5. *On the Change in the Heights of the Monthly Mean Sea-level at Aburatubo and Hosozima.*

By Seiti YAMAGUTI,

Earthquake Research Institute.

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Introduction.

In his previous papers,[1] the writer compared curves of the monthly mean sea-levels for Aburatubo, Sagami Province, and for Hosozima, Hyûga Province, corrected for the effect of the cyclones that frequent the Pacific Coast, and also for that of the "Kurosiwo" ocean current, when it was shown that a parallelism was observed between the two curves. The present paper is a continuation of these papers. It deals with changes in monthly mean of the sea-levels at Aburatubo, at Hosozima, and also at Kusimoto, Kii Province, the object of the study being to obtain the small residual anomalies of the monthly mean sea-levels after making due corrections for the effects of the cyclone and for the ocean current, and to detect the actual deformation of the earth crust, if any, from the mareograph data.

The data of the sea-level for Aburatubo and Hosozima were taken from the "Tidal Record," published by the Military Land Survey, and that for Kusimoto from "Tidal Observation" published by the Imperial Marine Observatory, Kobe. The latter data are grouped according to the Moon's age, that is, monthly mean values were taken for the period between two successive full moons.

The data of the ocean current were taken from "Reports of Ocean Current," published by the Hydrographic Department of the Imperial Japanese Navy, and those of the barometric pressures from the Monthly Report of the Central Meteorological Observatory in Japan. The values at Yokosuka, Siwonomisaki, and Miyazaki were used instead of those of the mareograph stations of Aburatubo, Kusimoto, and Hosozima.

Method of Investigation, and Results.

The procedure was as follows.

Taking the monthly mean sea-levels for the stations mentioned

1) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, 7 (1929), 115, 8 (1930), 75.

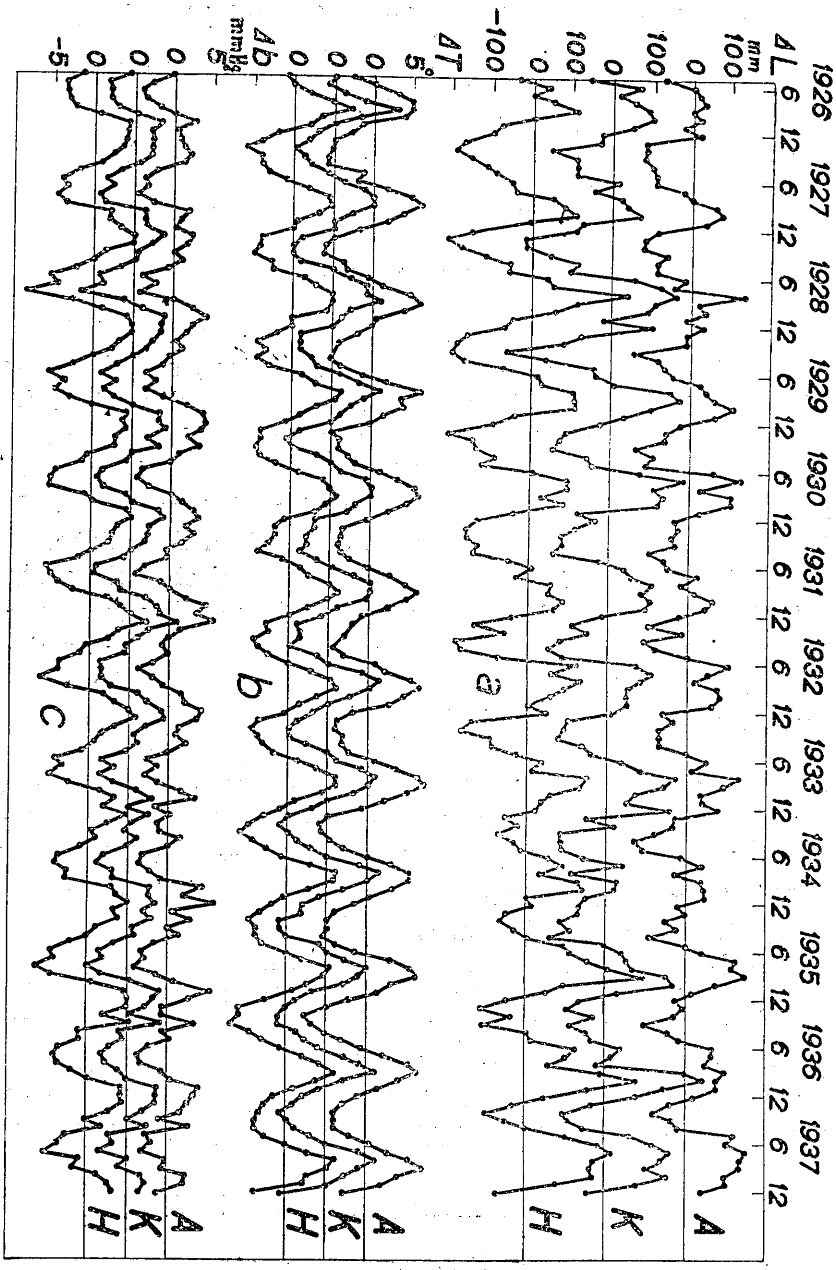

Fig. 1. a: Observed sea-levels, b: Sea water temperatures, c: Barometric pressures.
A: Aburatubo, K: Kusimoto, H: Hosozima.

during a period of 11 years and 8 months, namely, from May, 1926 to Dec., 1937, the values of the deviations ΔL (140 in number) from the mean values for the eleven years and eight months were calculated and plotted against the month which was taken as abscissa, as shown in Fig. 1, a. It will be seen that there is a marked variation in the heights of the monthly mean sea-level with an annual period, which is minimum in March or April and maximum in September or October, and which may be due in part to variations in the sea water temperature or density, probably the effect of the ocean current and other meteorological causes, with results similar to those shown in the writer's earlier papers just cited.

The values of the sea water temperatures and the east and the north velocity components of the ocean current were taken from the values for points not far off the coasts of the respective stations on the chart, "Reports of Ocean Current." Their monthly mean values were calculated, and the values of the respective deviations ΔT, ΔV_e, ΔV_n deduced from the mean values for 140 months, and the values of ΔT plotted as shown in Figs. 1, b.

The monthly mean barometric pressures, which may be regarded as including the monthly mean cyclonic effect upon sea level, were also taken, and the values of the deviations Δb from the mean for 140 months were calculated and plotted, as shown in Fig. 1, c.

The values of the correlation coefficients r between ΔL and Δb, ΔT, ΔV_e, ΔV_n for Aburatubo and Hosozima were calculated by the usual formula $r=\frac{\sum \Delta x \Delta y}{\sqrt{\sum (\Delta x)^2 \sum (\Delta y)^2}}$, the probable error in r being $\frac{1-r^2}{\sqrt{n}}$ where n is the total number, the results being shown in the annexed Table.

Table I, (a). Correlation Coefficients for Aburatubo between the two elements in the first column, top row.

	Sea level (original)	Sea level (corrected)	Sea water temperature
Barometric pressure	$-0{\cdot}294\pm0{\cdot}077$		$-0{\cdot}302\pm0{\cdot}077$
Sea water temperature	$0{\cdot}750\pm0{\cdot}037$		
N-comp. of current velocity	$0{\cdot}165\pm0{\cdot}082$	$0{\cdot}044+0{\cdot}084$	$0{\cdot}147\pm0{\cdot}083$
E-comp. of current velocity	$0{\cdot}157\pm0{\cdot}082$	$0{\cdot}100\pm0{\cdot}084$	$0{\cdot}129\pm0{\cdot}083$

Table I, (b). Correlation Coefficients for Hosozima between the two elements in the first column, top row.

	Sea level (original)	Sea level (corrected)	Sea water temperature
Barometric pressure	$-0{\cdot}578 \pm 0{\cdot}056$		$-0{\cdot}547 \pm 0{\cdot}059$
Sea water temperature	$0{\cdot}765 \pm 0{\cdot}035$		
N-comp. of current velocity	$0{\cdot}076 \pm 0{\cdot}084$	$-0{\cdot}171 \pm 0{\cdot}082$	$0{\cdot}085 \pm 0{\cdot}084$
E-comp. of current velocity	$-0{\cdot}072 \pm 0{\cdot}084$	$-0{\cdot}023 \pm 0{\cdot}084$	$0{\cdot}009 \pm 0{\cdot}093$

It will be seen from these tables that although the effect of sea water temperature upon sea-level is very marked, followed by that of barometric pressure, the dynamical effect of the ocean current falls short of that expected.

In view of these results it was assumed that the height of the sea-level is affected only by the barometric pressure and by the temperature of the sea water not far off the tide gauge station, that is, $\Delta L = p\Delta b + q\Delta T$. In determining coefficients p and q by taking first the theoretical value for p, namely $p = -13{\cdot}2$, the values of $\Delta L' = \Delta L - p\Delta b$ were calculated, and the $\Delta L'$-ΔT-*diagram* was then drawn as shown in Figs. 2, a, b, c. The values of q thus obtained graphically were 20

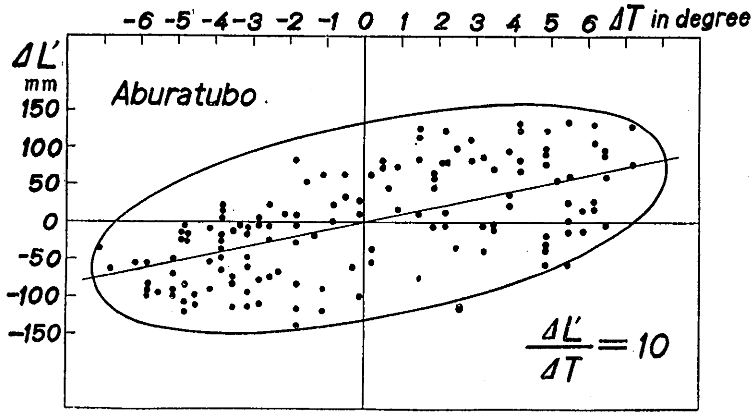

Fig. 2, a. $\Delta L' - \Delta T$ – diagram.

for Hosozima and 10 for Aburatubo, which results may not be far out, judging from the probable range of the change in density $\Delta\rho = \pm 10^{-3}$, and also from the mean depths of the water not far off Hosozima and Aburatubo, which are about 170 and 90 metres respectively.

With the aid of these values of q, the heights of the monthly mean sea-level were corrected, that is, $\Delta L'' = \Delta L' - q\Delta T$ were calculated and plotted

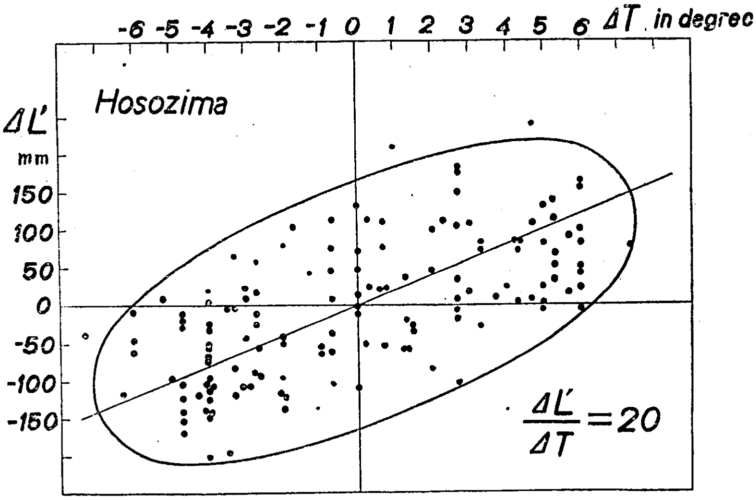

Fig. 2, b. $\Delta L' - \Delta T$ - diagram.

against the month that was taken as abscissa, as shown in Fig. 3. Even then, parallelism will be seen between the two curves that show

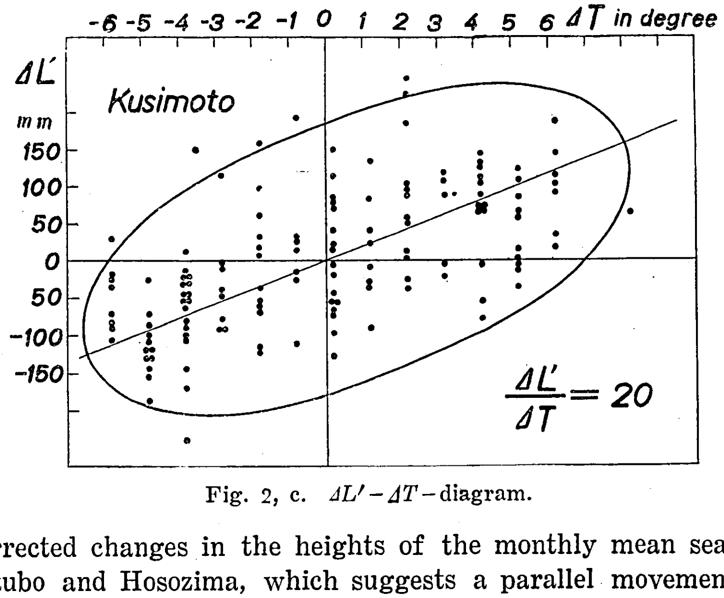

Fig. 2, c. $\Delta L' - \Delta T$ - diagram.

the corrected changes in the heights of the monthly mean sea-level at Aburatubo and Hosozima, which suggests a parallel movement of the earth's crust in that region where the two stations are situated.

To check this possible conclusion, the data for Kusimoto were also treated in the same way as in those of the above two stations. The curves for sea-levels, both original and corrected for both the sea water temperature and the barometric pressure, the *ΔL′-ΔT-diagram* is plotted for comparison, as shown in Figs. 1, 2, 3, respectively, the value of q, obtained graphically, being 20. The correlation coefficients in this case are shown in Table 1, c.

Table I, c. Correlation Coefficients for Kusimoto between the two elements in the first column, top row.

	Sea-level (original)	Sea water temperature
Barometric pressure	$-0{\cdot}425\pm0{\cdot}069$	$-0{\cdot}596\pm0{\cdot}054$
Sea water temperature	$0{\cdot}741\pm0{\cdot}038$	

Next, the values of the coefficients p and q in the equation $\Delta L=p\Delta b+q\Delta T$ were determined by the method of least squares, using the formulae

$$p=\frac{\sum\Delta L\Delta b\sum(\Delta T)^2-\sum\Delta L\Delta T\sum\Delta b\Delta T}{\sum(\Delta b)^2\sum(\Delta T)^2-(\sum\Delta b\Delta T)^2},$$

$$q=\frac{\sum(\Delta b)^2\sum\Delta L\Delta T-\sum\Delta b\Delta T\sum\Delta L\Delta b}{\sum(\Delta b)^2\sum(\Delta T)^2-(\sum\Delta b\Delta T)^2},$$

or

$$p=\frac{r_{\Delta L\Delta b}-r_{\Delta L\Delta T}r_{\Delta b\Delta T}}{1-r^2_{\Delta b\Delta T}}\sqrt{\frac{\sum(\Delta L)^2}{\sum(\Delta b)^2}},$$

$$q=\frac{r_{\Delta L\Delta T}-r_{\Delta L\Delta b}r_{\Delta b\Delta T}}{1-r^2_{\Delta b\Delta T}}\sqrt{\frac{\sum(\Delta L)^2}{\sum(\Delta T)^2}},$$

when $\left.\begin{matrix}p=-1{\cdot}5\\ q=\ 13{\cdot}3\end{matrix}\right\}$, $\left.\begin{matrix}p=\ 0{\cdot}92\\ q=20{\cdot}8\end{matrix}\right\}$ and $\left.\begin{matrix}p=-7{\cdot}1\\ q=19{\cdot}5\end{matrix}\right\}$ were obtained for Aburatubo, Kusimoto, and Hosozima, respectively, ΔL and Δb being measured in millimetres and mm Hg, and ΔT in degrees. With these values of p and q, the residual values of the sea-levels $\Delta L''=\Delta L-p\Delta b-q\Delta T$ were calculated and plotted, the general trend of the changes in the corrected sea-level $\Delta L''$ being shown by dotted lines in Fig. 3.

Comparing these three curves for Aburatubo, Kusimoto, and Hosozima, it will still be seen that they are parallel for many months, and that the correlation coefficients between each two of them are very nearly 1, as shown in Table 2, which may be due to some unknown factor that may affect the heights of the sea-levels.

In order to ascertain the gradual changes in the heights of the

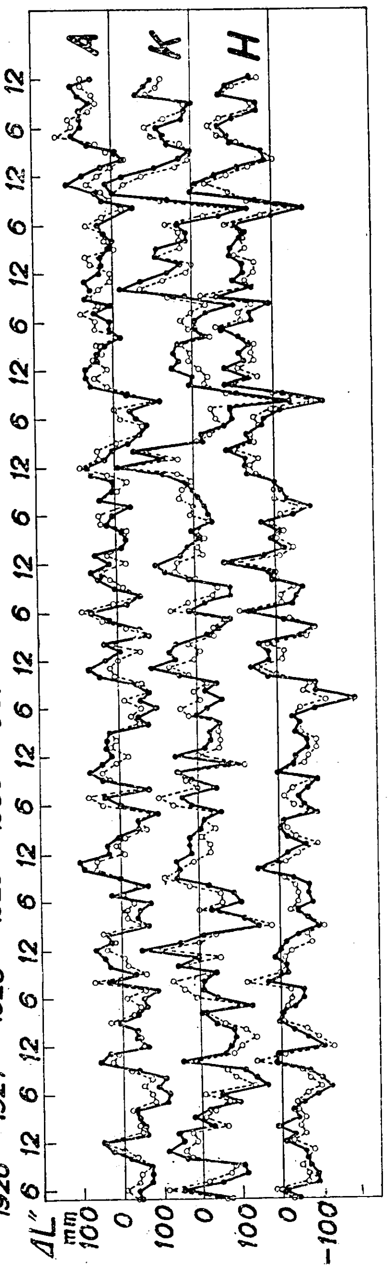

Fig. 3. Sea levels, corrected graphically and by the method of least squares.
A: Aburatubo, K; Kusimoto, H: Hosozim.

mean sea-levels, the values of the annual mean sea levels for a number of mareograph stations were calculated and plotted as ordinates against the year taken as abscissa, as shown in Fig. 4. All these graphs seem to show appreciable downward displacement of the earth's crust from 1927 to the end of 1937 at the rates of 8 mm a year for Aburatubo and Kusimoto, and 13 mm a year for Hosozima. Moreover, marked parallelism is seen between the two corrected curves of the yearly mean sea-levels for Aburatubo and Kusimoto, showing rather conspicuous minima in 1927 and 1934, with an interval of about 7 years. The conspicuous minima in 1934 for Aburatubo and Kusimoto, but not for Hosozima, may show the effect of the cold ocean current "Oyasiwo" upon the sea-levels.

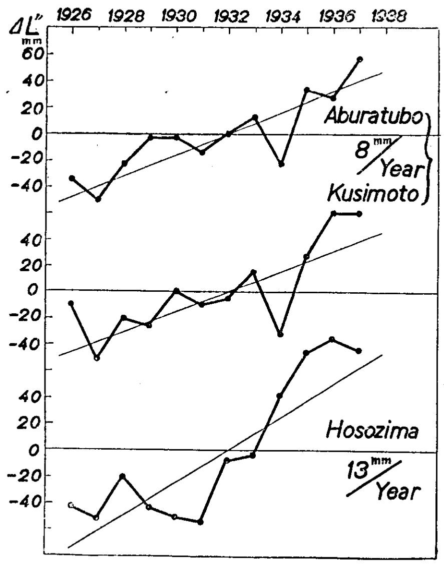

Fig. 4. Annual mean sea-levels.

From the results of the studies described in the papers already cited, and of the present study, it may be said that at Aburatubo, at any rate, a downward displacement of the earth's crust continued from the Great Earthquake of Sept. 1, 1923, until the end of 1937, showing some small vertical oscillatory motions with a period of about three or four years—a point that may be worth following up.

Next, the correlation coefficients between the monthly mean sea-levels, observed or corrected, for Aburatubo, Kusimoto, and Hosozima were calculated and tabulated, with results as shown in the annexed Table.

Table II. Correlation Coefficients between Sea-levels.

Between two stations	Sea-levels		
	Observed (or original)	Corrected graphically	Corrected by the method of least squares
Aburatubo and Hosozima	0·806±0·030	0·655±0·048	0·645±0·049
Aburatubo and Kusimoto	0·817±0·028	0·533±0·061	0·608±0·053

The correlation coefficients between two stations for the observed or original values of the sea-levels seem to have greater values than those for the residual values, which is probably because of the parallel variation in the sea water temperatures and the barometric pressures at the stations mentioned.

Finally, the probable errors $\varepsilon=0.6745\sqrt{\frac{\sum\varDelta^2}{n-1}}$ of the observed, as well as of the corrected deviations $\varDelta L$ and $\varDelta L''$ from the monthly mean sea-levels were calculated, resulting in the numerical figures of the following Table.

Table III. Probable Errors ε in millimètres.

Stations	Sea levels				
	Observed ε_0	Corrected graphically ε_1	Corrected by the method of least squares ε_2	Deviations from inclined time axis ε_3	$\frac{\varepsilon_3}{\varepsilon_0}$
Aburatubo	49	37	32	28	0·57
Kusimoto	69	56	46	43	0·62
Hosozima	75	49	46	34	0·45

By taking into account the downward motion of the earth's crust shown in Fig. 4 and deducing the deviations in the sea-levels $\varDelta L'''$ from the inclined time axis with proper inclination (8 mm a year for Aburatubo and Kusimoto, and 13 mm a year for Hosozima), instead of taking the original mean for 140 months, the probable errors can be reduced from those given in the third column of Table 3. The results are shown in the fourth column of the same table. Such small values of probable errors for the residual values of the sea-levels, which are about 60 percent for Aburatubo and Kusimoto and 45 percent for Hosozima of the probable errors of the observed or original values, may show the importance of the corrections for the barometric and density effects. Consequently, by applying the corrections for atmospheric pressure and for the ocean current, or the density effects (the dynamical effect of the ocean current may be negligible here) upon the observed values of the monthly mean sea-levels, it may be possible to detect an actual deformation of the earth's crust from the mareograph data.

In conclusion, I wish to express my best thanks to Dr. N. Miyabe for the many useful suggestions made me in the course of this study.

5. 油壺及細島に於ける海水面變化に就て

地震研究所 山口生知

著者は嘗て大正十二年より昭和二年迄の五年間に於ける油壺，細島，花咲，輪島の海水面變化に及ぼす低氣壓の影響，海流の影響等を調査して之等の影響の著しいことを知つた．又之等の諸影響を取り去つた殘りの海水面變化に就て調べて見ると油壺と細島とは著しい類似變化をしてゐることを知つた．

之に關して此の兩地方の地盤が，同じ樣な動き方をするのであらうと云ふ說を出された人もあつたが，當時吾々は五年間の材料では，判然としたことが斷言出來ないから，今少し長年月の材料が集つてから決論しやうと考へてゐた．適々本年の春頃宮部直巳博士より，海流の材料が大部集つたから海水面變化を調べて見ないかといふ助言を承けたので早速，陸地測量部の「驗潮記錄」と水路部の「海流通報」それから海洋氣象臺の「潮汐觀測」及中央氣象臺の「氣象要覽」とを借用して，先づ大正十五年五月より昭和十二年十二月迄滿十一年八ケ月の間の月々の平均海水面に及ぼす氣壓の影響並に主として海流の影響を調査して見た．次で之等の影響を除去した殘りの海水面變化に就いて，比較研究を試み更に其の年平均も取つて見た．又參考の爲に串本の海水面變化に就ても同樣の調査を試みた．其の結果は次の通りである．

1. 月々の平均海水面變化に及ぼす影響の最も大なるものは，海流の靜力學的影響即ち海水密度變化の影響であり，氣壓の影響が之に次ぎ海流の動力學的影響は豫期に反して案外小である．

2. 海流の影響や氣壓の影響を除去した殘りに就いても，油壺，串本，細島に於ける月々の平均海水面は類似の變化を爲してゐる．

3. 年平均海水面に就いても，油壺と串本とは類似變化を爲してゐる．即ち關東大震災以來地盤は何れも3年乃至4年の週期を以つて小なる上下運動を繰返しながら1年に8粍の割合を以つて徐々に沈降を續けてゐることが推定される．又細島に就いても，同樣に地盤が1年に 13 粍の割合を以って沈降してゐることが推定される．油壺と串本に於ては昭和9年（1934）に著しい海水面變化の極小を示してゐるが細島に於ては之を示さない．之は恐らく油壺と串本とは海水表面下或深さの所より寒流の影響を受けたものと推量される．