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A Comparative Study on the Energy Potential of Geothermal Fields along the Qinghai-Tibet Railway in China

Luo Lu[1], Pang Zhonghe[1], Xie Ejun[2], Fan Zengcai[2], Wang Yingchun[1]

1, Institute of Geology and Geophysics, Chinese Academy of Sciences, 19 Beituchengxilu, Chaoyang district, Beijing, China, 100029, 2, Tibet Geothermal Exploration Team, Lhasa, Tibet, China, 850000

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ABSTRACT

Qinghai-Tibet Plateau is rich in high temperature geothermal resources, among which the graben along the Qinhai-Tibet Railway is a favorable zone in terms of development. However, which of the fields has the highest energy potential has been an unsettled issue. In August 2012, we collected water samples from four geothermal fields including: Gulu, Jidaguo, Ningzhong, and Yuzhai, on which we analysed water chemistry and isotopes to get insights into their sources of water recharge and probable reservoir temperatures. Similar analysis found in the literature for Yangbajing geothermal field has been used for a comparison. The geothermal waters are originated from local meteoric precipitation, but exhibit obvious oxygen shift at different extents due to strong water-rock interactions at elevated temperatures. The oxygen shift in Gulu hot spring waters is the most intensive, higher than 2.7%, while this value is lower than 2% for the other geothermal waters considered. The elevation of recharge area for the geothermal waters has been estimated from 5700 m in Jidaguo to less than 5000 m for other systems. The geothermal reservoir temperatures have been estimated using cation and silica geothermometers. The highest temperature is 240^{o}C at Gulu geothermal field, slightly lower than that of Yangbajing but higher than other fields. In conclusion, Gulu is the best geothermal field among those that have not been developed and utilized in the study area.

1. INTRODUCTION

Tibet is located in the southwest China, and is also the main part of Qinghai-Tibet Plateau, which is called the roof of world and the third pole of earth. Qinghai-Tibet railway is from Xining to Lhasa and is 1,956 km long. It is one of the key advances in transportation projects in the new century in China. The railway and its related infrastructure offer an unprecedented accessibility that has made the geothermal resources in the rift valley the easiest to be developed. There are several geothermal fields distributed along the Qinghai-Tibet railway. They are among the more than 600 geothermal manifestations found in Tibet, in the form of hot springs, boiling springs, fumaroles and geysers.

Geothermal development has a relative long history in Tibet. In 1970s, the first geothermal power plant was constructed in Yangbajing Geothermal field, which now has an installed capacity of 25 MWs and has been in operation ever since and has provided more than 50% of the annual electricity demand of Lhasa, the capital city of Tibet. However, no new geothermal fields hace been developed until now. In order to promote geothermal development in the region, it is necessary to select those with favorable conditions for exploration and development, to this end, a survey was made to evaluate the reservoir temperatures of the selected geothermal fields.

Because of the bad geographic position and natural condition, the exploration of geothermal resources is limited. At present, there have been discovered 43 boiling springs and they have good potential for generate electricity with well cover, thick reservoir and high flow. But only Yangbajing and Yangyi geothermal field are already developed for generating electricity. Besides, there are more than 700 hot springs have lower temperature could used to be bathing and other life purpose (Hu, 2013).

2. STUDY AREA

The Indian and Eurasian plates are colliding, which has led to three obvious tectonic styles: crustal double thickening, large-scale syntaxis in the eastern and western ends of the collision zone, a series of W-E trending and N-S trending normal faults systems which cross India - Yarlung Zangbo suture zone and Bangonghu suture zone by stretching after collision. N-S trending normal fault systems in the plateau are mainly reflected to the N - S trending rifts and graben basins (Hou et al., 2004; Li et al., 2005). These graben basins induced strong modern hydrothermal activities and they become a major sector of the famous Himalayan geothermal belt as a part of the Alps-Meditteranean to Hymalaya geothermal belt. There are a series of such graben type geothermal zones, i.e.: Yadong-Gulu geothermal zone, Tangra Yumco-Gucuo geothermal zone, Shenzha-Xietongmen geothermal zone and Sangri-Cuona geothermal zone.

Thermal springs are mainly distributed in the south of Bangongcuo – Nujiang suture zone. Thermal springs with temperatures higher than 60^{o}C are patchy distribution and mainly distributed in Yangbajing-Dangxiong, Shiquanhe- Mapangyongcuo, Dagejia, Kawugudui and other geothermal fields. These are also areas with high heat flow values.

The tectonic position of Nyainqentanglha Mountains is located between Yarlung Zangbo River suture zone and Bangongcuo – Nujiang suture zone. Geothermal springs coincide with several groups of fault intersection sites. Active faults are essential to the occurrence of geothermal springs. They often constitute the boundary fractures of rift basins, induce fractures in the Quaternary cover, and promote compression torsion fault transfer to extension torsion fault. We choose five springs in study area and they are all distributed along the Qinghai-Tibet railway (Figure 1and 2).

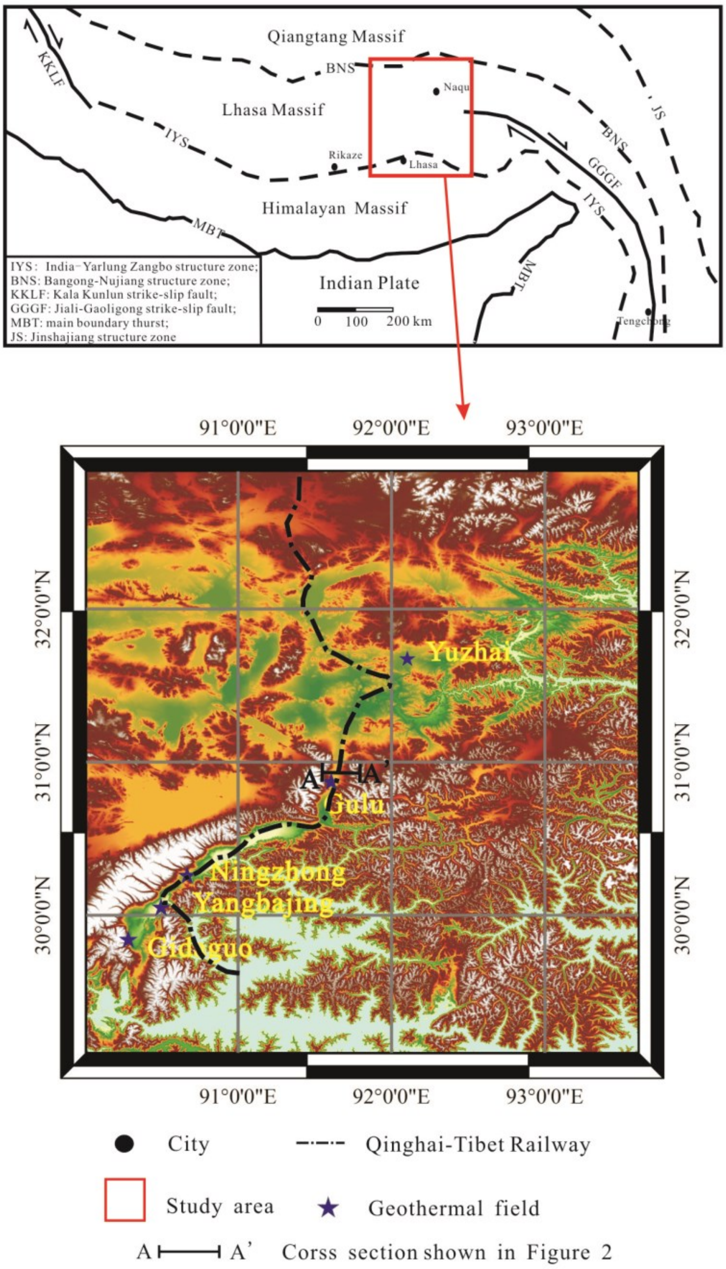

Figure 1: Location of the study area

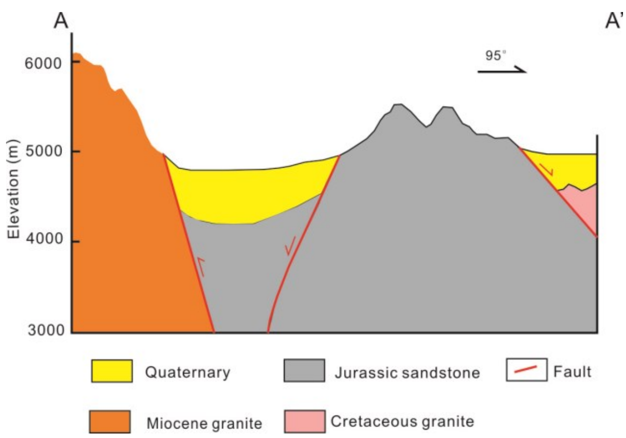

Figure 2: W-E geological cross section of the rift valley along the Qinghai-Tibet Railway (Huang, 2006)

3. ENVIRONMENTAL ISOTOPES AND THE SOURCE OF RECHARGE WATER

3.1 The recharge sources to the geothermal water

Craig (1966) raised a hypothesis that geothermal water origins in a dynamic circulation of precipitation through sediments to a subterranean reservoir. The hypothesis is verified by water isotopic composition of world famous geothermal fields, including Yangbajing geothermal field in Tibet (Wei, 1983).

Table 1 shows that the δD values of geothermal waters in study area range from -156.7~-138.2% and $\delta^{18}O$ range from -20.1~-14.9%, which are close to the isotopic composition of global meteoric water line (Fig. 3)and greatly different with the isotopic composition of magmatic waters (δD=-40~-80, $\delta^{18}O$=6~9). It can also exclude the possibility of geothermal waters were recharge from precipitation and surface water in the basin by comparing isotopic composition of surface waters to precipitation in the basin (Table 2). Apparently, geothermal waters in study area were recharge from atmospheric precipitation in the mountains that surrounding the basins. The δD and $\delta^{18}O$ values of geothermal waters in study area are the most depleted around the world, it may be due to the average elevation of geothermal zone is higher than 4000 m.

Table 1: The water isotopic composition and additional information for water samples (The data of Yangbajing are collected from Zheng et al., 1982)

Number	Location	Type	$\delta^{18}O$ (%)	δD (%)	$\delta^{18}O$-shift (%)	Number	Location	Type	$\delta^{18}O$ (%)	δD (%)	$\delta^{18}O$-shift (%)
1	Ningzhong	spring	-18.9	-150.1	-1.1	14	Yangbajing	well	-17.8	-147.8	-1.9
2	Yuzhai	spring	-18.5	-143.7	-0.7	15	Yangbajing	well	-18.0	-148.0	-1.8
3	Yuzhai	spring	-18.7	-143.6	-0.5	16	Yangbajing	well	-18.5	-148.6	-1.4
4	Yuzhai	spring	-18.5	-144.2	-0.7	17	Yangbajing	well	-18.2	-150.7	-1.9
5	Jidaguo	spring	-20.1	-156.2	-0.7	18	Yangbajing	well	-18.8	-149.3	-1.2
6	Jidaguo	spring	-20.1	-156.7	-0.7	19	Yangbajing	well	-18.2	-150.0	-1.8
7	Gulu	spring	-15.2	-138.2	-3.3	20	Yangbajing	well	-18.7	-150.3	-1.3
8	Gulu	spring	-15.7	-138.2	-2.9	21	Yangbajing	well	-18.7	-151.0	-1.4
9	Gulu	spring	-16.1	-140.6	-2.7	22	Yangbajing	well	-18.4	-151.8	-1.8
10	Gulu	spring	-16.0	-139.7	-2.7	23	Yangbajing	well	-18.4	-153.2	-2.0
11	Gulu	spring	-14.9	-134.7	-3.2	24	Yangbajing	well	-19.2	-153.6	-1.3
12	Yangbajing	well	-17.7	-147.3	-1.9	25	Yangbajing	well	-19.4	-154.8	-1.3
13	Yangbajing	well	-17.8	-147.3	-1.8						

Table 2: The water isotopic composition of surface water and rain water near the thermal springs and wells (The data of Yangbajing are collected from Zheng et al., 1982)

Number	Location	Type	$\delta^{18}O$(%)	δD(%)
1	Gulu	surface water	-16.8	-122.2
2	Yuzhai	surface water	-15.5	-118.5
3	Yuzhai	surface water	-15.9	-122.3
4	Jidaguo	surface water	-18.9	-137.9
5	Yangbajing	surface water	-15.7	-111.2
6	Yangbajing	surface water	-16.0	-112.9
7	Yangbajing	surface water	-17.0	-120.4
8	Yangbajing	surface water	-16.1	-113.9

9	Yangbajing	surface water	-16.1	-116.0
10	Yangbajing	rain water	-16.2	-114.2

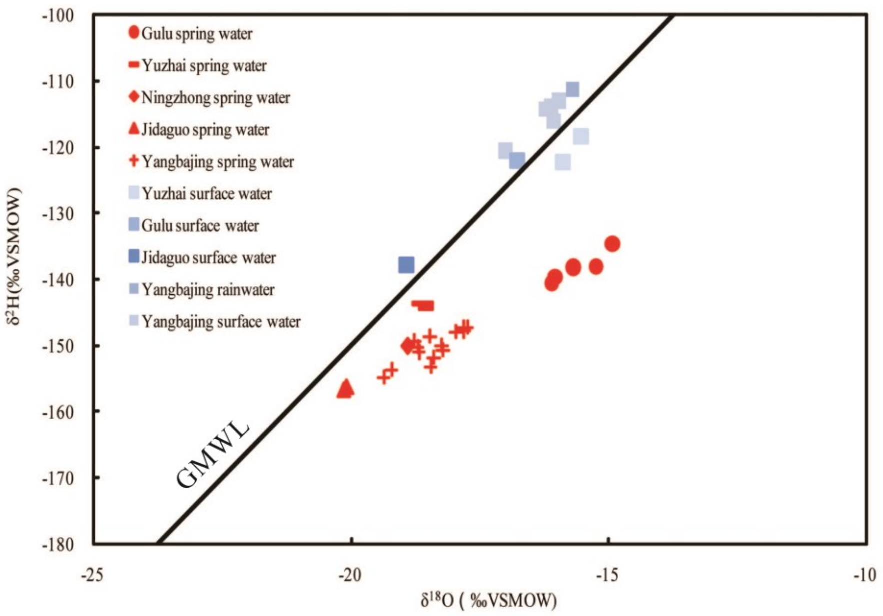

Figure 3: δD-δ^{18}O plot showing the stable isotope composition of the geothermal waters in the study area. The Global Meteoric Water Line (GMWL) is δD= 8δ^{18}O+ 10.

3.2 The elevation of recharge area

The recharge area of geothermal fields is generally in the mountains with higher elevation. Based on the altitude effect of δD and δ18O in precipitation, it can determine the altitude of recharge area. Because of the δ18O-shift in high temperature geothermal field, using δD instead of δ18O to calculate the altitude of recharge area is more accurate. Yang (2009) collected various water samples in Tibet, these samples and its altitudes can give the elevation gradient for δD of average annual precipitation: 0.17%/100 m. The isotopic composition of surface waters are close to the global meteoric water line, which can be the representative value of local atmospheric precipitation, so Jidaguo river sample can be selected to be reference point (δD=-137.9%,H=4617 m).

The results show that the elevation of recharge area in Ningzhong is 5220 m, Yuzhai is 4810-4850 m, Jidaguo is 5700-5730 m and Yangbajing is 4740-5230 m. the elevation of recharge area in Yangbajing is consistent with previous research (Wei et al., 1983). However, the calculation results of Gulu are lower than the elevation of hot springs, it may infers that hot water mixed with cold water in upwelling process.

4 GEOTHERMAL RESERVOIR TEMPERATURES

4.1 Oxygen shift in the geothermal waters

The content of ^{18}O in rocks is higher than geothermal water. Because of oxygen isotope exchange between geothermal water and rocks, the content of ^{18}O in geothermal water is higher than recharge source. The content of hydrogen in rock-forming minerals is lower, thus the δD in geothermal water would not change during isotope exchange reaction. In δD-δ^{18}O diagram (Figure 3), the δ^{18}O values of geothermal water deviate from the world meteoric water line and this phenomenon is called "oxygen isotope shift ". "Oxygen isotope shift" values depend on initial content of ^{18}O in rock and geothermal water, lithology, geothermal reservoir temperature, contact duration of rock and water, as well as aquifer property etc. Geothermal reservoir temperature and contact duration are the most important factors. In the medium-low temperature geothermal field, as a result of long contact duration of rock and water (>30000yr), "oxygen shift" has been discovered in the Guanzhong basin (Pang et al., 2010). However, "oxygen isotope shift" is very rare in the medium-low temperature geothermal field. It has been interpreted as a result of isotopic exchange at high temperature between the water and rock minerals which are richer in δ^{18}O. So "oxygen isotope shift" can be used as a deep temperature qualitative indicator in geothermal system. The value of "oxygen isotope shift" is bigger, the higher temperature in deep geothermal reservoir.

Figure 4 shows δ^{18}O-shift in the geothermal field, based on which they can be divided into two groups. The δ^{18}O-shift values of group A are higher than 2.7% and group B are lower than 2%. Meanwhile, their δD values are different, too. The δD values of group A are higher than -142% and those of group A are lower than -142%. The depleted δD is related to the elevation of recharge area. The higher the elevation is, the more depleted the δD values are. The recharge elevation of Gulu geothermal field is the lowest. Nyainqentanglha Mountains is the main recharge area in the study area. δ^{18}O-shift in high temperature geothermal field is mainly controlled by reservoir temperature. δ^{18}O-shift of Gulu geothermal field is the biggest, and it implies highest geothermal reservoir temperature in Gulu.

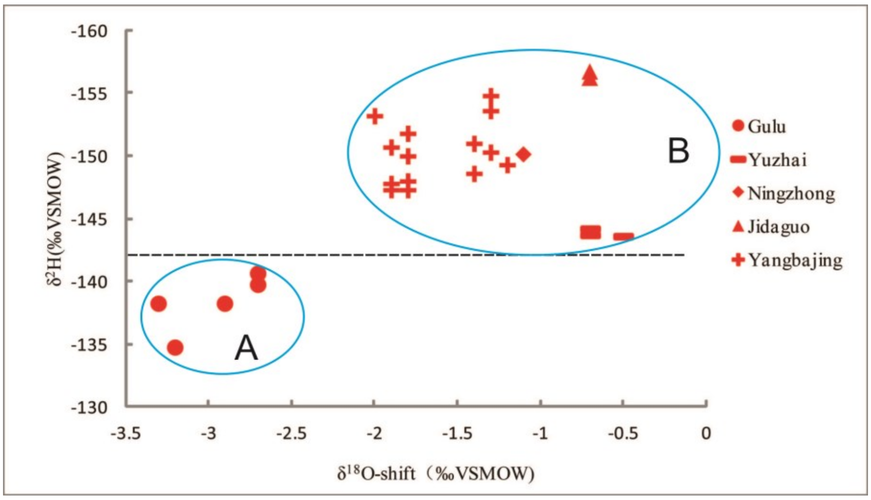

Figure 4: The relationship between δD and δ18O-shift of geothermal waters

4.2 Solute geothermoetry and the geothermal reservoir temperatures

The temperature of deep geothermal reservoir is one of important factors in evaluating geothermal resources. During initial exploration of geothermal field, geochemical geothermometer often be used to calculate the geothermal reservoir temperature. At present, the most useful geothermometers are silica and cation.

Figure 5 is the Na-K-Mg equilibrium diagram, the geothermal water in Gulu and Yangbajing geothermal field are close to the full equilibrium and their reservoir temperatures are ~240^{o}C and 260^{o}C. Other geothermal waters are partial mature or immature, due to the hot water mixed with cold water in upwelling process.

Sinter deposition of these five geothermal fields is relatively common and their types are mainly siliceous deposit. The composition of siliceous deposit is SiO_2 and the content is generally greater than 80%. So the content of SiO_2 in geothermal water samples is lower and the results of silica geothermometer are lower. The results of silica geothermometer can be used to comparing the reservoir temperatures of different geothermal fields. Table 3 gives the results of silica geothermometers (Fournier, 1977). The reservoir temperature of Gulu is the highest.

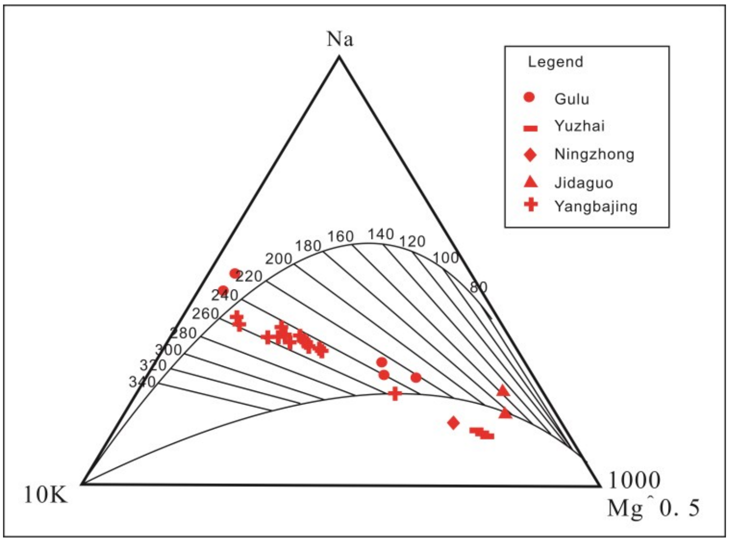

Figure 5: Na-K-Mg equilibrium diagram of geothermal waters (Giggenbach，1988)

5. CONCLUSIONS

1) The five geothermal fields are all located along the Qinghai-Tibet railway. The geothermal waters are recharged by precipitation. Using the altitude effect of stable isotopes of precipitation to calculate the recharge elevation of the five geothermal fields. The results show that the recharge elevation of Ningzhong is 5220 m, Yuzhai is 4810-4850 m, Jidaguo is 5700-5730 m and Yangbajing is 4740-5230 m.

2) The “oxygen isotope shift” is an indication of high temperature in the geothermal reservoir. Gulu geothermal field has the strongest shift so may imply highest reservoir temperature. Using cation and silica geothermometers reservoir temperature of the

five geothermal fields were calculated. Gulu geothermal field shows a reservoir temperature of 240°C, higher than other geothermal fields, with respect to the results of silica geothermometer.

3) After the comparative study, we found that Gulu is more promising than others so should be given a higher priority in development.

Table 3: Silica geothermometry results for geothermal waters

Number	Location	Type	SiO_2 mg/L	Silica geothermometer °C	Number	Location	Type	SiO_2 mg/L	Silica geothermometer °C
1	Ningzhong	spring	89.5	128	12	Yangbajing	well	205	170
2	Yuzhai	spring	88.5	127	13	Yangbajing	well	206	170
3	Yuzhai	spring	83.2	124	14	Yangbajing	well	224	175
4	Yuzhai	spring	92.2	129	15	Yangbajing	well	214	172
5	Jidaguo	spring	85.3	125	16	Yangbajing	well	216	172
6	Jidaguo	spring	79.7	122	17	Yangbajing	well	217	173
7	Gulu	spring	246	180	18	Yangbajing	well	238	178
8	Gulu	spring	264	184	19	Yangbajing	well	248	180
9	Gulu	spring	212	171	20	Yangbajing	well	241	179
10	Gulu	spring	280	188	21	Yangbajing	well	260	183
11	Gulu	spring	284	189	22	Yangbajing	well	247	180
					23	Yangbajing	well	256	182

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