Comparison of Geochemical characteristics of geothermal fluids from Eastern and Western Syntaxes, Himalayan belt, China

Yiman Li[1,2,*], *Zhonghe* Pang[1,2,3], and *Yifan* Fan[1,2,3]

[1]Key Laboratory of Shale Gas and Geoengineering, Institute of Geology and Geophysics, Chinese Academy of Sciences, 100029, Beijing, China
[2]Institute of Earth Sciences, Chinese Academy of Sciences, 100029, Beijing, China
[3]University of Chinese Academy of Sciences, 100049, Beijing, China

Abstract. High temperature geothermal systems are widely present along the Himalayan belt in the NW China. Strong manifestations have been observed in the Eastern syntax, where geothermal fluids are alkaline with pH almost higher than 9.0 due to boiling and waters are mainly Cl·HCO_3-Na and HCO_3-Na types. Large amounts of CO_2 from carbonate metamorphism are thought to be one of the reasons of calcite scaling and will be a problem for geothermal energy utilization. However, in the Western syntax, there are no obvious manifestations and geothermal fluid is Cl·SO_4-Na type with pH about 7.0. High content of Mg, comparing with that of the Eastern syntax, is assumed to be sourced from dissolution of Mg containing minerals and longer water-rock interactions. Calcite is under-saturated indicating no scaling problem in the utilization. Both of the geothermal fluids are recharged by the local precipitation but with different water vapor sources based on water isotope analysis. Therefore, it's concluded that geothermal fluids from these two syntaxes have gone through totally different geochemical processes and should be carefully monitored in utilization due to the calcite scaling problem.

1 Introduction

The Eastern and Western Himalayan Syntaxes are two singular points of continental collision between Indian and Eurasian Plates and have been focused on by many geoscientists. Strong tectonic movements provide possibilities of formation of high-temperature geothermal systems, which are found in these two syntaxes where strong surface manifestations exist. This paper compares the geochemical characteristics of geothermal fluids between these two syntaxes based on water chemistry and isotopes to improve understanding the possible recharging sources and geochemical processes. In addition, scaling potential based on deep fluid reconstructions is assessed to provide suggestions for further geothermal energy utilization.

[*] Corresponding author: liyiman@mail.iggcas.ac.cn

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2 Geological settings

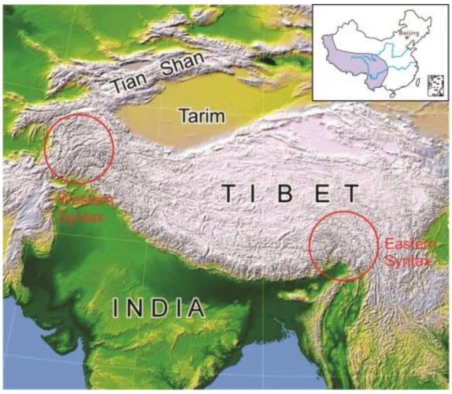

Fig. 1. Locations of the two syntaxes.

The Eastern and Western syntax are located along the Himalayan belt in the NW China (Fig. 1).Comparisons of geological data show that these two syntaxes share some similarities: (1) both of these syntaxes lost the Himalayan sediments of Cambrian – Tertiary, causing the high pressure metamorphic rocks directly contacting the main faults of mantle; (2) the original crystalline rock system is mudstone-clastic rock and acid intrusive rock and similar high pressure metamorphic rocks which overprinted by the re-melting of crust and migmatization younger than 10 Ma; (3) they experienced similar rapid uprifting since 25 Ma, especially since 10 Ma [1]. The deep re-melting of crust and migmatization begins earlier in the syntax in larger scale and longer time, comparing with other parts of the Himalayan belt [2]. This may provide special conditions for the high temperature systems occurring in these two syntaxes.

The main reservoirs for the Western syntax are probably syenite of Himalaya period and gneiss of Proterozoic period while those for the Eastern syntax are biotite granite and sandy slate of Triassic period.

3 Comparisons of Geochemical characteristics

3.1 Samples descriptions

There are no obvious surface manifestations for high temperature systems in the Western syntax and all the samples are collected from springs (T=9-15℃) and newly drilled wells (T=27-155℃) [3]. Two high temperature geothermal systems of Eastern syntax (Kangding-KD and Batang-BT) are studied [4, 5]. In the KD area, geothermal fluids are mainly from boreholes and springs with temperature ranging from 48-178℃ and in the BT area, all the samples are collected from the boiling or close to boiling springs (the local boiling temperature is about 88℃). All the data here are cited from the mentioned references.

3.2 Geochemical characteristics and processes

The pH values measured in-situ indicate that boiling ubiquitously happens in the Eastern syntax causing the formation of more alkaline geothermal waters, while this is not the case in the Western syntax. This is probably because the reservoir temperature of the geothermal fluid in the Western syntax is under saturated vapor line. Geothermal fluid in the Western syntax is dominated by $Cl\cdot SO_4$-Na type while for the KD and BT area of the Eastern syntax, water is mainly of $Cl\cdot HCO_3$-Na and HCO_3-Na types (Fig. 2).

Mg content of geothermal fluid is much higher in the Western syntax (about 10.3-15.4 mg/L in springs and 2.2-15.2 mg/L in geothermal water from boreholes), compared with that of Eastern syntax-BT which is just 0.02-0.64 mg/L (Fig. 2, Fig. 3a). This means that more minerals containing Mg from reservoir are dissolved into the geothermal fluid from

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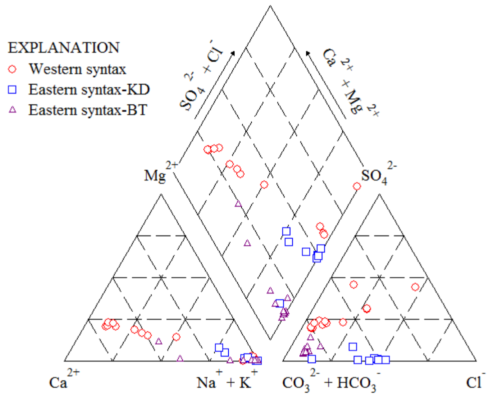

Fig. 2. Piper diagram for geothermal fluids.

the Western syntax. Rock properties indicate that the reservoir mineral compositions are almost the same, but reservoir temperature of Eastern syntax-BT is about 40-50 ℃ lower. Therefore, it is assumed that water-rock interactions in the Eastern syntax-BT are weaker or the circulation time is shorter. SO_4^{2-} in the fluid of the Western syntax is much higher which is assumed to be caused by oxidation of H_2S or dissolution of gypsum (Fig. 3b). HCO_3^- behaves differently and is much higher in the Eastern syntax (Fig. 3c) and is proved to be from thermo metamorphism of marine limestone [5] (Eq.1). Cl^- in springs is much lower than that from boreholes especially for the KD geothermal system of the Eastern syntax (Fig. 3d). The high Cl^- content for geothermal fluid of KD geothermal system is thought to be caused by contributions from a magmatic source [4].

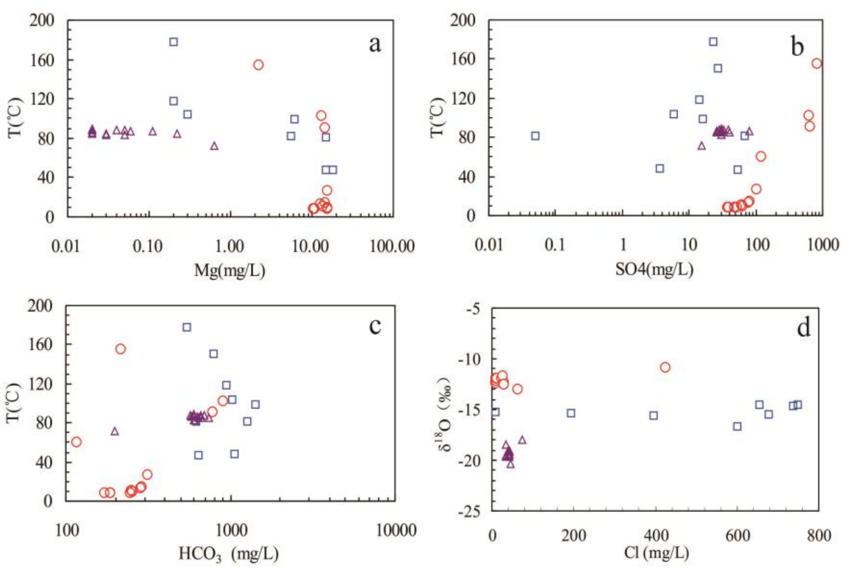

Fig. 3. Ions correlations with temperature and isotopes.

Rock properties indicate that the reservoir mineral compositions for the Western syntax are K-feldspar, quartz, plagioclase, biotite, magnetite and amphibole while those for the Eastern syntax are quartz, K-feldspar, plagioclase, biotite, amphibole and little chlorite. As refers to the reservoir rock properties and regional tectonic movements, the main geochemical processes includes (1) thermo-metamorphism of limestone (Eq. 1); (2) dissolution of carbonates ($CaCO_3$, $MgCa(CO_3)_2$, e.g. Eq.2) and alumino-silicate minerals ($KAlSi_3O_8$, $CaAl_2SiO_8$-$NaAl\ Si_3O_8$, $K\ (Mg,Fe)_3(AlSi_3O_{10})(OH,F)$ 2, e.g. Eq.3);

$$CaCO_3 \xrightarrow{400^\circ C} CaO + CO_2 \uparrow \quad (1)$$

$$CaCO_3 + H^+ \leftrightarrow Ca^{2+} + HCO_3^- \quad (2)$$

$$5KAlSi_3O_8 + 4H^+ + 16H_2O \rightarrow KAl_5Si_7O_{20}(OH)_4 + 8H_4SiO_4 + 4K^+ \quad (3)$$

3.3 Recharge sources

The Local Meteoric Water Line for the Western syntax (LWML-Western syntax) is from [6] and shows that both springs and geothermal fluid from boreholes are recharged by the meteoric water (Fig. 4). However, geothermal fluids from KD and BT geothermal system of the Eastern syntax are isotopically much depleted. This is probably because of different vapour sources for precipitation or earlier recharge time. The main vapour source for the Western syntax is Westerlies while for the Eastern syntax, it is more complicated as it is dominated by both Indian Ocean monsoon and Pacific Ocean monsoon. In addition, oxygen-18 shift is observed in geothermal fluids from the Eastern syntax especially in the BT geothermal system which is about 4‰, which is probably caused by contributions from oxygen exchange with underlying thermo-metamorphism of limestone with enriched oxygen-18 (Fig. 4). Another possibility is longer water-rock interactions in the Eastern syntax which will be verified by geothermal fluid dating in future research. For geothermal fluid in the Western syntax, it plots along the LWML indicating quick circulation.

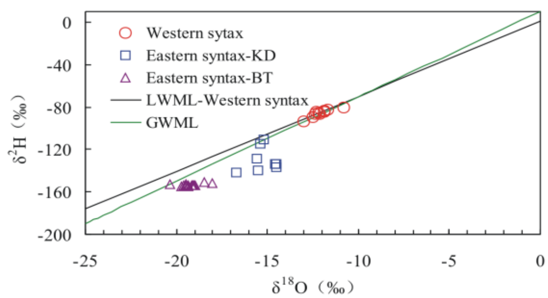

Fig. 4. Water isotopes of geothermal fluids.

4 Assessment of scaling potential

Borehole samples from Eastern syntax-KD & Western syntax and hot springs from Eastern syntax-BT are chosen to assess the calcite, quartz and chalcedony scaling potential. Due to lacking of steam data, all the chosen samples are calculated with the spring boiling model in the WATCH code when reconstructing the deep reservoir fluid compositions [7].

Results show that geothermal fluids from the Western syntax are undersaturated with calcite and calcite scaling may not be a problem (Fig. 5 & 6). However, water from Eastern syntax, calcite is almost over-saturated and the saturation indexes (SI) are all over 0.5 which means calcite scaling will happen [8] (Fig. 5 &6). These results are consistent with observations in the field that travertine appears around geothermal systems in the Eastern syntax but not that in the Western syntax. The main reason for calcite scaling in the Eastern syntax is over-saturation of carbonate in the fluid due to high concentration of HCO_3^- from metamorphism.

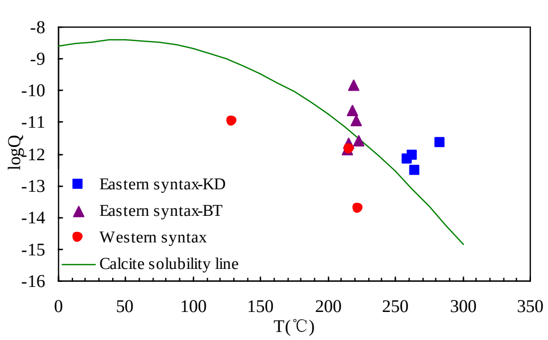

Fig. 5. Calcite saturation state in geothermal fluid.

It is concluded that quartz, chalcedony and amorphous silica. are all under-saturated in the reservoir conditions. Therefore, for geothermal fluid exploitation in the Eastern syntax, scaling assessment and prevention should be considered carefully before projects are initiated. In the Western syntax, calcite scaling may not be a serious problem.

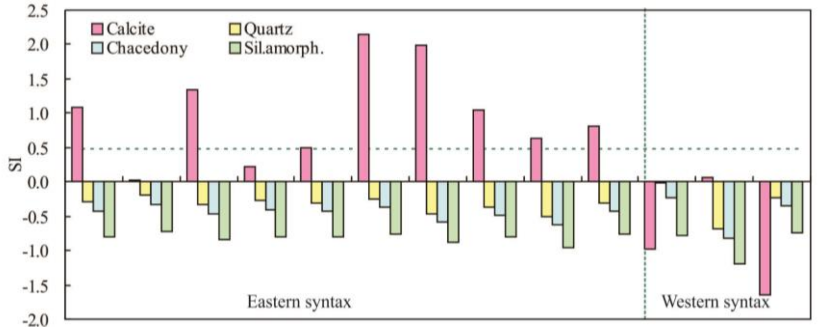

Fig. 6. Typical mineral SI of geothermal fluids from the two syntaxes.

5 Conclusions

Water chemistry and scaling potential of geothermal fluids from geothermal systems in both the Eastern syntax and Western syntax of the Himalayan belt are studied and analyzed. Comparisons show that deep reservoir fluids from these two syntaxes have gone through different geochemical processes during the circulation. Geothermal fluid from the Western syntax is $Cl\cdot SO_4$-Na type dominated and more Mg is released due to water-rock interactions; in addition, it's recharged by precipitation with the vapor source of westerlies. However, for geothermal fluid from the Eastern syntax, it's mainly $Cl\cdot HCO_3$-Na and HCO_3-Na type with pH around 9.0 indicating boiling may have happened before sampling and contribution of CO_2 from thermo-metamorphism of limestone controls the anions. Water isotopes show that geothermal fluid is recharged by precipitation from mountains around and the vapor is sourced from Indian Ocean monsoon and Pacific Ocean monsoon. Calcite scaling is thought to be a problem for geothermal fluid production in the Eastern syntax with SI higher than 0.5 while in the Western syntax, it shows under-saturation based on fluid compositions reconstruction. Therefore, geothermal fluid should be treated differently in the exploitation for these two syntaxes.

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