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Subsurface Temperature Estimation of Geothermal Reservoirs in the Hengjing Hot Spring Area, Jiangxi Province, SE-China

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ABSTRACT

It presents a geochemical study of 10 thermal springs in the Hengjing Hot Spring Area, southern Jiangxi Province, SE-China. The surface temperatures of these springs are in the range 26 to 73°C. They are grouped in two types of water: Na-HCO3 and Ca-HCO3. The quartz geothermometer and silica-enthalpy diagram indicate the reservoir temperature in the range 80 to 155ºC. The evidences show that the geothermal waters are from the low to moderate temperature geothermal reservoirs.

1. INTRODUCTION

The primary objective of an exploration and evaluation programme in a geothermal area is to determine as inexpensively and rapidly as possible its capacity to produce economically geothermal fluids for industrial exploitation. Geochemical techniques, applied during the various stages of exploration and evaluation as well as exploitation, are particularly important because of information they supply at costs that are relatively low compared to geophysical methods and drilling. For the past several decades, the water chemistry and gas chemistry of geothermal fluids have proved very effective in evaluating subsurface temperature, determining water origin, identifying and eliminating mixing effects, and predicting scaling and corrosion (e.g. Fournier, 1977; Arnorsson, et al., 1983; Giggenbach, 1988; Armannsson, et al., 1986; Tole et al., 1993; Sun & Armannsson et al., 2000).

The Hengjing Hot Spring Area is located in Xunwu County, south Jiangxi Province, SE-China. Strata exposed in the area include the Upper Cretaceous system (K_2) composed of sandstone and conglomerates, the Jurassic system (J_1 and J_3) characterised by sandstones and conglomerates, the Sinian-Cambrian system (Z-Є) consisted of metamorphic sandstone, and migmatite as well as the Yanshanian rhyolite porphyry ($\lambda\gamma_5^2$) and biotite-granite ($b\gamma_5^2$) (Figure 1). Since 1960's, the geological and hydrogeological surveys have identified 13 thermal springs in the area. These thermal springs distribute along the recently active NE faults and are controlled by the NW faults. Their temperatures are in the range of 26 to 73°C at surface. In this paper, the chemical analyses of thermal springs from the Hot Spring Area were used to estimate subsurface temperatures in geothermal systems.

2. WATER CHEMISTRY

The analytical methods used to obtain the data for the paper are presented in Table 1. The chemical analysis of the samples in the Hengjing Hot Spring Area are reported in Table 2. The chemical composition of the waters is investigated in terms of relative Cl^-, SO_4^{2-} and HCO_3^- concentrations (Figure 2), and relative Na+K, Ca and Mg concentrations (Figure 3).

Table 1. Analytical methods for natural waters in the area.

Constituents	Analytical method
pH, CO_2	Titration, HCl/pH-titrator
SiO_2	Spectrophotometer (Ammonium molybdate used)
Na, K	Atomic absorption spectrophotometer (flame, Cs added)
Ca, Mg	Atomic absorption spectrophotometer (flame, La added)
SO_4	Ion chromatography
Cl	Ion chromatography

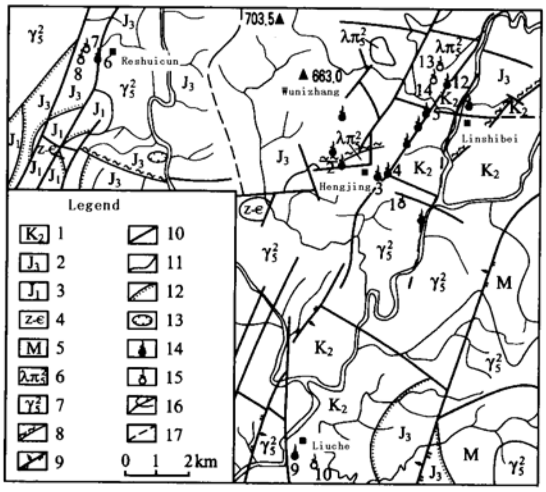

Figure 1: Distribution map of thermal springs in Hengjing area. 1.Sandstone and conglomerates for the upper Cretaceous system; 2. Tuff and conglomerates for the upper Jurassic system; 3. Sandstone and conglomerates for the lower Jurassic system; 4. Metamorphic sandstone for the Sinian-Cambrian system; 5. Migmatite; 6. The Yanshanian rhyolite porphyry; 7. The Yanshanian biotite-granite; 8. Silicated fracture zone; 9. Normal fault; 10. Unidentified fault; 11. Line of geological limitation; 12. Discordant contact line of limitation; 13. Inferred volcanic crater. 14. Thermal spring and number. 15. Cold spring and number. 16. Surface water system. 17. Surface divide.

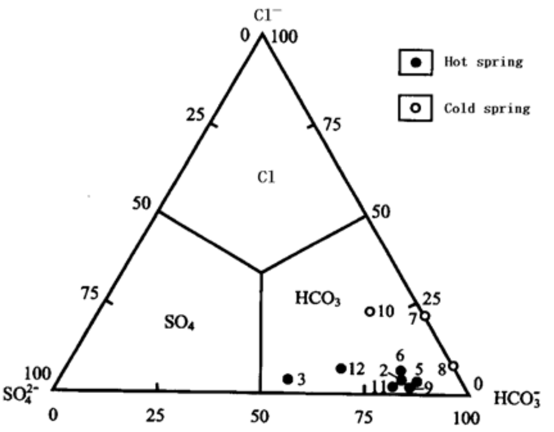

Figure 2: Relative Cl$^-$, SO_4^{2-} and HCO_3^- concentrations in the Hengjing area

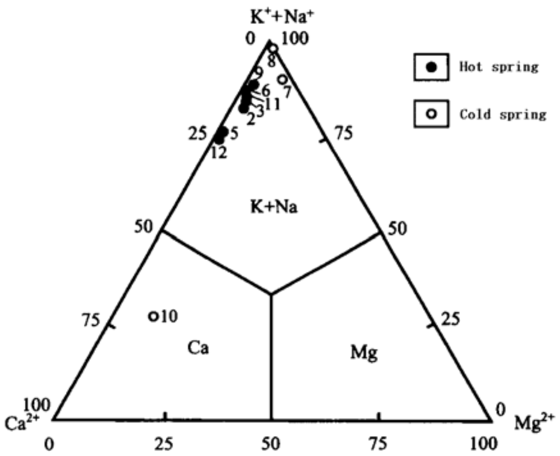

Figure 3: Relative K++Na+), Ca2+ and Mg2+ concentrations in the Hengjing area

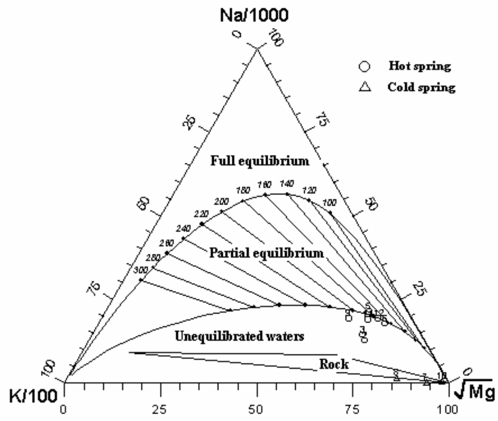

Figure 4 Na-K-Mg triangular diagram of thermal spring waters in the Hengjing area

An inspection of these plots points out the existence of two types of water: The first type is Na-HCO_3 water. This group includes all the samples except sample no. 10. The second type is Ca-HCO_3 water. This type of water includes only one cold-water sample (sample no. 10). The hydrochemical characteristics of the two types of waters suggest that the waters originate from local meteoric water. The oxygen and hydrogen isotopic evidence supports the inference (Sun et al., 1992).

The dissolved carbon dioxide concentration of all hot spring samples except samples 5 and 6 is higher than 250 mg/l, and the TDS of all the hot springs range from 163.14 to 2696.31 mg/l. In comparison, the TDS of cold springs in the area are much lower than those of hot springs.

All the data points are plotted in the Na-K-Mg triangular diagram (Figure 4, Giggenbach, 1988). It shows that all the waters in the two areas are unequilibrated ones (immature ones) and are not suitable for the application of cation geothermometers.

Table 2. The chemical compositions of waters from Henjing area(in mg/l)

No.	type	°C	pH	CO_2	SiO_2	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}	HCO_3^-	TDS
2	thermal spring	26	6.52	1263	99	138.5	15.73	84.6	698.6	81.18	325.0	1886.1	2286.66
3	thermal spring	48	6.67	725	94	117.1	10.95	71.8	679.1	70.19	764.9	1004.2	2216.14
5	thermal spring	37	6.74	22	78	29.12	0.09	4.42	93.63	8.51	26.5	216.95	270.72
6	thermal spring	73	7.30	9	81	9.85	0.09	3.09	71.47	8.51	17.0	106.14	163.14
9	thermal spring	27	6.50	547	43	106.9	10.4	81.97	969.8	50.69	350.0	2253.1	2696.31
11	thermal spring	48	6.77	722	135	107.8	6.74	43.17	711.2	35.1	300.0	1428.1	1918.06
12	thermal spring	44	6.63	250	82	52.25	0.33	6.85	154.4	28.71	115.0	276.83	495.99
7	cold spring	18	6.72	21	19	0.09	0.36	3.67	1.25	2.20	0.00	7.99	11.63
8	cold spring	18	6.92	16	17	0.00	0.01	1.49	1.95	2.20	0.00	25.2	18.30
10	cold spring	22	6.18	16	15	33.41	4.46	3.4	11.08	21.98	12.00	63.4	118.04

3. SUBSURFACE TEMPERATURE ESTIMATION

The chemical geothermometers have been extensively used to calculate and evaluate the geothermal reservoir temperature. The commonly utilized geothermometers are the aqueous, gaseous and isotopic geothermometers. In terms of the chemical data obtained from the thermal spring waters in the Hengjing area, this section only considers the aqueous geothermometers of Na-K, Na-K-Ca, Na-K-Mg and silica. As discussed above, all the thermal waters in the two areas are immature waters, so cation geothermometers such as Na-K and Na-K-Ca geothermometers are not applicable for these hot waters. The only option is to use silica geothermometers.

There is considerable ambiguity in the interpretation of dissolved silica concentrations in thermal spring waters because of uncertainty about the solid material which is controlling dissolved silica, and uncertainty about the amount of steam that may have separated from the up-flowing fluid. Thus, a range in possible reservoir temperatures is calculated: the lowest temperature assuming the maximum of boiling, and the highest temperature when no boiling is assumed.

3.1 No Mixing With Surface Waters

The first case considered is that the fluid is in equilibrium with quartz in the reservoir, the pore-fluid pressure in the reservoir is fixed by the vapor pressure of pure water, there is no mixing of hotter and colder waters during up-flow. Two sub-cases are further considered:

1. There is conductive cooling of the ascending water

   We can calculate the geothermal reservoir temperatures of thermal spring waters in the Hengjing area using the following quartz geothermometer equation (Fournier and Potter, 1982).

$$t = -42.198 + 0.28831S - 3.6686\times10^{-4} S^2 + 3.1665\times10^{-7} S^2 + 77.034\log S \qquad (1)$$

   where, t is the estimated geothermal reservoir temperature (in °C), and S is the silica concentration (in mg/kg or mg/l).

   The calculated temperatures are listed in Table 2. They are in the range of 95 to 155°C.

Table 3. Estimated temperature of geothermal reservoir in the Hengjing area (in □)

No.	T_{quartz}	$T_{silica\text{-}enthalpy}$	$T_{chalcedony}$	$T_{silica\text{-}mix}$
2	137	118	210	122
3	134	117	206	119
5	124	105	192	108
6	126	109	195	110
9	95	78	153	83
11	155	134	236	138
12	127	107	196	112

2. There is adiabatic cooling with steam separation at any temperature and pressure.

   Under this conditions, we can use the dissolved silica-enthalpy diagram for adiabatic cooling (Truesdell and Fournier, 1977)(see Figure5) to calculate the geothermal reservoir temperatures of thermal spring waters in Hengjing area. The calculated results are listed in Table 3. The geothermal reservoir temperatures are in the range of 78 to 134°C.

In terms of the above calculations, the lowest temperatures of geothermal reservoir in Henjing area are in the range of 78 to 134°C and the highest temperatures are in the range of 95 to 155°C. Because the above calculated temperatures of geothermal reservoir are less than 180°C, chalcedony may control the dissolved silica. In the case, the geothermal reservoir temperatures of thermal spring waters in the area can be calculated by the following chalcedony geothermometer equation (Fournier, 1977):

$$t = 1032 \div (4.69 - \log S) - 273.15 \qquad (2)$$

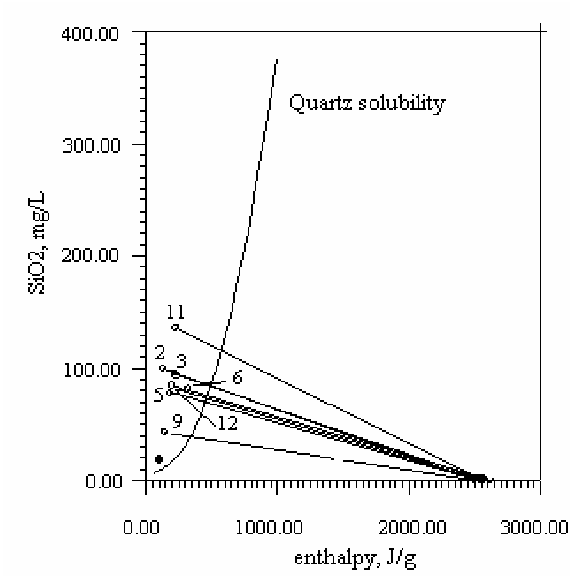

Figure 5 Enthalpy –silica graph for adiabatic cooling

where t and S are the same as those in equation (1). The calculated results listed in Table 2 are in the range of 153 to 210°C. However, the occurrence possibilities of high-temperature geothermal systems in Jiangxi Province with normal geothermal gradients are very minor, and results of drilling show that the temperature of thermal waters from wells above 1000 m depth is not higher than 100 °C in the Province (Sun, 1998), so the chalcedony geothermometer temperatures are not reliable.

3.2 Mixing With Surface Waters

The second case assumes that the fluid is in equilibrium with quartz in the reservoir, the pore-fluid pressure in the reservoir is fixed by the vapor pressure of pure water, there is mixing of hotter and colder waters during upflow, silica has not precipitated before or after mixing, and there has been no conductive cooling of the water. Again, two sub-cases are considered:

1. The steam was lost before mixing with the cold water. Using the dissolved silica-enthalpy diagram for mixing model (See Figure 6, the intersections of the horizontal lines with the maximum steam loss curve), we can calculate the geothermal reservoir

temperatures of thermal spring waters in Henjing area. The calculated results are listed in Table 5. The geothermal reservoir temperatures are in the range of 83°C to 138°C. The results are near to ones calculated by the dissolved silica-enthalpy diagram for adiabatic cooling. This indicates that the mixing of cold water slightly affects the calculation of geothermal reservoir temperature under the adiabatic cooling in Henjing area

2. The steam was not lost before mixing with the cold water. We can not calculate the geothermal reservoir temperatures of thermal spring waters in the Hengjing area using Figure 6 because the lines drawn from the black point representing the mean cold spring waters in the Henjing area through the mixed-water thermal spring points to the quartz solubility curve have no the intersections, except for the thermal spring 6. This indicates that the assumptions are not suitable.

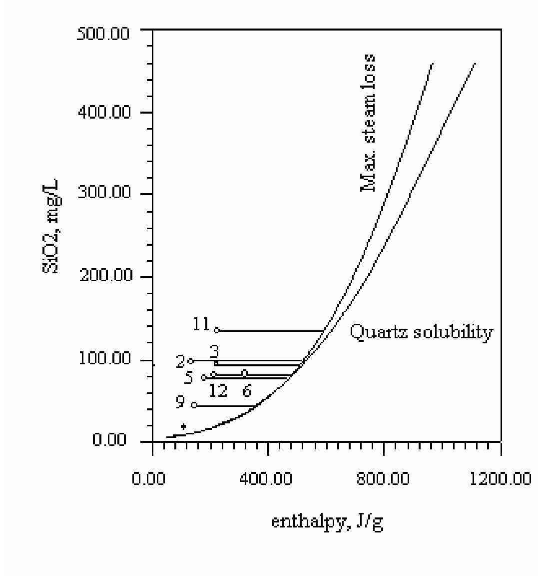

Figure 8: Enthalpy-silica graph for in Hengjing area for the mixing model

4. CONCLUSIONS

In summary, the geothermal waters in the Hengjing Hot Spring Area have temperature in the range 78 to 155ºC.

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