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THE CHEMICAL CHARACTERISTICS OF GEOTHERMAL FLUIDS IN JIAODONG PENINSULA, SHANDONG, CHINA

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ABSTRACT

In order to trace the processes controlling the fluid composition, fluid mixing, fluid origin and reservoir temperatures, major, trace and water isotope analysis were performed for groundwaters (boreholes and springs) in the Shandong area, China. A total of 16 hot springs were sampled, with the geothermal fluid temperatures ranging from 28 to 81°C, pH from 6.95 to 8.44, Cl from 58 to 5316 ppm, SiO_2 from 61 to 137 ppm, B from 0.21 to 0.91 ppm, HCO_3 from 60 to 573 ppm, δD from -72.0 to -48.0‰, and $\delta^{18}O$ from -9.8 to -6.6‰. Based on geochemical relations, geothermal water in study area are mainly recharged by modern atmospheric precipitation mixed with seawater or shallow groundwater with the hydrology controlled by deep faults with a NNE strike.

1. INTRODUCTION

In China, low and medium temperature geothermal fields are widely distributed. Jiaodong Peninsula is one of the regions rich in low temperature geothermal resources in Shandong, Northeast China, with fractured geothermal reservoirs controlled by deep and large faults, as well as convective heat sources. Utilization of low and medium temperature geothermal fluids is an alternative energy source to fossil fuels and plays an important role in space heating and other direct uses in Northern China. The distribution of the geothermal activity, the fluid chemistry and origin and reservoir temperatures are, however, still largely unexplored.

2. REVIEW MATERIAL

The strata of Jiaodong Peninsula are intrusive rocks, metamorphic rocks, cretaceous sediments, volcanic accumulation and loose deposits of the Quaternary period. As shown in Figure 1, geothermal resources in Jiaodong Peninsula are mainly distributed on the east side of the Qingdao-Laizhou line. So far, 16 hot springs have been found in the middle-east part of the Jiaobei uplift and Jiaonan-Weihai orogenic belt (Weihai uplift and east margin of Jiaolai depression). All the hot springs flow out in points formed at cross positions of structures in which the fracture belt provides runoff passages from water infiltration towards the outlet. The strikes of faults that control the formation of hot springs occur in four types: NE, NW, NNE and NNW.

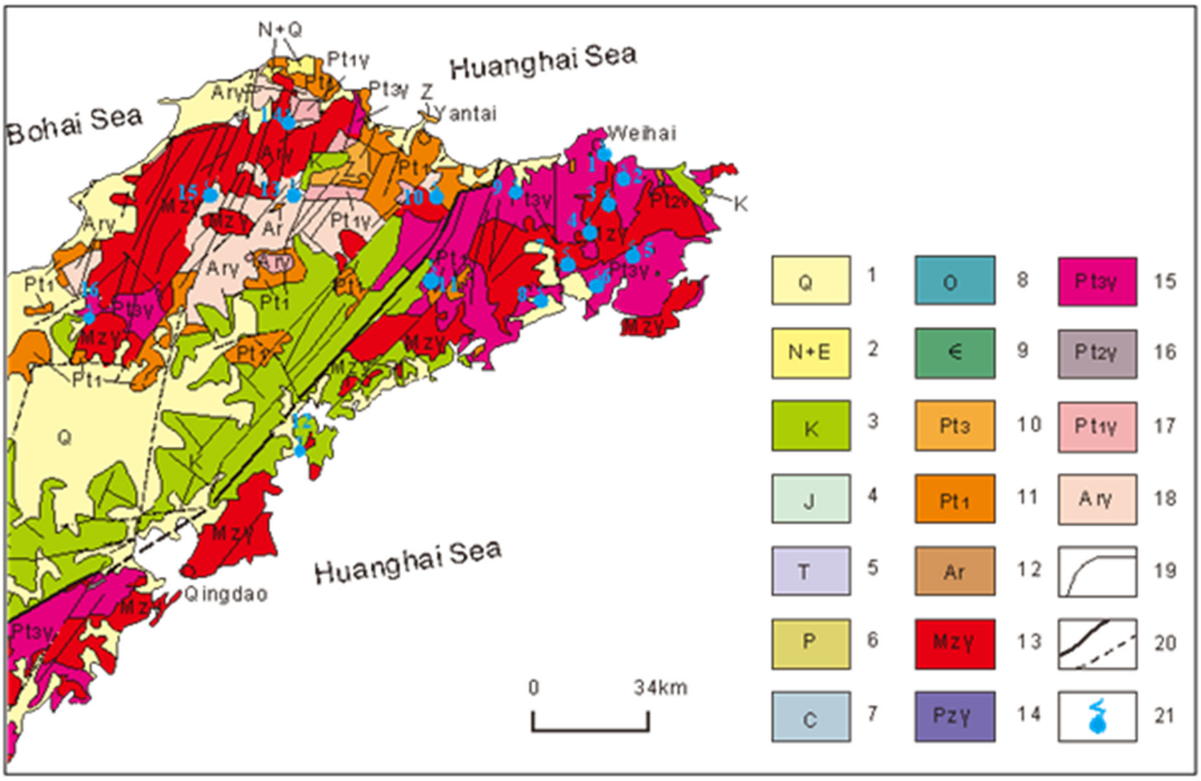

FIGURE 1: Simplified geological map of Jiaodong peninsula, Shandong, China
(mod. from Zheng and Kang, 2015)
1-Quaternary, 2-Paleogene+Neogene, 3-Cretaceous, 4-Jurassic, 5-Triassic, 6-Permian, 7-Carboniferous, 8-Ordovician, 9-Cambrian, 10-Neoproterozoic, 11-Palaeoproterozoic, 12-Archaean, 13-Mesozoic intrusive rock, 14-Paleozoic intrusive rock, 15-Neoproterozoic intrusive rock, 16-Mesoproterozoic intrusive rock, 17-Paleoproterozoic intrusive rock, 18-Archaean intrusive rock, 19-Geological boundaries, 20-Faults, 21-Hot springs

3. DESCRIPTION OF WORK

This paper presents part of my study in University of Iceland, aiming to provide background information for later work on sustainable yield assessment of geothermal fields in China. The process of this study is still on the way and here will be shown the first stage conclusions and discussed what to do next.

The chemistry data used here were collected from former work of Shandong Provincial Bureau of Geology and Mineral Resources (Shi et al., 2015). The elements and solutes concentration of hot springs are shown in Table 1. The geothermal fluid temperatures range from 28 to 81°C, pH from 6.95 to 8.44, Cl from 58 to 5316 ppm, SiO_2 from 61 to 137 ppm, B from 0.21 to 0.91 ppm, HCO_3 from 60 to 573 ppm, δD from -72.0 to -48.0‰ and $\delta^{18}O$ from -9.8 to -6.6‰.

4. RESULTS AND DISCUSSTIONS

4.1 Geochemical characteristics

Many geochemical processes affect the water composition during its moving. Fluid chemistry have been used to provide useful information on the processes affecting the geothermal water origin, to understand the mixing processes in the geothermal systems. It also can be used to estimate reservoir temperature for further study on sustainable development and predict in-well problems such as scaling and corrosion (Fournier, 1977; Arnórsson, et al., 1983; Arnórsson et al., 2000; Giggenbach, 1988).

TABLE 1: Elements and solutes concentrations of hot springs (in ppm)

No.	**Location**	**Temp. (°C)**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**CO_2**	**Cl^{-}**	**SO_4^{2-}**	**SiO_2**	**B^{-}**
JDR1	Baoquan tang	67	211.2	467.2	2781.0	120.3	119.6	5316.2	344.0	75.7	0.91
JDR2	Wenquan tang	55	55.8	7.5	308.2	20.3	163.0	349.4	135.1	83.2	0.29
JDR3	Hongshuilan tang	71	29.3	0.8	179.4	13.7	211.9	64.5	102.1	119.4	0.28
JDR4	Qili tang	66	18.1	0.8	170.7	9.0	173.9	57.7	113.1	122.1	0.28
JDR5	Hulei tang	60	37.6	0.8	299.2	15.2	65.2	254.4	293.7	121.1	0.40
JDR6	Tangcun tang	51	716.6	15.1	1599.0	60.4	43.5	3341.7	287.4	61.2	0.55
JDR7	Daying tang	62	234.2	0.8	483.1	12.6	43.5	878.7	226.2	70.9	0.29
JDR8	Xiao tang	56	231.4	9.2	665.3	17.9	65.2	1184.0	213.6	76.0	0.35
JDR9	Longquan tang	59	15.3	4.2	151.0	4.1	163.0	71.2	66.0	71.6	0.21
JDR10	Yujia tang	57	9.8	0.4	109.9	5.6	119.6	64.5	1.3	106.1	0.24
JDR11	Xingcun tang	28	5.6	0.8	165.6	4.8	70.7	91.6	97.4	74.7	0.22
JDR12	Dongwenquan	62	191.0	421.6	2291.0	121.4	43.5	4780.1	141.4	96.2	0.80
JDR13	Aishan tang	52	15.3	5.9	226.3	7.5	206.5	91.6	141.4	81.4	0.21
JDR14	Wenshi tang	54	53.0	6.3	385.5	18.9	413.0	122.1	270.1	114.1	0.35
JDR15	Tangdongquan	81	136.6	2.5	1175.0	96.2	141.3	1781.1	122.5	136.7	0.41
JDR16	Jiudian	61	26.5	10.5	239.4	16.6	130.4	152.7	212.0	124.2	0.29

The concentration contour maps of different elements in geothermal water are shown in the figures below. Distributions of concentration of non-reactive elements such as Cl and B can show the source of water in geothermal systems. There are four high Cl concentration areas distributed around the springs JDR1, JDR6, JDR12 and JDR15 (Figure 2), and the distribution of B gives the similar character.

Figure 3 shows the variation of the concentration of B with Cl. It shows there is a mixing trend which following the sea ratio line (JDR1, 12, 6, 15, 8 and 7), while the other samples seem to be controlled more by the rock- water interaction processes. Both Figures show that there might be seawater inflows at the eastern, south-western and north-western coasts.

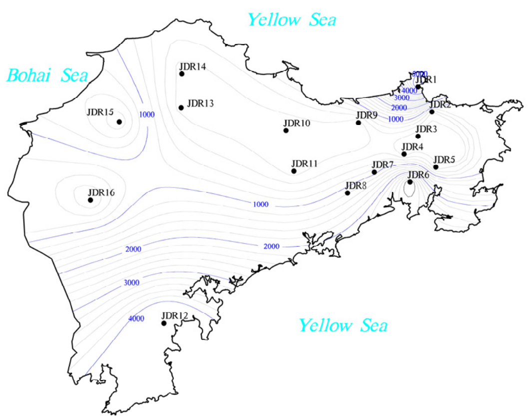

FIGURE 2: Concentration contour map of Cl^{-} in geothermal water, Jiaodong Peninsula

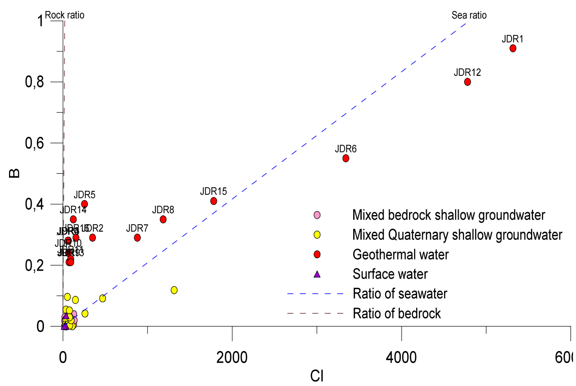

FIGURE 3: Variation of B with Cl (in ppm) in surface water, geothermal water and mixed shallow colder water

However, the distribution of SO_4 made a quite different picture from Cl and B (Figure 4). Figure 5 shows that part of the geothermal water samples from hot springs are following the cold shallow groundwater mixing line, which means there might be mixing with shallow groundwater in hot springs JDR2, 3, 4, 5, 9, 11, 13, 14, 16.

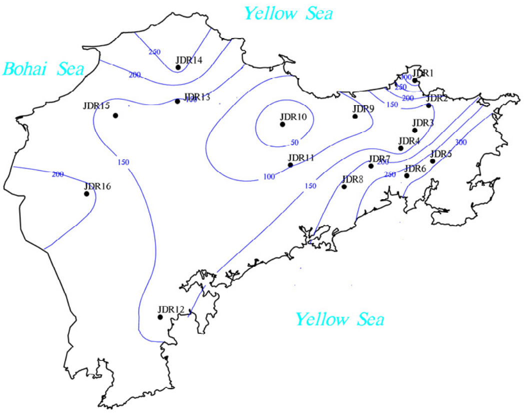

FIGURE 4: Concentration contour map of SO_4^{2-} in geothermal water, Jiaodong Peninsula

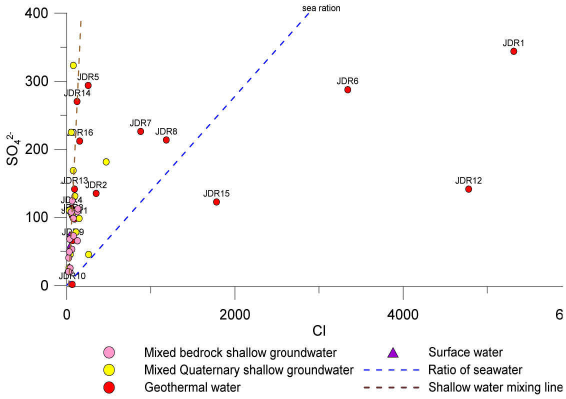

FIGURE 5: Variation of SO_4^{2-} with Cl (in ppm) in surface water, geothermal water and mixed shallow colder water

Different concentrations of SiO_2 can reflect the distribution of reservoir temperature. Variation of SiO_2 with Cl shows that most of the samples are following the SiO_2 and Cl ratio in the rock (Figure 6), which means that SiO_2 of most hot springs are from water rock interaction. Higher concentration of SiO_2 indicates higher reservoir temperature.

Relatively, from Figure 7 it can be seen that the reservoir temperatures have two significant high areas: the eastern coast and the north-western coast of the peninsula (JDR 3, 4, 5, 14 and 15), which might be hot water out flows.

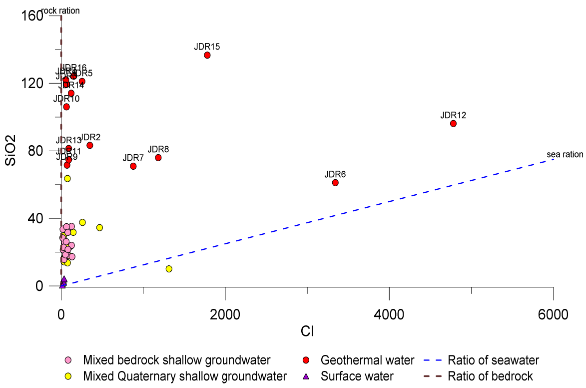

FIGURE 6: Variation of SiO_2 with Cl (in ppm) in surface water, geothermal water and mixed shallow colder water

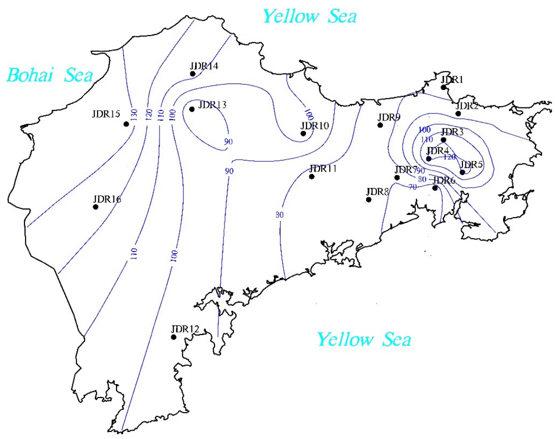

FIGURE 7: Concentration contour map of SiO_2 in geothermal water, Jiaodong Peninsula

Mg is a very reactive element and a lot of geochemistry processes could affect the concentration of it. The variation of Mg with Cl in water samples (Figure 8) shows that some samples were mixed with seawater, but the others are plotting below the sea mixing line (JDR 2, 5, 6, 7, 8 and 15). That means there were secondary minerals forming and decreasing the concentration in the fluid.

The other solutes such as SO_4 are also showing a similar process (JDR1, 6, 12 and 15 in Figure 4).

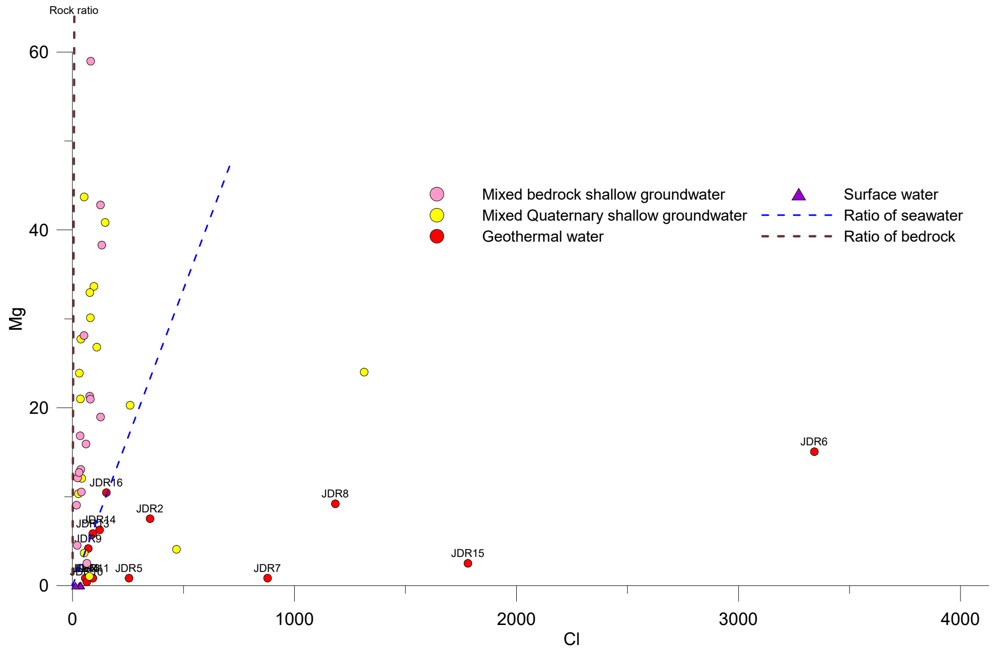

FIGURE 8: Variation of Mg with Cl (in ppm) in surface water, geothermal water and mixed shallow colder water

4.2 Hydrogen and oxygen stable isotopes

The plot of δD with $\delta^{18}O$ for the hot springs, shallow groundwater, surface water, rain water and sea water in the study area are given in Figure 9. The rain water seawater isotopes were from former studies in this area. From Figure 9, it can be seen that all the isotopes data of geothermal water, shallow groundwater and surface water are close to the GMWL, indicating a meteoric origin. The figure also shows the seawater mixing line (SMOW), which indicates inflow of sea to the system.

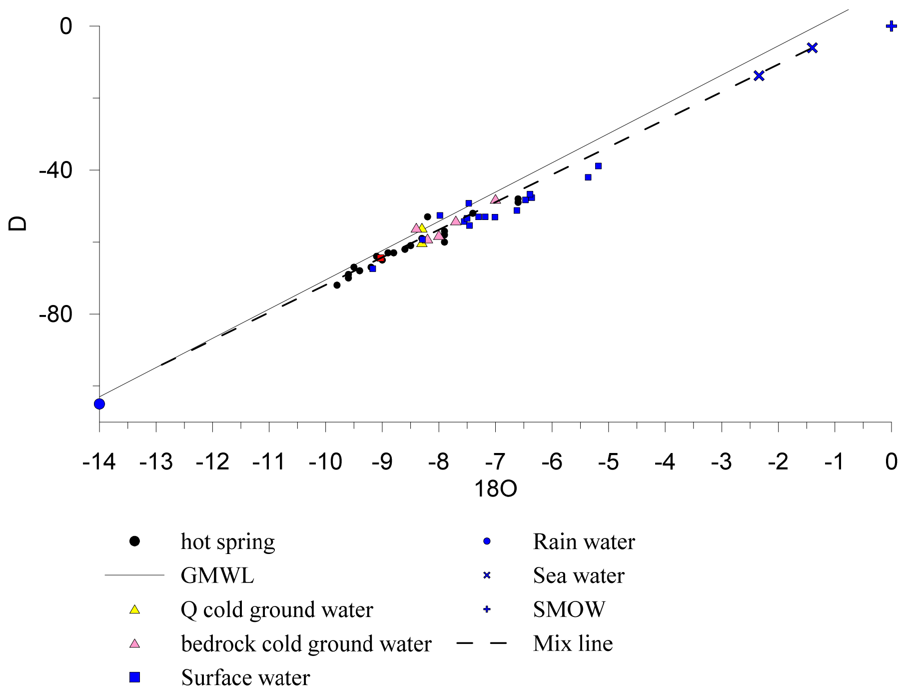

FIGURE 9: Plot of δD vs. $\delta^{18}O$ for the hot springs, shallow groundwater, surface water, rain water and sea water in the study area

4.3 Work to do next

The next step for this study is going to focus on using programmes to calculate the mineral saturations, find suitable models to estimate the reservoir temperatures, calculate the mixing percentages of the different sources and combine geochemical processes to the reservoir conceptual model.

5. CONCLUSIONS

Based on geochemical relations, the water composition is controlled mainly by two processes:

(1) Water-rocks interactio and formation of secondary minerals; and
(2) Variable source waters and mixing between them.

Geothermal waters in Jiaodong Peninsula are mainly recharged by modern atmospheric precipitation mixed with seawater or shallow groundwater with the hydrology controlled by deep faults with north-northeasterly strike and the distribution of Mesozoic intrusive rocks.

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REFERENCES

Arnórsson, S., Gunnlaugsson, E., and Svavarsson, H., 1983: The chemistry of geothermal waters in Iceland. III. Chemical geothermometry in geothermal investigations. *Geochim. Cosmochim. Acta, 47,* 567-577.

Arnórsson, S., D'Amore, F., and Gerardo-Abaya, J., 2000: *Isotopic and geochemical techniques in geothermal exploration, development and use: Sampling methods, data handling, and interpretation.* International Atomic Energy Agency, Vienna, 351 pp.

Fournier, R.O., 1977: Chemical geothermometers and mixing model for geothermal systems. *Geothermics, 5,* 41-50.

Giggenbach, W.F., 1988: Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators. *Geochim. Cosmochim. Acta, 52,* 2749-2765.

Shi, M., Yuan, F., Zhang, S.H., Zhu, H.C., Hu, S.T., Tao, Z.B., Han, M.Z., Yin, T., and Yin, A.H., 2015: *Research report of deep geothermal occurrence conditions in Jiaodong Peninsula, Shandong.* Third Institute of Geology and Mineral Resources, Shandong, report (in Chinese), 96 pp.

Zheng, T.T. and Kang, F.X., 2015: Sustainable yield of hot springs in Shandong Peninsula, China. *Proceedings of the World Geothermal Congress 2015, Melbourne, Australia,* 9 pp.