Some considerations on flow, heat and chemical composition of Italian hot springs

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SUMMARY. — The flow, the temperature and the chemical composition of Italian hot springs are considered from the geophysical and geochemical points of view. At Guardia Piemontese, the spring temperature decreases in the rainy season while the flow increases, the phase lag of this variation from the rain being about two months. This may suggest that the precipitation aliments the source of the hot spring itself or it causes an increase of groundwater mixing to the hot spring.

In Italy, the hot water output of each hot spring is generally less than the quantity of corresponding recharged water from the precipitation in the basin, and this relation is also kept in the geothermal steam field of Larderello. The annual thermal outputs of Italian hot springs are of order of 10^{14} cal at maximum. We can extract geochemically some groups of water from the Italian mineral waters: they are a high saline water being regarded as fossil or oil-field water, a water being similar to the sea water, a water of which main soluble component is $CaSO_4$, and a middle type between last two waters.

RIASSUNTO. — Si riferisce sulla temperatura, portata e caratteri chimici delle acque termo-minerali italiane. La temperatura delle acque termali di Guardia Piemontese diminuisce dopo il periodo di massime precipitazioni, mentre la portata aumenta; però il massimo e il minimo della portata si verificano circa due mesi dopo il periodo di massime e minime precipitazioni. Questa tendenza suggerirebbe che le sorgenti siano interamente alimentate dalle acque piovane, oppure che le precipitazioni provochino un aumento del miscelamento delle acque piovane con le acque termali risalienti.

In Italia, generalmente, le portate complessive delle sorgenti termominerali in ogni bacino sono minori della quantità di acqua piovana che viene assorbita dalla terra. Questa relazione vale anche nella regione di Larderello.

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La produzione termale annuale delle sorgenti termali italiane è al massimo dell'ordine di 10^{14} cal. Nel complesso delle acque minerali italiane possono individuarsi, dal punto di vista geochimico, alcuni tipi caratteristici: cioè, acque ad alto contenuto salino tipo acque fossili o acque madri; acque analoghe a quelle marine; acque il cui principale componente solubile è il $CaSO_4$; acque derivanti dal mescolamento dei due ultimi tipi.

1. – Introduction.

Italy is the most abundant country of hot springs in Europe. There are a great many thermal establishments and spa resorts, and the total number of the hot springs may, comprehending the disuse springs, reach several thousands. The therapeutic effects of these hydrothermal waters have drawn attention and been studied from the Roman Period.

While, the hot spring is the most interesting natural phenomena connecting with the volcano, therefore, it is very important to study the hot spring phenomena not only geologically but also physically and chemically to clarify the thermal and hydrological structure of the earth crust, and results of these studies may contribute to the utilization of the geothermal energy. Basing on this point of view, the author will, in this paper, consider geophysically and geochemically the Italian hot springs, and the discussions will be developed comparing with the results of Japanese hot springs which have been studied.

The hot spring is, scientifically, a phenomenon that the thermal water comes from the deep ground with more or less chemical contents, and the problems include the origins of heat, water and chemical elements, their space and time change, and the motion of the hydrothermal wather. The discussion of these problems must be based on the precise data, but they are not sufficient because of the difficulties of accurate observation in the complicated natural conditions. Therefore, we are anxious to get the precise data as many as possible by the progress of the technical observation.

2. – Flow change of hot spring by rainfall.

It is well known that many Japanese hot springs change their flow by the rainfall. The most of these springs flow out of Quaternary alluvium, form aquifers more or less artesian, and have close relations with the surrounding cold ground-water. On the contrary, many Italian hot springs flow from Tertiary and Mesozoic limestone and may have some different behaviors from that in the alluvium in respect of the relation with the cold ground-water.

As the mechanism of the flow change of hot spring by the rainfall, we can generally consider the following three cases. (I) The rainfall aliments the source of hot water itself, that is, at the start of a great circulation in which rain-water permeates into deep ground, being heated by the magmatic heat source, and comes again up to the surface, the rainfall controls the quantity of the circulation water. In this case, it needs quite long time for the effects of the rainfall to appear on the flow of hot spring, and if the capacity of the heat source is constant the increase of the circulation water brings a fall of base temperature and a decrease of the chemical concentration of hot water. But practically, spring temperatures are kept nearly constant because the fall of the base temperature is compensated by the reduction of cooling in way ascending of the hot water due to higher flow speed. (II) When there are leakages of hot water separating from the main ascending flow into underground strata, the rises of ground-water level by rainfall act as some stoppers to this leakage. In this case, the chemical concentrations are kept in nearly constant but the spring temperatures rise up according to the reduction of the cooling, and the phase lag of the precipitation effects on the flow would be generally small. (III) If the hot waters are mixing with cold waters, rainfalls increase the mixing rate of the latter, decrease the spring temperature and the chemical concentration, and the phase lags are very small.

These three cases of the rainfall effects are summarized, in Table I.

Table I – CHANGE OF HOT SPRING ELEMENTS BY RAINFALL

Case	Flow	Phase lag	Spring temperature	Chemical content
I	increase	large	a little change	slightly decrease
II	increase	little	increase	nearly constant
III	increase	little	decrease	decrease

The statistical results of Beppu Hot Springs [1], Japan, show that the mean flow and the mean spring temperature increase in the rainy season and the phase lag is not appreciable (Fig. 1). These phenomena could be explained as the case II, that is, in the whole region of Beppu Hot Springs the rainfalls act mainly as the stopper for the leakage of hot water to the ground. Naturally, in the individual case there are many hot springs which may be explained as case I or case III, and these three cases may practically overlap each other.

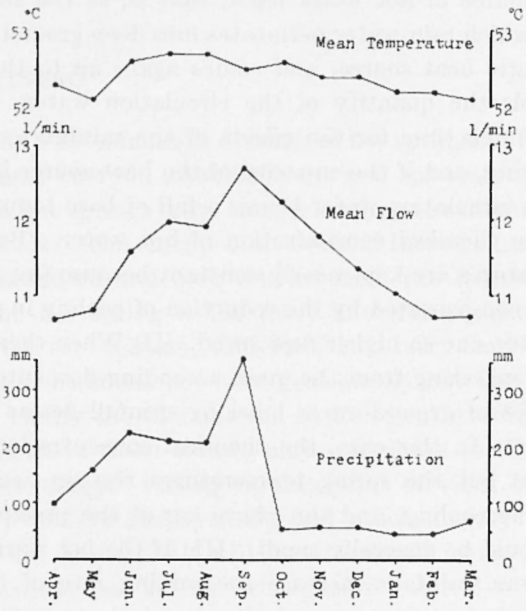

Fig. 1 – Temperature and flow changes in Beppu Hot Springs. Japan,

On the other hand, in the literatures of Italian hot springs, we can find many descriptions that the flow is kept in constant in all seasons, but they lack real observed data. The monthly observations of some physical elements on Guardia Piemontese Hot Springs (2), Italy, are very interesting. In Guardia Piemontese there are three hot springs and cold one named Galleria Calda, Caronet, Minosse and Galleria Fredda. The total flow and the mean spring temperature of main three hot springs are compared with the meteorological data in Table II and Fig. 2, in which we can find the remarkable correlations among the flows, the spring temperatures and the precipitations. First, the flow increase with the rainfall but the maximum and minimum of the flow delay about two months from that of rainfall, second, the spring temperature decreases with the rainfall. Although the change of the spring temperature seems to correspond with air temperature change, the correlation is less than

Table II – ANNUAL VARIATION OF TEMPERATURE AND FLOW IN GUARDIA PIEMONTESE HOT SPRINGS (2).

	Galleria-Fredda		Galleria-Calda		Caronet & Minosse		Total (except Gall. Fredda)		Meteorological data (3) (Reggio Calabria)	
	tem. °C	flow l/s	tem. °C	flow l/s	tem. °C	flow l/s	tem.* °C	flow l/s	air tem. °C	precipi-tation, mm
Jan.	21.5	70	40.5	26	41	38	40.8	64	11.1	74
Feb.	22	70	40	24	41	38	40.6	62	11,1	76
Mar.	22	70	40	22	41	38	40.6	60	13.2	56
Apr.	22	70	41	22	42.5	38	42.0	60	15.4	52
May	22	70	42	22	43.5	38	43.0	60	19,0	26
Jun.	21.5	68	43	22	44	36	43.7	58	23.1	13
Jul.	21	68	43.5	22	44.5	34	44.1	56	25.9	6
Aug.	20	68	44	21	45	33	44.7	54	26.3	9
Sept.	20	68	44.5	21	45	32	44.8	53	23.9	36
Oct.	21	69	42.5	22	44	32	43.5	54	19.3	53
Nov.	21	70	43	22	44	38	43.6	60	17.3	70
Dec.	20	70	4 3	22	43.5	41	43.3	63	13.2	97
Total	—	—	—	—	—	—	—	—	—	568
Mean	21.2	69.3	42.3	22.3	43.3	36.3	42.9	58.7	18.2	—

(*) Weighted mean of Galleria Calda, Caronet and Minosse.

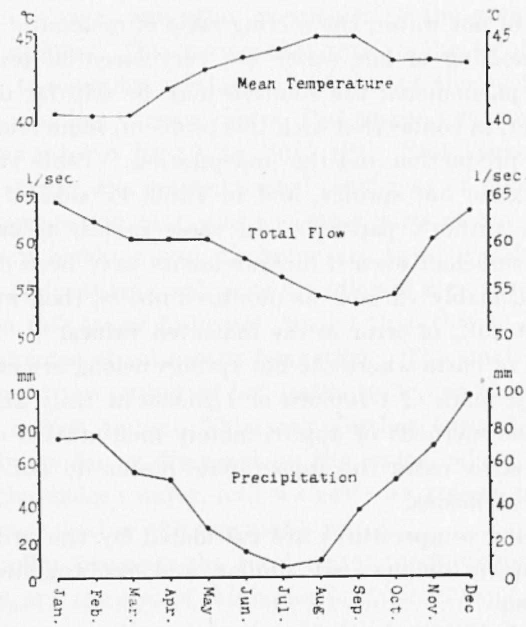

Fig. 2 – Temperature and flow changes in Guardia Piemontese Hot Springs.

that between the spring temperature and the flow, therefore, the change of spring temperature must be caused mainly by the change of the flow. This behavior would be explained as case I if the phase lag is taken as important much than the spring temperature, and as case III in the opposite case. Practically both effects may be piled up.

3. – Relation between hot water production and precipitation.

According to the case I, that is, precipitations aliment the source of hot spring itself, we would acknowledge that the most parts of hot water consist of vadose water. This theory has been discussed by many authors after Bunsen, but we could not deny that a part of hot water is magmatic, because considering the heat source of hydrothermal water we must generally take it magmatic and further must assume some of the magmatic water as the heat transporter from the magma whether it may be gaseous or liquid.

The mixing ratios of the magmatic water in each hot water have been estimated with various methods (1,4,5,6), but these methods have strong and weak points respectively and are not yet conclusive. Though the formation of hot water, the mixing ratio of magmatic water and the process of ascending of hot water are very essential problems to the hydrothermal phenomena, the solution may be still far distant. Then we will consider, in connection with this problem, some relations between the hot water production and the precipitation. Table III shows these relations of Italian hot springs, and in Table IV that of Japanese are cited from an author's paper (7). In these tables, accuracies of each value are not sufficient even if measurements have been done precisely. The flow is seasonably variable as discussed above, then we must admit, at most, about 20% of error in the indicated values.

The areas of basin where the hot springs belong are calculated from the topographic maps of 1/100.000 or 1/25.000 in Italy and 1/50.000 in Japan, with the methods of approximately mensuration or planimeter. Naturally, in some cases the topographic basins do not coincide with the hydrological basins.

Many spring temperatures are calculated by the arithmatic mean when temperatures or flows are similar, and the weighted mean when they are not so.

The annual precipitation is represented by that of a meteorological observation point in or near the basin. It may also have an error as large as the flow, because the topography affects on the rainfall and the precipitation varies from year to year. Therefore, other calculated numbers from above values in the table show only the orders not effective in detailed discussions.

We define " specific flow " as the ratio of the annual total flow to the area of the basin. This corresponds to the depth of water when the total flow is assumed to stagnate in the flat basin, and gives a number directly comparable to the precipitation. Then, the ratio of this specific flow to the precipitation, here we call it " precipitational coefficient " of the flow, suggests the contribution degree of the precipitation to the hot spring.

The flows of most of Italian hot springs have the order of less than 10^3 m^3/day which is smaller by an order than that of Japanese. However, this does not suggest the difference of scales of hydrothermal manifestation between both countries, but the difference of artifisial exploitation of the hydrothermal fields owing to the different custom of using the hot water.

The fairly many precipitational coefficients of flow in Italy are practically smaller than that Japanese. In general, a part of precipitation evaporates directly to the atmosphere and a part flows on the ground surface as river and other permeates to the ground to aliment cold and hot springs. This permeation rate to the total precipitation is affected by topography, geology, condition of the surface and type of the rainfall, and has various values. But we can very roughly estimate the permeation rate to be 10 to 80% ([26]). From this estimation it seems that, in Japan, the precipitational coefficient of flow may roughly equal to the permeation rate, and the most parts of hot water may be vadose of which recharge and discharge are kept in balance. On the other hand, in Italy, these coefficients are often of several percent, though the permeation rate seems to be not smaller than that in Japan because of the predominance of calcareous formation. The small values of this coefficient suggest the output of hot water to be less than the quantity of recharged vadose water. This may further suggest that the hot waters in Italy, so far as discussed on the water balance, may also be explained as the vadose water, and we have no reason to support the mixing of a great deal of the magmatic water.

In Larderello, Tuscany, the total steam production was 24.960.737 ton ([27]) at 1958, and the area of this region is about 200 km^2 ([3]). Considering the annual precipitation at Larderello, 777.2 mm([25]), we can calculate precipitational coefficient of flow, 0.161. This shows that the quantity

Table III – Relation between flow of hot springs and

	Water temp. °C	Flow 10^3 m^3/d	Literature	Area of basin 10^4 m^2	Specific flow m
Merano	5.0 *	1.0	(8)	—	—
Bagni di Salmone . . .	8.0	1.728	(9)	—	—
S. Pellegrino	26.0	0.96	(10)	500	0.070
Abano	75.8 *	10.005	(11)	—	—
Monteortone	63.0 *	1.054	(11)	—	—
Montegrotto	69.6 *	6.048	(11)	—	—
Battaglia	56.5 *	9.072	(11)	2625	0.1261
Salice	14.0	0.303	(12)	—	—
Vinadio	62.0	0.085	(13)	3725	0.00083
Equi	26.0	8.640	(14)	1050	0.300
S. Giuliano	35.0 *	1.0	(14)	—	—
Casciana	36.0	5.0	(14)	300	0.608
Caldana	44.0	0.072	(15)	—	—
Bagnolo di Monterotondo	43.4	0.07	(14)	31	0.0824
Bagno la Perla	37.3 *	0.50	(14)	405	0.0451
Sasso Pisano	50.6 **	0.035	(14)	53	0.0241
Galleraie	25.6 **	1.728	(14)	2675	0.0236
Rapolano	39.0	1.728	(16)	224	0.282
Vignoni	52.0	1.73	(14)	100	0.631
Asciano	32.5	0.102	(14)	100	0.0372
Tolentino	12.0	0.058	(17)	—	—
Roselle	38.8	6.048	(14)	—	—
S. Casciano	37.9 *	5.5	(14)	700	0.287
S. Filippo	39.0 *	1.3	(18)	775	0.0612
Acqua Santa	38.6	15.	(19)	425	1.288
Saturnia	37.0	8.0	(14)	800	0.365
Bagni Orientino . . .	37.0	0.36	(14)	466	0.0282
Acque Albule	23.0	170.0	(20)	—	—
Castellammare	15.3	2.410	(21)	—	—
Guardia Piemontese . .	31.2	11.059	(2)	2125	0.190
Alì	38.0 **	0.380	(22)	903	0.0154
Calatafimi	47.5 **	16.600	(22)	9925	0.0611
Monreale	31.0	4.960	(22)	—	—
Termini Imerese . . .	43.0	0.691	(23)	—	—
Sciacca	41.2 **	0.604	(24)	575	0.0383

(*) Arithmatic mean; (**) Weighted mean.

PRECIPITATION, AND THERMAL OUTPUT OF ITALIAN HOT SPRINGS.

Meteorological data in 1959 (25)			Precipitational coefficient of flow	Temperature difference °C	Thermal output per year 10^{13} cal.
Station	Precipitation mm/year	Mean temperature °C			
Merano	701	11.4	—	- 6.4	—
Debbicco	908.1	5.4	—	2.6	0.16
S. Pellegrino	1822.0	12.3	0.038	13.7	0.48
Padova	941.4	13.6	—	62.2	22.7
Padova	941.4	13.6	—	49.4	1.9
Padova	941.4	13.6	—	56.0	12.4
Padova	941.4	13.6	0.134	42.9	14.2
Voghera	929.6	12.8	—	1.2	0.01
Vinadio	1505.1	8.4	0.001	53.6	0.17
Aulla	1235.6	13.5	0.243	12.5	3.9
Pisa	865.2	15.1	—	19.9	0.73
Livorno	743.6	15.8	0.818	20.2	3.7
Suvereto	776.6	16.7	—	27.3	0.07
Larderello	777.2	14.1	0.106	29.3	0.07
Larderello	777.2	14.1	0.058	23.2	0.42
Larderello	777.2	14.1	0.031	36.5	0.05
Larderello	777.2	14.1	0.030	11.5	0.73
Siena	698.6	13.7	0.404	25.3	1.6
Montalcino	882.8	12.6	0.715	39.4	2.5
Siena	698.6	13.7	0.053	18.8	0.07
Tolentino	844.0	12.1	—	- 0.1	—
Grosseto	775.2	15.2	—	23.6	5.2
Radicofani	737.5	10.8	0.389	27.1	5.4
Abbadia S. Salvatore	1592.9	10.5	0.038	28.5	1.4
Terni	1087.4	15.1	1.184	23.5	12.9
Manciano	997.2	13.4	0.366	23.6	6.9
Manciano	997.2	13.4	0.028	23.6	0.31
Tivoli	917.3	16.0	—	7.0	43.4
Piano di Sorrento	1004.0	16.0	—	- 0.7	—
Paola	739.6	18.4	0.257	12.8	5.2
Taormina	775.0	17.6	0.020	20.4	0.28
Castellammare	444.1	19.1	0.138	28.4	17.2
Palermo Aer.	614.2	18.0	—	13.0	2.4
Palermo	446.0	18.5	—	24.5	0.62
Sciacca	705.8	18.1	0.054	23.1	0.51

Table IV – Relation between flow of hot springs and precipitation in Japan.

	Flow $10^3 m^3/day$	Area of basin $10^4 m^2$	Precipitation mm/year	Precipitational coefficient of flow
Beppu (in city) . . .	18.8	2310	1650	0.16
Beppu (whole region)	47.0	10800	1650	0.10
Atami	28.0	1870	1660	0.33
Ito	45.0	4900	1660	0.20
Shirahama	22.8	323	1950	1.97
Obama	15.2	790	1970	0.37
Noboribetsu	7.4	1140	1120	0.21
Kusatsu	49.0	647	1830	1.05
Kami-Suwa	11.0	38000	1010	0.01
Ibusuki	16.0	2040	2170	0.11
Tamagawa	13.0	1490	1790	0.18

of the steam production is the same order as can be supplied by the precipitation in spite of that the steam is supposed by some men as magmatic from its high temperature, pressure and boric-acid content.

4. – Classification of mineral waters from the chemical composition.

Analitical results of Italian mineral waters have been reported in many papers of each hot spring. Residues at 180 °C vary from 180.176 g/l (Tolentino) (28) to 0.038 g/l (Merano) (8), and chemical compositions of the waters are various. But they will be divided into some groups from the geochemical point of view.

At first, we take up the main anions, SO_4, Cl and HCO_3, for the discussion, in order to keep away from the confusion caused by the simultaneous consideration of all the elements. Millival percentages of the main anions are shown in a triangular diagram (Fig. 3), in which the mineral waters are plotted conveniently by different marks according to total residues. This figure shows roughly that the waters of high concentration gather near the apex of Cl, the medium near the left part os SO_4-HCO_3 axis and the low near the right part of the same axis.

Further, we can extract some groups of water from the entirety by the detailed inspection of this figure, that is,

(*a*) waters having nearly 100% of Cl,

(*b*) waters having 80 ~ 90% of Cl,

(*c*) waters having 50 ~ 80% of Cl and less than 10% of HCO_3

(*d*) waters having 50 ~ 100% of SO_4 and less than 10% of Cl.

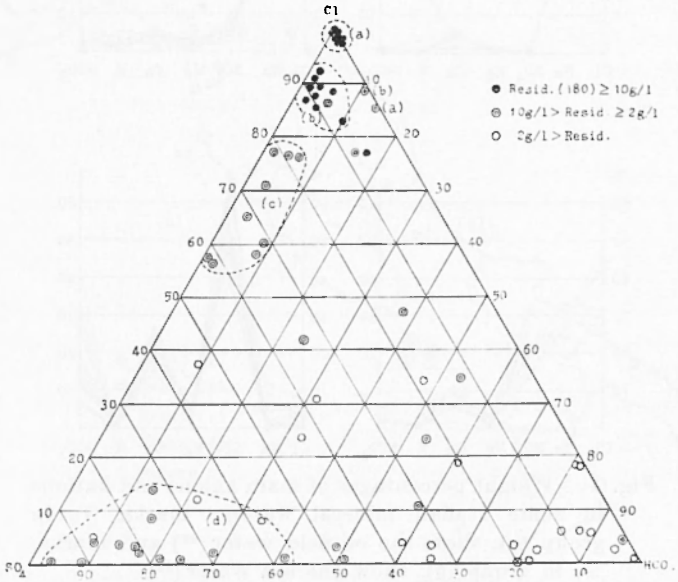

Fig. 3 – Millival percentages of main anions in some Italian mineral waters.

In order to clarify the meaning of these groups, weight percentages of main anions and kations are diagrammatized in Fig. 4. It is clear from this figure that the mineral waters within the same group have very similar chemical compositions in spite of their different concentrations, and they must be essenially the same kind of water. Further, an interesting point is that the waters of group (*a*) contain little SO_4 ions and are very similar to the oil-field water ([29]), while group (*b*) to the sea water ([30]). The mineral springs of group (*a*) are Tolentino ([28]), Salsomaggiore ([31]), Salice ([32]), Fratta ([33]), Castrocaro ([34]) and S. Andrea ([35]), and have temperature of 12 to 16.2 °C. They are aligned along the NW-SE direction at the foot of Appennines as seen in Fig. 5 and may have connection with the Appennine Anticline(3). The fact that a little oil was spouting with the saline water in Salsomaggiore and Salice verifies also that the water of (*a*) is a king of oil-field or fossil water. In group (*b*),

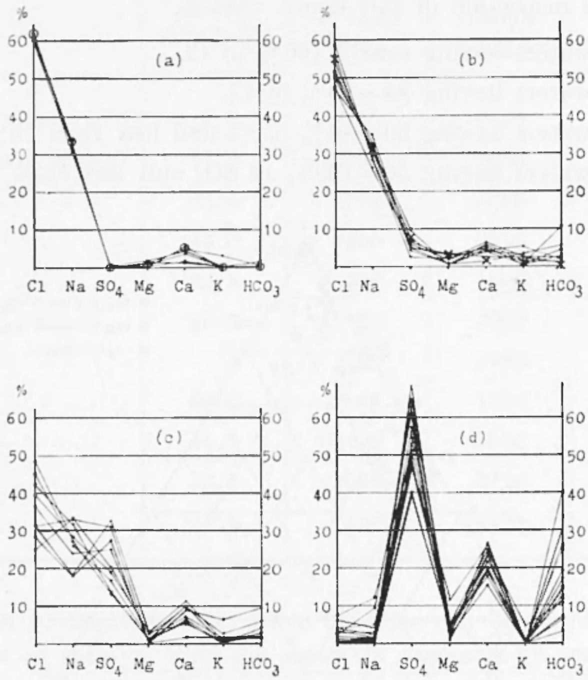

Fig. 4 – Weight percentages of main anions and kations in some Italian mineral waters; marks, ⊙, in group (*a*), show the oil-field water (29) and marks, ×, in group (*b*), show the sea water (30).

there are Castellammare (21), Termini Imerese (23), Sciacca (24), Ali (36), Montecatini (37), Pozzuoli (38), Torre Cane (39), Torre Annunziata (40), Livorno (41), Palermo (41) and Lacco Ameno (42). They are situated near the seashore except Montecatini, the possibility of sea water intrusion to them being very large. For the waters of Acireale (43) and Porretta (44), we cannot judge, from the chemical composition, which group do they belong to, but geographically, Acireale may be in group (*b*) and Porretta in gruppo (*a*). The mineral waters of group (*d*) have $CaSO_4$ as a main solube substance as seen in Fig. 4. S. Pellegrino (10), Caldana (15), Terme Traiane (41) Chianciano (45), Lucca (46), Tabiano (47), Galleraia (48), Casciana (49), Saturnia (50), Viterbo (51), Masino (52), Bracca (53) Boario (54), Crodo (55), Caramanico (56) and S. Casciano (57) belong to the group (*d*), and many of them are in Tuscania Region (Fig. 5). They have little relation to the sea water chemically, geographically and geologically. Finally, hot springs in the group (*c*) including Guardia Piemontese [2],

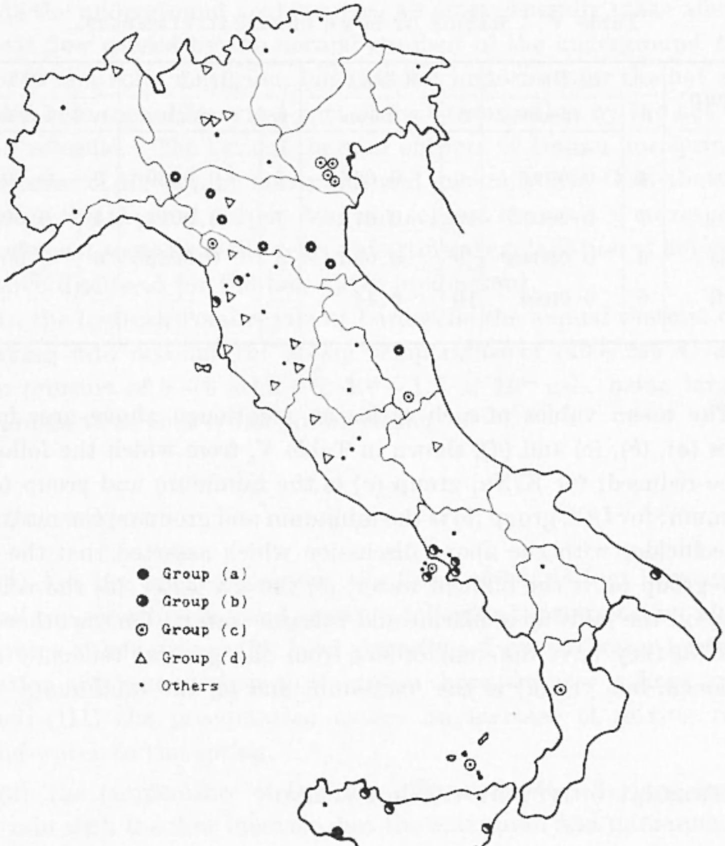

Fig. 5

Abano [11], Montregrotto [11], Monteortone [11], Battaglia [11], Acquasanta [41], Gallicano [41], Lipari [58] and Forio [59] are situated near not only the seashore but the recent volcanic zone. They have a chemical type which is in midway between (*b*) and (*d*). Thus, they may be said to be the mixture of marine and volcanic waters.

Generally speaking, ratios of Li/Na are in order of 10^{-5} for the sea water, 10^{-4} for the oil-field water and much larger for volcanic salt water [60]; K/Na are small for the see water and smaller for the oil-field water (61); Br/Cl are in the same order for all waters; I/Cl are small for the sea water and large for the volcanic water (62).

Table V – Ratios of some chemical elements.

Group	Li/Na		K/Na		Br/Cl		I/Cl	
	n	mean	n	mean	n	mean	n	mean
(*a*)	4	0.0021	5	0.026	5	0.0029	6	0.00098
(*b*)	7	0.00075	10	0.073	7	0.0014	4	0.00072
(*c*)	6	0.00048	9	0.035	5	0.0032	6	0.0015
(*d*)	6	0.0080	10	0.44	—	—	—	—

The mean values of such ratios as mentioned above are, for the groups (*a*), (*b*), (*c*) and (*d*), shown in Table V, from which the followings can be reduced; for K/Na, group (*a*) is the minimum and group (*d*) the maximum; for I/Cl, group (*b*) is the minimum and group (*c*) the maximum. This coincides with the above discussion which asserted that the water of the group (*a*) is the oil-field water, (*b*) the sea water, (*d*) the volcanic, and (*c*) on the midway of marine and volcanic waters. On the other hand, for Li/Na they have different orders from the general tendency above mentioned, but yet (*d*) is the maximum and (*c*) the minimum.

5. – Thermal output by the hot spring.

Annual mean of ground temperature near the surface is roughly equal to the annual mean of the corresponding air temperature. If there is no heat source heating the earth except the sun, the temperature of the earth crust and the water in it would be kept at the annual mean temperature of the air, therefore, when the water which comes from the ground has temperature higher than the mean air temperature, it suggest to exist a heat source in the ground. The heat which is originated from the underground heat source and transported by the hot water to the surface can be expressed by $Fq\ (t_w\text{-}t_a)$, where t_w is the spring temperature, t_a the annual mean temperature of the air, F the volume production of the hot water, and q the heat capacity of the water per unit volume.

Supposing t_w to be nearly constant in all seasons, putting $q \doteq 1$ cal/deg. cm³ and taking the annual values as *F;* then we can estimate the annual heat outputs, which are also tablated in Tabel III.

As the underground heat sources, we must generally make allowance for heat flow caused by the normal gradient of the underground temperature in non-volcanic region, but it is not important for the hot spring, then we here regard the most part of heat transported by the hot water, as the volcanic. The annual thermal outputs of Italian hot springs are of the order of 10^{14} cal. at maximum and generally less than that order. However, the thermal output does not suggest the scale of corresponding volcanic heat source but the degree of artificial exploitation of hot springs, as above discussed for the hot water productions.

In the hydrothermal region of Larderello the annual thermal output is, taking into account the steam temperature of $140 \sim 230$ °C and the steam pressure of $3 \sim 6$ atm. [63], $1.6 \sim 1.7 \times 10^{16}$ cal., being larger by two orders than that of hot spring region.

6. – Conclusion.

(1) For the phenomena that the flows of hot springs increase after rainfall, we can suppose some resons as follows; (I) precipitation aliments the source of hot spring; (II) level ascending of ground-water by the precipitation acts as a stopper to the futile thermal water leakage into the ground; (III) the precipitation causes an increase of mixing rate of ground-water to the spring.

(2) The temperature of Guardia Piemontese Hot Springs decreases after rain with the flow increase, but the maximum and minimum of the flow delay about two months for that of rain. It may suggest these springs to belong to the Case I if the delay is taken as important much than the spring temperature, and to the Case III in the opposite case. The flow and temperature changs of Guardia Piemontese contrast with that of Beppu, Japan, in which both temperature and flow increase after rain without appreciable delay from the rainfall.

(3) In this paper the " precipitational coefficient " of the flow which shows the contribution degree of the precipitation to the hot spring is calculated for many hot springs in Italy. The values of this coefficient are generally from several to scores percent, meaning that output of the hot water is less than the quantity of recharged rain-water. This relation is kept also in the geothermal steam field of Lardarello. This

may suggest that the hot water in Italy can, so far as the water balance, be explained as the vadose water, and we have no reason which supports the mixing of a great deal of magmatic water.

(4) From the geochemical consideration of the analitical results of Italian mineral waters, some groups of water are extracted from the entirety as follows; (*a*) high saline waters which are regarded as fossil or oil-field water from not only chemical composition but also geographical and geological circumstances; (*b*) waters being very similar to the sea water, in which the sea water intrusion may be very probable; (*c*) waters being chemically between (*b*) and (*d*) types and showing a mixture of marine and volcanic waters; (d) waters of which main soluble component is $CaSO_4$, and many of them are in Tuscany Region.

(5) The annual thermal outputs of Italian hot springs are of the order of 10^{14} cal. at maximum, but generally less than that order. In the Larderello, the thermal output amounts to about 10^{16} cal.

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NOTE. — Flow, temperature and chemical composition of Italian hot springs are discussed with the actual data. The hot water output is generally less than the recharge from the precipitation. From the geochemical consideration, some characteristic groups of mineral water may be extracted from the entirety.

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