49. *On the Rendaizi Thermal Spring in Southern Idu Peninsula.*

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I. Introduction.

At the time of the strong Idu Earthquake of March 21, 1934, changes occurred in temperature and rate of flow of water in thermal springs distributed in the strongly shaken area, for example, in Rendaizi, Toi, Yugasima etc[1].

Although such changes accompanying great earthquakes have been frequently noticed by many authors[2], the mechanism of occur-

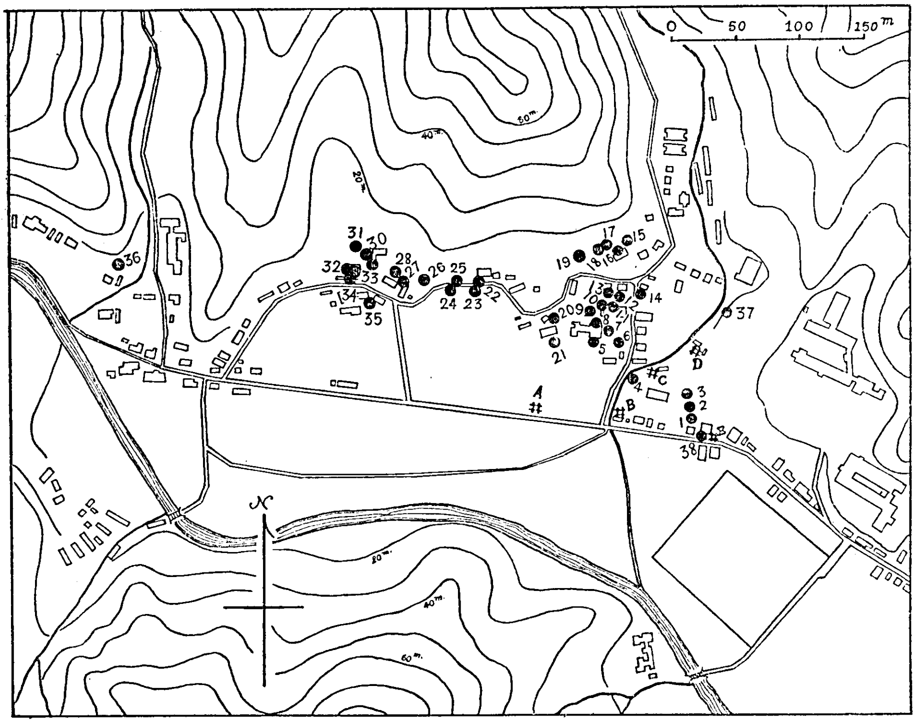

Fig. 1.

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[1] T. FUKUTOMI, *Bull. Earthq. Res. Inst.*, **12** (1934), 527.

rence of such changes have not been sufficiently elucidated owing to lack of knowledges regarding the physical nature of thermal springs.

The present paper discusses some properties of the Rendaizi thermal spring in southern Idu Peninsula in its normal condition.

The village of Rendaizi is situated at the northern side of a tributary of the River Inôzawa on the small Alluvial plain; a long valley running from W to E and practically surrounded by mountains which are composed of propylite and its tuff and breccia of the lower Tertiary age. There are about 40 thermal springs at present, mostly in the Alluvial plain as shown in Fig. 1.

The writers made observation of temperature and rate of flow of a hot spring (No. 38 in Fig. 1) which belongs to Mr. A. Sawazi to whom our best thanks are due for his courtesy.

II. Temperature of the Rendaizi Thermal Spring.

There are two quite different systems of cold water in Rendaizi, one is underground water which is obtained by normal well, the other is mineral spring which is obtained by artesian well. The latter contains nearly 10 times of Cl amount compared with that of the former and has weak basicity while the former has weak acidity though these two types of water have nearly equal temperature. In the following paragraphs, therefore, "thermal spring" means hot springs as well as tepid ones including the mineral spring in ordinary temperature.

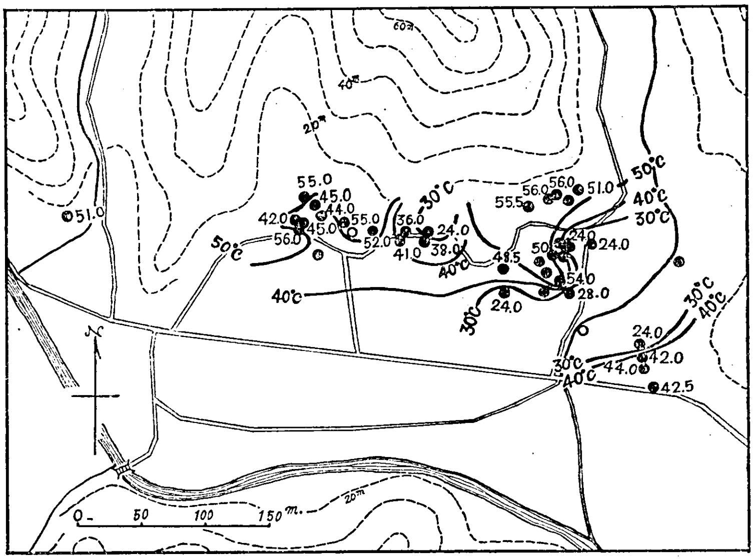

Fig. 2. Distribution of orifice temperature of thermal springs.

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2) For example, see N. Miyabe, *Disin*, **5** (1933), 21.

Table I.

No.	Orifice temperature of thermal spring.	Rate of flow of hot water.△*	Flow speed. (v)	Depth of the vertical pipe.*	Internal radius of the vertical pipe.*	Height of the orifice above mean sea level.*	Depth of water head below the surface of the ground.*	Height of water head in the vertical pipe above mean lsea evel.	Some chemical constituents. (化學的性質)	
(番號)	(湧出溫度)	(湧出量)	(湧出速度)	(穿井の深さ)	(穿井内徑)	(湧出口海面上高)	(地表下湧出面深)	(湧出面海面上高)	Cl g/l	PH
	°C	l/min.	cm/min.	m	cm	m	m	m		
1	44·0	18·05	396	106	3·81	8·89	0·49	8·40	0·152	8·13
2	42·0	36·2	——	8	——	8·74	9·91	7·83	0·110	8·40
3	24·0	7·2	57	40·2	6·35	8·89	0·49	8·40	——	——
4	——	——	——	——	——	9·34	——	——	——	——
5	——	——	——	2	——	10·34	1·00	9·33	——	——
6	28·0	——	——	——	22·73	9·55	0·64	8·90	——	——
7	54·0	2·35	51·6	39	3·81	9·55	0·39	9·15	0·169	7·39
8	——	——	——	3	——	9·45	0·43	9·05	0·164	7·75
9	——	——	——	3	——	9·63	0·82	8·81	0.127	7·25
10	50·0	0·22	4·8	46	——	10·24	0·61	9·62	——	——
11	——	——	——	——	——	9·87	0·55	9·32	——	——
12	24·0	——	——	2	16·66	10·14	0·79	9·35	0·080	7·10
13	——	——	——	2	——	10·24	0·91	9·33	0·173	7·80
14	24·0	——	——	4	——	10·27	0·89	9·68	——	——
15	51·0	27·10	594	65	3·81	13·20	2·12	11·10	——	——
16	——	——	——	2		11·40	0·79	10·62	——	——
17	56·0	72·3	56·9	55	6·35	13·08	1·82	11·27	0·173	8·28
18	56·0	90·3	71·2	35	6·35	13·63	1·89	11·28	0·173	8·28
19	55·5	144·3	3167	61	3·81	13·47	2 14	11·33	0·173	8·28
20	48·5	3·61	79·2	73	3·81	10·70	0·57	10·33	——	——
21	24·0	0·72	15·8	76	3·81	9·74	1·82	7·92	——	——
22	24·0	——	——	0·9	(78·79 ×73·33)	10·03	0·42	9·60	0·098	7·29
23	38·0	0·90	1·25	3	15·14	9·28	0·30	8·97	——	——
24	41·0	1·81	——	1	——	9·77	0·52	9·24	——	——
25	36·0	1·81	——	1	——	10·06	0·34	9·71	0·132	7·85
26	52·0	9·0	197	29	3·81	14·41	2·12	12·29	0·166	7·50
27	——	——	——	——	——	10·84	——	——	0·171	7·85
28	55·0	126·3	2770	42	3·81	11·76	1·21	10·54	——	——
29	44·0	3·61	7·8	2	12·11	10·55	0·91	9·33	——	——
30	45·0	9·10	——	1	——	10·09	0·45	9·62	——	——
31	55·0	28·9	633	61	3·81	11·78	0·00	11·78	——	——
32	42·0	3·61	5·0	0·9	15·14	9·80	0·79	9·01	0·147	8·15
33	45·0	1·81	2·79	1	14·38	9·80	0·30	9·50	0·163	7·88
34	56·0	94·12	2064	52	3·81	9·80	0·00	9·80	——	——
35	45·0	6·34	——	4	——	9·40	0·30	9·08	0·153	7·90
36	51·0	90·3	4450	91	2·54	13·71	1·17	12·54	0·161	7·84
37	——	——	——	——	——	——	——	——	0·164	8·35
38	42·5°	——	——	110	3·55	8·90	0·49	8·41	0·140	8·02
A	(Normal well)								0·016	6·67
B									0·021	6·80
C									0·018	6·75
D									0·013	6·70
E									0·054	6·75

* Measurement by the Rendaizi Thermal Spring Association.

△ This data is not so accurate.

From the result of observation made by the Rendaizi Thermal Spring Association in July, 1929, map of temperature distribution was drawn as shown in Fig. 2. (See Table I.) The temperature ranges between 57°C in maximum and 25°C in minimum, and it is high at the northern hill-side, decreasing gradually towards the southern plain.

In general, orifice temperature depends on the depth of artesian well; it is high in deep well as shown in Fig. 3.

We examined the relation between orifice temperature and the rate of flow of hot water, and get the result as shown in Fig. 4, that the temperature tends to a constant value for large flow speed. This fact may be due to the escape of heat to the surrounding medium through the conduction in the course of ascent of the hot water. We may assume that the temperature of the Rendaizi thermal spring tends in the deep to nearly 60°C.

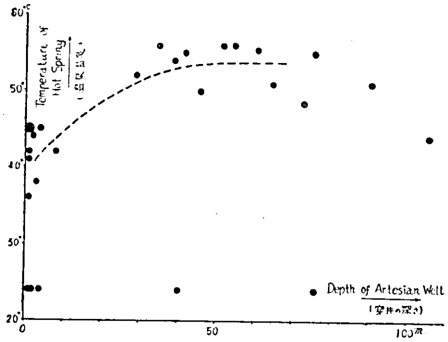

Fig. 3. Relation between orifiice temperature and depth of the artesian well.

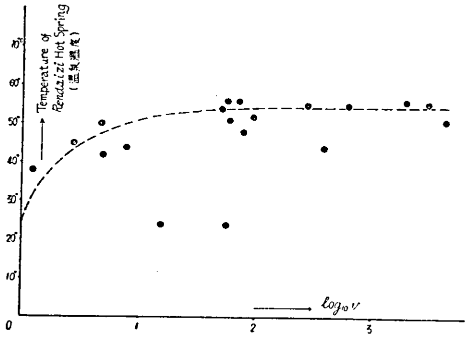

Fig. 4. Relation between orifice temperature and the rate of flow of hot water.

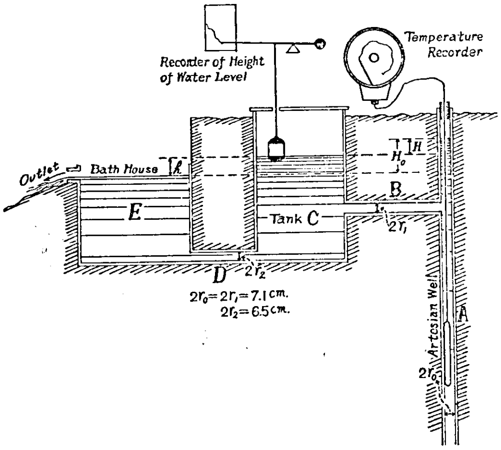

Fig. 5 The elevational sketch map of the Sawazi's hot spring.

Next, we may mention the result of observations at the Sawazi's thermal spring. The well is situated 8.4 m higher than the level of the sea, and 3·0 km distant from the nearest sea coast. It is about 110 m deep, and its water level is 49 cm below the surface of the ground. Fig. 5 is the elevational sketch map. A is the artesian well, the wall of which consists of stout iron tube 7·1 cm in diameter, and hot water which flows out from A is lead to the tank C by aid of the pipe B, cooled here appropriately and then lead to the bath E by means of the pipe D. Superabundant water overflows from the brim of the bath.

Temperature was recorded automatically inserting the cylindrical part of the recording thermometer made by Nippon Keiki Seisakusyo in the artesian well about 1 m below the junction of pipe B. The water head in tank C was also recorded in magnification of 2 times by aid of a float. Record of temperature and height of water head were continuously taken from April 15 to Aug. 27 and from June 26 to Aug. 27 in 1934.

An examination of the records of temperature leads us to the following conclusions:–

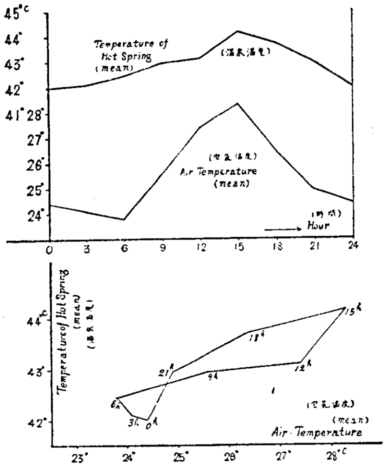

Fig. 6. Relation between the daily change of orifice temperature and that of air temperature.

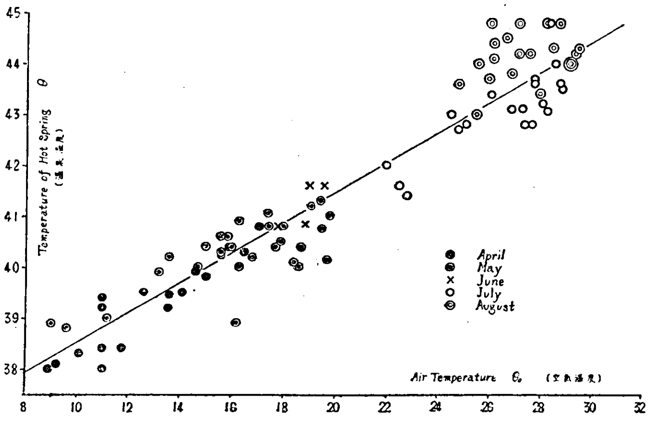

Fig. 7. Relation between the daily mean of orifice temperature and that of air temperature.

1. Orifice temperature shows the obvious daily change reaching maximum at about 4 p.m. and minimum at about 1 a.m., the change being correlated with slight lag of phase to the air temperature as shown in Fig. 6, and its double amplitude varies from 1∼3°C. Daily

mean or monthly mean of temperature of the hot spring has also close relation with the daily mean or monthly mean of air temperature as shown in Fig. 7.

2. Relation between change in water level in the tank C and orifice temperature is shown in Fig. 8. There exists the tendency that the temperature approaches to a constant value with the increase of height of water level, though dots were more or less scattered owing to the effects of air temperature.

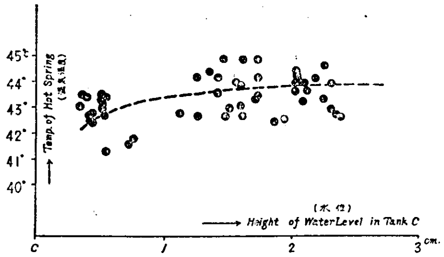

Fig. 8. Relation between orifice temperature and change of water level in tank C.

3. For the sake of simplicity, we assume that orifice temperature θ is the function of cooling of the underground hot water due to loss of heat to air and to the surrounding earth near the surface, and let θ_1 be the underground temperature of the hot spring, ρ the density of water, V the flow speed, c the specific heat, θ_0 the air temperature, S the effective area for heat loss, A the sectional area of the vertical pipe, and K the proportional constant, then we get:–

$$\theta = \frac{\theta_1}{1+\lambda} + \frac{\lambda}{1+\lambda}\theta_0, \text{ where } \lambda \equiv \frac{KS}{AVc\rho}. \tag{1}$$

If we assume that Fig. 7 shows just this relation, we can calculate θ_1 as 51°C. This is nearly equal to the above-mentioned value of underground temperature of hot spring at Rendaizi. We can recognize, therefore, that usual temperature, 40∼43°C, of the hot spring is produced as the result of cooling of underground water owing to the loss of heat to air and surrounding earth.

III. Change of Water Level in Tank C.

The Rendaizi thermal spring in general has not so great power to project the hot water with great velocity, but its water level ranges 40∼200 cm in the vertical well below the surface of the ground.

Between water head $\varDelta h$ in the tank C and $\varDelta H_0$ in the vertical well A in steady state, the following relation exists:–

$$\varDelta h = \frac{\left(\frac{r_1}{r_2}\right)^4}{1+\left(\frac{r_1}{r_2}\right)^4}\varDelta H_0 \text{ or } \varDelta h = 0{\cdot}59\,\varDelta H_0. \tag{2}$$

As the difference between the height of pipe B and the water head in the vertical well A has much effect to the rate of flow of hot water, the quantity of hot water derived per unit time is irregular for every spring.

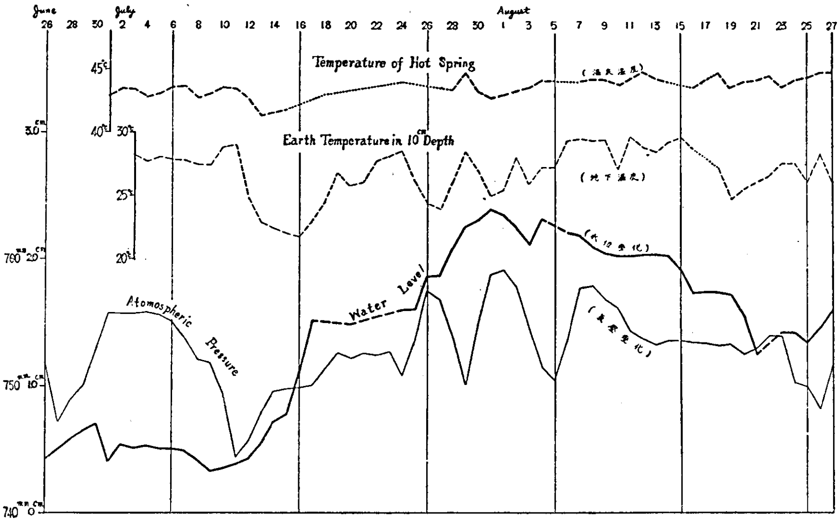

Fig. 9. Relation between the level change in tank C and change in barometric pressure.

The following is the result of observations of the change in water level in the tank C:–

1. Though it is not so definite, there exists some relation between the change in water level in the tank C and change in atmospheric pressure recorded there as shown in Fig. 9. Then, the correlation factor $r^{3)}$ between daily mean of water level x and daily mean of atmospheric pressure y is calculated as shown in the following (Fig. 10).

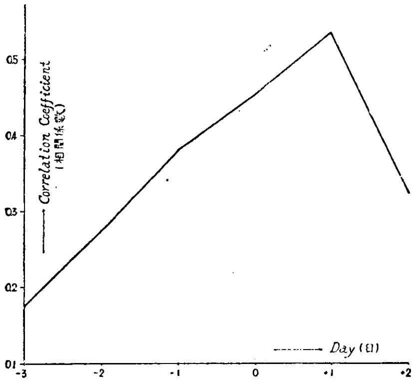

Fig. 10. Correlation factors between the daily mean of level change and that of barometric change.

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3) $r = \dfrac{\sum(xy)}{\sqrt{\sum(x^2)\sum(y^2)}}$.

Level change—Baro. change, 2 days after; $r=0{\cdot}322\pm0{\cdot}094$.[4]
" — " 1 day " ; $r=0{\cdot}535\pm0{\cdot}074$.
" — " the day; $r=0{\cdot}454\pm0{\cdot}076$.
" — " 1 day before; $r=0{\cdot}381\pm0{\cdot}086$.
" — " 2 days " ; $r=0{\cdot}276\pm0{\cdot}093$.
" — " 3 " " ; $r=0{\cdot}108\pm0{\cdot}102$.

We can see that daily mean of level change occurs nearly in the same phase as barometric change, and the high barometer causes the rising of the level, and the low one the descent of the level. Fig. 11 is the correlation diagram between the daily mean of height of water level in the tank C and the barometric pressure of the day. It may be, then, safely concluded that a certain amount of barometric change in mercury column produces corresponding level change in the vertical well A magnified about 5·6 times.

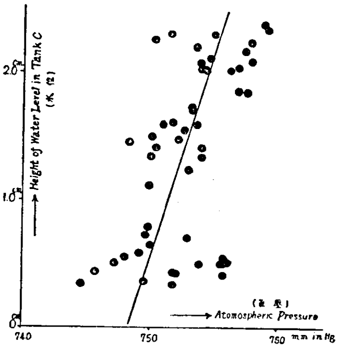

Fig. 11. Correlation diagram between level change in tank C and barometric change on the day.

This is interesting compared with the facts that the level change in the deep artesian well[5] at Tôkyô Imperial University and the rate of flow in a Kamisuwa thermal spring[6] have negative correlation factors with the change in barometric pressure.

2. To examine the effect of rain fall to the change of water level, correlation factor r between the daily mean of the residual change in which the effect of barometric change is taken away and total rain fall during 24 hours from 6 a.m. of the day is also calculated as shown in Fig. 12. We can see that the water level rises abruptly about 3 days after rainfall.

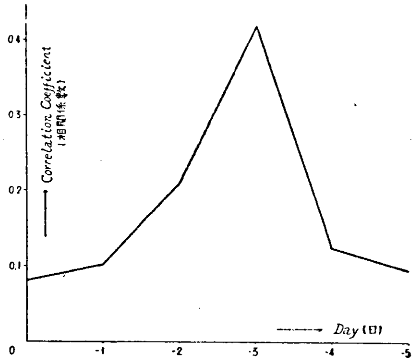

Fig. 12. Correlation factors between the daily mean of level change and daily rain fall.

Effect of the ocean-tide is not noticed, as far as this observation is concerned.

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4) Probable error.

5) K. HONDA, *Publ. Earthq. Inv. Comm.*, **18** (1904), 73.
K. MAEDA, *Disin*, **6** (1934), 275.

6) S. YOSHIMURA and K. MISAWA, *Geograph. Rev., Jap.*, **7** (1931), 239.

IV. Geographical Distribution of Height of Water Level in Artesian Well.

Next, the geographical distribution of the height of water head in artesian wells above mean sea level in the Rendaizi thermal springs is examined as shown in Fig. 13. It is high in the north and low in the south. We can assume that the thermal spring in underground passage fulfill approximately the Bernoulli's equation, which may be written

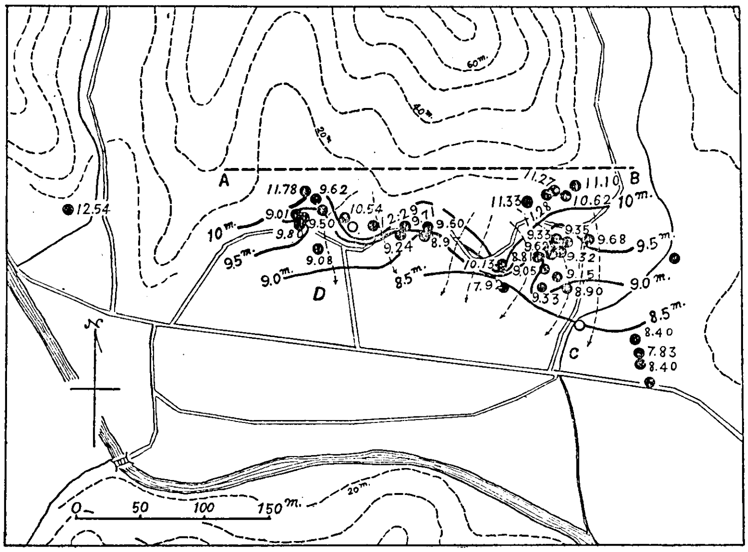

Fig. 13. Distribution of the height of water head in artesian well.

$$Z+\frac{P}{\gamma}+\frac{C^2}{2g}=H, \tag{3}$$

where Z is the height of the passage above a constant plane, P the pressure, $\gamma=\rho g$, ρ the density of water, C the velocity of stream, g the acceleration of gravity at the earth-surface, H the constant.

In general, if energy loss due to hydraulic resistance exists in the course of ascent of hot water in vein, we get

$$Z+\frac{P}{\gamma}+\frac{C^2}{2g}+h=H, \tag{4}$$

where h is the function of energy loss which will become large with the length of path. Now if we take $A=Z+\frac{P}{\gamma}$ as the height of water level in the artesian well, then

$$A=Z+\frac{P}{\gamma}=H'-\frac{C^2}{2g}-h. \tag{5}$$

Thus we can recognize that the contour line in Fig. 13 as the line of equal $(H'-\frac{C^2}{2g}-h)$, and the orthogonal curve to the contour line will give the horizontal direction of underground stream in the thermal spring, for H' is a constant, h being the increasing function of the path, and $\frac{C^2}{2g}$ the quantity concerned with velocity of underground stream, though the sense of the flow is not definite.

If we take the facts into consideration that the distribution of orifice temperature of the thermal spring which is high in the northward and low in the southward resembles to that of height of the water level, and that in the southern galleries of the Kawazu Mine, which has its galleries under the whole region of the vicinity of Rendaizi, the underground temperature is 13°C, and hot water is not found at all, but in the northern galleries there are 3 or 4 hot springs flowing out and there are also some places where the underground temperature was 41°C at the time of the writers' measurement on March 14, 1935, we can recognize that the heat source of Rendaizi thermal springs is in the northward.

If it is permitted to assume that in the underground of Rendaizi thermal spring there is no change in speed of stream, that is, no change in size of the passage and distribution of the height of water level of hot springs depends on the energy loss in the course of stream, and the path is linearly inclined from north upward to south by angle φ to the surface of the ground, then the height of water level of hot spring A from the mean sea level may be given in the form

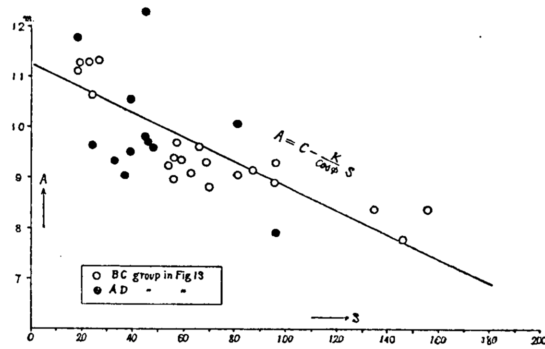

Fig. 14. Hydraulic gradient in the Rendaizi Thermal Spring.

$$A = \text{const.} - \frac{K}{\cos\varphi}\, x, \tag{6}$$

where x is length measured along the line orthogonal to the contour line of the height of water level from an origin, and K is the head of energy loss in the unit length of path.

From the $A\,B$ line which is taken tentatively in Fig. 13, perpendicular distance to the orifice of hot springs x is measured and the relation between A and x is plotted in Fig. 14. We can see that the relation is approximately linear as shown in equation (6). If we put $\varphi = 11°$, we obtain for the value of K

$$K = 5{\cdot}7 \times 10^{-2}\ \text{C.G.S.}$$

V. Some Chemical Properties.

As already mentioned, water taken from the normal well indicates 6·7∼6·8 in PH (weak acidic) and 0·0015% in Cl, while mineral springs show 7·0∼8·4 in PH (weak basic) and 0·010∼0·017% in Cl. These mineral constituents of the Rendaizi thermal spring measured in Oct. 1934, are shown in Table I. There is a tendency that Cl content increases with the ascent of temperature just like the case of the Simosuwa thermal spring[7] (Fig. 15). Distribution of PH is shown in Fig. 16.

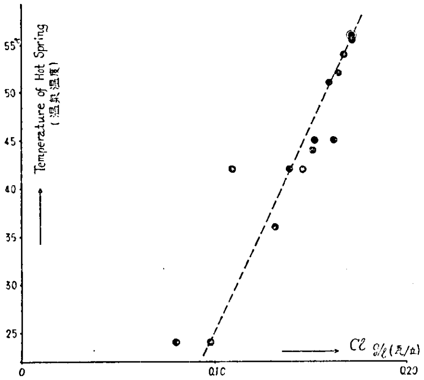

Fig. 15. Relation between Cl content and orifice temperature.

These mineral constituents change to some extent with the rate of flow of hot water. Fig. 17 shows change of Cl content or value of PH in a few days after rain-fall of Dec. 17, and of Dec. 4, 1934. We can see that there is a tendency that Cl content decreases and value of PH increases 3 or 4 days after rainfall, though it is not so

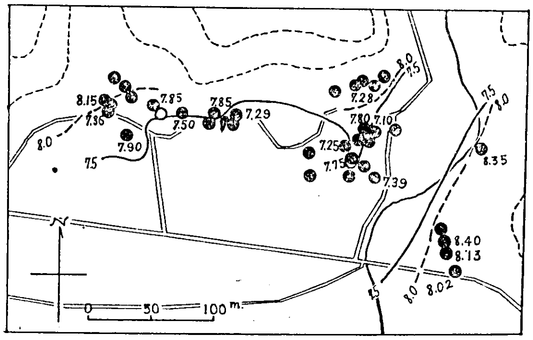

Fig. 16. Distribution of PH.

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[7] S. YOSHIMURA, *Geograph. Rev., Jap.*, 8 (1932), 482.

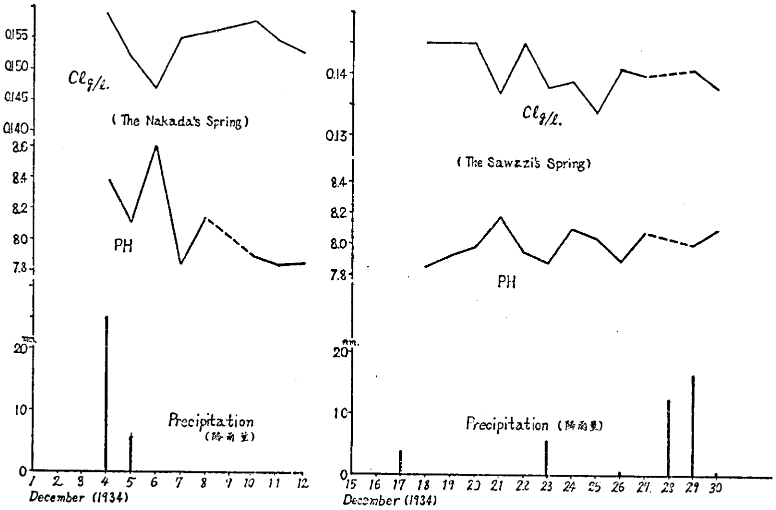

Fig. 17. Change of Cl and value of PH several days after rainfall.

distinct.

If we take into consideration that the rate of flow increases abruptly 3 or 4 days after rain fall, we come to conclusion that Cl content decreases and value of PH increases as the effect of increase in quantity of hot water after rainfall.

This fact suggests us a mechanism in regard to the mixing of the Juvenile water and the Vadose water, that is, the increase of quantity of the Vadose water after rainfall causes the decrease of Cl in amount and the increase of value of PH as the effect of dilution and as the effect of instability of non-buffered solution accompanied by dilution of the buffered solution, $CaCO_3$ etc. But, we may reserve this problem to the more particular study in future.

In conclusion, the writers express their cordial thanks to Professor Takeo Matuzawa and Dr. Chûji Tsuboi for their kind advices.

49. 南伊豆，蓮臺寺溫泉に就て

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地震に伴つて溫泉に異狀の現れる事が屢々注意せられて居るが，溫泉の性質や，構造があまりよく知られてない今日では，其依つて來る所を知る事は困難である．それ故に溫泉研究の一つの試みとして靜岡縣賀茂郡稻生澤村蓮臺寺に於て一溫泉の溫度，涌出面の昇降を測定した．此結果と昭和4年7月蓮臺寺溫泉組合に依る測定結果とに就いて次の諸性質を吟味した．

1. 蓮臺寺溫泉の涌出溫度は氣溫に伴つて著しく變化する．又涌出速度が大となると約 60°C の一定値に近づく．

2. 溫泉穿井中の水位は氣壓變化と位相の遲れなく，正の相關關係にて變化し，又降雨後 3～4 日の後水位上昇を來たす．

3. 溫泉涌出面の高さの分布から地下に於ける溫泉流動の水平方向が求められた結果，蓮臺寺に於ては其泉源が北方に在る事が想像される．

4. Cl，PH 等の化學的成分の分布，並びに降雨に依る變化に就いて一言した．