23. *Physical and Chemical Properties of the Simogamo, Rendaizi and Simokawazu Thermal Springs in Southern Idu Peninsula. I.*

By Takaharu FUKUTOMI,

Mitsui Geophysical Observatory.

(Read Feb. 18, 1936.—Received Mar. 20, 1936.)

The writer recently had an opportunity of observing the orifice temperatures besides analysing some of the chief chemical constituents of the water of a number of springs in the Simogamo, Rendaizi, and Simokawazu thermal regions in southern Idu peninsula. The results, in conjunction with the known physical properties of these springs, give some clue to constructions of the springs in the respective locality.

The results of this investigation are briefly described as follows:

I. Relation between the orifice temperature of a hot spring and the air temperature.

In a previous communication[1] the writer pointed out the close relation apparently existing between the orifice temperature of a certain hot spring at Rendaizi, records of which were taken continuously at about 2 metres below the ground, and those of the air temperature in the place as shown in Fig. 1.

For an explanation of the phenomena, the writer considered first the effect of loss of heat on the air and on the surrounding earth near the surface, and obtained as a relational formulae between the orifice temperature θ and air temperature θ_0 the following equation as first approximation:—

$$\left.\begin{aligned} \theta &= \frac{\theta_1}{1+\lambda} + \frac{\lambda}{1+\lambda}\theta_0, \\ \lambda &= \frac{KS}{Vc\rho}, \end{aligned}\right\} \tag{1}$$

where θ_1 is the underground temperature of the hot spring, V the volume output, ρ the density of water, c the specific heat, S the effective area for heat loss, and K the proportional constant.

---

[1] T. FUKUTOMI and M. NAKADA, *Bull. Earthq. Res. Inst.*, **13** (1935), 616.

But, the fact that the amplitude of the diurnal change of the orifice temperature 2 metres below the surface was one half of that of the air temperature contradicts our common knowledge that the range of the diurnal change of underground temperature is very small in depth of 1 metre in general. This apparent contradiction suggests there is another effect to explain this phenomenon.

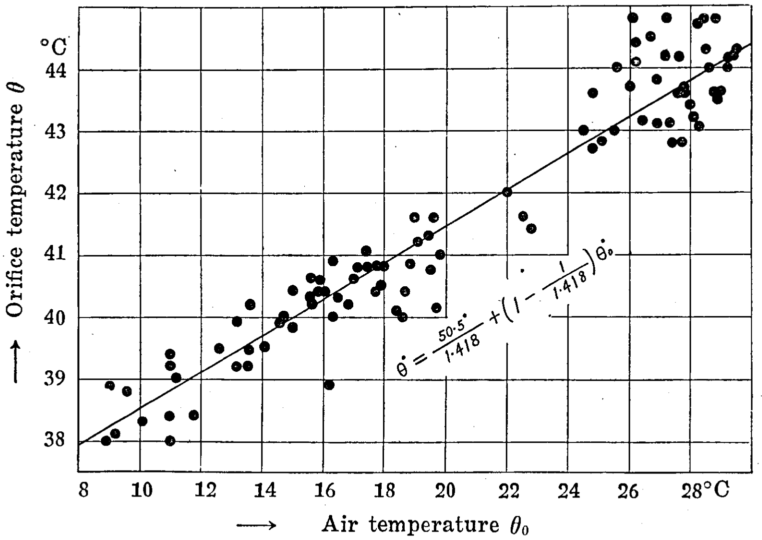

Fig. 1. Relation between the daily mean of orifice temperature in a Rendaizi hot spring and that of air temperature.

It is well next to consider the effect of mixing underground water that has nearly the temperature of air with the original hot spring in underground passages. The writer here uses "underground water" to mean, not the so-called underground water that flows at the slow speed of 1~10 m/day, but streams that flow in the underground fissures of rocks at moderately speed. According to the results[2] of recent observations of the water-heads of hot spring that flowed from the fissure of rock in the underground gallery of the Kawazu mine at Rendaizi, mixing of such underground water was distinctly traced in the shallow layer of the ground.

We shall consider a hot spring of temperature θ_1 mixed in a shallow layer of the ground with cold underground water of temperature θ_2 in volume proportion of $\mathfrak{v}:v=1/R$, and flows out at the orifice in temperature θ.

---

2) T. FUKUTOMI, Read. Sept. 17th, 1935, at the meeting of the Earthquake Reserch Institute, Tokyo Imperial University.

We then get,

$$\theta = \frac{\theta_1}{1+\dfrac{c_u}{c_h}\dfrac{\rho_u}{\rho_h}R} + \frac{\dfrac{c_u}{c_h}\dfrac{\rho_u}{\rho_h}R}{1+\dfrac{c_u}{c_h}\dfrac{\rho_u}{\rho_h}R}\theta_2\,, \tag{2}$$

where c_h, c_u is the specific heat of the original hot spring and the underground water, ρ_h, ρ_u the density of these waters. Appoximately we can assume $c_h = c_u$, $\rho_h = \rho_u$, $\theta_2 = k\theta_0$, and therefore obtain

$$\left.\begin{aligned} \theta &= \frac{\theta_1}{1+R} + \frac{R}{1+R}k\theta_0\,, \\ R &= \frac{v}{\mathfrak{v}}\,. \end{aligned}\right\} \tag{3}$$

If volume proportion R between the underground water and the original hot spring is constant, and k is nearly equal to 1, formulae (3) for the relation between orifice temperature and air temperature is exactly the same form as that of (1).

If the assumption[3] that the original hot spring, which was subjected first to the effect of mixing with the cold underground water as shown in equation (3), suffered through heat loss as shown in equation (1) is taken into consideration, then we get

$$\theta = \frac{\theta_1}{(1+\lambda)(1+R)} + \left[1 - \frac{k}{(1+\lambda)(1+R)} + \frac{k-1}{1+\lambda}\right]\theta_0. \tag{4}$$

If θ_1, R be constant, and also the output of spring V is constant or moderately large, we can express θ as a simple linear function of θ_0 as shown in equation (4). The linear relation between θ and θ_0 shown in Fig. 1 may represent this relation.

II. Relation between orifice temperature and the amount of chemical substances of a number of spring in a locality.

The simple relation between orifice temperatures of springs and the amounts of mineral substances dissolved in the water of springs was not known with for springs scattered over a very wide region, though it was frequently noticed in the case of springs within a narrow range

---

[3] In another combination of these two effects, we obtained a different equation

$$\theta = \frac{\theta_1}{(1+\lambda)(1+R)} + \theta_0\left[k - \frac{1}{(1+\lambda)(1+R)} + \frac{1-k}{1+R}\right]$$

to equation (4).

of locality. According to Mr. Yoshimura's investigation[4] with respect to the Kamisuwa thermal springs in Nagano Prefecture, a linear relation exists between the amount of Cl-compounds in water of many springs and the corresponding orifice temperatures.

Similar relations were ascertained in the cases of Simogamo, Rendaizi, and Simokawazu thermal springs connection with the Cl- and Ca-compounds. Water taken from many of these thermal springs contained 4·5∼12·5 g/l, 0·10∼0·17 g/l, 0·02∼1·21 g/l of Cl respectively. These relations are shown in diagrams (Figs. 2∼4) in which the abscissa represents the orifice temperature, and the ordinate, the Cl-contents of the springs in their respective localities.

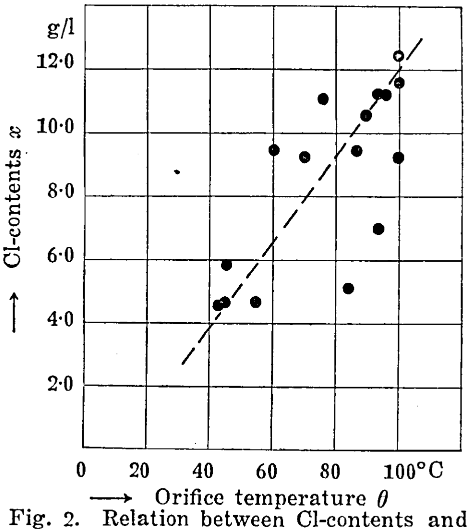

Fig. 2. Relation between Cl-contents and orifice temperatures in Simogamo thermal springs.

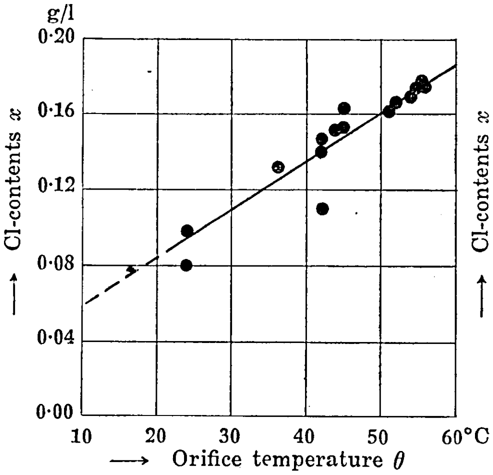

Fig. 3. Relation between Cl-contents and orifice temperatures in Rendaizi thermal springs.

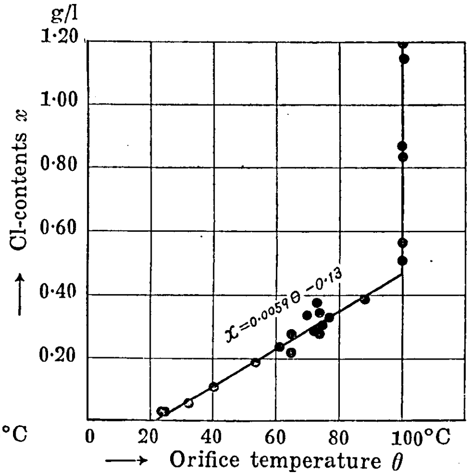

Fig. 4. Relation between Cl-contents and orifice temperatures in Simokawazu thermal springs.

In explanation of this phenomena, a theory that first occurred in our minds is that though there are some exceptions, as $CaSO_4$, Na_2SO_3 etc., the solubility

---

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

of many materials in water, generally, was large in the case where the temperature of water was high in the extent of temperature in question, so that the amounts of the mineral constituents contained in springs of high temperature may be larger than those contained in springs of low temperature, so far as springs of equal output and non-saturated materials are concerned. Although this theory may be reasonable to a certain extent, we can not accept it in this case as a suitable explanation of the phenomena, first, because in above thermal and mineral springs regions, the temperatures and the amounts of the chemical constituent differed markedly, notwithstanding the short distance of only 20∼30 m between their sites, an example being the Simogamo springs the temperatures and Cl-contents of which change over the range 30∼100°C and 4∼12 5 g/l. If the above mentioned idea were justified in this case, we should unreasonably recognize the existence of many springs of different temperatures and of different chemical constituents that flow out independently from the deep in a narrow area.

Second the relations between the amounts of these chemical constituents and the corresponding orifice temperature in the Simogamo springs in which NaCl, $CaCl_2$ were its chief chemical constituents, with $Mg(HCO_3)_2$, etc., also in small amount, show positive linear relations with respect to the Cl- and Ca-compounds, but show negative linear relation with respect to the CO_3-compound, notwithstanding that $Mg(HCO_3)_2$ is similar to NaCl and $CaCl_2$, both of which are unsaturated in the temperature in question, and is more soluble in water of high temperature than in that of low. This facts can not be explained by the foregoing theory.

To explain these phenomena, the above quoted theory that the cold underground water mixies with the original hot spring in the superficial crust layer is most acceptable–(assuming that the chemical change or deposition of the materials do not taken place accompanied mixing).

If we now put N g/l (gram per litre) as the amount of a chemical constituent dissolved in the original hot spring, n g/l as that in the underground water, x g/l as that in the hot spring after mixing, and $R=\frac{v}{\mathfrak{v}}$ as the volume ratio of mixture of the underground water to the original hot spring, we then get

$$x=\frac{N}{1+R}+\frac{R}{1+R}n. \tag{5}$$

Eliminating R between (4) and (5), we obtain,

$$x=\frac{(N-n)(1+\lambda)}{(\theta_1-k\theta_0)}\theta+\left[n-\frac{(N-n)(1+\lambda)\theta_0}{(\theta_1-k\theta_0)}\left\{1+\frac{k-1}{1+\lambda}\right\}\right] \qquad (6)$$

This is relational equation between the amount of the chemical constituents of the spring x and orifice temperature θ. If we take N, n, θ_1, $k\theta_0$, θ_0 as constant, and V also as constants, or so large, so that λ is so small in comparison with 1, as to be neglected, we can see that the relation between x and θ is linear, as shown in equation (6), and also recognize that whether the linear relation be positive or not is determined by the sigh of $(N\text{-}n)$. Since the relations between the Cl-contents and orifice temperatures in the above-mentioned three springs are all positive, as shown in Figs. 2~4, we concluded that Cl-compounds are largely contained in the original hot springs in this case.

III. A note on the relation between the Cl-contents and the orifice temperatures of the Simokawazu springs.

The relation between the Cl-contents and the orifice temperatures of a number of springs in Simokawazu is shown in Fig. 4. As to springs, the Cl-contents of which are less than 0·50 g/l, a positive linear relation exists between the Cl-contents and the orifice temperatures as just mentioned. As to springs, the Cl-contents of which are more than 0·50 g/l, the orifice temperatures are always constant at about 100°C displaying the phenomenon of a "Boiling spring".

This may be attributed to the loss of the excess heat of water of high temperature, which is less than that of boiling point under high pressure at depth as latent heat of evaporation due to lowering of pressure at the earth's surface. Before the phenomena of boiling occurs at depth, we may assume that the linear relation $x=A\theta+B$, as shown in Fig. 4, must be satisfied between the Cl-contents and the temperatures. Let θ' be the temperature of a spring before boiling, x g/l the amount of a chemical constituent in the spring before boiling, m g/l the amount of the same material in water at the orifice, V the volume output at the orifice, y the volume of the water that is evaporated, and l the latent heat of evaporation. We then get approximately

$$\left.\begin{aligned}(V+y)\rho c\theta'&=V\rho c\cdot 100+ly\rho\,,\\(V+y)x&=Vm\,.\end{aligned}\right\} \qquad (7)$$

Eliminating y from these equations, we obtain

$$m=\frac{x}{1-\dfrac{c}{l}\dfrac{(\theta'-100)}{1-\dfrac{c}{l}100}}\,. \qquad (8)$$

Now put $x=A\theta+B\cdots(6)'$, ($A=0{\cdot}0059$ g/l degree $B=-0{\cdot}13$ g/l), then we get

$$\theta'=\frac{m-B(1-\frac{c}{l}100)}{m\frac{c}{l}+A(1-\frac{c}{l}100)}. \tag{9}$$

Assuming for example that $c=1{\cdot}007$, $l=539{\cdot}1$ cal., we then have $\theta'=120°\mathrm{C}$ or $185°\mathrm{C}$ for $m=0{\cdot}60$ g/l or $1{\cdot}20$ g/l respectively. Thus we can estimate the approximate temperature of the original hot spring of Simokawazu at depth as more than 185°C.

IV. Relation between two chemical constituents of a number of springs in a locality.

If the questions discussed in II are generally applicable, we can deduce a relational equation between two chemical constituents contained in water of one or more springs in a locality. Let N_a, N_b be the amounts of chemical constituents A, B in the original hot spring, n_a, n_b of those in the cold underground water, and x_a, x_b of those in the thermal spring after mixing. Then eliminating R from the two equations of (5) with respect to A and B, we have

$$x_b=\frac{N_b-n_b}{N_a-n_a}x_a+\frac{N_a n_b-N_b n_a}{N_a-n_a}. \tag{10}$$

If we take x_b in the ordinate and x_a in the abscissa, equation (10) is an equation of a straight line joining the two points (N_a, N_b), (n_a, n_b). We can also see that the relation between the amounts of two chemical constituents is linear and that whether the relation is positive or not depends on the sign of $\frac{N_b-n_b}{N_a-n_a}$.

According to the result of analysis[5] of a certain hot spring in Simogamo, NaCl and $CaCl_2$ were its chief chemical constituents, the amounts of other chemical constituents being negligible compared with those of NaCl and $CaCl_2$. From the total amounts of Cl and Ca that were obtained by our chemical analysis[6], we calculated, therefore, the residual amounts of Cl in every spring of Simogamo subtracting the the amounts of Cl that combine with Ca to form $CaCl_2$. The relation between the residual amounts of Cl that correspond to the amounts of NaCl, and the amounts of Ca that correspond to the amounts of $CaCl_2$

---

[5] Pan-Siduoka thermal spring association, "Onsen no Idu."

[6] See Table I in the second report.

are shown in Fig. 5, from which it is well be sèen that a simple linear relation exists between the amounts of NaCl and those of $CaCl_2$. Other example of such a relation are also shown in Fig. 6 with regard to CO_3-compounds and Cl-compounds. These results are in fair agreement with the expectation from the equation (10). Thus, we come to the conclusion that NaCl and $CaCl_2$ are the chemical components of the original hot spring, where as the CO_3-compounds, on the contrary, are those of the cold underground water.

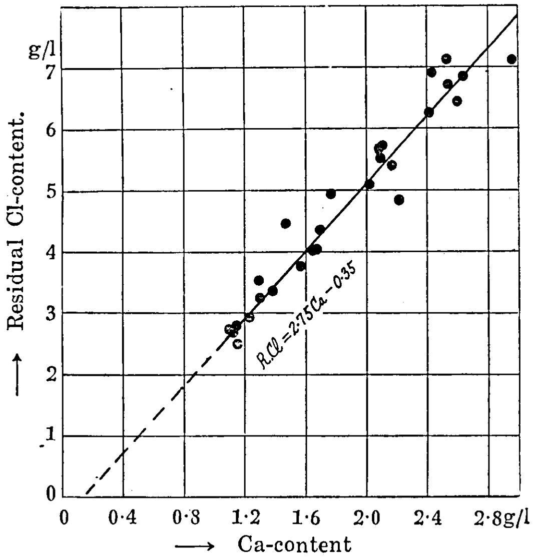

Fig. 5. Relation between residual amounts of Cl which correspound to the amounts of NaCl and amounts of Ca which correspond to the amounts of $CaCl_2$ in Simogamo thermal spring.

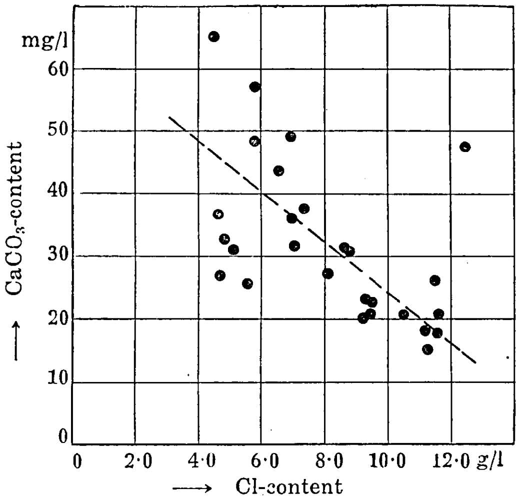

Fig. 6. Relation between amounts of CO_3-compounds and amounts of Cl-compounds contained is Simogamo thermal springs.

V. Relation between orifice temperature and volume output of spring.

It is a well-known fact that the temperature of some ordinary hot springs rises with increase in volume output of the springs, neumerous cases(7) are also recorded of changes in the same sense in the output and temperature of hot springs accompanied by earthquakes. The mechanism of these phenomena is, however, not yet sufficiently understood. According to recent observations made by Mr. K. Maeda(8) in an Asamusi hot spring, the relation between change of orifice temperature and volume output of a spring is well

---

7) For example, see N. MIYABE, *Disin*, **5** (1933), 21.
8). K. MAEDA, *Disin*, **8** (1936), 1.

indicated by the following equation

$$\left.\begin{aligned} \theta &= \theta_1 - \frac{\lambda'(\theta_1-\theta_0)}{V+\lambda'}, \\ \lambda' &= \frac{KS}{c\rho}, \end{aligned}\right\} \tag{11}$$

which is another expression of equation (1).

Considering now the effect of mixing of the underground water, we change the form of equation (4), and get

$$\theta = \theta_0 + \left(\frac{\theta_1-\theta_2}{1+R} + \theta_2 - \theta_0\right)\frac{V}{\dfrac{KS}{c\rho}+V}. \tag{12}$$

When the temperature of the underground water is equal to air temperature, it takes the form

$$\theta = \theta_0 + \frac{\theta_1-\theta_0}{1+R}\,\frac{V}{\dfrac{KS}{c\rho}+V}, \tag{13}$$

$$\text{or}\quad \theta = \theta_0 + \frac{\theta_1-\theta_0}{1+R} - \frac{\theta_1-\theta_0}{1+R}\cdot\frac{\dfrac{KS}{c\rho}}{\dfrac{KS}{c\rho}+V}, \tag{13$'$}$$

and relation between orifice temperature θ and output V is *esteris paribus* hyperbolic relation, and the asymptotic value of temperature was $\theta_2 + \dfrac{\theta_1-\theta_2}{1+R}$ or $\theta_0 + \dfrac{\theta_1-\theta_0}{1+R}$ for (12) or (13) on the other hand that was θ_1 for the case of (11).

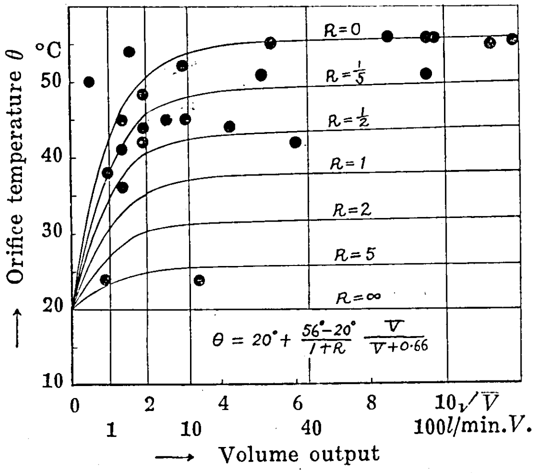

Fig. 7. Relation between orifice temperature of many springs in Rendaizi and the corresponding output. (Points are plotted by the normal scale θ in the oridinate, but by the functional scale $\sqrt{V}$ in the abscissa.)

The points plotted in Fig. 7 give the relation between the orifice temperatures of several springs at Rendaizi and the corresponding outputs, the full lines being the graphic expression of equation (13) for $\theta_1=56^\circ$C, $\theta_0=20^\circ$C, $KS/\rho c=0{\cdot}66$. The relation is not so simple as that in a spring. This may be attributed to the fact that the values of R were moderately different for respective springs in a locality, on the contrary that was fairly constant in regard to a spring. It seems, therefore, that the distinguishing phenomena with respect to the positive relation between change in the orifice temperature of a spring and that of volume output may be attributed to the constancy of R.

There are however some exceptions to this phenomena, examples of which are the Kageyu spring(9) in Nagano Prefecture, Unzen-digoku spring(10) in Nagasaki Prefecture, Sakurazima spring(11) in Kagosima Prefecture, the orifice temperatures of which sink after rain-fall. There are also cases in which fall of orifice temperature and increase in the output of hot springs are accompanied by earthquakes as in the Tazawa and Kutukake springs(12) in Nagano Prefecture at the time of the Kwantô earthquake of 1923.

It seems that in such a case the mixing ratio R between the underground water and the original hot spring is moderately variable and becomes temporarily large after rain-fall, or becomes temporarily or permanently large as the result of earthquake motion or crustal deformation accompanied by earthquakes.

VI. Conclusive remarks.

From the above results, the existence of the effect of heat loss of the hot spring to air and to the surrounding earth near the surface and that of the effect of mixing of the underground water with the original hot spring in the superficial crust layer is scarcely to be doubted, although the relation is not so simple as cited above.

It seems, therefore, that the line of investigation here taken up promises to throw some light on the studies of thermal springs in a locality if duly pursued with more sufficient data and more elaborate methods. At the present stage, we may conclude that if the abovementioned two effects are taken into consideration, the apparent differences in the orifice temperatures and amounts of the chemical constituents between many thermal springs in a locality may be eliminated, leaving only a original hot spring of which temperature and chemical constituents be able to be estimated approximately as following

---

9) S. KATAOKA, *Glove*, **10** (1923), 179.
10) T. SIGA, "*Umi to Sora*", **5** (1925), 51.
11) S. ATA, *Journal of Geography*, **43** (1931), 504.
12) S. KATAOKA, *lcc. cit.*

for Simogamo; 130°C(?)$>\theta_1>$100°C, 16 g/l$>$Cl-content$>$12·5g/l,
3·5 g/l$>$Ca-content$>$3·0g/l,
for Rendaizi; $\theta_1=$58°C, Cl-content$=$0·18 g/l,
for Simokawazu; $\theta_1>$185°C, Cl-content$>$1·20 g/l.

It seems also highly desirable to investigate in future the differences in temperature and chemical properties between these three original hot springs in southern Idu peninsula, distance the distance separating them being only about 10 km.

---

23. 南伊豆，下賀茂・蓮臺寺・下河津3溫泉の物理，化學的性質に就て（第1報）

三井地球物理研究所 福富孝治

最近南伊豆，下賀茂，蓮臺寺，下河津3溫泉の多くの溫泉穿井の採水，測溫を行ひ，主要なる化學成分の分析を行つた．之等の結果と從來研究して來た物理的性質とを簡單に纒めた研究の第1報である．

其概括を述べれば次の樣である．

1. 溫泉湧出溫度θは通常氣溫θ_0と正の相關（Fig. 1）を示し，夏は高溫冬は低溫を示す．此關係の說明として湧出口附近に於て空中や地中へ逃去る熱の影響と，地殼の極めて淺所に於て氣溫に近き溫度の地下水が溫泉に混入すると云ふ影響とが考へられたが，夫等の關係は近似的に（4）式の如く表された．
2. 次に上記3溫泉の各々に就き主要化學成分含有量と湧出溫度との關係を吟味したのに，近似的には直線的關係が認められた（Figs. 2～4）．此の關係の說明として (a) 物質の水に對する溶解度は概して溶媒の溫度が高い程大であるから湧出量の略々等しい溫泉では，高溫な湧出溫度のもの程未だ飽和に達しない物質の含有成分量は大であると云ふ考と (b) 上に述べた地下水混入の影響とが考へられたが，此場合には (a) の影響は問題にならず，大部分 (b) の影響であるらしい事が判つた．然して其含有量xと湧出溫度θとの關係は（6）式で近似的に表はされた．
3. 下河津溫泉に於ける Cl 含有量と溫度との關係は Cl 含有量 0·50 g l 以下の溫泉では上に述べた如く直線的關係を示したが，夫より大なる含有量の溫泉では湧出溫度は 100°C 附近に一定し水蒸氣を噴出して所謂沸騰泉の現象を呈す．之等の溫泉の湧出口で採水された Cl 含有量から沸騰直前の溫度が推定されたのに下河津源泉は 185°C 以上の高溫を有すべき事が判つた．
4. 次に下賀茂溫泉に於ては NaCl と $CaCl_2$ とが其の主成分であるが，分析の結果から，之等の含有量の間には極めて簡單な正の相關關係（Fig. 5）の存在すること，又 CO_3 化合物と Cl 化合物との間には負の相關關係（Fig. 6）が存在する事が判つた．然して之等の關係は地下水の混入を考へて導かれた（7）式とよく符號し，NaCl, $CaCl_2$ の如きは地下源溫泉中に含有され，CO_3 化合物等は地下水中に含有される事が確められた．

5. 上記の影響を考慮して溫泉の湧出溫度 θ と湧出量 V との關係を求めたのに (12) 式又は (13) 式が得られた．之と蓮臺寺溫泉の多くの溫泉の溫度，湧出量の測定結果と比較したが (Fig.7)，地下水と溫泉との混入比 R が溫泉毎に可成り異つて居るので，あまり明瞭な關係を示さない．然して一溫泉に就ては可成り規則正しく變化する事が知られて居て，雨後湧出量の增加に伴つて湧出溫度が上る事はよく知られて居る．又地震時の溫泉變化に於ても湧出量，溫度變化に正の相關のある事は屢々注意されて居る．之は一溫泉に於ては混入比 R が略々一定である事に依るらしい．之等には稀に例外のある事に就ても一言した．

以上に述べた地表附近での熱の逃避の影響と，地下水混入の影響とを考慮すると，一地方の溫泉の湧出溫度や，化學性質の可成りの喰ひ違ひも大體消え去つて，上記の3溫泉に於て各々只一つづゝの源溫泉が得られる．

第2報以下に於ては之等の尙精密な調査と他の物理的性質に就て吟味を行ひ度い．