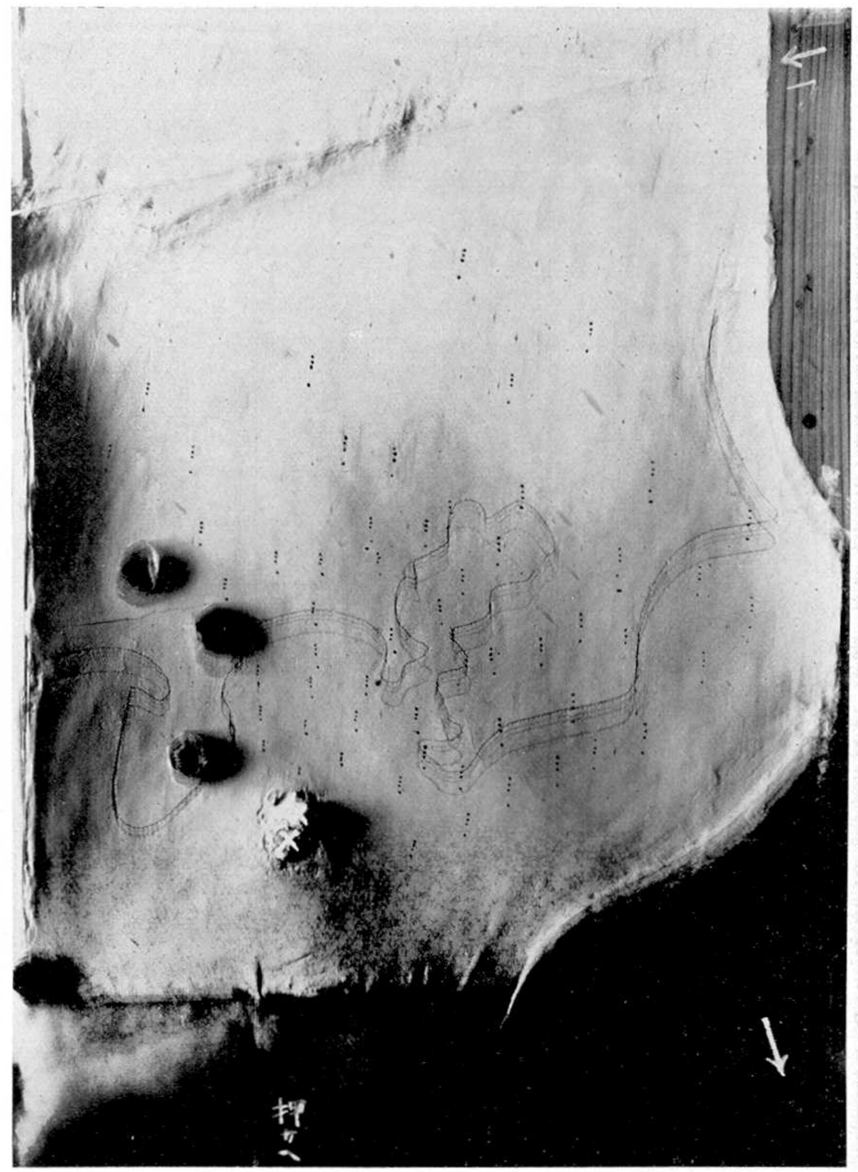


Fig. 4 b.

Fig. 4 a.