45. *Geographical Distribution of Hot and Mineral Springs and Deformation of Earth's Crust.*

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In a previous paper,[1] one of the authors pointed out a probable relation which seems to exist between the horizontal divergence $\Delta=\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}$ of the earth's crust, obtained from the result of repeated triangulations, and the frequency of occurrence of hot and mineral springs in the corresponding district.[2] A discussion was also made to the effect that such a relation might well be expected from some physical consideration. As, on the other hand, there exists a certain correlation between Δ and the vertical displacement of the earth's crust as revealed by repeated precise levellings, except in the districts recently disturbed by severe earthquakes, we may expect that the frequency of occurrence of hot and mineral springs in a district may also show some relation with the secular vertical movements of bench-marks situated in that district. An example of such a relation was shown in the previous paper with regard to the levelling route from Nagaoka to Okitu. In the following, the results of similar investigations made with regard to the other routes (Fig. 1) will be briefly described.

The localities of hot and mineral springs[3] were marked on 1/200000 maps of Land Survey Department, those with the temperature greater and less than 100°F being distinguished by different marks respectively. Taking the levelling route along which the relation now in question is to be investigated, a zone of 20 km breadth was taken on each side of the route parallel to it. From the site of each spring situated within this zone a straight line was drawn which meets the route nearly orthogonally. The point of intersection of this line with the line of route was marked and allotted as belonging to that spring. On the other hand, a diagram (Figs. 2∼9) was drawn of which the abscissa represents the route, taking the distance between successive bench-marks,

1) T. TERADA, *Proc. Imp. Acad.*, **10** (1934), 410.
2) Literatures regarding this point are given in the previous paper cited.
3) Data for the geographical distribution of springs were mainly taken from "Nihon-Kôsensi" (日本鑛泉誌), (1886) and R. ISHIZU, "The Mineral Spring of Japan", (1915).

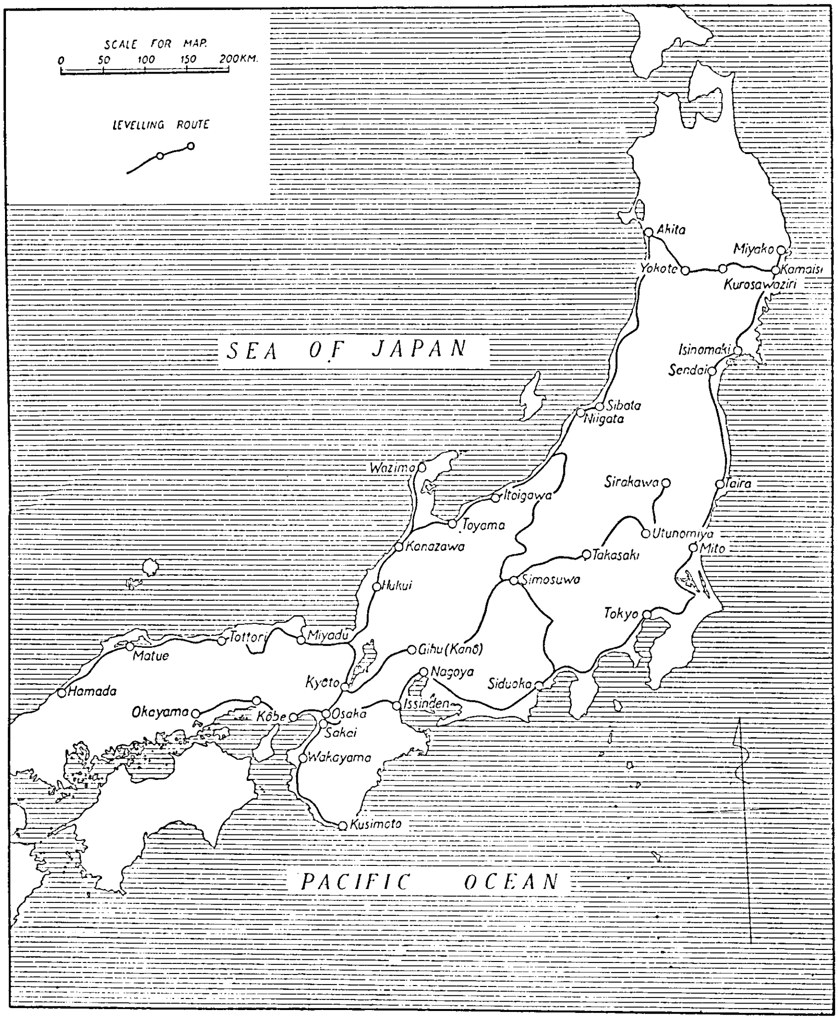

Fig. 1. Distribution of levelling routes.

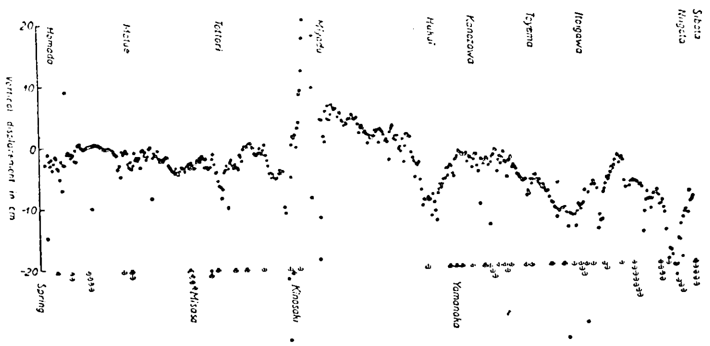

Fig. 2

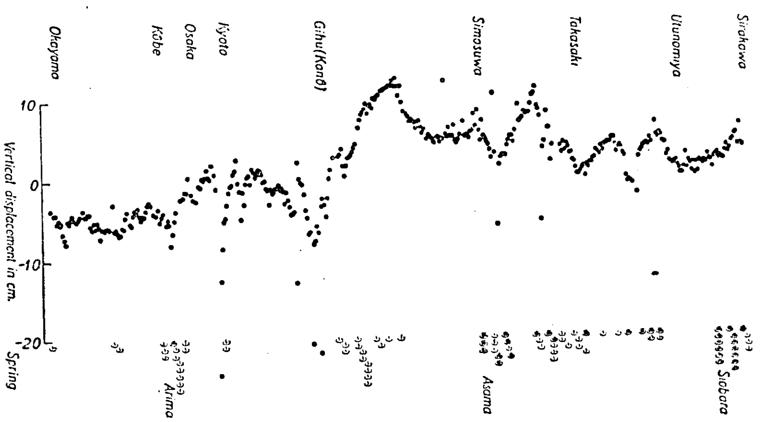
Okayama
Kōbe
Osaka
Kyoto
Gihu(Kanō)
Simosuwa
Takasaki
Utunomiya
Sirokawa
10
0
-10
-20
Vertical displacement in cm.
Spring
Arima
Asama
Siobara

Fig. 3.

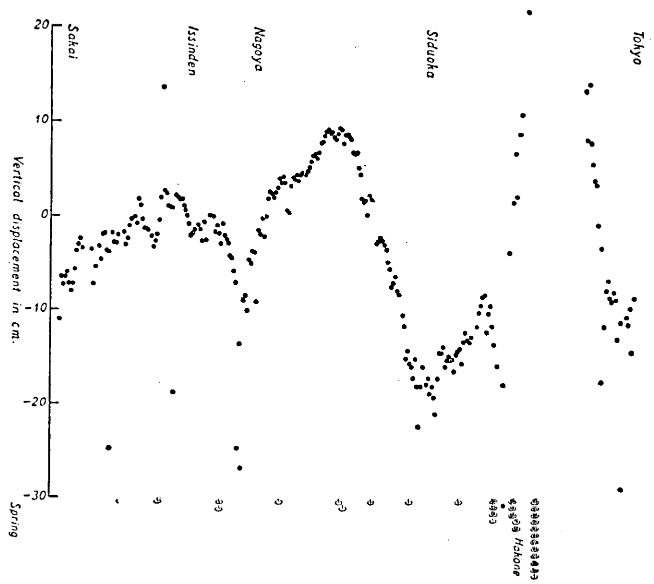
20
10
0
-10
-20
-30
Sakai
Issinden
Nagoya
Sidzuoka
Tokyo
Vertical displacement in cm.
Spring
Hakone

Fig. 4.

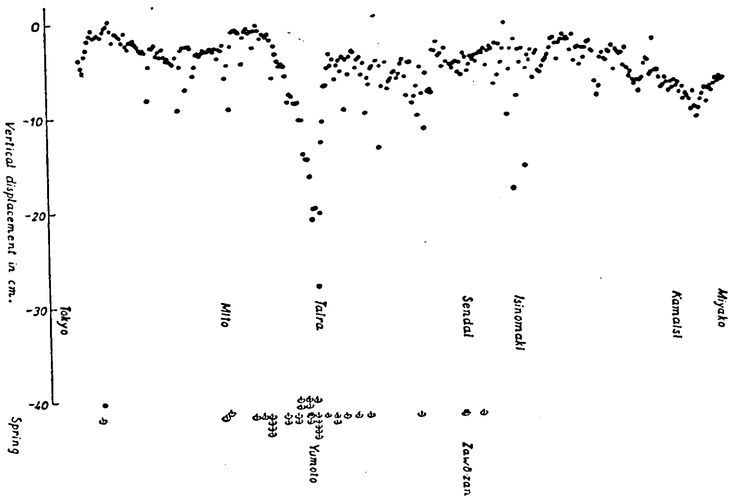
Vertical displacement in cm.
0
-10
-20
-30
-40
Spring
Tokyo
Mito
Taira
Sendai
Isinomaki
Kamaisi
Miyako
Yumoto

Fig. 5.

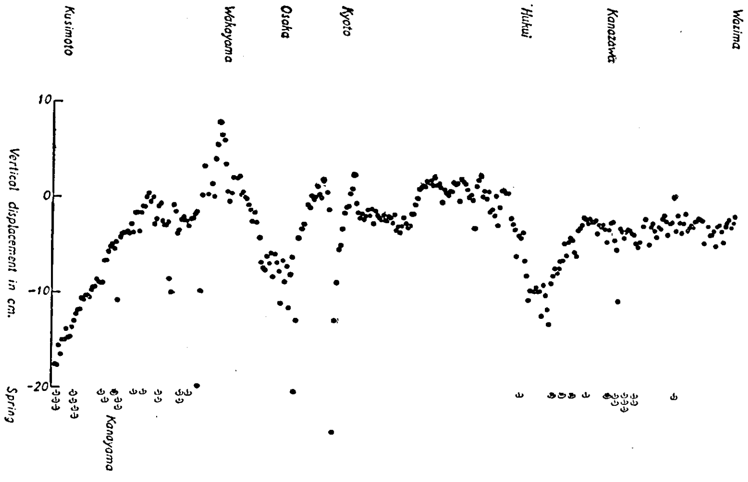
Kusimoto
Wakayama
Osaka
Kyoto
Hukui
Kanazawa
Wazima
10
0
-10
-20
Vertical displacement in cm.
Spring
Kanayama

Fig. 6.

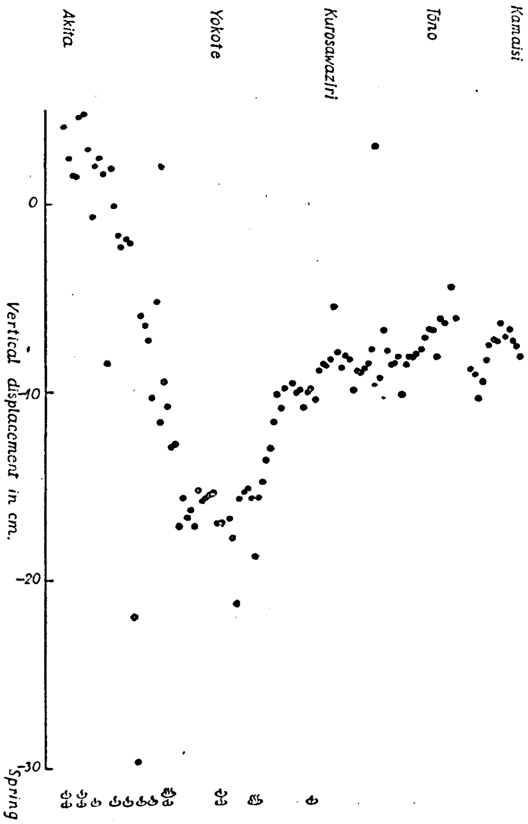
Akita
Yokote
Kurosawaziri
Tōno
Kamaisi
Vertical displacement in cm.
0
-10
-20
-30
Spring

Fig. 7.

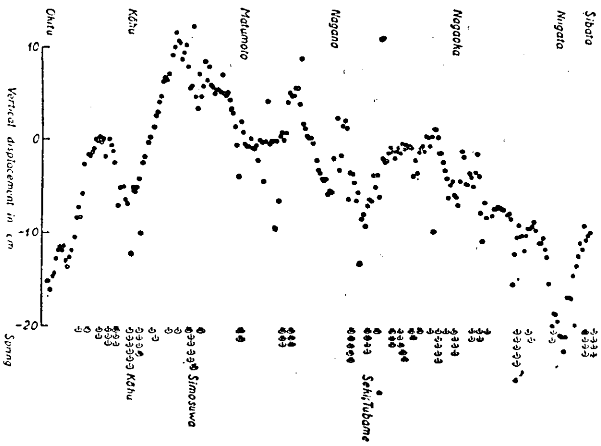
Ohtu
Kôhu
Matumoto
Nagano
Nagaoka
Niigata
Sibata
Vertical displacement in cm
10
0
-10
-20
Spring
Kôhu
Simosuwa
Seki-Tubame

Fig. 8.

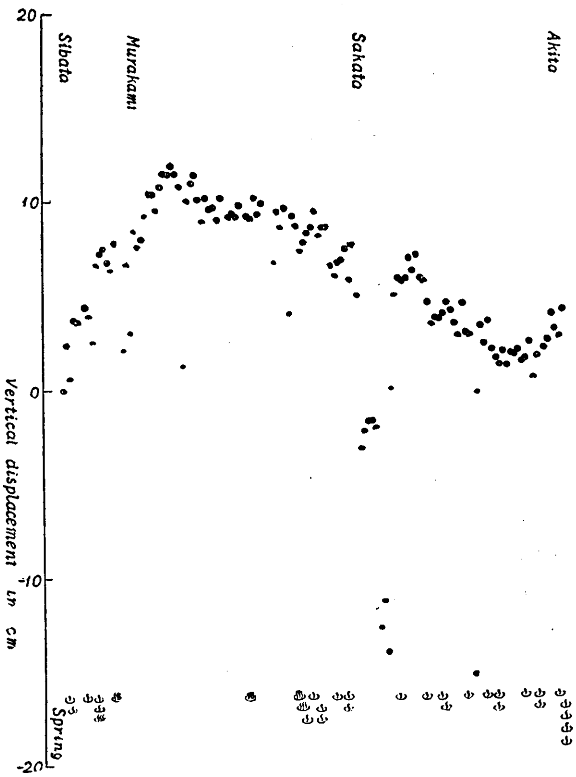

Fig. 9.

supposed all equal, as unit, and the ordinates the vertical displacements of the bench-marks. The positions of the springs on the route, conventionally allotted as in the above described manner, were marked on the axis of abscissa (♨ $<$ 100°F; ♨ $>$ 100°F). Next, the mean vertical displacement $\delta h'_m$ for each segment of the route comprising 25 consecutive bench-marks, i.e., a segment about 50 km in length, was calculated. The number N' of the hot and mineral springs falling in each segment was counted. For the second process of smoothing, the overlapping means δh_m and N over successive three segments were respectively taken.[4] Plotting then N against δh_m for the successive segments, we obtain diagrams as shown in Figs. 10～17. If there exists a simple relation between the two quantities, the points plotted will show a more or less systematic arrangement according to more or less close correlation.

4) In the abstract of this paper given in *Proc. Imp. Acad.*, **11** (1935) 99, the description of this second process of smoothing was dropped.

In the following, brief explanations will be given of the results of investigation with reference to the different levelling routes.

1) Route from Hamada in Iwami to Sibata in Etigo, along the Japan Sea coast. Figs. 2 and 10.

The relation between N and δh_m for this route is shown in Fig. 10 by the points marked ●. These points are arranged within a belt between the two straight lines, say,

$$N = N_0 - k\delta h_m \quad \text{and} \quad N = N_0' - k\delta h_m\,.$$

This is in good agreement with our expectation. Referring to Fig. 2, it is interesting to remark that in the part of the route between Miyadu and Hukui, for which δh_m is generally positive, no hot or mineral spring is met with at all.

2) Route from Okayama in Bizen to Sirakawa in Iwaki, along the central line of Honsyû. Figs. 3, 10 and 11.

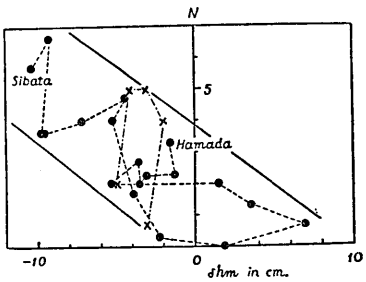

Fig. 10.

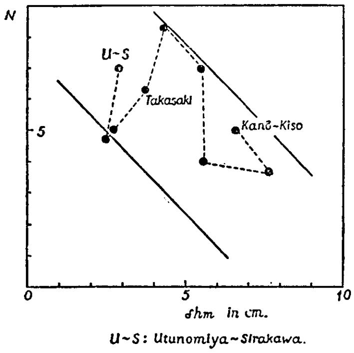

Fig. 11.

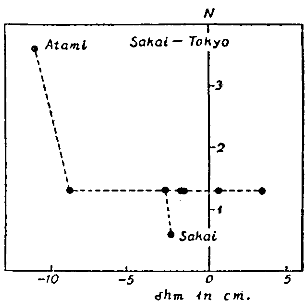

Fig. 12.

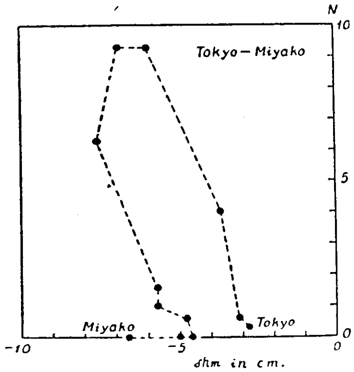

Fig. 13.

The vertical displacement along this route (Fig. 3) shows a remarkable discontinuity in general level near Kanô in the middle part of the route. Hence, the route was divided into two parts respectively extending on the two sides of Kanô. Taking the part *W* of Kanô, N-δh_m relation falls in with the belt named in Fig. 10 as shown by the points plotted with the mark ×. The other part, *E* of Kanô, seems to form another group of points as plotted in Fig. 11.

3) Route from Sakai near Osaka to Tokyo, via Nara, Yokkaiti, Nagoya, Hamamatu, Numadu and Atami. Figs. 4 and 12.

Along this route, the springs are generally rare except in the province of Idu and neighbouring districts, where conspicuous hot springs are abundunt. This latter region was, however, considerably disturbed by the recent destructive earthquakes of 1923 and 1930, so that we could scarcely expect a simple relation between N and δh_m. On the other hand, it was shown in the previous paper cited, that some of the remarkable groups of spas of this region fall within the areas with negative values of divergence Δ. It may therefore be suggested that this region belongs to those portions of the earth's crust which are subjected to secular subsidence interrupted by occasional abrupt upheavals.

4) Route from Hunabasi near Tokyo to Miyako in Rikutyû, via Mito, Sendai and Kamaisi, along the Pacific coast. Figs. 5 and 13.

Along this route, the mineral springs are almost concentrated in the region between Mito and Tomioka. It is just this region where a very conspicuous V-shaped depression of the route is observed.[5]

5) Route from Kusimoto in Kii to Wazimazaki in Noto, across the central part of Honsyû. Figs. 6 and 14.

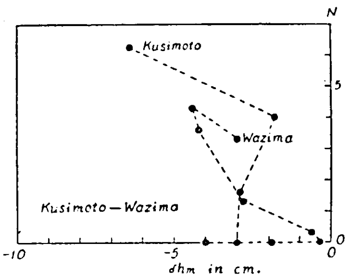

Fig. 14.

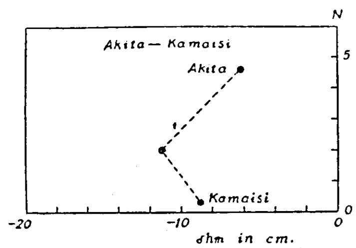

Fig. 15.

Along this route the correlation between N and δh_m is not very conspicuous. Still we may observe that most of the hot and mineral springs in this route fall in with the region with $\delta h_m < -20$ mm.

5) T. Terada and N. Miyabe, *Proc. Imp. Acad.*, **10** (1934), 557; *ibid.*, **11** (1935), 99.

6) Route from Akita, Ugo, on the Japan Sea coast to Kamaisi, Rikutyû, on the Pacific coast, via Yokote, Kurosawaziri and Tôno. Figs. 7 and 15.

Along this route the correlation is not conspicuous, but we may observe that the springs with the temperature higher than 100°F are found all near the minimum of δh–curve (Fig. 7).

7) Route from Okitu, Suruga, on the Pacific coast to Sibata, Etigo on the Japan Sea coast, via Kôhu, Matumoto, Nagano and Niigata. Figs. 8 and 16.

This route which was already dealt with in the previous preliminary report, was revised by means of the same method as used here for the other routes. The result is rather complicated, but we may observe firstly that the general tendency of the negative correlation between N and δh_m may still be traced, except some irregularities, and secondly that very conspicuous swarms of hot springs are mostly met with at or near the minima of δh–curve (Fig. 8).

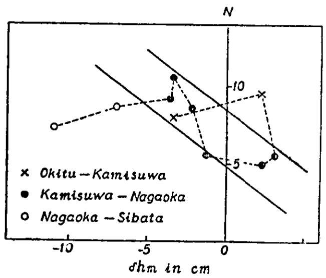

Fig. 16,

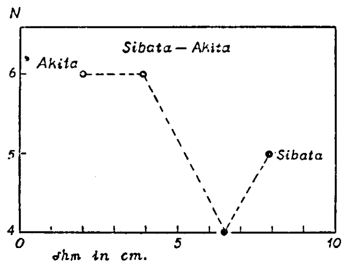

Fig. 17.

8) Route from Sibata in Etigo to Akita in Ugo along the Japan Sea coast. Figs. 9 and 17.

This route was recently revised and it wants some scrutiny before we may bring the δh–curve obtained in connection with the curve for the route (1) above named, as the dates of the surveys are different for the two routes though they form two consecutive parts of the same continuous route along the Japan Sea. It will be seen that the springs are relatively abundant in region with relatively less value of δh.[6]

From the above results, the existence of some correlation between N and δh_m can scarcely be doubted, though the relation is not quite simple. A simple relation can, however, not be expected from the first outset, firstly because we are here comparing N with δh_m instead of

6) The δh-curve along the route from Sibata to Akita is reproduced from the data given in Prof. A. Imamura's paper: A. IMAMURA, *Disin*, 7 (1935), 185.

Δ directly. The displacement δh_m and divergence Δ are not always positively correlated, especially in the regions disturbed by recent earthquakes. Secondly, even the relation between N and Δ cannot be so simple that we may express N as a simple linear function of Δ. It may well be possible that N depends on the mean value of Δ over a very wide region, as well as on the relative value of Δ within a rather narrow locality. Thirdly, the above results may be modified in some measure, if we take the breadth of the zone parallel to the route, which was chosen here as 20 km on either side of the route, as 10 or 30 km, or if we prefer some other method of allotting each spring to a point on the route.

It seems, however, that the new line of investigation here taken up promises to throw some unexpected light on the studies of crust movement if duly pursued with more sufficient data and more elaborate methods. At the present stage, we may suggest already (i) that a segment of the route within which the negative correlation between N and δh_m is very conspicuous is situated on a region which is free from the disturbance due to recent severe earthquakes and (ii) that at a locality which forms a junction between two segments of a route such that the two segments if taken separately show good correlation within themselves, but if taken together show no apparent correlation, we may suspect a real tectonic discontinuity which is active in the present geological age.

It seems highly desirable to investigate the similar relation for the other parts of the worlds.

45. 溫泉及鑛泉の分布と地殼運動

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地殼水平移動のダイヴァージエンス $\varDelta$ が負量を示す地方に溫泉や鑛泉の湧出が多いであらうと期待される理由がある．一方では又この $\varDelta$ と地殼の垂直運動との間に正相關が屢々認められると云ふ事實がある．それで，實測資料の少ない $\varDelta$ の代りに資料の豐富な垂直運動の實測値と，水準測量沿線地方の溫泉及鑛泉の分布密度とを比較して見るのも多少の興味がある譯である．この目的で次のやうな方法をとつた．

水準線路の兩側に並行に各 20 km の幅の地帶をとり，その中にある溫泉及鑛泉をこの線路に所屬させた．次に各泉地點から水準路線に大體垂直な線を劃しそれが線路を切る點を其溫泉所屬の點とした．次に水準線を横軸とし各點の垂直運動の量を縱軸とした圖を作り，その横軸の下に溫泉鑛泉の所屬位置を記入した．此圖により垂直運動の正負によつて泉の分布密度がどうちがふかを見ることが出來る．

次には，線路に沿ひ相隣る 25 點の平均垂直運動の量 h'_m とその區間の泉の總數 N' とを計算し，更に此の如き區間を三つづゝ取つて平均した重合平均値 h_m と N とを計算し，この二つを座標軸にとつて相關圖を作つて見た．もし兩者の相關が顯著なれば圖の點は一線上に乘るわけである．

調査の結果は決して簡單ではないが，可成の相關が認められる場合も少くない．殊に長い線路全體としての相關は見えなくても部分的にそれが見られる場合があり，又 h_m の或値が泉の有無の限界を示す場合もある．

問題の相關はあるとしても，その外に色々の原因が共同作用してゐるから，さう簡單な結果が得られないのは當然であるが，それに拘らず，こゝで見られるやうな結果を得たのは，寧ろ最初想像されるやうな物理的關係が可成密接に存する證據とも考へられる．それで更に多くの材料につき又より適當な方法により研究の歩を進めることが出來ればその結果として地殼運動の研究に多少でも新しい光明を與へるやうなものが得られるかも知れないと思はれる．當論文ではこの新しき方向への第一歩として試みに手近な方法をとつて見ただけである．