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RE-ASSESSMENT OF THE EQUILIBRIUM TEMPERATURE OF THE REHAI (HOT SEA) GEOTHERMAL FIELD, TENGCHONG COUNTY, YUNNAN PROVINCE, CHINA

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ABSTRACT

The reservoir temperature of Rehai geothermal field has been estimated from various geothermometers. The average temperature in the shallow reservoir, which occurs in a weathered layer at the top of a Late Cretaceous granite, is about 170°C; deeper in the this granite, it is about 230°C. The temperature of parent water in the deep reservoir is about 275°C.

INTRODUCTION

Geological and geochemical data from Rehai (Hot Sea) geothermal field (24 57.5'N/98 26'E) were first reported at the 3rd New Zealand Geothermal Workshop by Liao et al.(1981). Unfortunately, no water analyses data were presented at that time. Zhang et al. (1989) presented chemical analyses of some springs and discussed equilibrium temperature(SiO_2, Na/K, Na-K-Ca), boiling and dilution. In this paper, the reservoir temperature of Rehai geothermal field is re-assessed using a complete set of chemical data submitted by Zhang et al.(1989).

THE CHEMICAL CHARACTER

The reservoir of the Rehai field consists of a Late Cretaceous granite(69 Ma), and has no natural capping structure. The top of granite is a thick weathered layer with a network of fractures, which constitutes a shallow reservoir(at 100m depth); this aquifer is also indicated by a resistivity anomaly Fig.1). There are no deep wells at Rehai,one shallow well encountered an overpressured aquifer(<25m) and had to be abandoned. Water samples for chemical analyses were obtained from 11 springs. The locations of the sample sites are shown on Fig.2 and results of the analyses are presented in Table 1.

Generally, the waters can be divided into four types on the basis of the proportions of major dissolved constituents and concentration of dissolved solids:

1) hot waters from springs are generally sodium chloride-bicarbonate waters;
2) diluted sodium bicarbonate-chloride waters;
3) steam heated sodium sulphate waters;
4) non-thermal calcium-sodium bicarbonate-sulphate water (No 19 in Table 1) with low total dissolved solids (107 mg/kg).

INFERRED RESERVOIR TEMPERATURE

Different chemical and isotopic reactions can be used as geothermometers to infer equilibrium temperatures. The reservoir temperature of the Rehai geothermal field was estimated using the silica(quartz-no steam loss),Na/K, Na-K-Ca,T_{KNa}, T_{KMg} and $\Delta^{18}O(SO_4-H_2O)$ geothermometers. The results for the springs are given in Table 2. Different geothermometers give different temperature estimates since eqilibrium is attained at different depths(i.e. different temperatures); in addition, the rate of equilibrium varies between the various geothermometers.

Fig.3 shows a comparison of reservoir temperatures estimated from the silica(quartz-no stem loss) and the Na-K-Ca geothermometer. Waters that plot on or very near the equal-temperature line are likely to be mixed waters or waters that have re-equilibrated after mixing(Fournier et al.,1979). Waters that plot above the equal temperature line have undergone evaporation or contain additional dissolved silica from the aquifer(amorphous quartz). Waters that plot below the equal-temperature line may have (1) mixed with another type of water without sufficient time to re-equilibrate with the surrounding rock (in mixed waters, silica equilibrium occurs more rapidly than Na-K-Ca equilibrium); (2) precipitated silica during cooling (the Na-K-Ca proportions remain unchanged);or (3) precipitated calcite(aragonite) during boiling due to loss of carbon dioxide (adjustment of the Na and K concentrations through reaction with clays, zeolites, or other minerals has not occurred, (Fournier et al., 1970). Fig.3 shows that all waters sampled at Rehai plot below

Table 1. Chemical compositions of the springs in Rehai geothermal field (mg/kg)

No	3	5	6	7	8	10	11	12	13	15	19
T(°C)	88	91	95	42	48.5	83	69.5	92	95.8	95.8	23
pH(field)	8	5.5	8	6	7.5	7.5	6.5	7	7.5	7.5	
pH(lab.)	8	3.1	9.4	7	7	7.5	7.3	7.8	8.55	8.2	6.4
Na	840	58	680	133	180	420	380	440	340	450	5
K	120	23	110	25	30	55	50	63	61	43	4
Ca	0.1	9.43	0.29	2.86	3.4	4.72	2.86	2.72	10.7	0.86	6.43
Mg	0.02	3.21	0.02	0.18	0.21	0.09	0.11	0.22	1.79	0.17	1.83
Li	8.31	0.60	6.20	6.20	2.10	3.90	3.80	3.80	3.40	4.00	0.04
Rb	1.73	0.20	1.40	1.40	0.33	0.63	0.60	0.70	0.70	0.50	0.03
CS	0.96	0.15	0.96	0.74	0.15	0.44	0.22	0.44	0.37	0.15	0.15
NH_4	0.8	4	0.9	-	0.2	0.5	0.2	0.8	0.8	0.2	-
	-	-	261	-	-	-	-	-	37	22	-
HCO_3	1168	-	700	250	353	637	606	615	512	522	44
Cl	698	16	559	57	93	256	217	295	269	372	1
SO_4	31	303	11	18	56	38	26	47	24	27	16
F	20	1.2	14	2.2	3.5	8.3	7	7.8	7	0.7	-
Br	2.2	0.05	1.8	0.4	0.4	0.9	1	1	0.9	0.8	0.05
I	0.2	0.19	0.19	0.32	0.2	0.2	0.4	0.34	0.2	0.2	0.05
HBO_2	52	3	42	8	11	17	16	19	18	14	-
As	0.9	0.04	0.8	0.1	0.12	0.32	0.35	0.22	0.13	0.23	0.01
SiO_2	450	195	340	105	108	175	163	180	170	118	51
TDS	2811	617	2379	482	615	1305	1175	1365	932	1325	107
$\delta^{18}O(H_2O)$‰	-6.0		-8.1				-9.2	-9.0	-8.8		
$\delta^{18}O(SO_4)$‰	2.8		0.03				-0.6	-0.3	0.07		

Samples 5 and 19 have a 10% ionic imbalance.

- : below detection limit.

Chemical data after Zhang et al. (1989).

Isotopic data after Xia J. (1984).

Table 2. Estimated equilibrium temperature for Rehai (Hot Sea) field (in C)

No	3	5	6	7	8	10	11	12	13	15
1 T_{SiO_2}	243	178	219	140	142	171	166	173	169	147
2 $T_{Na/K}$	250		262	283	265	241	242	250	272	211
3 T_{NaKCa}	303	253	292	234	230	229	233	243	237	227
4 T_{KNa}	262		274	293	277	255	255	263	284	227
5 T_{KMg}	272	103	267	151	154	195	187	182	142	171
6 $^{18}O(SO_4-H_2O)$	200		212				204	202	198	

T_{KNa}, T_{KMg} (Giggenbach, 1986); other temperature estimated using Fournier (1981).
1,2 and 3 after Zhang et al. 1989; 6 after Xia J. (1984).

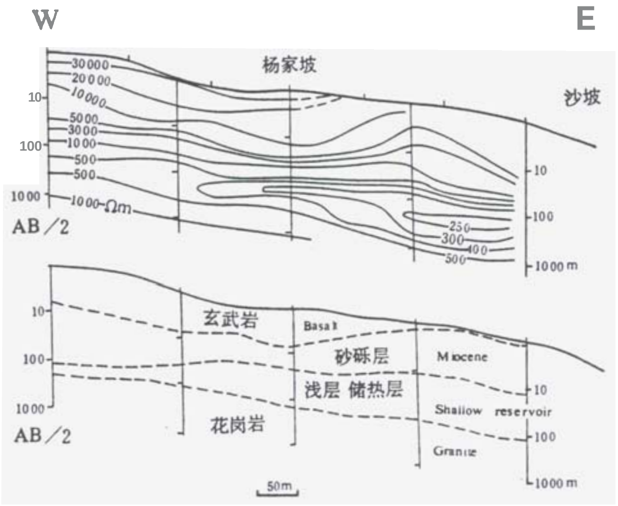

Fig.1 Geology and resistivity sections in Rehai (Hot Sea) geothermal field.

the equal-temperature line indicating a mixed water that has not re-equilibrated with aquifer minerals after mixing (rapid ascent of hot fluids).

When the T_{SiO_2} data are compared with the T_{KMg} data(Fig.4), we find that: (1) the T_{SiO_2} of samples 3 and 6 are higher than the T_{KMg} by about 29 and 48°C respectively; (2) the T_{KMg} data of samples 7,8, 10, 11, and 15 are close to the T_{SiO_2} value indicating that precipitation of silica occurs at shallow levels but some re-equilibration is indicated; (3) the data points for samples 5, and 13 plot above the equal-temperature line. If we use for sample 13 the chalcedony geothermometer, the T_{SiO_2} (chalcedony) is 146°C, which is close to the T_{KMg} value. Neither the chalcedony nor the amorphous quartz geothermometers can be used to explain the SiO_2 content in sample No.5 but it is possible that this sample contains some amorphous silica. Samples 3 and 6 have low concentrations of Ca and Mg (Table 1), and have the highest concentrations of non-reactive constituents (i.e. Cl and HCO_3). Since high Ca and Mg values are indicative of mixing with shallower colder waters (Giggenbach,1986), the very low Ca and Mg values (Table 1) and the high equilibrium temperature (Table 2) for samples 3 and 6 suggest that these samples come from deep fluids in the system (see Figs.3 and 4). It is possible that samples 3 and 6 have enriched chemical contents due to surface evaporation and impediment of running water (Liao et al., 1981, and Zhang et al.,1989). All other samples are affected by mixing.

An isotopic geothermometer study of the sulphte-water (high temperature hydrothermal) systems in Yunnan Province was made by Xia Juanjuan (1984). In the pH range of the most of the deep geothermal waters studied, the rate of oxygen isotope exchange between sulphate and water is slow compared with the chemical exchange between silica, cations and water. This can be advantageous for geothermometery because once equilibrium is attained after a prolonged residence time in a reservoir at high temperature, there is little re-equilibration of the oxygen isotopes of sulphate as the water cools during ascent to the surface. The temperatures calculated with the $\Delta^{18}O(SO_4-H_2O)$ geothermometer (see Table 2) are lower than the likely reservoir temperature of 230 C; this is probably caused by oxidation of H_2S at low temperature (samples 3 and 6), or by mixing with cold water (samples 11, 12 and 13).

The $T_{Na/K}$ and T_{KNa} values of most samples are about 240-290°C, which indicates the likely temperature of the deep reservoir; this is also the temperature range (276°C) predicated using a chloride-enthalpy graph by Zhang et al.(1989).

CONCLUSION

The reservoir temperatures estimated for the Rehai hot water system using the potassium-mannesium, sodium-potassium-calcium, and sodium/potassium geothermometers are considered to be representative values. The T_{KMg} values indicate the temperature in the shallow reservoir while the T_{KNa} data indicate the temperature range of parent water in the deep reservoir because the Na-K concentrations re-equilibrate slowly and the KMg equilibria adjust faster(Giggenbach, 1986). The reservoir temperature in the study field could be close to that calculated by the Na-K-Ca geothermometer. The equilibrium temperatures calculated from the silica and the sulphate oxygen isoyope geothermometers are thought to be affected either by mixing of hot and cold waters or by oxidation of H_2S.

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REFERENCES

Fournier,R.O., SOrey,M.L., Mariner,R.L., and A. H.Truesdell, (1979) Chemcal and isotopic prediction of aquifer temperatures in the geothermal system at Long Valley,California. Journal Volcanology and Geothermal Research, 5,pp.17-34.

Fournier,R.O.,(1981) Application of water geochemistry to geothermal exploration and reservoir engineering. in Rybach,L. and Muffler,L.J. P. (eds.) Geothermal Systems: Principles and Case Histories. John Wiley and Sons Ltd.

Giggenbach,W.F. (1986) Graphical techniques for the evaluation of water/rock equilibration conditions by use of Na,K, Mg, and Ca contents of discharge waters. Proc. of the 7th NZ Geothermal Workshop 1986, **pp.37-41**.

Liao Zhijie, Zhang Zhifei and Guo Guoying (1981) Geology and geochemistry of Rehai (Hot Sea) *pee*thermal field in Tengchong, Yunnan Province, China. Proc. of the 3rd NZ Geothermal Workshop

Liao

1981, pp.19-24.

Xia Juanjuan (1984) The isotopic geothermometer study of sulphate-water systems. Master thesis, Peking University (in chinese with English abstract).

Zhang Zhifei, Liu Shibin and Zhao Fengsan (1989) Geochemistry of hydrothermal fluids in Tengchong. in Tong Wei and Zhang Mingtao (eds.), Geothermics in Tengchong. Science Press, Beijing, pp. 81-101

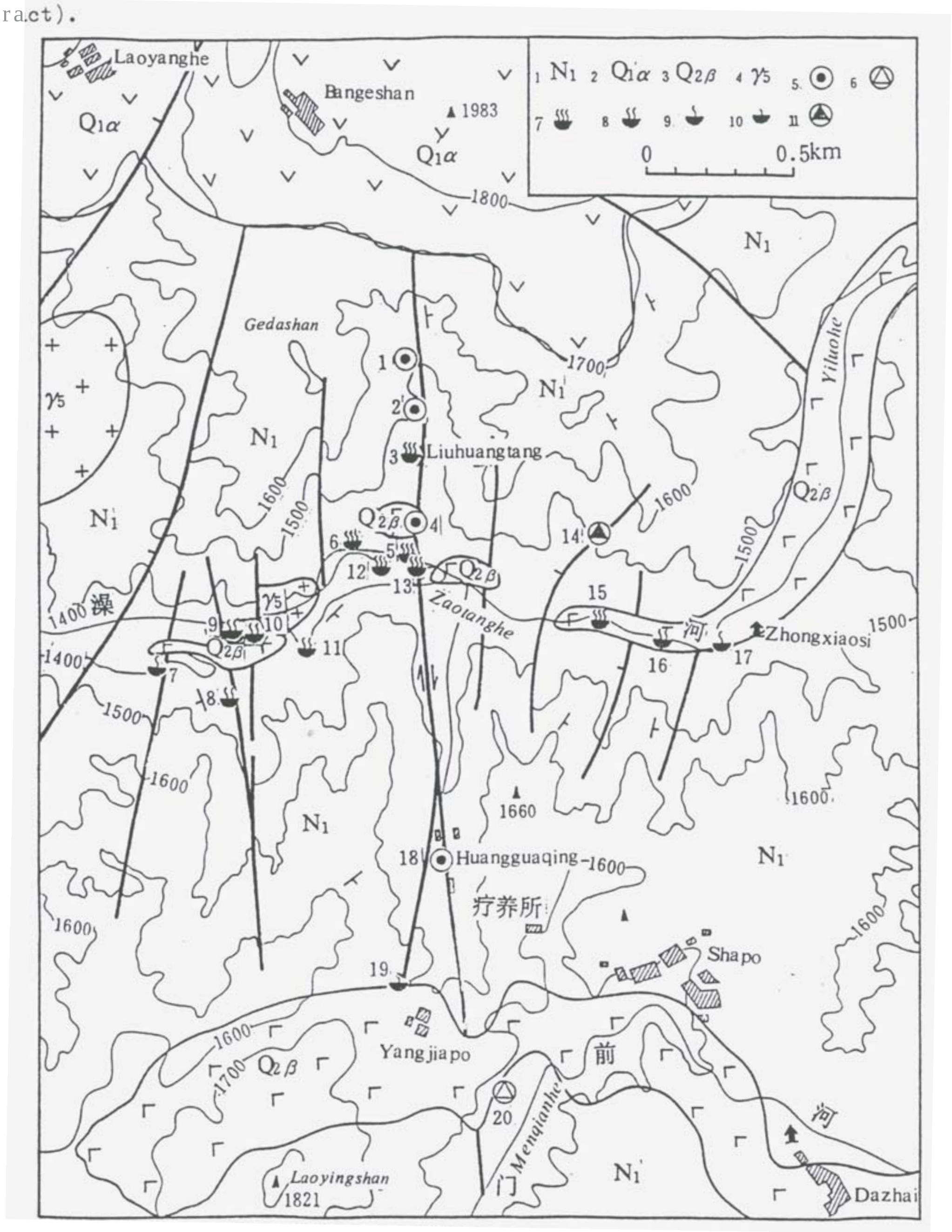

Fig.2 Geological map of Rehai (hot Sea) field. Explanation of symbols in insert: 1) Miocene, 2) Lower Pleistocene andesite, 3) Middle Pleistocene basalt, 4) Late Cretaceous granite, 5) steaming ground, 6) thermal ground and pyrite, 7) boiling spring, 8) hot spring, 9) warm spring, 10) tepid spring, 11) pyrite-binarite vein.

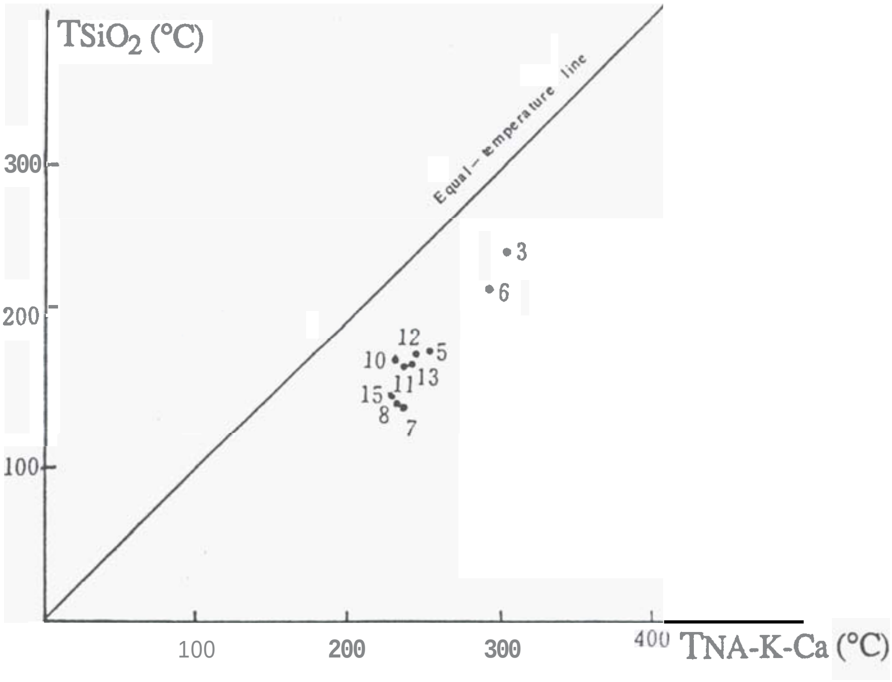

Fig.3 Plot of silica and Na-K-Ca geothermometers.

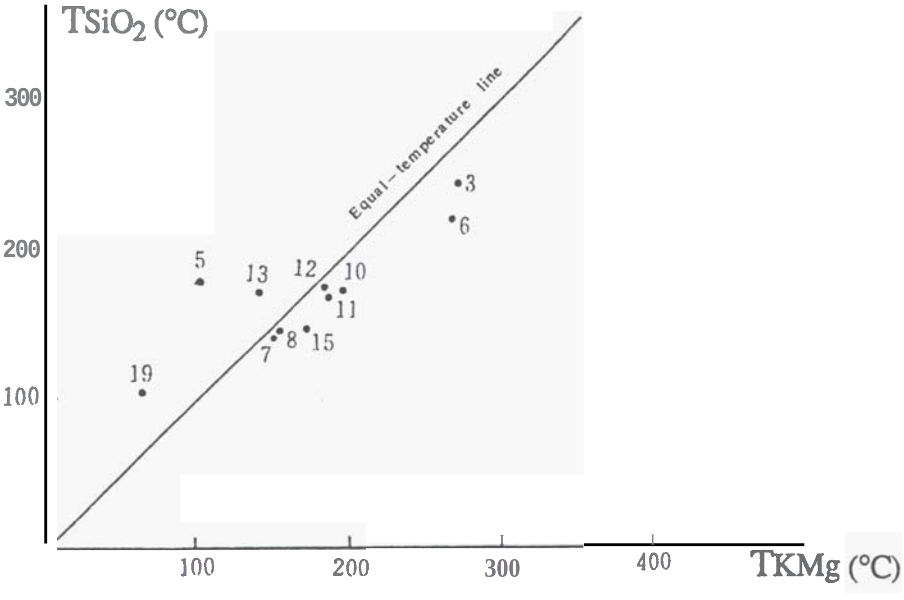

Fig.4 Plot of silica and K-Mg geothermometers.