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24. Horizontal Secular Deformation of Land Deduced from Retriangulation Data.

1. Land Deformation in Central Japan.

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Abstract

The Geographical Survey Institute conducted resurvey of the first-order triangulation net in central and western Japan during the period of 1948–1958. Comparison of the present data with that of the previous survey in 1889–1909 enables us to study the pattern of horizontal crustal deformation which occurred during the past several decades.

The authors took the data from 86 triangulation stations in central Japan and computed various sorts of strain components, such as dilatation, maximum shear, rotation, and principal axes, where displacement and strain of the earth's surface were assumed to be continuous all over the district.

Generally speaking, the total amount of strain accumulation thus obtained does not exceed $5 \cdot 10^{-5}$ in every part of the district except the Mikawa Bay and Itoigawa areas. We may roughly say, therefore, that the average rate of strain accumulation is mostly less than the order of 10^{-6}/year, although it is not certain whether the event did occur at a constant rate or not.

There have been numerous large earthquakes in central Japan during the period between the two surveys. Naturally, the observed strain must be attributed partly to the crustal deformation appearing at the time of earthquake occurrence. This assumption is particularly likely on the large shear strain observed in the Mikawa Bay area, which is not far from the epicenters of destructive shocks in 1944, 1945, and 1946. The Itoigawa area is believed not to be affected so much by earthquakes and the large amount of strain (more than 10^{-4}) observed there might be an indication of present activity of the tectonic belt that crosses the Japanese Island. Further field surveys are needed to make this point clearer.

The mountainous part of central Japan shows contraction as much as $2\sim3\cdot10^{-5}$. According to the results from repeated levellings, this area is subject to a general tendency of continuous upheaval, though its cause is not yet clearly understood. The above-stated information would be useful in clarifying the mechanism of the event.

Other notable information is obtained through comparison of the principal axes of strain with the focal mechanism of shallow earthquakes in the same area. Direction of the compressional force at their origins, seismometrically determined by several authors, harmonizes well with the present data so far as the earthquakes in the coastal districts of the Japan Sea are concerned. On the Pacific side of Japan, such as the Kanto and Tokai areas, however, good harmony cannot be concluded.

1. Introduction

Repeat of precise triangulation is considered as a dependable technique for studying crustal deformations over a large area of land. Application of this technique to land deformations associated with destructive shocks has provided a lot of valuable information of the mechanisms at their origins. Excluding these special cases, however, secular horizontal movements of the earth's crust have not been surveyed very well, though this sort of information is urgently needed from seismological and tectonophysical points of view.

The Geographical Survey Institute started resurvey of the first-order triangulation net in Japan about twenty years ago, and completed the work for the central and southwestern parts of Japan in 1958. Comparison of the present data with that of the previous survey in 1889–1909 enables us to study the pattern of horizontal deformation of the land accumulated during the past several decades.

The chart published by the Geographical Survey Institute illustrates displacement of triangulation stations as vectors (Fig. 1)[1], which is a suitable expression for general purpose. However, we sometimes need to study crustal deformation with respect to the strain components, such as dilatation, shear and the principal axes of strain. Equi-value line charts of these components must be useful for the study of land

1) GEOGRAPHICAL SURVEY INSTITUTE, *Bull. Geograph. Survey Inst.*, **6** (1960), 59-61.

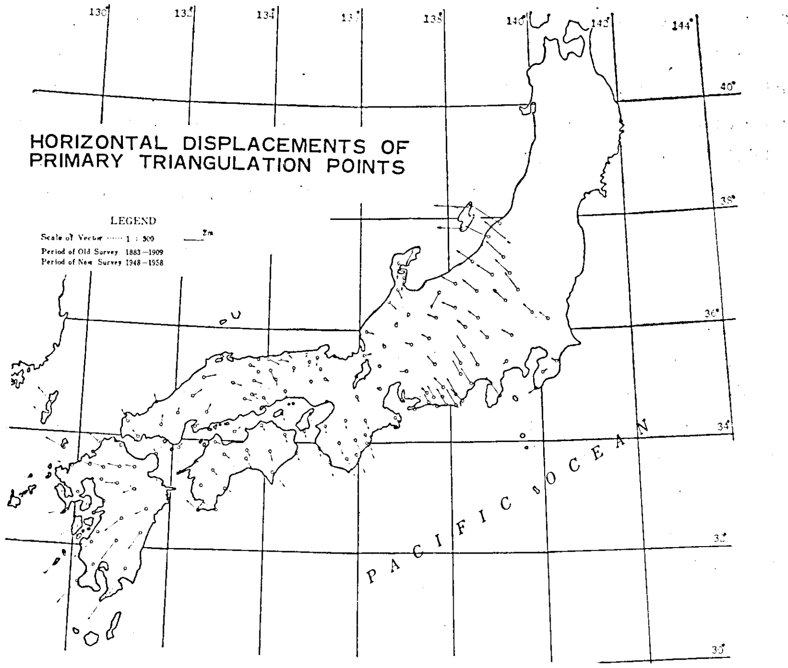

Fig. 1. Displacement of triangulation stations deduced from retriangulation (after the Geographical Survey Institute).

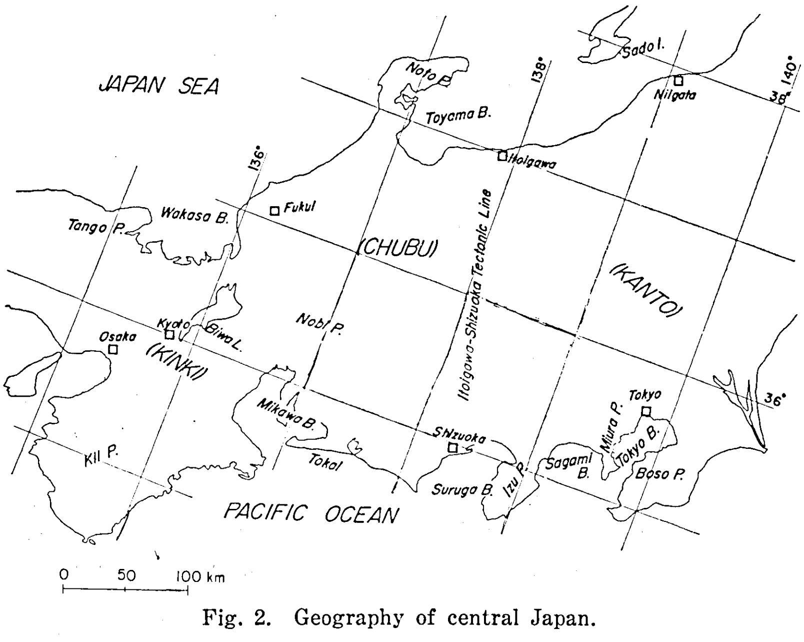

Fig. 2. Geography of central Japan.

deformation from various view-points. Another advantage of such charts is that the strain components are not affected so seriously by changing assumptions on net adjustments. In the following, therefore, the authors would like to present the charts of various strain components in central Japan, together with short discussions on the related problems. Deformations in southwestern Japan will be dealt with in the next paper.

2. Technique

Computation techniques of strain components from the data of irregularly distributed triangulation stations have been discussed by several authors.[2] Basic procedure of the present analysis is similar with their scheme, though several modifications have been applied to make programming easier.

Let us take a square portion of land and assume that the deformations inside it are well approximated by the following expressions,

$$\left.\begin{aligned} u&=a_0+a_1x+a_2y+a_3x^2+a_4xy+a_5y^2 \\ v&=b_0+b_1x+b_2y+b_3x^2+b_4xy+b_5y^2 \end{aligned}\right\} \qquad (1)$$

where the x- and y-axes are taken in the eastward and northward directions, while u and v represent the x- and y-components of displacement, respectively. In order to determine the constants in (1), we have to take the data of six independent stations.

Actually, the area chosen for the present analysis is the central part of Honshu, Japan, which lies between the longitudes of 135° and 139°, and contains 86 stations in it. Taking the density of the given triangulation net into consideration, a square of 88 km × 88 km is taken as a unit area, so that it may conveniently contain six stations in it. Numbers of such unit squares are arranged to cover the region, these being overlapped suitably with each other, with their sides parallel or perpendicular to the meridian. Distribution of u and v in each square is computed on the basis of a_i and b_i ($i=0\sim5$), which are determined so that they may satisfy the data of the stations representing the same square.

Figs. 3 and 4 are drawn by repeating the procedure from square to square. Some adjustment is necessary to obtain smooth lines in the overlapped area because the equi-value lines drawn for different squares

2) *f. i.* T. TERADA and N. MIYABE, *Bull. Earth. Res. Inst.*, **7** (1929), 223-239.

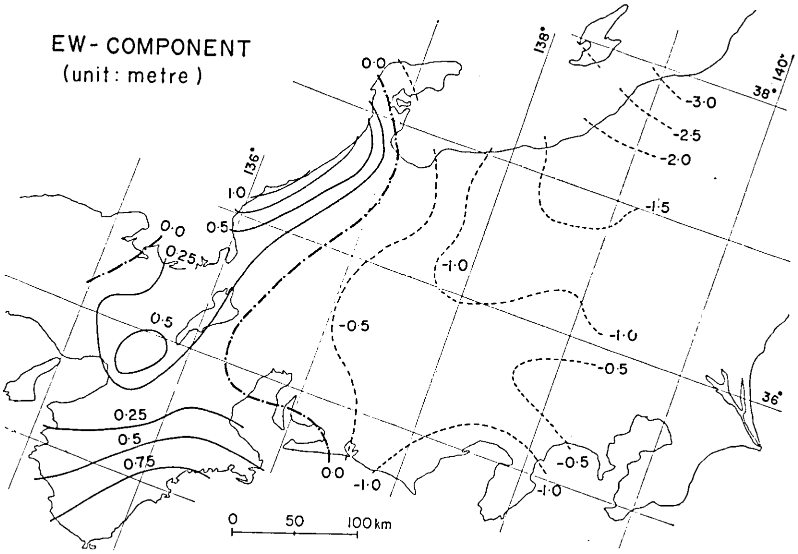

Fig. 3. Distribution of the eastward component of displacement, u.

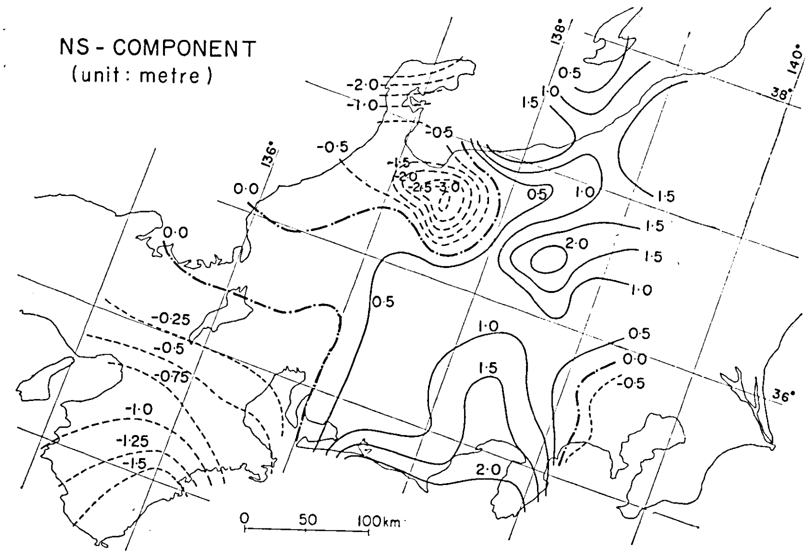

Fig. 4. Distribution of the northward component of displacement, v.

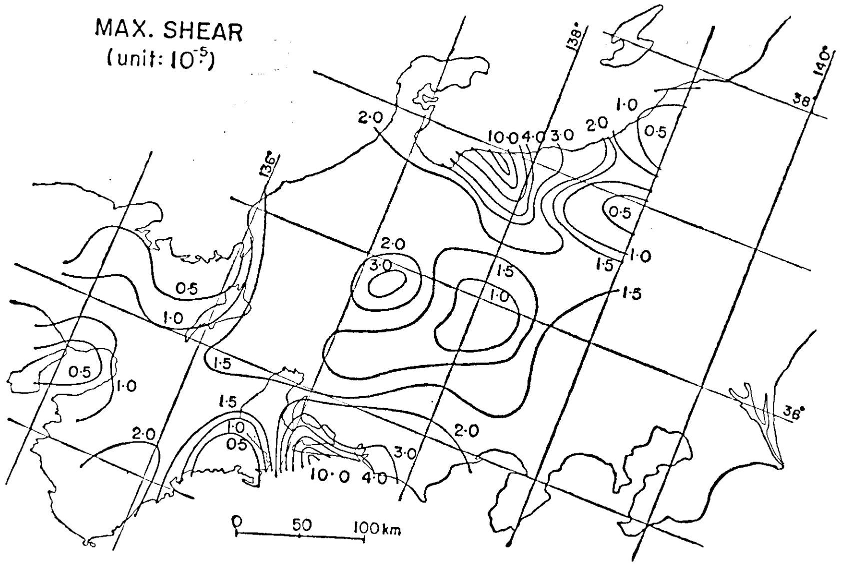

Fig. 5. Maximum shear in the unit of 10^{-5}.

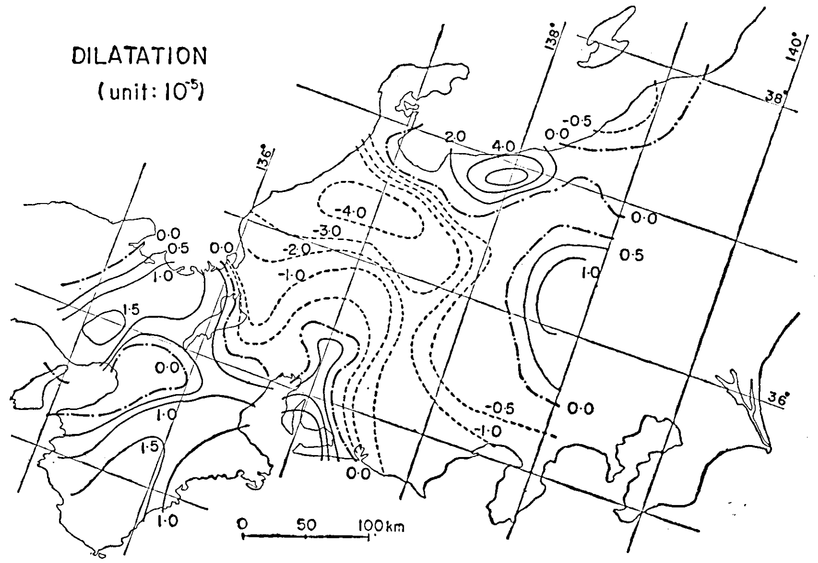

Fig. 6. Dilatation in the unit of 10^{-5}.

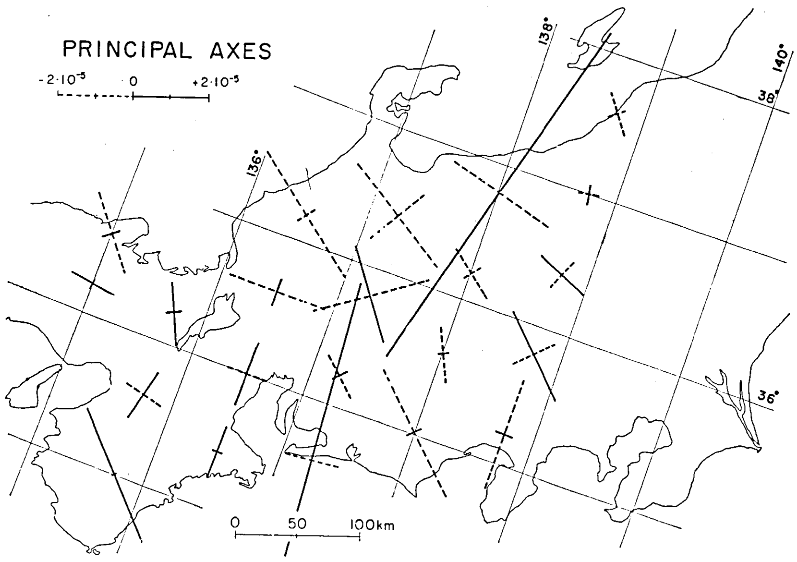

Fig. 7. Amplitude and direction of the principal axes.

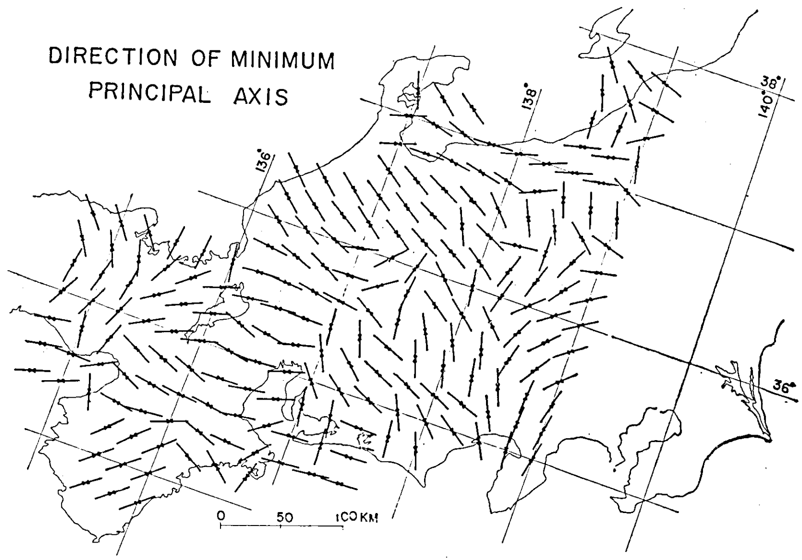

Fig. 8. Direction of the minimum principal axis.

do not always harmonize well. Manual adjustment of lines at this stage is believed, however, not to affect the following discussions seriously.

Once the constants, a_i and b_i ($i=0\sim5$), are known, it is easy to compute various strains by differentiating (1) with respect to x or y. Maximum shear, dilatation, and the parameters of the principal axes are computed in this way and are compiled as illustrated in Figs. 5~8.

3. Discussions

The most outstanding event in Fig. 5 was observed in the Itogawa and the Mikawa Bay areas, where the maximum shear exceeded 5.10^{-5} during the past several decades. There have been numerous large earthquakes in central Japan in the same period, so that the observed large strain must be attributed partly to the direct effect of the earthquakes rather than to gradual accumulation of the earth's strain. This assumption is particularly likely on the event in the Mikawa Bay area, which is believed to have been affected by the three major shocks in 1944, 1945, and 1946.

The situation in the Itoigawa area seems somewhat different from the above, this area not having suffered from destructive shocks larger

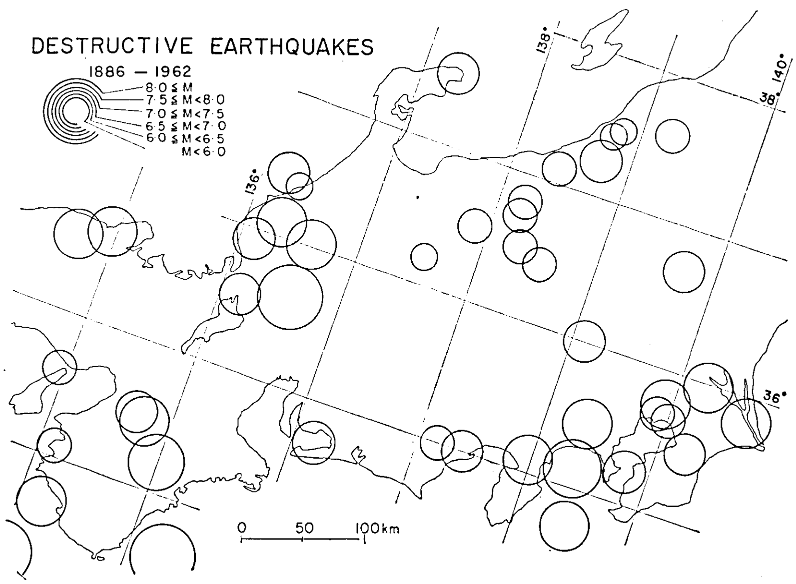

Fig. 9. Destructive shocks during the period between the two surveys.

than $M=7.0$ during the above-stated period (Fig. 9). Consequently, the direct effect of the observed strain must be very small.

It is notable that the northern part of the Itoigawa-Shizuoka tectonic line[3] runs across the present area, where the zone of large strain extends in parallel to the line (Fig. 5) and the directions of principal axes are oblique to that of the tectonic line (Fig. 7). These aspects give the authors the impression that the tectonic line is still active, causing shear strain accumulation at an average rate of $2\sim3\cdot10^{-6}$/year.

Unfortunately, no concrete data is available at presesnt for checking this suspicion further. The authors consider that some definite evidence for the present speculation can be obtained within several years if precise geodetic surveys across the line are repeated frequently. Because the assumed rate is so high that the strain accumulation would soon reach the order of 10^{-5}. Modern techniques of geodetic surveys could detect this amount of deformation without much difficulty.

A large area of contraction in Fig. 6 falls on the mountainous part of the Chubu district. Structures and geophysical characteristics of the crust in this part have been discussed by many authors. Briefly speaking, geophysical conditions of this locality are characterized by the large crustal thickness and the negative Bouguer anomalies.[4] Repeated precise levellings have clarified that the present part is in the region with the tendency of continuous upheaval.[5] Simple combination of the negative gravity anomalies with the land upheaval might give the impression that the crust of this part is in a stage of isostatic readjustment similar to the land of the Fennoscandia.[6]

However, this speculation should be examined very carefully because the simple model of viscous mantle, which was successfully applied to the Fennoscandia, cannot explain the surface contraction and the land upheaval simultaneously. The authors suppose that lateral forces in the earth's crust might play an important rôle in the present case, though a definite proof for this supposition has not yet been obtained.

It would also be interesting to compare the focal mechanism of shallow shocks with secular strain as illustrated in the foregoing figures.

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3) The Itoigawa-Shizuoka line is a major tectonic line that crosses the Honshu Island as shown in Fig. 2. This is believed to be formed during the later Cenozoic age as the western border of the "Fossa Magna".

4) H. KANAMORI, *Bull. Earthq. Res. Inst.*, **41** (1963), 761-779.

5) E. INOUE, *Bull. Geograph. Survey Inst.*, **6** (1960), 73-134.

6) W. A. HEISKANEN and F. A. VENING MEINESZ, *The Earth and its Gravity Field*, (McGraw-Hill Inc., 1958), pp. 1-470.

On the basis of the double-couple model of an earthquake origin, H. Honda and A. Masatsuka[7], and M.Ichikawa[8] studied the mechanism of shallow shocks in Japan. Fig. 10 illustrates horizontal projection of the compressional axes reproduced from their papers.

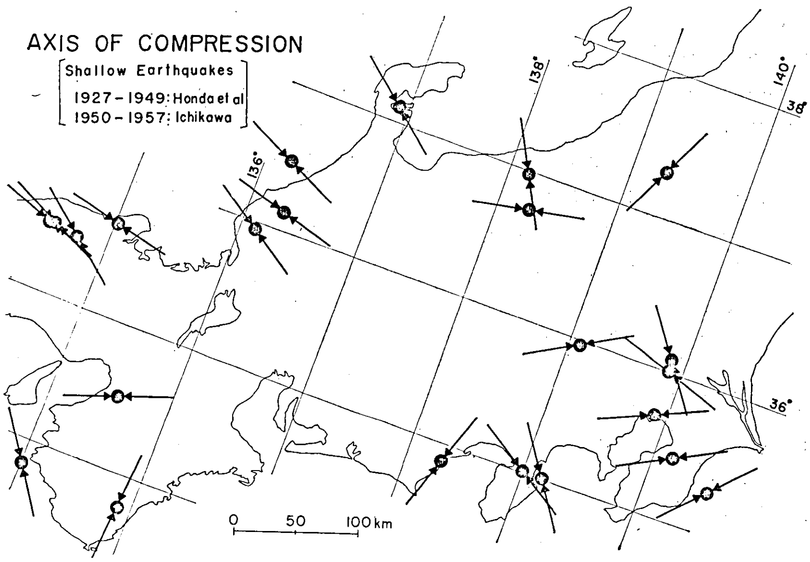

Fig. 10. Horizontal projection of the compressional axis at the origins of shallow earthquakes.

The most impressive aspect of the figure would be the axes of the shocks in the districts along the Japan Sea. They are almost in parallel with each other in the direction of NW-SE, approximately. This tendency is in good accord with a systematic arrangement of the negative principal axes in Figs. 7 and 8. A. Sugimura and T. Matsuda who investigated several geological faults in the same localities, discovered that their strike-slip movements in the past could almost be explained by a stress system with the principal axes of the above-stated direction[9]. Good similarity among the force systems, concluded from the three independent studies, seems to suggest that the force of this common type is the actual one causing tectonic movements in this district.

7) H. HONDA and A. MASATSUKA, *Sci. Rep., Tohoku Univ., Ser. 5, Geophys.*, **4** (1952), 42-60.

8) M. ICHIKAWA, *Geophys. Mag.*, **30** (1960), 355-403.

9) A. SUGIMURA and T. MATSUDA, *Bull. Geol. Soc. Am.*, (in press).

The minimum axis changes its direction to E-W as we travel inland from the coastal areas. This tendency is seen most clearly in the western part of the Chubu district and the eastern part of the Kinki district. According to reports by K. Iida[10] and H. Miki[11], who studied the mechanism of local shocks and ultra-micro earthquakes respectively, the compresssional axis in the E-W direction predominates in these districts. Therefore, this might be another example of the close relationship of secular deformation and earthquake mechanism. Moreover, N. Izawa[12], who worked out resurvey of the triangulation net in the Kitamino area after the earthquake of 1961, reported that the direction of the minor principal axis during the last 10 years is N63°W, which agrees well with the result given in Fig. 8.

No positive conclusion is drawn from the events in the districts along the Pacific Ocean. As can be seen from Fig. 8, the minimum axis of strain in these districts changes its direction from place to place to such an extent that we can hardly conclude the predominant direction to each locality. The compressional axes of focal mechanism drawn in Fig. 10 are also similarly confused. The authors cannot make any comment on the present case except a supposition that these spatial disturbances of the directions might reflect complicated stress conditions in the crust of these localities.

4. Concluding remarks

The authors took the retriangulation data produced by the Geographical Survey Institute and computed various sorts of strain to draw patterns of secular strain which accumulated in central Japan during the past several decades. On the basis of the charts thus obtained, they made a short discussion on several notable aspects as follows:

1) Extraordinarily large shear strain was accumulated in the Itoigawa area, which might be an evidence of the continuous activity of the Itoigawa-Shizuoka tectonic line.

2) The mountainous part of central Japan showed surface contraction, making simple application of the isostatic readjustment model difficult.

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10) K. Iida, Read at the Annual Meeting of the Seismological Society of Japan, May 7, 1974.

11) H. Miki, et al., Read at the Annual Meeting of the Seismological Society of Japan, May 7, 1964.

12) N. Izawa, Read at the Annual Meeting of the Geodetic Society of Japan, May 8, 1962.

3) Predominant direction of the minimum principal axis in the districts along the Japan Sea is NW-SE, approximately. This tendency harmonizes very well with the compressional axis of earthquake mechanism and the remaining evidence of geological faults in the same localities.

The authors' thanks go to the Geographical Survey Institute for giving them the detailed data of retriangulation as used for the present analysis.

24. 三角測量結果から算出した土地の水平変動

1. 中部日本における変動

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国土地理院による一等三角網改測結果に基ずいて，土地の水平変動に関する各種歪成分の分布を算出し，併せて若干の考察を行つた．Shear にせよ，dilatation にせよ，一般に歪量は 5・15^{-5} 以下になつている．前後2回の三角測量が数十年を隔てて行われたことを考え合わせると，これら地域における地殻歪の平均進行速度が 10^{-6}/年以下であることを示している．

歪が例外的に大きい地域としては，糸魚川および三河湾地域が注目される．後者における顕著な歪は，あるいは三河・東南海・南海などの大地震に伴う変動によるとも考えられるが，前者に対してはこの種の説明が適用し難い．その位置が糸魚川一静岡構造線の北部とほぼ一致することや，shear 歪の分布が同構造線の方向に延びていることを考えると，あるいはこの顕著な歪は同構造線が現在も活動していることの現われかもしれない．各種の測地学的，地球物理学的観測手段を動員して，この疑問を明らかにする必要がある．

Dilatation については中部山岳地帯全般にわたり負の値 (contraction) を示している点が興味深い．従来から知られている隆起運動の機構を確立する上に，上記の結果は無視できない事実であろう．

歪主軸の方向と，発震機構から推定される震源力の向きとは，日本海側の地域一帯にわたり，よい調和を見せている．この地方にあるいくつかの地質断層の動きについては既に構造地質学的調査が行われているが，その結果は上記歪主軸の性質とも調和しているように見える．これら三種の現象に共通的に想定される，北西一南東方向の圧縮（力または変形）は中部日本の地殻がもつ最も基本的な傾向ではないかと想像される次第である．同様の調和は，内陸の岐阜から琵琶湖にわたる地域にも見られるようである．一方，東海地方から関東にかけての地域においてはそのような一致が全く認められない．その理由の解明は今後の研究にまたなければならないが，あるいはこの地域の地殻性状の複雑さによるものかも知れない．