PRELIMINARY GAS AND ISOTOPE GEOCHEMISTRY IN THE REHAI GEOTHERMAL FIELD, P.R. CHINA

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SUMMARY - Based on gas and sulphur isotopic composition, two types of steam in Rehai geothermal field are identified. One is with higher CO_2 and H_2S Concentration, the $\delta^{34}S$ of H_2S is in the range 2.49‰ to -1.04‰ (vs CDT), from which the H_2S-temperature is over than 250°C. The other is with lower CO_2 and H_2S concentration, the $\delta^{34}S$ of H_2S is in the range -4.0‰ to -8.36‰, fiom which the H_2S- and H_2-temperatures are 180°C-210°C, in good agreement with quartz temperature. The thermal water in the Rehai field is of local meteoric origin. Maximum $\delta^{18}O$-value shift is less than 2.0‰ (vs SMOW). Mixing is widespread and could be identified on isotope and solute chemistry.

1. INTRODUCTION

Rehai geothermal field is one of the high-enthalpy geothermal fields in S.W. China. It is southwest 10 km from Tengchong town, Yunnan Province with extensive geothermal manifestations including fumaroles, boiling springs, steaming ground, sulphur, alunogen, siliceous sinter etc. The Rehai field is closed to the convergent collision zone between the Indian and Eurasian plates. Several faults run through the region from north to south. The surface geological formations are mainly Neogene gravestone, Quaternary alluvium and volcanic rocks. The reservoir is Cretaceous granite in the north side of river (Zaotanghe) and Gaoligongshan group (Metamorphic rock) of Precambrian in Songmuqing, southern part of the field. Volcanic activity began in the Upper Miocene/Pliocene, approached the maximum about one million years ago, lasted the whole Pleistocene period (Liao 1993). Magneto-telluric signals revealed the crustal resistivity anomaly between 5 and 25 km depth in the region that has been interpreted as a cooling magma chamber in deep (Bai et al. 1994). The latest hydrothermal explosion occurred last year.

2. GAS AND ISOTOPE COMPOSITION OF THERMAL FLUID

In the past years, relative percentages of dry gases (non-condensable gases) have been analyzed (Tong and Zhang 1989, Shangguan and Gao 1991, Wang et al. 1993, Dai et al. 1994). The hydrogen sulphide content was not detected except the results from Tong and Zhang (1989). Some authors reported there were over 50% nitrogen in the dry gases, which were contaminated by atmosphere during sampling and analysing. The $^3He/^4He$, the $\delta^{13}C$ and $\delta^{18}O$ of CO_2 in steam have been detected (Wang et al. 1993, Dai et al. 1994). Current work is focused on quantitative analysis of steam and isotope composition of thermal fluid. Sampling locations are shown in Figure 1. Collection of representative samples include dry gas, condensate, steam in 40% NaOH solution and hot water. The CO_2 and H_2S in condensate, thermal water and NaOH solution were titrated in the field. $Cd(CH_3COO)_2$ solution was used to absorb H_2S in steam, prepared for $\delta^{34}S$ determination. Compositions of steam from fumarole and boiling spring are listed in Table 1. The isotopic composition and chloride content of condensate, boiling spring, warm spring, cold spring and river are listed in Table 2.

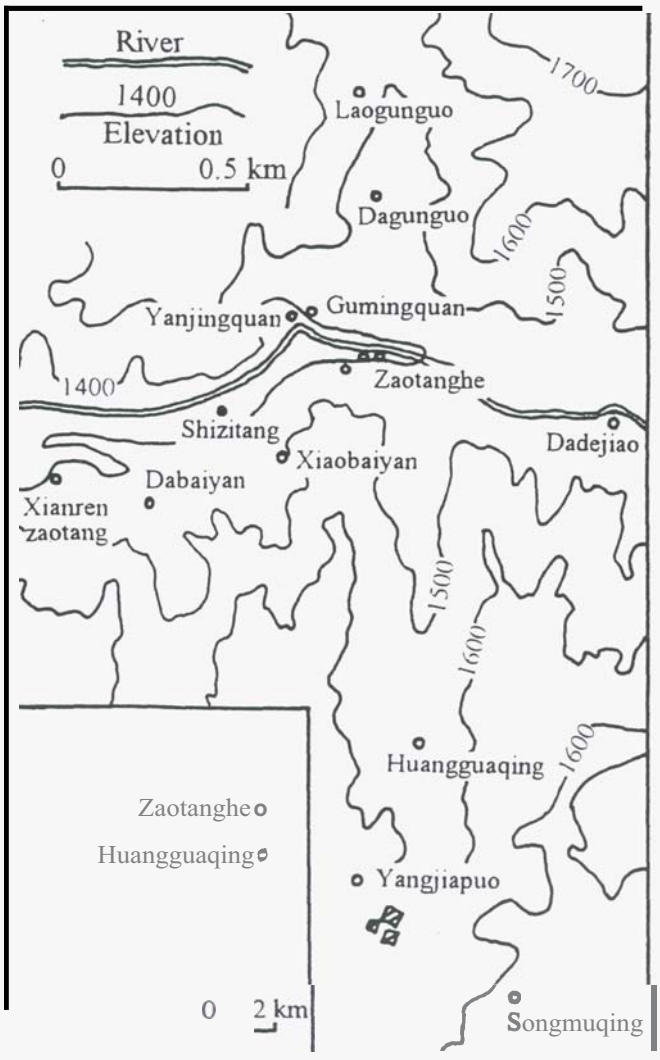

Figure 1 - Sampling locations in the Rehai geothermal field, Tengchong, Yunnan Province

Table 1 - Composition of steam from fumarole and boiling spring (mmoles/kg steam)

Location	Sample No.	Date	Type	CO_2	H_2S	H_2	CH_4	N_2
Huangguaqing	H1	94-12-11	Fumarole	3570.3	15.94	3.16	28.44	34.4
Laogunguo	R2	94-12-13	BS	4155.6	16.73	1.57	15.90	31.2
NE Dagunguo	R3	94-12-08	Fumarole	4541.1	26.94	3.70	34.17	53.2
Zaotanghe-1	R4	94-12-09	BS	496.00	2.56	0.27	0.18	3.8
zaotanghe-2	R5	94-12-09	Fumarole	128.9	2.59	0.20	nd	0.4
zaotanghe3	R6	94-12-14	BS	253.1	1.85	0.39	nd	0.7
Gumingquan	R7	94-12-10	BS	210.7	3.04	0.62	nd	2.5
Yanjingquan	R8	94-12-13	BS	356.9	3.33	0.42	0.13	5.2

"BS" ,refers to boiling spring.

Table 2 - Isotope composition and chloride content of fluids in the Rehai geothermal field

Location	T (°C)	Type	δD (‰)	$\delta^{18}O$ (‰)	Cl^- (mg/L)
Huangguaqing	96	Condensate	-85.7	-13.06	0.4
NE Dagunguo	94	Condensate	-101.9	-13.49	0.8
Zaotanghe	97	Condensate	-87.9	-11.71	1.2
Gumingquan	93	Condensate	-95.2	-13.19	1.6
Laogunguo	89	Condensate	-91.9	-12.54	0.5
Zaotanghe	97	Boiling spring	-68.8	-8.27	349
	93	Boiling spring	-69.3	-7.93	541
Laogunguo	89	Boiling spring	-68.0	-8.55	416
Reshuitang	87	warm spring	-69.7	-8.83	343
Dadejiao	82	Warm spring	-71.5	-8.44	366
Shizitang	79	warm spring	-71.9	-9.15	271
Dabaiyan	46	warm spring	-70.2	-9.33	93.5
Xiaobaiyan	46	warm spring	-70.1	-9.24	123
Xianrenzaotang	42	warm spring	-68.6	-9.46	60.2
Yangjiapuo	23	Cold spring	-67.1	-9.15	0.7
Heshui	10	River	-65.7	-9.25	0.8

3. DISCUSSION

31 Gas Geochemistry

The steam $^3He/^4He$ ratio in the Rehai geothermal field is in the range 3.21×10^{-6} to 6.02×10^{-6} ,high 'He is thought to be the degassing of upper mantle (Wang et al. 1993). The CO_2/H_2S ratios of most samples are over than 100 (Table 1). In steam composition, two types of steam could be distinguished. The first type includes the sample H1, R2 and R3, which is with higher CO, and H_2S concentration, higher CH_4/H_2S ratio, lower chloride in condensate (Table 2), the $\delta^{34}S$ of H_2S is m the range 2.49‰ to -1.04‰ (vs CDT). In Huangguaqing, there are only fumaroles and cold ground water heated by steam, no high salinity thermal water is found. The $\delta^{13}C$ of CO_2 m the steam is -3.8‰ (vs PDB) , which reflects the CO, is inorganic *origin* and probably derives from the lower reservoir or a magma chamber. Predicted temperature in the deep is over than 400°C based on CO_2-H_2O isotopic geothermometer. It is 251°C of the H_2S-geothermometer, 231°C of the &-geothermometer (Table 3). The CO_2-temperature is much higher, it maybe shows there is excess CO, in the reservoir, cause of magmatic activity in the region. The chemical composition of the steam collected at Laogunguo boiling spring is similar to that of the fumaroles at Huangguaqing and NE Dagunguo. This group of steam is thought to be directly fiom the lower reservoir.

The second type includes the sample R4, R5, R6 and R7, which is with relative lower CO, and H_2S, lower CH_4/H_2S, slightly higher chloride in condensate, the $\delta^{34}S$ of H_2S is in the range -4.0 ‰ to -8.36‰. They are believed to be released from the upper reservoir. The H_2S- and H_2-temperature are around 200°C. The CO_2-temperature is also higher than others. These two types of steam mentioned above probably have the same origin initially, but undergo different chemical or physical precess on the way to the surface. Regional extensive fracture controls geothermal fluid channels and mixing.

Table 3 - Reservoir temperature calculated from selected gas geothermometers (°C)

Sample No.	Location	CO_2	H_2S	H_2
HI	Huangguaqing	369	251	231
R2	Laogunguo	375	253	220
R3	NE Dagunguo	378	266	234
R4	Zaotanghe-1	310	200	190
R5	Zaotanghe-2	271	200	185
R6	Zaotanghe-3	291	191	197
R7	Gumingquan	297	205	204
R8	Yanjinquan	279	207	198

Note: gas geothermometers are selected from Amorsson and Gunnlaugsson (1985)

3.2 Isotope Geochemistry

The thermal fluid in the Rehai geothermal field is of meteoric origin and has a small $\delta^{18}O$-value shift (Fig. 2). Mixing involves simple lowering of concentrations and moving $\delta^{18}O$-value to the local meteoric line. Figure 3 shows the relation between chloride content and oxygen-18 of fluids. The highest Cl^- and Na^+ content are detected at Gumingquan boiling spring. The steam separation temperature calculated from its condensate and hot water is 102°C for hydrogen fractionation, 99.5°C for oxygen fractionation. They are slightly higher than the local boiling point (97°C). Up to now, there is no obvious evidence to hint the sample has been diluted before sampling. It is less than 0.04 mg/L of magnesium in the solution. Na^+, K^+ and Ca^{++} are 704ppm, 99.2ppm, 0.35 ppm respectively. Calculated temperatures of conventional chalcedony (Amorsson et al. 1983, maximum steam loss), quartz (Fournier and Potter 1982) and Na/K geothermometer (Amorsson et al. 1983) are 185°C, 205°C and 249°C correspondingly.

Reed and Spycher (1984) have proposed that the estimation of reservoir temperature can be attained by evaluating the saturation of several minerals as a function of temperature. If a group of minerals converges to equilibrium at a particular temperature, this temperature corresponds to the most likely reservoir temperature, or at least the source equilibrium temperature of the particular water considered (Tole et al. 1993). Figure 4 shows the mineral equilibrium diagram of the sample at Gumingquan with the aid of the WATCH program (Amorsson et al. 1982). Temperatures for minerals approaching Log (Q/K) = 0 are relative scatter, most of them are in the range 170°C to 200°C, in accordance with the H_2S- and H_2-temperature. Calcite is undersaturation when temperature is

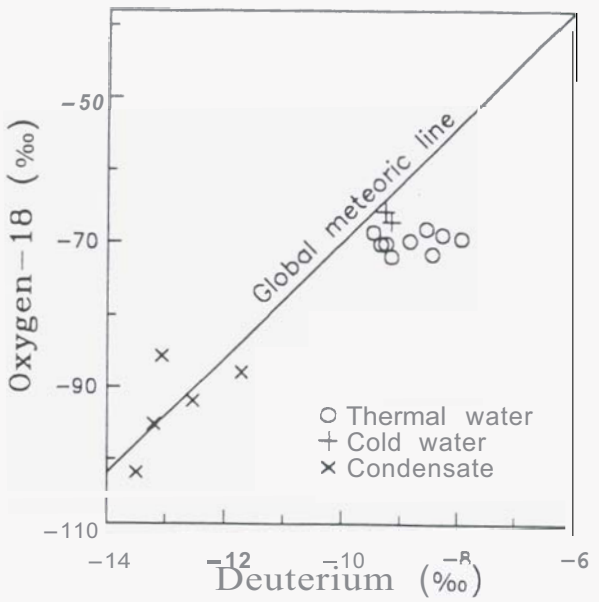

Figure 2 - δD versus $\delta^{18}O$ in the Rehai geothermal field

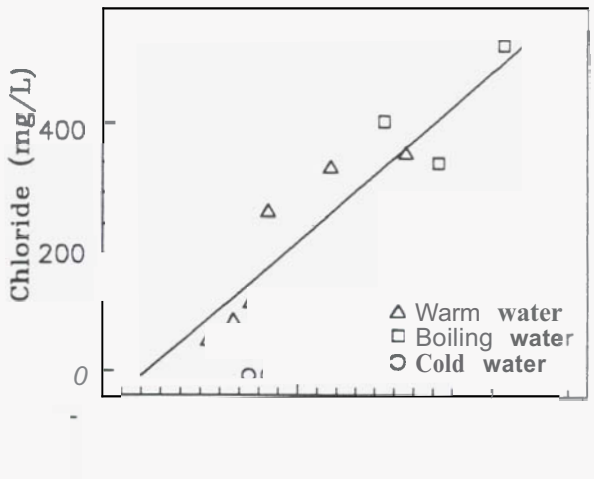

Figure 3 - δ^{18}

less than 250°C. It is plausible that this geothermal fluid could reflect its composition in the reservoir. The lower Na/K (=7) ratio indicates the fluid has been at higher temperature. If fluid upflowing is adiabatic process, the calculated compositions in the reservoir are -74.3 ~ -72.7‰ of deuterium and -8.94— -8.63 of oxygen-18. The $\delta^{18}O$-value shift in the deep is around 1.7‰. The recharge areas of the Rehai geothermal field are its surrounding mountains.

The oxygen fractional temperature at Laogunguo is much higher than hydrogen's. It is mixture of the lower steam and the upper fluid, and then combined with the cold ground water. The fluid does not approach isotope equilibrium before its boiling Deuterium exchange rate is faster than oxygen's, so the calculated temperature is relatively closing the local boiling point Similar situation occurred at Zaotanghe. Compared with the chemical and isotopic compositions of Gumingquan sample, it could be estimated that Zaotanghe thermal fluid is mixed with 30~35% cold ground water. The mineral equilibrium diagram (Fig. 5) shows a typical mixing model. A convergent section is located in 190°C ~ 210°C, which is accordant with the H_2S-temperature of the second type steam

and probably reflects the temperature of thermal fluid before mixing. There is another group of curves intersecting at 120–130°C With Log(Q/K)= -2, it corresponds to the hydrogen fractional temperature. The mechanism is unclear.

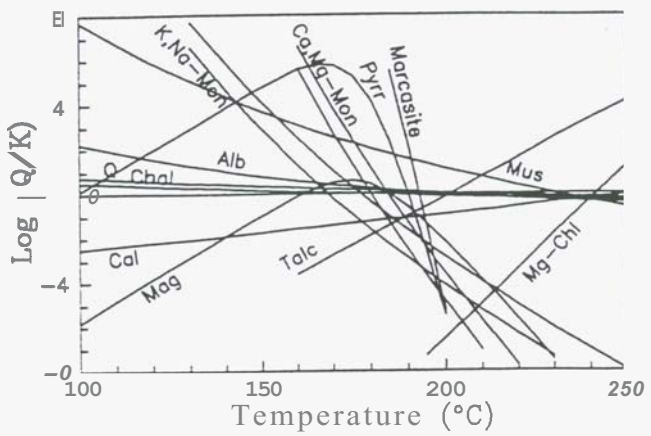

Figure 4 - Mineral equilibrium diagram for the sample collected at Gumingquan

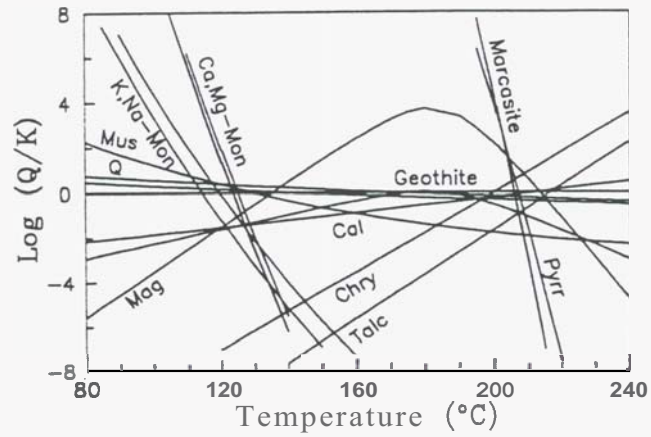

Figure 5 - Mineral equilibrium diagram for the sample collected at Zaotanghe

The condensate collected at Huangguaqing is diluted with cold ground water heated by steam. Its isotopic composition is different from that at NE Dagunguo fumarole. The latter is thought not to be single stage separation. The composition and temperature of warm spring in the Rehai field depends on the mixing ratio. The rain isotope composition varies a lot between the rains and the drought in the region, but it is located in the global meteoric line.

4. CONCLUSIONS

There are two potential reservoirs in the Rehai high-temperature geothermal field. Estimated temperature is 170°C-200°C for the upper reservoir and 250°C for the lower one. There is excess CO_2 in both reservoirs. Gases mainly originate from the degassing of the magma chamber. Thermal water is of meteoric origin with 1.7‰ $\delta^{18}O$-value shift. The Sample collected at Gumingquan is probably closed to the thermal fluid in the upper reservoir. The fractures in the region controls the mixing of the thermal water with cold ground water.

5. ACKNOWLEDGEMENTS

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