38. *Change of Depth in the Bay of Tosa.*

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In 1928, Hydrographical Department of the Imperial Japanese Navy undertook a thorough revision of the bathymetric chart of the Bay of Tosa. The chart hitherto in use was based on the results of earlier soundings made during 1884-1891. As the result of the revision of sounding survey in the Bay of Sagami carried out just after the Great Kwantô Earthquake has revealed a very remarkable change in the profile of the sea-bed, it is a matter of great interest to carry out a similar revision of sounding in the Bay of Tosa, firstly because no destructive earthquake has been experienced in the latter region since the previous soundings and secondly because we cannot deny the probability of a future occurrence of severe earthquakes in this very region which was already repeatedly frequented by notorious catastrophs such as those of Keityô (1605), Hôei (1707) and Ansei (1854).

The new sounding was carried out during April-August of 1928 and the complete data of the results obtained were kindly placed at the disposal of the research staff of our Institute by the courtesy of Rear-Admiral Yonemura, Director of the Department at that time, to whom the present author is greatly indebted for his interest shown and assistance given during the course of our research work.

The present author has already published some brief notes[1] regarding the changes in depth of sea-bed which were found after the destructive earthquakes of Kwantô (1923), Tazima (1925) and Tango (1927) and attempted some discussions on the probable significance of change in depth thus found. The abnormally large amount of change found in the case of Sagami Bay seems to have been an object of sceptical criticism in some quarter, though the present author believes to have sufficiently proved on the basis of his statistical investigations that the change found must be real in the main. As no destructive earthquake was experienced in the vicinity of the Bay of Tosa in the

1) T. TERADA and N. MIYABE, *Proc. Imp. Acad.*, 4 (1928), 45; T. TERADA and S. HIGASI, *ibid.*, 296 and 394.

interval of time between the old and new sounding, the change in depth, if any, cannot be attributed to any sudden deformation of the sea-bed associated with earthquake, and consequently it must be considered to have been produced gradually and more or less monotonously during the said interval of time. If, therefore, a sensible change in the sea-bed be established as real in the present case of the Bay of Tosa, we may at least assume with a stronger conviction than ever that the greater part of the change in Sagami Bay might also have been produced gradually or chronically. Unfortunately, the depth of the part of the Bay of Tosa recently resurveyed is generally less than 120 m., whereas in the case of the Sagami Bay the greater part is of depth greater than 1000 m. so that any reliable discussion cannot be made on the relative magnitudes of deformation in the two cases.

The method here used of finding the apparent change in depth is as follows:

Contour lines were drawn corresponding to 10, 20,.... 120 m. depths on the old and new charts respectively. Reducing the scale of the new chart (1/75,000) into that of the old one (1/175,000), a rectangular net of 1 cm. mesh was drawn on each of these two charts. The old and new depths at each of the net-points were read off by interpolation and the difference, (new depth) minus (old depth) $=\Delta$, was calculated. Then this difference Δ, i.e. the depression, was plotted on another chart and the lines of equal Δ's were drawn, as shown in Fig. 1. It will be seen at first glance that the middle part of the Bay is generally depressed while the parts near the west and east ends are upheaved. Moreover, it seems that a zone of maximum depression may be discerned running parallel to the entire coast line. Such a zonal character was also observed in the cases of the deformation of sea-bed found after the earthquakes of Kwantô, Tazima and Tango respectively, as was pointed out in the papers cited. On the other hand, such a mode of systematic distribution of Δ can by no means be explained by the accidental errors of sounding.

The bay was divided into four parts (1), (2), (3) and (4) by the three straight lines (shown in Fig. 1) drawn nearly normal to the general trend of coast line at the places near Kaminokae, Urado and Ioki respectively. For each of these parts, the area was again divided into twelve zones bounded by successive contour lines proceeding with 10 m. step, and the mean value of Δ was calculated for each of these zones. This mean Δ for each zone was then plotted along the axis of

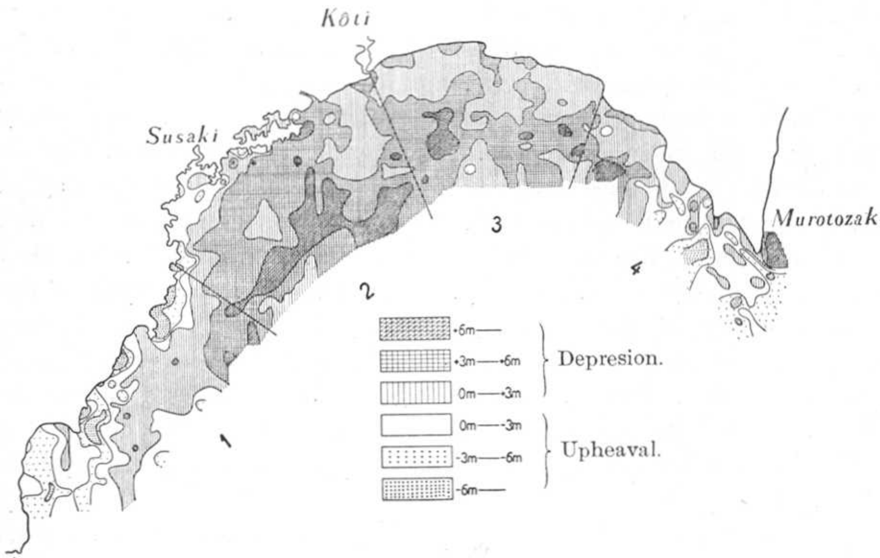

Fig. 1.

ordinates against the corresponding mean depth as abscissa as shown in Fig. 2. It will be seen that for the parts (1), (2) and (3) the slopes of the curves are such that the depression Δ increases off the coast, whereas for the part (4) the opposite is the case. For the depth greater than 40 m. (2) is nearly parallel to (1) and the difference of Δ of the two curves is generally 4 or 5 m. Again, for the depth 20–80 m., (3) resembles (2) in its general trend, while for the depth greater than 80 m., the curve (3) shows a general tendency to run in the same sense as (4). Thus, the apparent

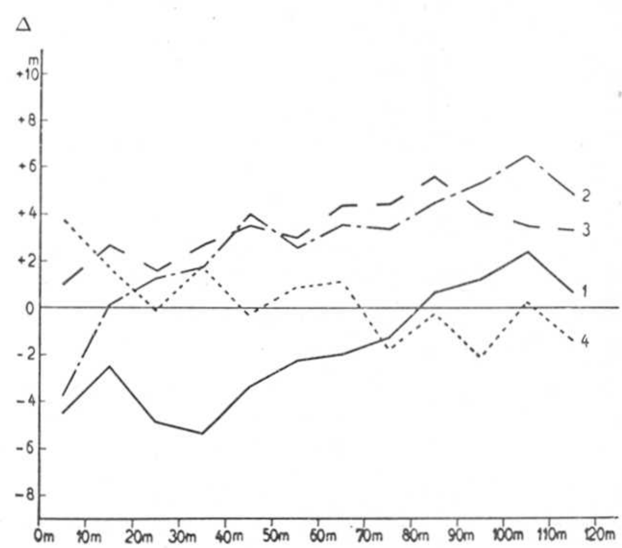

Fig. 2. →Depth

tilting of the sea-bed in (4), i.e. the eastern end of the bay, has taken place in the sense opposite to that of (1) and (2), i.e. the western half of the bay.

Next, the bay was divided into three narrow belts nearly parallel to the coast line and bounded by the three pairs of contour lines, i.e., 0 m.–50 m., 50 m.–80 m. and 80 m.–120 m. Each of these zones was again divided into ten segments of nearly equal length along the length of the zone. The mean depths of these segments belonging to a belt were plotted against the ordinal number of the segments counted from W to E, as shown in Fig. 3. The general mode of warping of the sea bed is made quite clear by the three curves there drawn. The three curves are all of inverted U-shape showing that the bed of the bay is generally bent such that the middle part is depressed while W and E ends are relatively upheaved. By tilting the curve (3), which corresponds to the shallow belt 0–50 m. depth, in such a manner that the eastern end is depressed and the western end is raised, it may be brought to coincide roughly with the curve (2) or (1).

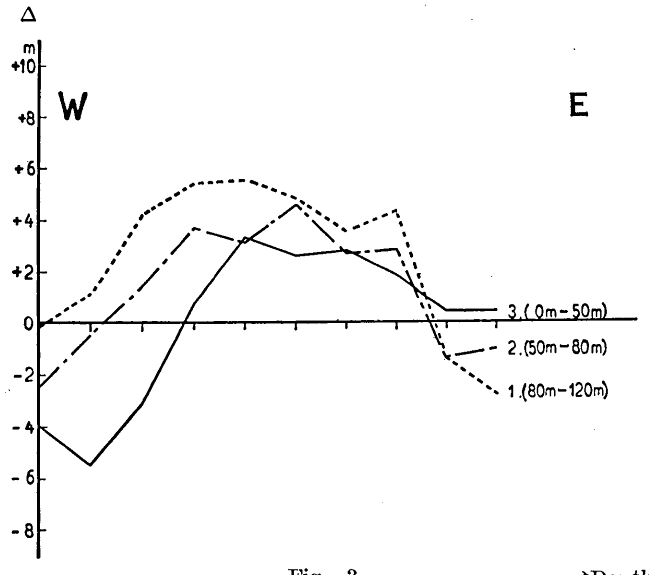

Fig. 3. →Depth

As already remarked, such a systematic mode of the change in depth cannot be explained as merely due to the accidental error of sounding. Nor, it is difficult to be attributed to the error due to the inclination of sounding wire. Again, the general slope of the sea bed is small (6/1000 say) so that the effect due to the error in the position of observation may be put out of account. It may, however, be questioned whether the observed change is not due to the horizontal transport of muddy deposits caused by the joint action of waves and current.

The tidal or ocean current must in any case decrease in its velocity towards the sea-bed and it is highly improbable that the current by itself may cause the transport of any submarine deposit in several ten metres depth. On the other hand, the effect of waves, though periodic, may stir up the lighter deposits to a sensible height and, on this account, the time-integral of the effect of current may turn out sensible under a favourable circumstance, even if the velocity of current may be very small. It is said that on some occasions of very rough sea the muddy deposits are stirred up from a depth of 40 fathoms. Such thing granted as possible, the favourable condition may obtain only rarely throughout the course of a year. Assume that such a condition prevails during 10 days in a year on the average. Next, assume that a deposit of 400 cm. in height has been transported through a distance of 40 km. during the 40 years, i.e. 400 stormy days. As for the velocity of current we must in any case assume a value much lower in the order of magnitude than in the case of superficial ocean current, as the velocity near the bed is usually assumed as practically zero relative to the surface velocity. Assuming a velocity of 10 m. per day, for example, it is equivalent to only 4 km. in 400 days. To obtain 40 km. we must assume a velocity of 100 m. per day which seems in any case improbable. Granting, however, this latter velocity as possible, we must next assume that the depth of the deposits stirred up and carried forth during a single day amounts to one centimetre. This may or may not be probable. A difficulty arise, however, from other side. If such a rate of submarine erosion has been continued for hundreds of centuries, as we must assume in that case, the ocean bed showing large positive values of $\varDelta$ may be expected to be exposing bare rock surface entirely stripped off from its muddy coating. As a matter of fact, however, the part of the bay with positive $\varDelta$ is generally covered either with mud or fine sand as far as may be judged from the hydrographical chart at hand.

In the case of Tazima and Tango earthquakes, the amounts of the vertical deformation of the sea bed were of the same order of magnitude as in the present case of the Bay of Tosa. In the sea off Tango a discontinuity of depth was found along a line forming the prolongation of the Gômura fault. The sense of the relative vertical displacements on the two sides of the line was the same as along the land fault, though the amount of displacement was decidedly larger in sea than on land. Such a discontinuity is also difficult to explain on the basis of mud-transport theory.

The chief origin of scepticism towards the reality of the vertical deformation obtained by sounding seems to lie in the large absolute magnitude of displacement. It is, however, not the absolute amount of deformation which determines the strain and stress of the earth's crust, but its space-derivative. A depression of 6 m. along a distance of 20 km. in 40 years is equivalent to an annual tilting of about $0{\cdot}8\times10^{-5}$ radian. A tilting of such an amount is by no means rare even on the land area. For an example, Mr. Miyabe[2] has recently found a tilting of just this order, or even a little more, along a local levelling route in Hukagawa, Tokyo. In the case of land, however, the direction of tilting changes rapidly along the horizontal distance, perhaps due to the complicated block structure, as was revealed by the results of recent repeated levelling surveys carried out in a number of earthquake districts. Denoting the vertical displacement by ζ and the length along a levelling route by s, the differential coefficient $d\zeta/ds$ varies irregularly along s frequently changing its sign, so that the absolute amount of relative vertical displacement between two places given by

$$\zeta_2-\zeta_1=\int_{s_1}^{s_2}\left(\frac{d\zeta}{ds}\right)ds$$

can never attain a large amount. According to the hypothesis forming the very foundation of Wegener's land-drift theory, the material composing ocean bed must be of a decidedly different nature compared with the rocky crust constituting land blocks. One of the characteristics of sea-bed quoted by Wegener is the general flatness of relief on its surface. This characteristic flatness seems to harmonize well with the assumption that for sea-bed $d\zeta/ds$ is slowly varying along s and even if its magnitude be small the integral taken along a long distance may attain a sensible amount much greater than the amount ever attainable on land area. Hence, it is not necessary to assume any marked difference in the elastic property of the materials composing land and ocean bed, at least for explaining the observed difference in the order of magnitude of vertical displacement, if we only assume a difference in some structural characters of the earth's crust on land and sea respectively.

In 1904, an ephemeral volcanic island[3] appeared near Minami-

2) The paper is not yet published, but will appear in a near future.

3) T. Wakimizu, *Report of the Imperial Earthquake Investigation Committee*, No. 56 (1908); *Publication of I.E.I.C.*, No. 22C (1908). D. Sato, *Tigakuzassi*, No. 201 and 202 (1905).

Yuwôzima. It rapidly disappeared and a sounding carried out by I.J.N. in 1911 gave a depth of 200 fathoms at the very site of the vanished volcano. In 1914, another volcano[4] emerged nearly at the same spot as before, which disappeared again in the course of a few years. The explanation of this phenomenon seemed difficult at that time. The present author alluded to the effect of wave erosion combined with current as one of the possible cause, as the island was built up of very loose masses of ash and pumice, though it seemed rather doubtful whether the said speedy erosion could reach a depth as large as 200 fathoms. If, however, we could once admit that the earth's crust forming the ocean-bed is capable of vertical displacements far greater in the order of magnitude than ever experienced on land area, another possibility of actual depression must be taken as well into consideration. It will be interesting to repeat occasionally the detailed sounding survey in the vicinity of the former ephemeral volcanic island. On the other hand, it is reported not infrequently in the history of hydrographical survey that a dangerous shoal marked on a chart cannot be traced by a subsequent survey, or that an abnormal depth observed by a previous sounding cannot be detected by a careful revision carried out after many years. In such an occasion, the result of the previous survey was indiscriminately cancelled as erroneous. It seems, however, to be well worth repeating careful revision of sounding with a regular interval of a few years, in the vicinity of the spots where some remarkable discrepancy have been found between two successive soundings.

The difference in magnitude of vertical displacements for land and sea-bed, granted as real, may partly be due to the effect of the bouyancy of water, if we assume that the possible limit of the vertical displacement is laid by the claim of isostasy or of the elastic limit of the earth's crust. Thus, an upheaval of h m. in the case of sea-bed is tantamount to that of $(\rho_1-\rho_3)/\rho_2$ on land where the densities ρ_1, ρ_2 and ρ_3 are respectively for sima, sial and sea water. Taking roughly $\rho_1=3{\cdot}0$, $\rho_2=2{\cdot}7$ and $\rho_3=1$, this amounts to $0{\cdot}74$. Thus, the difference due to this cause may be put out of amount with regard to the present problem, where only the order of magnitude is in question.

Admitting the reality of the vertical displacement of the surface of the earth's crust in the case of the Bay of Tosa, we must also admit

4) I. OGURA, *Report of I.E.I.C.*, No. 79 (1915). T. TERADA, *Tôyôgakugeizassi*, **31** (1914), 149; *Tisitugakuzassi*, **21** (1914), No. 246. T. WAKIMIZU, *Tôyôgakugeizassi*, **37** (1920), 257.

the probability of similar displacements of secular nature in the cases of the beds of the Bay of Sagami, the sea off Tazima and Tango, which are taking place slowly but continuously. This is of no wonder, if we consider that we have already a large number of infallible evidences of such a phenomenon on the land area. It is very interesting to remark that the order of magnitude of the rate of deformation turns out somewhat different for land and sea, if we take the space derivative of the displacement, i.e. the strain, into account, instead of the absolute amount. A further discussion of this point will be given in a next paper.

Returning to the present result of investigation, we may spend a few words with regard to the geotectonic history of the Bay of Tosa. According to the recent investigation of Mr. Watanabe[5] we may draw a curved line of demarcation along the eastern part of the coast of this Bay marking the boundary line separating the region of upheaval from that of depression from each other. These vertical movements are considered to have been completed in a recent geological age. The variation of the vertical displacement along the present coast line, there shown, is in remarkable harmony with the general tendency of the present motion of sea-bed shown by the curves of Fig. 3, i.e., a general upheaval towards Murotozaki and a depression near the middle part of the Bay, though as for the detailed feature, some depression is found in Fig. 1 in the immediate neighbourhood of the shore line near Murotozaki.

H. Kishinouye and T. Kodaira[6] suggested from the result of their investigation regarding the distribution of the slope-angle of sea-bed along the entire coast of Tosa, that the sea-bed in the eastern part of the Bay seems to have been elevated in an unknown past by an amount of twenty to thirty metres relative to the other parts. This is also in harmony, at least partly, with the present result.

In connection with the above investigation of Kishinouye and Kodaira, the present author[7] made some studies on the topographical features of Sikoku, especially of the southern coastal regions of Tosa, and suggested that in a recent geological age the central part of Southern Sikoku seems to have been depressed by a considerable amount, connected with an upheaval of the eastern part.

These results taken together are also in harmony with the result of

5) A. Watanabe, *Bull. E.R.I.*, 10 (1932), 209.
6) H. Kishinouye and T. Kodaira, *Bull. E.R.I.*, 4 (1928), 57.
7) T. Terada, *ibid.*, 67.

the present investigation and show that the vertical movement here revealed by sounding appears as a probable continuation or distant echo of what has been taking place since a remote past.

On the occasion of the notorious earthquake of Hôei[8], 1707, the eastern coast of the Tosa Bay was elevated by several syaku (shaku) while some parts of the middle and western coast are said to have been depressed. Again, in the occasion of Ansei Earthquake[9] of 1854 the eastern coast seems to have been subjected to a similar upheaval.

On the other hand, the recent result of precise levelling carried out along the coast of SE Sikoku[10] has revealed the remarkable fact that a region of triangular form, with Murotozaki at its vertex and lengths of thirty to forty km. for its sides, is subjected to a sensible tilting toward S. This is remarkable as this sense of movement of Murotozaki seems to be opposite to that of the different kinds of movement which may be supposed to have occurred in the geological past, while it is the same as is here observed in the sea-bed in the immediate neighbourhood of the coast near Murotozaki.

These different kinds of data regarding the vertical movement of the earth's crust in the southern part of Sikoku seem to throw considerable light on the mechanism of crust deformation upon which the occurrence of earthquakes depends. A further discussion may, however, be reserved for a future, as an extension of relevelling is going on at the present moment towards the western part of the coast of the Tosa Bay and we may expect a substantial addition of data from its results.

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38. 土佐灣の海底變化

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昭和三年に行はれた土佐灣水深測量の結果を舊海圖と比較して得た水深變化の量を圖上に記入し其等差線を引いて見ると或系統的な變形の模様が窺はれる。此の見掛け上の水深變化が果して實際の地殼の垂直變化を示すかどうかといふ疑問に對する若干の考察の徑路を述べ、此れが實測の誤差としても説明し難く、又海底のエロージョンによるとしても説明し難いと考へる理由を述べた。

海底變化の量が陸上で知られた變化に比して異常に大きく思はれ、從つて信し難く思はれるが、

8) M. TERAISI, "*Tosa kokonno Disin* 土佐古今の地震" (1923), issued by Tosa-Sidankwai 土佐史談會; A. IMAMURA, *Disin*, 2 (1930), 81; *Proc. Imp. Acad.*, 6 (1930), 101.

9) M. TERAISI, *loc. cit.*; A. IMAMURA, *Disin* 2 (1930), 357.

10) A. IMAMURA, *loc. cit.*

併し海底の變化の絕對値を考へる代りに、其の水平距離に對する微分係數、即ちストレーンとしての傾斜の量を計量して見ると、陸地で不斷に見られると全く同程度である。唯陸上では傾斜の方向が短距離內で交互に變化するから、此れを水準路に沿ふて積分したものゝ絕對値はいつも小さい。此れに反して海底では此傾斜方向の變化が緩徐であるとすれば、此の積分値が大きくなるのは當然である。海底の起伏が一體に陸上よりも緩徐であることは周知の事實であり、又陸上で認められるやうなブロック構造が海底では認められぬことから考へても、此想像は妥當であり、又一方ウエーゲナーの學說の基礎となつて居る陸塊と海底岩床との特質の差違に關する色々な目標とも合致するのである。

此處で得られた海底の垂直變化の分布が、渡邊光氏の研究された土佐東南部に於ける地質時代の地殼變動、岸上小平兩氏の研究された土佐灣海底の過去の變動、著者の調べた四國南部の過去の變形、又今村氏の調査された寶永安政地震當時の土佐海岸の地變及最近陸地測量部の水準測量の結果等に對して如何なる關係にあるかを解說しておいた。此等の種々の方面の證據から推測される地殼變動の樣式と此處で得た海底變化の樣式とが可也迄相照應することだけから考へても、此水底變化が單なる見掛け上のものでないであらうといふことが諒解される。

此のやうな海底の垂直變化の樣式の可能性を許容するとなれば、そこから色々な推論の可能性が生まれて來る。例へば一九〇四年と一九一四年との兩度に南硫黃島附近に噴出して間もなく消失した新島の出現消失過程の說明にも從來考へたとは稍ちがつた說明が考へ得らるゝので、此れに就て一言し、此の如き疑問の地點に於ける水深測量をなるべく頻繁に繰返して行ひ度いといふ希望を述べてある。