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Geochemical Study of Mongolian Hot Springs

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ABSTRACT

In this paper presents data analyses seven hot spring samples from northern Khangai area, central Mongolia. The chemical composition of these waters was analyzed by standard methods and subsequently classified by the use of the Cl-SO_4-HCO_3 triangular diagram. The other basic diagram, Na-K-Mg, was used to classify waters according to the state of equilibrium at given temperatures. The geothermal water types are sulphate-sodium and bicarbonate-sodium. Chemical geothermometer were used on geothermal waters to indicate reservoir temperatures. Values for chalcedony geothermometer and Na/K geothermometer values are used to define the source temperature of the geothermal water component. The results could be an evidence of mixing with cold waters in all the fields which were studied. The Ryznar Stability Index (RSI) and WATCH program were used to interpret the equilibrium state of the reservoirs and to predict scaling tendencies. Calcite scaling occurs at the high calcite Saturation Index values and low RSI values. Hence these indices show geothermal waters of the Khangai area no scaling tendency.

1. INTRODUCTION

Mongolia is located in the northern part of central Asia, far from the oceans, on a high plateau surrounded by mountain ridges and covers a vast territory of over 1.5 million km^2 and has a population of 2.7 million. Mongolia has 43 hot springs, with measured surface temperatures ranging from 20 to 92^0C and flow rate ranging from 1.2 to 50 l/s, mainly distributed in the central and western provinces. At that time, intense tectonic development gave the Mongolian mountains their present appearance. A geophysical survey on the crystal structure has established that accumulative thermal sources (magma lumps) are located near the surface under the Khangai, Khentii area. Geothermal resources in Mongolia are mainly distributed in Khangai, Khentii, around the Khubsugul, Mongol Altai plate forms. The Khangai geothermal area has attracted the interest of researchers and its location is favourable with regard to social and economic conditions. From 21 hot springs of the Khangai area, seven were selected (Tsenkher, Tsagaan sum, Shivert, Chuluut, Khuremt, Khujirt, Noyonkhangai). This area of hot springs has relatively highly developed infrastructure with access of central electric network and a highway located nearby. Furthermore, the area is rich with historical places, making it more attractive for tourism development.

In this report, chemical analyses selected hot springs from the northern Khangai area in central Mongolia, were used to evaluate the probable existing chemical equilibrium and to estimate subsurface temperatures in the geothermal systems. The mixing processes in the up-flow zones were assessed using two mixing models. The subsurface temperatures predicted by various geothermometers are evaluated by comparison with measured (downhole) temperatures. Most calculations were performed with the SOLVEQ and WATCH programs. Finally, the WATCH program and Ryznar Stability Index (RSI) are used to evaluate calcium carbonate scaling tendency in the hot springs in Mongolia.

2. CHARACTERIZATION OF GEOTHERMAL FLUIDS

The samples were collected from hot springs with artesian flow rate in the range 1.2-16 l/s. The temperatures measured during collection of the sample ranged from 37°C to 86.5°C. The pH is generally slightly alkalinity (8.5-9.45). The TDS of the samples is in the range 200-342 ppm. All analytical results are presented in Table 1. Ionic balance calculated by the WATCH program (Arnórsson et al., 1983a; Bjarnason, 1994) gives information regarding the quality of the analysis. For the selected samples the values were ranging from -11.03 to 32.87. These are relatively high but the samples nevertheless have been used for interpretation.

Figure 1 shows the Cl-SO_4-HCO_3 ternary diagram and the Na-K-Mg ternary diagram for the samples from the Khangai geothermal area. Most samples plot in the peripheral waters region. Samples number 5, 6 and 7 (1977-0302, 2000-0303 and 2002-0304) from the Shivert hot spring are though in steam heated waters region. As seen from the Na-K- Mg diagram, all plots are located between the boundaries immature and fully equilibrated waters. The Na-K-Mg ternary diagram yields a reservoir temperature range of 120-180°C for all the hot springs.

Subsurface temperatures in the study areas have been estimated by chemical geothermometry. As has been discussed, for various reasons different geothermometers may give different results. Table 2 shows the results for different solute geothermometers.

The WATCH and SOLVEQ programs were used to calculate the calcite saturation index. The SOLVEQ program was used to calculate saturation indices of 47 minerals. Five main minerals were selected, calcite, cristobalite, diopside, magnesioferrite and quartz. The results obtained are shown in Figure 2 with the broken line indicating measured temperature.

Two mixing models were applied to the water in this study; the silica-enthalpy and the silica-carbonate mixing models. Figure 3 depicts the silica-enthalpy and silica carbonate mixing models. The cold water point (A point) is assumed to represent the cold ground water (T=6°C, and SiO_2=12ppm) in the study area.

In order to study possible changes with time, available chemical analysis were entered into the WATCH program and the results were used to compute the saturation index. After that, the Ryznar Stability index was calculated using equation. The results are listed in Table 3. According to the WATCH program the saturation index boundary between calcite scaling and no scaling in the selected hot springs is 0.36-0.5. Figure 4 shows the relation between saturation index and temperature for selected hot springs. Results from the SOLVEQ program were used. The Ryznar stability index gives a qualitative estimate of the calcium carbonate scaling tendency of fluid and can be used in the temperatures range from 37 to 86.5^{0}C. The results are shown in Figure 4. It shows that the RSI increases with a decrease in the calcite calcite saturation index. Calcite scaling occurs at low RSI values and high SI values. The results from the WATCH program confirm the results from the Ryznar Stability Index.

3. CONCLUSIONS

For the Khangai hot springs in Mongolia, the results of the geochemical studies can be summarized as follows:

- The water in the Shivert hot spring are sulfate-sodium type, but in other hot springs waters of the bicarbonate-sodium type.
- Considering the major anions, the Shivert hot spring is classified as steam heated water, but that of the other hot springs as peripheral water.
- With reference to the major cations, the geothermal fluids are classified as partially equilibrated, with geothermal fluids of selected hot springs lying between Giggenbach's (1988) line for fully equilibrated waters and Arnórsson's (1991) line.
- The chalcedony, quartz, Na-K, and Na-K-Ca geothermometer temperatures were calculated. The Na-K geothermometer gives very high and sometimes unrealistic temperatures for all hot springs, whereas results for the Na-K-Ca geothermometer indicate that this empirical geothermometer appears to be applicable to low-temperature waters. Quartz geothermometer temperatures are realistic for hot springs in this area compared to estimated mineral-equilibrium temperatures. But the chalcedony geothermometer provides the most reliable temperatures for these fields, with predicted temperature values ranging from 69 to 123°C.
- The silica-enthalpy warm spring mixing model handles non-boiled and boiled mixed waters separately with mixing occurring after boiling, and the boiling hot spring waters indicate enthalpies from 908 to 1142 kJ/kg for the hot water component (212-261°C).

The calcite saturation index and the Ryznar stability index of hot springs of the Khangai area show that there is no scaling tendency. The values for hot spring water vary, but fall in the 'no calcite scaling' range.

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Table 1: Chemical composition of hot springs in the Khangai geothermal area, Mongolia (in ppm)

№	Sample number	T (^{0}C)	pH	SiO_2	Na	K	Ca	Mg	Fe	NH_3	CO_2	SO_4	Cl	F	H_2S	TDS
Tsenkher hot spring																
1	1977-0102	86.5	8.8	133.13	106.9	4.18	2.12	0.48	-	0.92	61.64	49.0	17.0	24.5	15.89	338
2	2002-0103	84.3	8.9	113.75	82.4	2.92	2.4	0.36	0.2	0.15	9.27	38.7	17.0	25.5	10.19	283
Tsagaan sum hot spring																
3	1977-0202	69	8.85	106.25	97.2	3.16	2.0	0.31	-	1.0	58.93	47.6	7.5	19.0	16.21	284
4	2002-0203	69.1	9.3	83.13	72.2	1.88	3.21	0.24	0.2	0.77	49.77	28.8	2.48	23.5	11.65	216
Shivert hot spring																
5	1977-0302	48	8.8	106.25	123.2	6.03	2.4	0.07	-	0.23	51.93	72.7	15.8	15.5	8.75	342
6	2000-0303	57.3	9.45	86.88	96.3	4.08	3.21	1.22	0.2	0.77	48.4	77.4	19.9	17.5	9.1	307
7	2002-0304	57.3	9.1	74.56	104.5	3.86	4.01	1.2	1.0	0.61	43.13	78.3	21.9	-	-	290
Chuluut hot spring																
8	1977-0402	45	8.7	91.87	105.4	3.9	1.87	0.06	-	0.77	68.24	51.1	12.1	17.0	10.68	284
9	2002-0404	44	9.3	64.94	89.39	3.3	4.0	1.22	-	1.38	55.61	55.73	18.7	-	-	239
Khuremt hot spring																
10	1977-0503	56	8.7	98.13	92.5	2.23	1.3	0.8	-	0.54	80.93	43.4	8.48	8.5	12.97	256
11	2002-0504	54	9.45	83.12	80.6	1.5	1.0	0.61	0.8	0.08	65.57	32.9	5.5	6.2	10.1	212
Khujirt hot spring																
12	1973-0603	54.5	8.5	79.38	117	5.0	2.0	0.1	-	0.77	64.85	31.1	14.7	17.0	12.47	267
13	1977-0604	55	8.7	103.75	97.9	3.9	1.6	0.1	-	0.31	72.13	32.1	7.17	13.5	11.55	260
14	2002-0605	48.5	9.35	104.38	82.4	2.81	2.0	0.24	0.2	0.08	54.17	33.3	15.2	16.1	7.86	257
Noyonkhangai hot spring																
15	2002-0702	37	8.8	56.56	60.78	2.1	5.1	2.32	-	0.19	48.08	50.99	11.2	10.5	3.0	200

Table 2: Results of different geothermometers for samples from hot springs in the Khangai geothermal area, Mongolia

Hot spring	Number	T_{meas}	T_{qtz}[1]	T_{qtz}[2]	T_{qtz}[3]	T_{chal}[4]	T_{chal}[5]	T_{NaK}[6]	T_{NaK}[7]	T_{NaK}[8]	T_{NaK}[9]	T_{NaKCa}[10]
Tsenkher	1977-0102	86.5	1491	154	142	123	126	115	105	15414	167	145
	2002-0103	84.3	39	145	132	112	116	108	98	8	161	135
Tsagaan sum	1977-0202	69	136	141	128	108	112	102	92	143	156	135
	2002-0203	69.1	116	127	114	87	99	88	77	130	144	118
Shivert	1977-0302	48	136	141	128	109	112	132	122	170	181	156
	2000-0303	57.3	114	129	117	85	101	121	111	160	172	144
	2002-0304	57.3	100	121	108	69	93	111	101	151	164	137
Chuluut	1977-0402	45	128	133	120	101	104	111	101	151	164	143
	2002-0404	44	104	114	101	73	86	111	101	151	164	135
Khuremt	1977-0503	56	132	136	124	104	108	83	73	125	140	125
	2002-0504	54	111	127	114	81	99	69	58	111	126	114
Khujirt	1973-0603	54.5	122	125	112	93	96	122	111	160	172	151
	1977-0604	55	135	139	127	108	111	116	106	156	168	146
	2002-0605	48.5	126	140	127	98	111	105	95	146	159	135
Noyon-khangai	2002-0702	37	104	108	94	74	79	106	96	147	160	125

1) Fournier and Potter (1982); 2) Fournier (1977); 3) Arnorsson et al. (1983b); 4) Fournier (1977)
5) Fournier (1979); 6) Truesdell (1976); 7) Arnorsson et al. (1983); 8) Fournier (1979);
9) Giggenbach (1988); 10) Fournier and Truesdell (1973).

Table 3: Calcite calculation and Ryznar Stability Index of selected hot springs

Name of hot spring	Sample №	Ionic balance (%)	LogK	LogQ	SI (Log(Q/K))	RSI
Tsenkher	1977-0102	1.69	-9.858	-9.925	-0.067	7.19
	2002-0103	-11.03	-9.652	-9.744	-0.092	7.24
Tsagaansum	1977-0202	6.24	-9.586	-9.773	-0.187	7.79
	2002-0203	-10.84	-9.223	-9.002	0.221	7.05
Shivert	1977-0302	25.35	-9.589	-9.795	-0.206	8.53
	2000-0302	-9.41	-9.188	-8.903	0.285	7.35
	2002-0304	24.2	-8.962	-8.52	0.442	7.6
Chuluut	1977-0402	11.7	-9.449	-9.745	-0.296	8.7
	2002-0404	26.45	-9.02	-8.731	0.289	7.64
Khuremt	1977-0503	7.18	-9.509	-9.823	-0.314	8.47
	2002-0504	3.67	-9.13	-9.175	-0.045	8.16
Khujirt	1973-0603	32.87	-9.325	-9.769	-0.444	8.54
	1977-0604	18.83	-9.57	-9.81	-0.24	8.42
	2002-0605	-4.77	-9.408	-9.251	0.157	8.06
Noyonkhangai	2002-0702	-2.13	-9.023	-9.088	-0.065	8.29

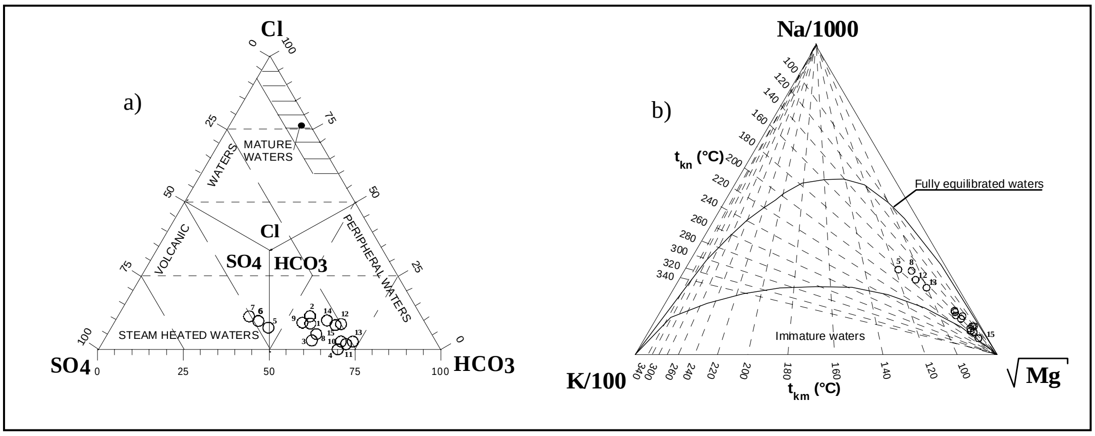

Figure 1. Ternary diagrams of a) Cl-SO_4-HCO_3 and b) Na-K-Mg

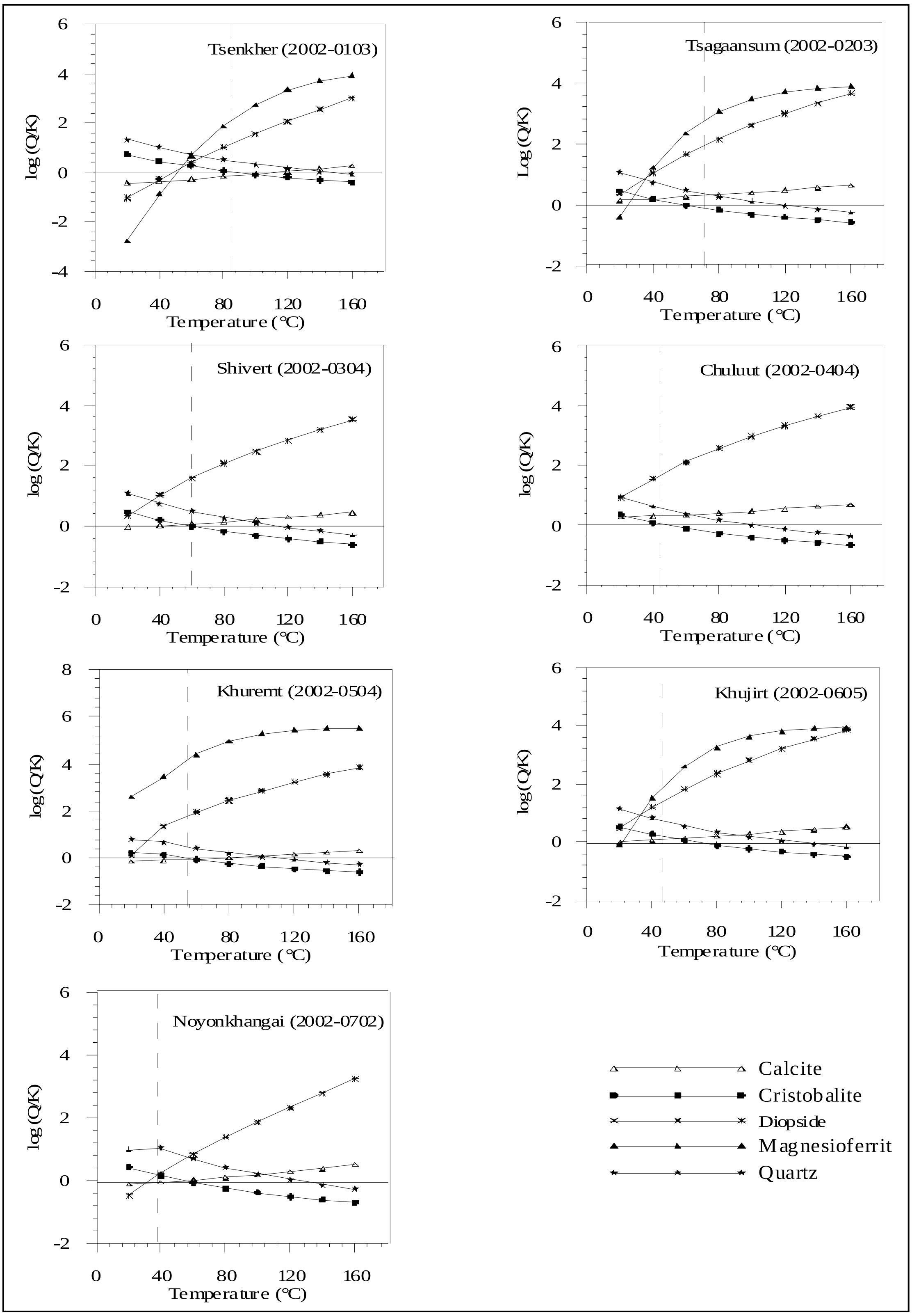

Figure 2: Mineral equilibrium diagrams for hot springs in the Khangai area, Mongolia

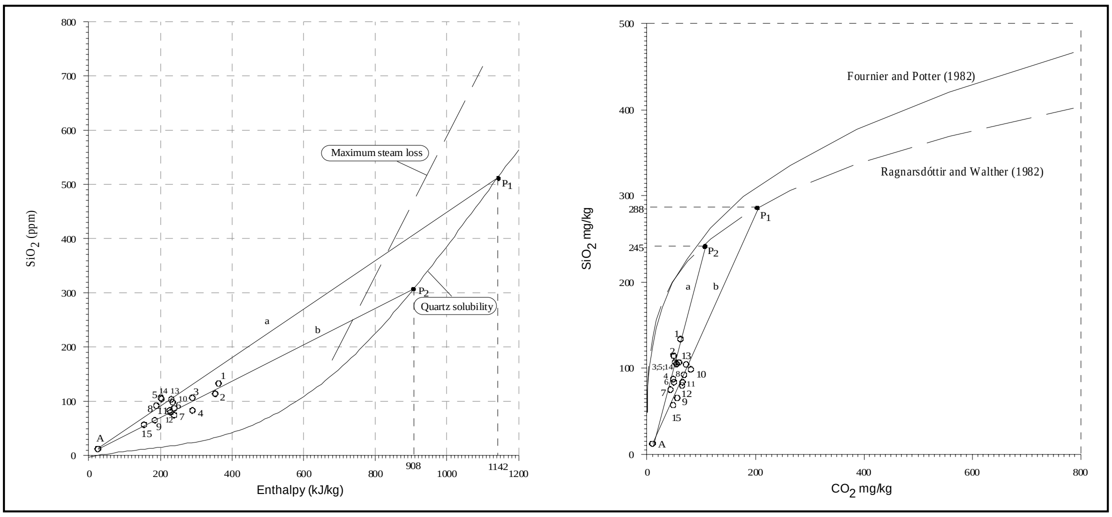

Figure 3. Mixing models of a) silica-enthalphy and b) carbonate-silica.

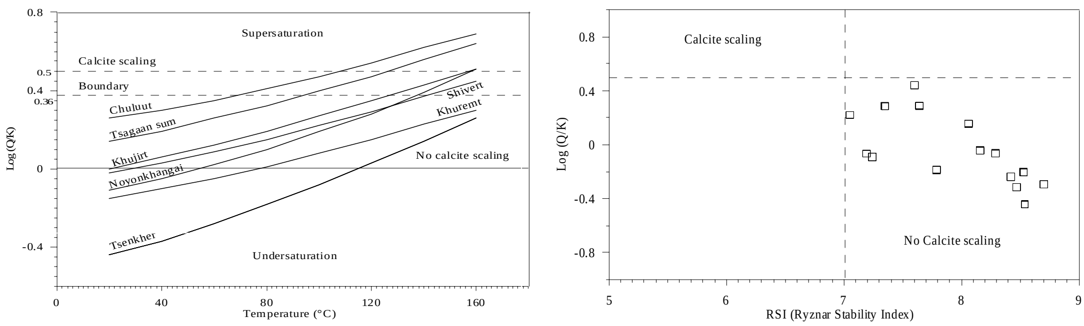

Figure 4. Calcite saturation index vs. temperature and Ryznar stability index.