3. *Deformation of Earthcrust in California.*

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Introduction.

The triangulation survey was revised in the time interval of 1922–1928 in the western part of California over 1000 kilometres along the Pacific coast from Ross Mountain in the north to Cuyamaca in the south. These regions are traversed by San Andreas fault and were much disturbed at the time of the California earthquake of 1906. The result of the recent survey was compared with the result of the former ones which had been carried out before the earthquake of 1906, and thence the horizontal displacements of the triangulation points were computed.[1] For these computations, the line connecting Mt. Lola and Round Top was taken as the base, which was compared afterwards with eastern triangulation points and found to be unchanged relative to them in the direction and the length of it, during the time interval of the two successive surveys, so that the reported displacements of triangulation points in these regions may be regarded as the actual displacements which have occurred relative to the continent of America.

We calculated, from these data, divergence, rotation, shear and principal axes of strain ellipse for every triangle, the vertices of which are the triangulation points, by the same method as we have already applied for the earth movement in the Kwansai districts[2] to elucidate the mode of deformation of the earth crust in these regions.

It may be remarked that these displacements of triangulation points are affected by two different sources of disturbances, i.e., the destructive effect of the earthquake and the slow cumulative deformation of the crust. These components of displacements due to different causes are, of course, not easily separable in practice and, in the present computations, we treated the both components inclusive.

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1) W. BOWIE, *Special Publication of the Coast & Geodetic Survey U.S.A.*, No. 151 (1928).
2) T. TERADA and N. MIYABE, *Bull. Earthq. Res. Inst.*, 7 (1929), 223.

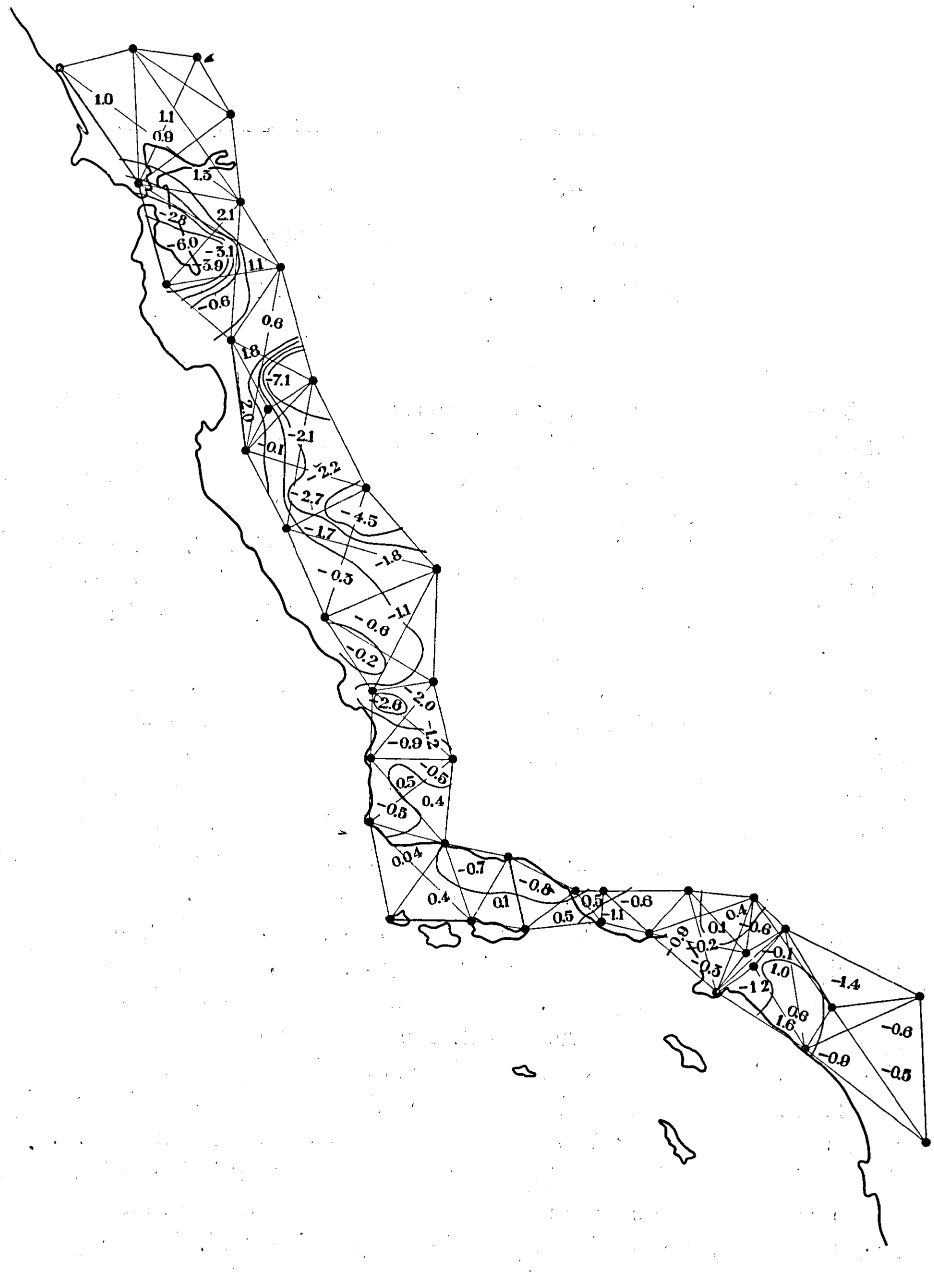

Fig. 1. Distribution of Divergence.

Fig. 2. Distribution of Rotation.
(+)······Region of Clockwise Rotation.
(−)······ „ „ Counterclockwise Rotation.

Fig. 3. Distribution of Shear.

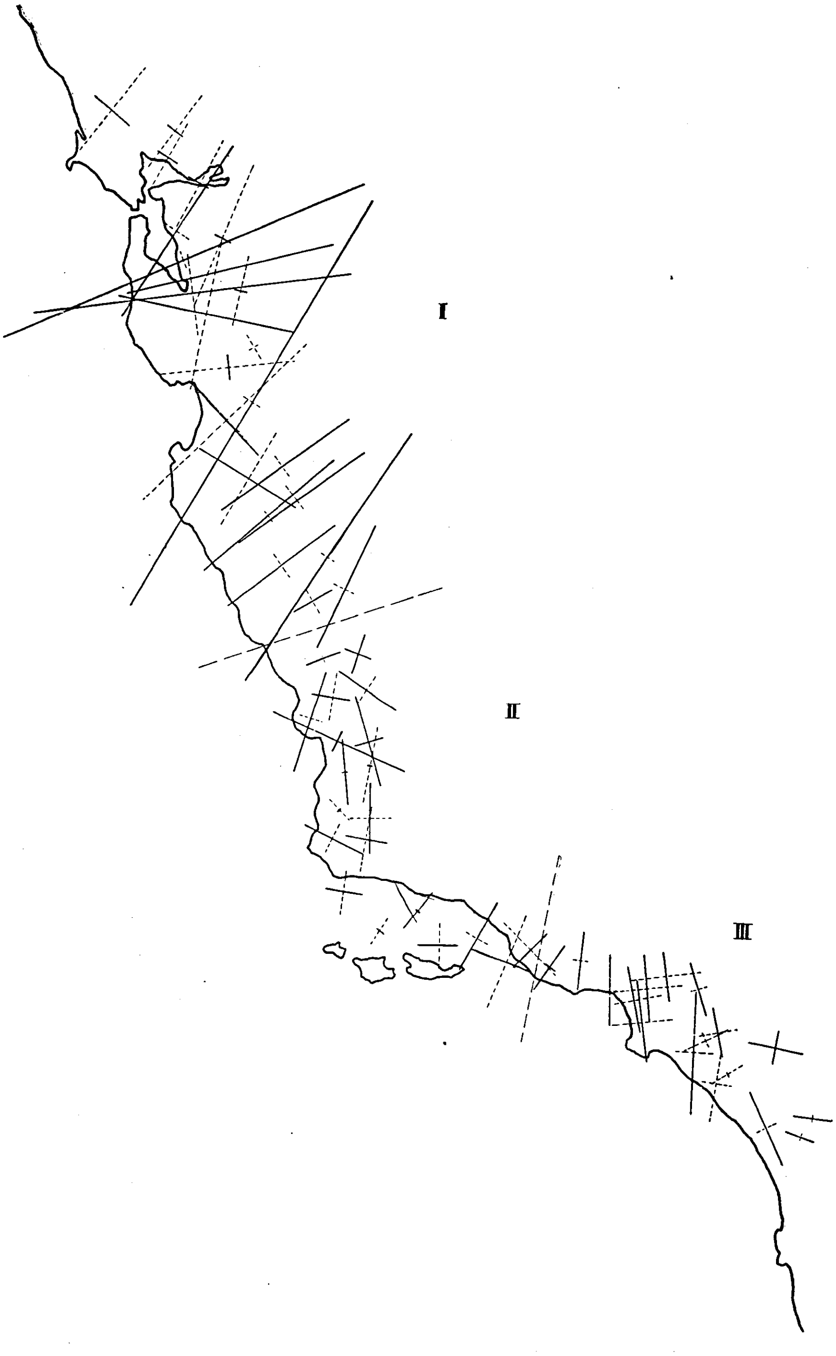

Fig. 4. Distribution of Strain Ellipses.

Full line ······Axes of Contraction.
Broken „ ······ „ „ Elongation.

Distributions of Divergence, Rotation, Shear and Strain Ellipses.

Calculations of divergence, rotation, shear and principal axes of strain ellipses in each triangle are carried out, as before, with the assumptions that the components of displacements u, v vary uniformly

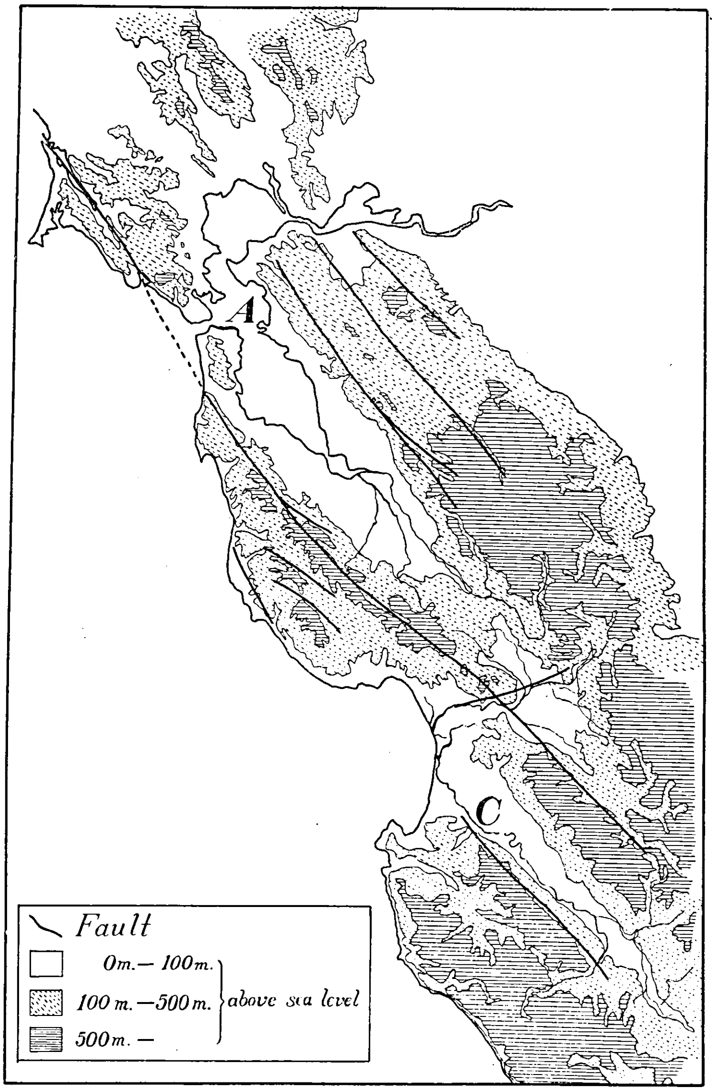

Fig. 5. Geographical Features in the Neighbourhood of San Francisco.

within a triangle and they are linear functions of the coordinates x and y. The origin of the coordinate axes was taken at Lospe, the x-axis being taken in EW-direction positive towards the east, and y-axis in NS-direction positive towards the north. Thus divergence Δ, rotation ζ, shear S, principal axes of strain ellipses γ_1 γ_2 and inclinations θ_1 of γ_1 to the x-axis are calculated in terms of $\frac{\partial u}{\partial x}$, $\frac{\partial u}{\partial y}$, $\frac{\partial v}{\partial x}$ and $\frac{\partial v}{\partial y}$, and the geographical distributions of them are shown in Figs. 1–4. Examining these figures, the followings may be noticed:

i) In the Fig. 1, showing the geographical distribution of divergence, two regions of negative divergence are remarkable which are found to correspond to the San Francisco Bay (A in Fig. 5) and the valley of the Vajaro River (C in Fig. 5) respectively. In the map showing the distribution of faults in these regions,[3] a fault is marked to the north boundary of the Vajaro valley. Between these two basins, there may be seen, on the geographical map, relatively elevated districts dividing the two basins. To the south of these regions, as a whole, the negative values of divergence are gradually decreased, that is, they tend to change into positive divergences, though accompanied with some fluctuations.

ii) As for the distribution of rotation, as shown in Fig. 2, it is somewhat interesting to see that the regions of counterclockwise and clockwise rotations are arranged alternately along the coast. In his study of the geographical features of Japan, Professor Fujiwhara[4] pointed out the existence of the same phenomena.

iii) The amount of shear is generally larger in the northern region where San Andreas fault passes, while in the southern region situated far from that fault, the amount of shear is smaller.

iv) For the investigation of the distribution of the strain ellipses, shown in Fig. 4, the whole area may conveniently be divided into three regions, I, II and III, according to the amounts and directions of principal axes of strain ellipses. In the region I, one or both of the principal axes are much larger than those in the other two regions. Examining more closely, there are some sub-regions in which the axes of elongation are larger, and other sub-regions in which the axes of contraction are larger, and these two sorts of sub-regions are alternately situated. In this region, the greater majority of longer axes, both elongation and contraction, are directed convergently, i.e., they seem to

3) Report of California Earthquake of April 18, 1906.

4) S. Fujiwhara, *Japanese Journ. Geophys.*, **3** (1925), No. 2.

converge to some limited portions to the west of the San Andreas fault. In the region II, the magnitudes of principal axes of strain ellipses are generally less than those in the region I, and yet their directional character is the same. In the region III, however, the magnitudes of the principal axes are generally smaller and the axes of elongation are directed generally in EW, while, those of contraction in NS.

Divergence and Topography.

In the study of the distribution of divergence, the distribution along the coast line is more significant than that in the direction perpendicular to it, for the triangulation points of which the horizontal displacements were calculated are poorly distributed in the latter direction. Hence, in the present case, the values of divergence for different triangles are projected on a straight line approximately parallel to the coast, which is shown in Fig. 6a.[5] In that figure, the amounts of divergence are taken as ordinates and the distance of the approximate centre of every triangle from the origin (here, the central part of Golden Gate was taken as the origin) is taken as abscissa. The mark ∘ gives the value of divergence for the individual triangle, while × means an averaged value of them for every 100 km.

The mean heights of profile[6] sections taken perpendicular to the above line were taken for every 25 km. distance from the origin and plotted on the same straight line as that for divergence, which is shown in Fig. 6b. The average height for every 100 km. is also marked by the symbol ×.

Examining these two curves, it may be noticed that, in both the cases, the curves are generally higher in the south. In the curve of divergence, however, this general tendency of the curve is interrupted by a discontinuous increase of convergence at the point corresponding to the valley of the Vajaro River. Thus, the variation of divergence may more likely be represented by the two straight lines AB and CD as shown in the figure. The southern boundary of the regions AB is roughly coincident with the conspicuous fault line.

The discordance between the above two curves may be understood, under the light of our previous results, to signify that the region corresponding to AB might be raised more or less to follow the variation of divergence. Such a rise of the crust may be expected from the

5) In the figure, abreviation G.G. means the origin, Golden Gate.
6) Profiles are due to the map issued by the "TIMES".

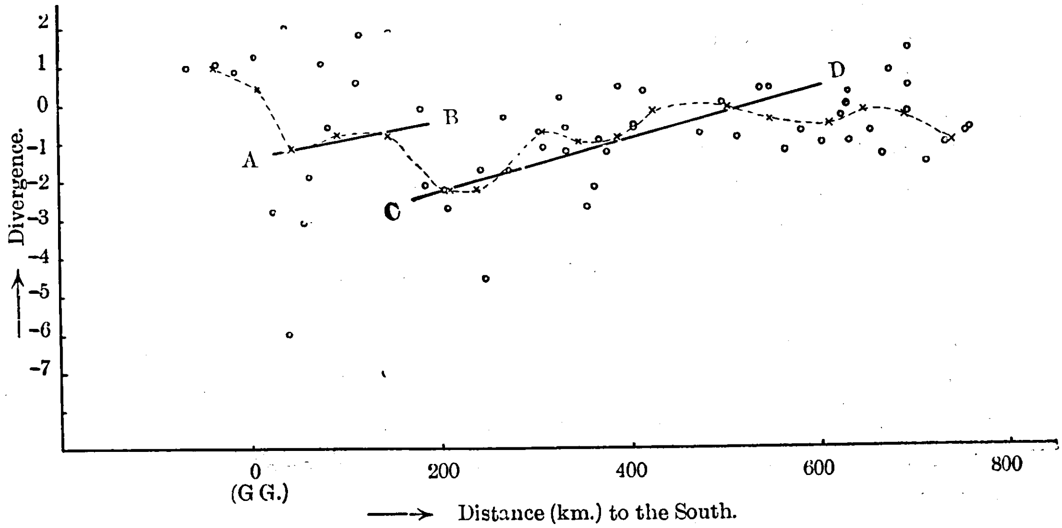
2
1
0
-1
-2
-3
-4
-5
-6
-7
Divergence.
A
B
C
D
0
(G G.)
200
400
600
800
Distance (km.) to the South.

Fig. 6a.

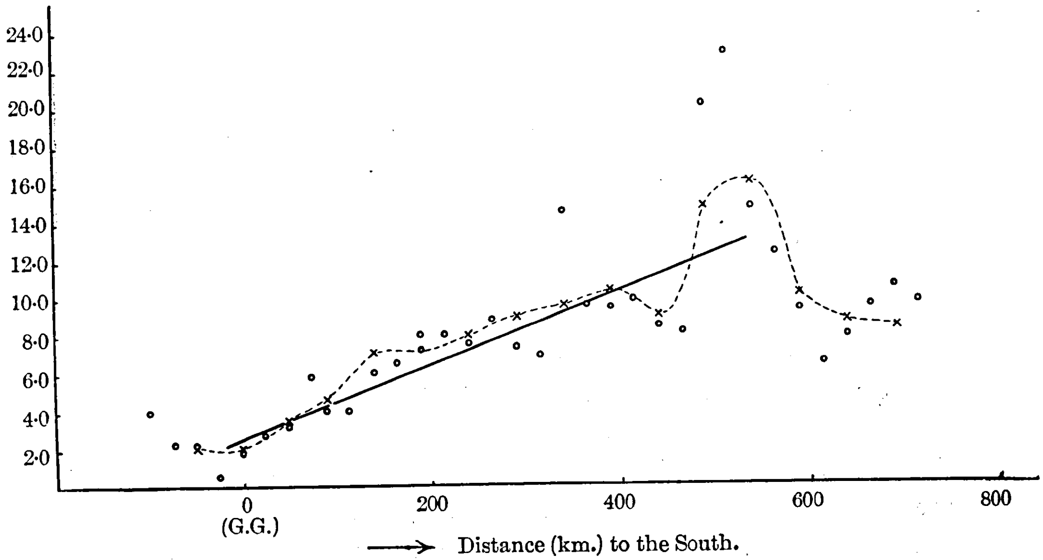
24·0
22·0
20·0
18·0
16·0
14·0
12·0
10·0
8·0
6·0
4·0
2·0
0
(G.G.)
200
400
600
800
Distance (km.) to the South.

Fig. 6b.

requirement of the theory of isostasy,[7] if the divergence may be associated with the actual density change of the crust.

Some evidences for the actual crustal movement in this region are supplied from the observations on upheaval and depression of the crust at the time of the earthquake of 1906. Professor Omori and other American authorities observed in various places near the Tomales Bay and Bolinas Lagoon that the crust was depressed on the eastern side of the San Andreas fault relative to the western side of it, by one or two feet at most. This relative upheaval of the west side of the fault near the San Francisco Bay may be considered to agree in some measure with our expectation, though such an evidence alone is not sufficient to determine whether the region AB is really rising or not. It may, however, be interesting to add here that those regions which should be raised to some extent from the analogy of the other examples to fit for the observed divergence, seem liable to be attacked by earthquakes. We have the same experience in the case of Tango earthquake of 1927. In that case, to make the distribution of divergence coincident with the topographical features, Tango-Peninsula should have been raised a little more,[8] in the neck part of which the origin of the principal shock of 1927 earthquake is located.

On the other hand, we have the data for gravitational anomalies in United States.[9] The values of gravitational anomalies of the stations in West California were taken out of them and their distributions along the coast (Fig. 7) was compared with those of divergence and mean heights. The comparison shows, as a whole, that the distribution curve of gravitational anomalies is, in some measure, negatively correlated with the latter two. It may, however, be remarked that these values of gravitational anomalies were computed on the assumption that the depth of isostatic compensation is 113.7 km., which was taken common for all the stations in U.S.A. Hence, the apparent correlation of the distribution of gravitational anomalies with that of the divergence or topographical features may be due to the adoption of this assumption, as the above depth may be unsuitable for the limited localities under consideration.

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7) T. TERADA and N. MIYABE, *Proc. Imp. Acad.*, (1928), 218.

8) T. TERADA and N. MIYABE, *loc. cit.* 2)

9) W. BOWIE, *Special Publication of Coast & Geodetic Survey, U.S A.*, No. 99 (1924).

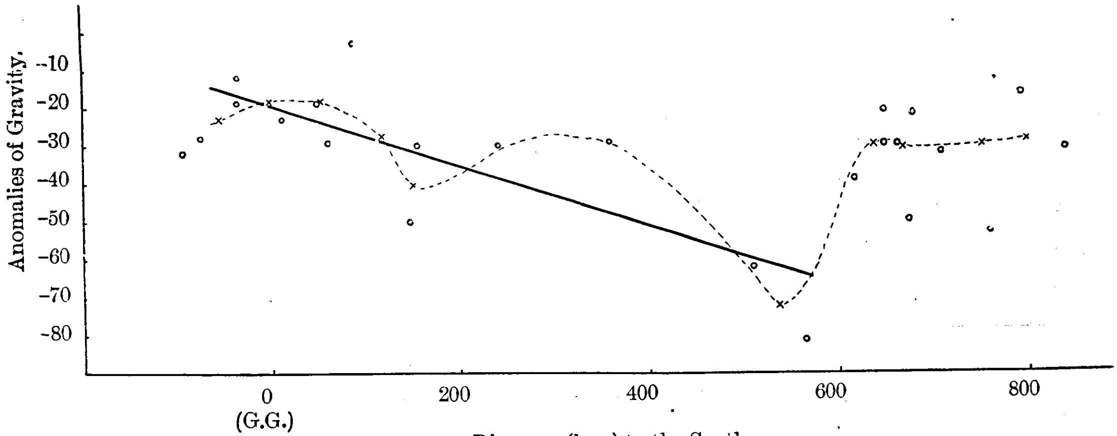

Fig. 7.

Principal Axes of Strain Ellipses and Feature of Coast Line.

We have already noticed that strain ellipses with longer axes of elongation and those with longer axes of contraction are distributed alternately in adjoining regions. A line approximately parallel to the coast was drawn as before and the components of the axes of elongation and contraction perpendicular to this line were plotted respectively, along the approximate coast line. Fluctuations in these two curves seem to be correlated negatively with each other, as shown in Figs. 8a and b. Comparing one of these curves with the geographical feature of the actual coast (Fig. 5), it may be noticed that the components of axes of contraction are larger in the region where the coast line is convex to the ocean side. This tendency is more clearly to be seen in the northern part where the magnitudes of the principal axes are comparatively larger. In the southern part, however, especially along the coast of Santa Barbara and San Pedro, the above mentioned tendency is not quite apparent. At present, we cannot say anything about what these facts may mean, without some more material evidences.

Formal Analogy with the Cases of Some Elastic Deformations.

The principal axes of the strain ellipses above obtained are joined by a system of continuous curves in such a way that the axes of contraction and those of elongation are connected respectively into lines of contraction

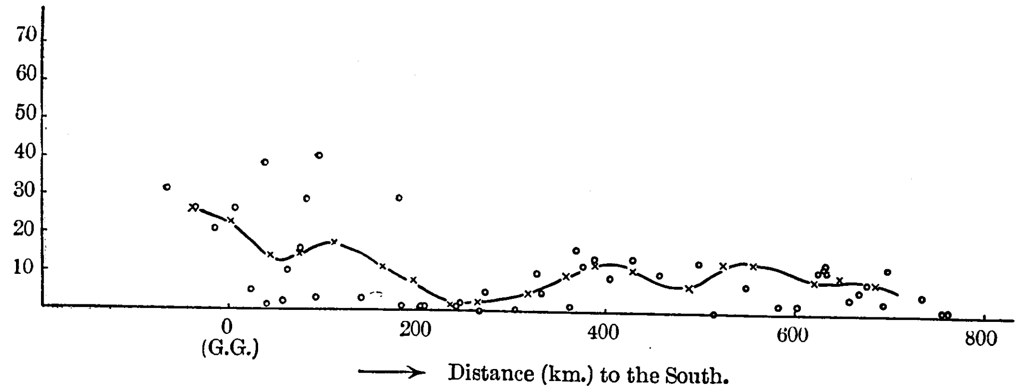

Fig. 8a. Components of Axes of Elongation of Strain Ellipses.

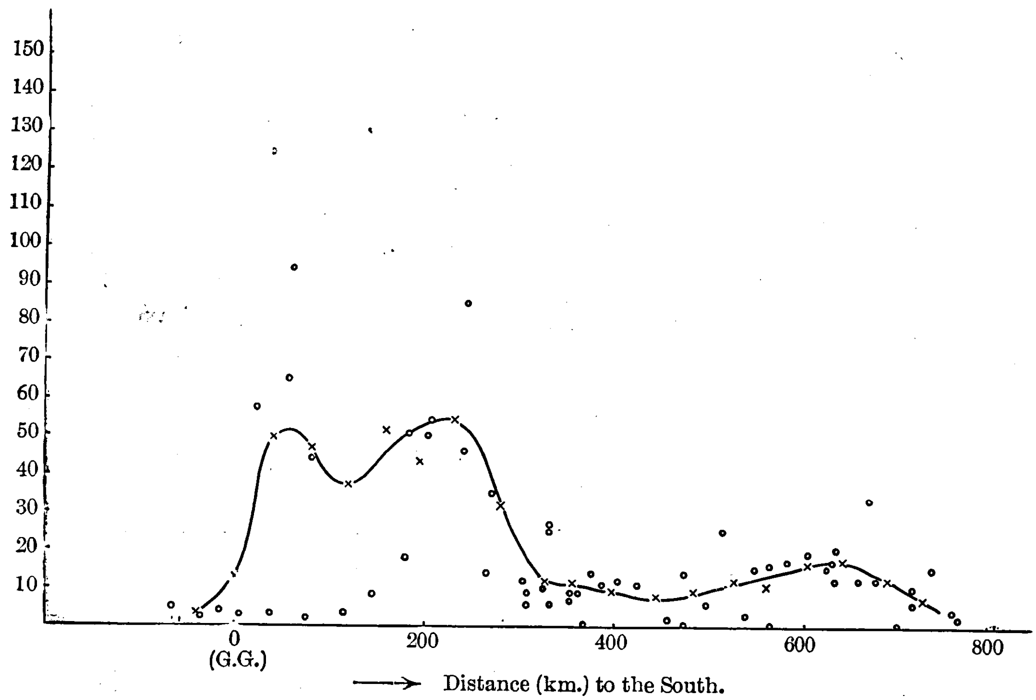

Fig. 8b. Components of Axes of Contraction of Strain Ellipses.

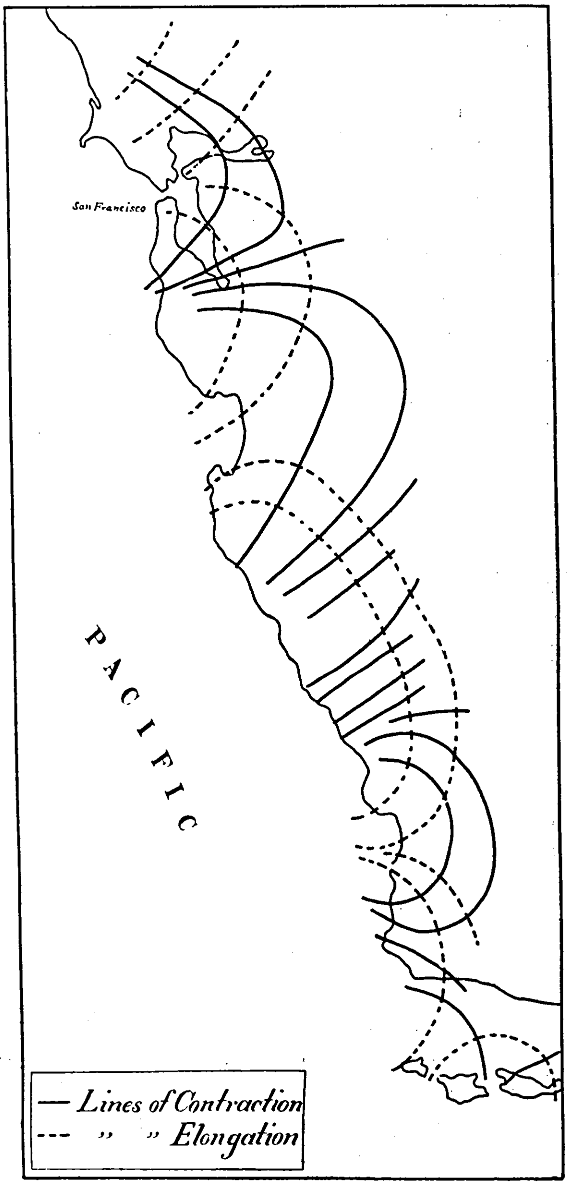

Fig. 9. Lines of Contraction and Elongation in Northern Part.

and elongation, to make up a diagram something like the diagrams of the fields of elastic strain or stress of some deformed materials as shown in Figs. 9 and 10. Glancing at these figures, we notice some characteristic differences of features existing between these two regions, north and south. In the northern region, the regions I and II in Fig. 4, the field of strain of the crust may be regarded as being composed of a coherent orthogonal system of the lines of contraction and elongation, of such a typical form as in Fig. 9. Considering the existence of such system of strain, the existing alternation of the regions of contraction and elongation may, in some measure, be elucidated. Closely resembling features may be shown in the field of stress in plastic or elastic materials when they are exposed to a lateral compression under a proper boundary condition.[10]

In the southern region, the region corresponding to III in Fig. 4, the field of strain of the crust seems to be uniform excepting some disturbed area (Fig. 10). An analogous field of stress may be produced by applying a uniform tension or compression to an elastic or plastic material with some disturbing mass within it.[11]

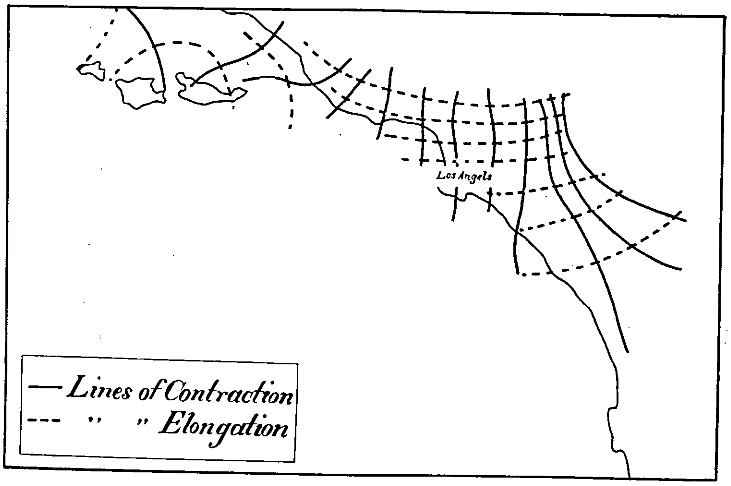

Fig. 10. Lines of Contraction and Elongation in Southern Part.

It may be worth while to remark that the analogy here mentioned is nothing but formal and any physical analogy in mechanism may be cited only when some other crucial evidences may have been brought forth, which are at present yet little known.

In conclusion, the present writer wishes his sincere thanks to Professor Torahiko Terada for his kind advices and guidance.

10) Some stress diagrams closely resembling to the field of strain of the crust here shown may be found in Th. WYSS's "*Kraftfelder in festen elastischen Körpern*" (1926), Tafel 33.
11) c.f. Tafel 26 of WYSS's "*Kraftfelder* etc."

3. カリフオルニアに於ける地殼の變形

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W. Bowie によつて調査されたカリフオルニアに於ける 1906 A.D. の地震前後の三角點の移動の結果について、著者等が、丹後地震の際の三角點の移動を取扱つたと同様の方法を應用し、Divergence, Rotation, Shear, Strain ellipse の主軸等の諸量を計算してその地理的分布を調べてみた。その結果は取纏めて次の如く約言することが出來る。

i) Divergence と地形との關係は大體に於いて、前と同様に高い所が正の Divergence, 低い所が負の Divergence の傾向を示してゐる。たゞ San Francisco 附近は、地形の方でもう少し上昇すれば、尙よく一致するのであるが、將來この附近の土地がもう少し上昇して Divergence の示す傾向に追隨すると考へれば、丹後半島が同様の傾向を示してゐた事と一致し、問題の地震がその附近に起つた事も偶然にも合致する。併し、現にこの地方が上昇しつゝあるといふ、直接の證據は擧げられない。重力殘餘の値の分布も之に負の相關を示す様に見えるが、之は補正した平衡層の厚さの 113.7 km. といふ値が、(113.7 km. は全米に一様な値) この地方のみに對しては不適當な爲めの見掛け上のものではないかと思はれる。

ii) Rotation の分布を見ると、左旋と右旋の地域が交互に存在するかの如く見え、嘗て、藤原教授の指摘された地形の渦の形成の途上にあるものの如き感を與へる。

iii) Shear は、三角網中 San Andreas の斷層の過つてゐる地方で大きく、他では小さい傾向を示し、三角點移動の分布より想像される所と大差はない。

iv) Strain ellipse の主軸の海岸線に略々直角なる方向の成分をとつて考へると、その大いさの fluctuation が、elongation の軸のそれと、contraction の軸のそれとで負の相關となる。又、是等と、海岸線の出入とを比較してみると、elongation の軸の成分の比較的大なる處では海岸線が內陸に灣入し、その小なる處では海の方へ突出してゐる傾向が見える。

v) Strain ellipse の分布の狀態は一瞥した所、ある plastic 又は elastic の物質がある歪を受けた場合のその中の力の場に似たものがある。

以上の如き事實が如何なる事を意味するかについては、更に多くの事實が見出されるまでは明かになし得ない。