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Isotope and chemistry study for genetic types of geothermal water in Gushi depression, Shaanxi Province, NW China

Zhi-yuan Ma[a], Wei-wei Hu[b,*], Cheng Hou[d], Bizhou Ge[c], Ting Li[d], Hui-ping Dou[a], Hua Yan[a], Xin Zhou[a]

[a]*College of Environmental Science and Engineering, Chang'an University, Xi'an, China*
[b]*Xi'an Engineering Design Co, Ltd, China Coal, China*
Email: huzhongwei636@126.com
[c]*School of Environmental & Municipal Engineering, Xi'an University of Architecture & Technology, Xi'an 710055, China*
[d]*Chang'an University, Xi'an, China*

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ABSTRACT

Sedimentary environment and possible origins of geothermal water in the Gushi depression, Shaanxi Province, NW China are discussed in this paper based on the isotope and hydrochemistry characteristics of the geothermal water. The results illustrate that isotope and hydrochemistry characteristics in different parts of the study area show obvious differences, which indicate their different storage environments, recharge resources, and genetic types. The study expound for the first time that genetic types of geothermal water are various and the main genetic types of geothermal water include: (1) modern circulating water which host on an opener thermal environment; (2) residual connate water that may exist in a closed geothermal reservoir; and (3) the mixed water between 1 and 2.

Keywords: Gushi depression; Isotope and hydrochemistry characteristics; Sedimentary environment; Connate water

1. Preface

Environmental isotopes are effective tools to study the origin, genesis, and storage of deep-earth geothermal fluids [1,2]. With large-scale development and utilization of geothermal water in Gushi depression, eastern Guanzhong basin, Shaanxi Province, there are important theoretical and practical significances to understanding the characteristics of deep geothermal waters for sustainable exploitation and utilization. The geothermal water must be desalted in some way, so it is better to learn how to desalt the highly total dissolved solids (TDS) groundwater.

*Corresponding author.

Traditional theories on groundwater are based on the understanding of shallow groundwater systems, with its main genesis type as infiltration water coming from precipitation. Nowadays, the hydrological study of water bodies has already transferred from the relatively stable geochemical reactions and slower speed solution processes at low temperatures to more active chemical reaction with complex sources of salts and diverse genetic types. For instance, the mining depth in Gushi depression has already reached 4,000 meters in the eastern Guanzhong basin, and the temperature in springs and bore holes has reached 123℃. TDS in the geothermal water is almost equal to that of seawater. More importantly, the $\delta^{18}O$ shift in the thermal water is so obvious that the characteristic is particular and significant in China [3–6]. Here, we attempt to offer isotopic evidence for the origin and cause of the deep geothermal water and possibility of existing sedimentary water.

2. Background

Gushi depression is located in the middle eastern part of Guanzhong basin, which is raised in the north and dips in the south. Highly developed faults seperated the Guanzhong basin into several fault blocks, and for further tectonic division, can be subdivided into three tectonic elements including Sanyuan faulted stage, Gushi faulted stage, and Erhua faulted stage. Because the basin was formed by a rapid subsidence process, groundwater in the stratum was inertly stored in the loose pore spaces, surface water, and meteoric water in bedrock mountain areas were another recharge source of its groundwater. With continuous sediment deposition in the basin, this storage water was pressured gradually, and heat exchange took place between it and the mantle heat source. This process gradually formed one kind of sealed geothermal water. On the other hand, modern precipitation may recharge the geothermal water weakly though some open deep faults. The thickness of Cenozoic stratum in the basin is more than 4,000 m, which is dominated in lake sediments with fine lithology and bad permeability, and provide a good storage conditions for geothermal resources. Its rich geothermal resources were buried most shallowly in Guanzhong Basin from arched Moho surface of the deep basin (Fig. 1), the initial head of the geothermal water is up to +57.5–340 m at 2,500–3,840 m below the surface, and the temperature is up to 123℃ [7]. Gushi depression was formed since the Paleogene period, its thickness is up to 6,800 m and the depocenter is located in the center of Gushi (Fig. 2).

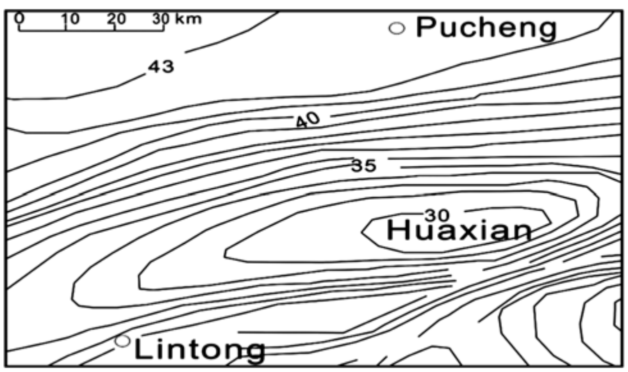

Fig. 1. Moho contour of Gushi depression.

3. Sampling and testing

Eight waters samples were collected from thermal springs and water wells in Gushi depression for isotope analysis (^{2}H, ^{18}O) between June and November of 2006. Most of the samples were taken near the major fractures of the basin or in the fracture blocks (Fig. 2). In addition, meteoric waters from different

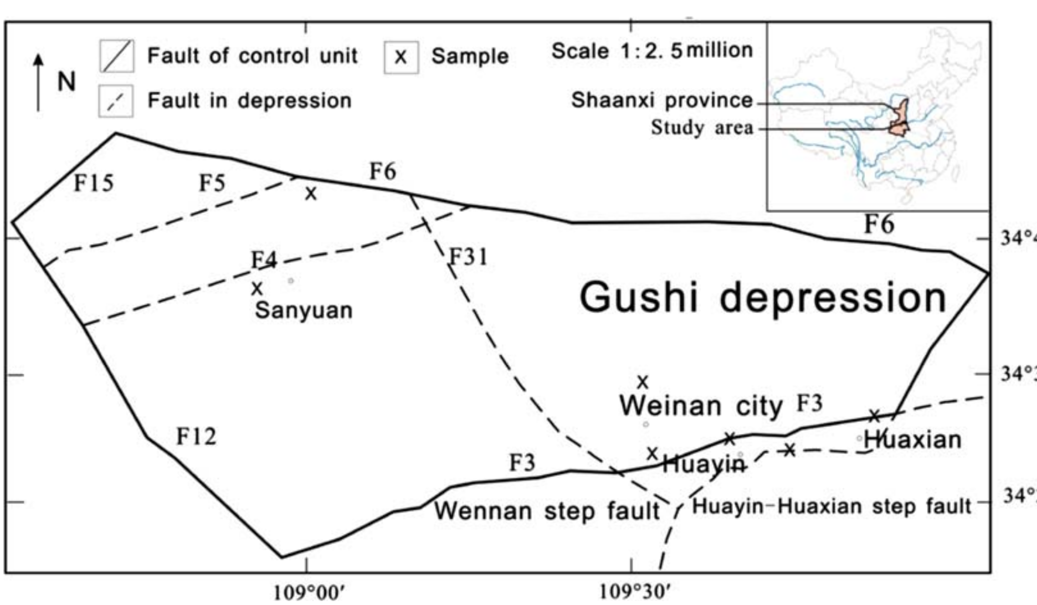

Fig. 2. Structural map and sample point of Gushi depression.

elevations in northern Qinling Mountain and southern Beishan Mountain were, respectively, collected and analyzed as well to obtain information on groundwater replenishment. The samples were analyzed in the isotope laboratory of the Science Academy of the Geology and Geophysics Institute of China. Measurement accuracies were within 0.01% for the oxygen-18 test, 0.1% for the deuterium test, and ± 1TU for the tritium test. The chemical analyses of the geothermal waters samples were carried out in the Laboratory of Chang'an University.

4. Isotope characteristics

Isotope contents of geothermal water in the Gushi depression are shown in Table 1 and Fig. 3. From Fig. 3, almost all the sample points, which the exception of samples 1 and 8, showed the signature of oxygen drift, which is mainly a result of water–rock interaction, the storage environment of geothermal water, retention time, and the character of geothermal water and its surrounding rock [8]. Oxygen shift in Gushi depression varies from −11.297 to −1.746%, which is so unique in China that there is significant indication for recharge and formation of geothermal water [8–10].

Table 1
Hydrogen and oxygen isotope results of Gushi depression

No	Sample point	δD/‰	δ^{18}O/‰
1	Fuping	−78.1	−11.297
2	Huayin	−80.69	−9.434
3	Sanyuan	−82.08	−8.47
4	Huaxian	−77.14	−7.903
5	Huayin 051	−61.129	−3.339
6	Weinan city	−56.38	−2.813
7	Weinan college	−54.546	−1.746
8	Jingyang	−67.38	−10.2

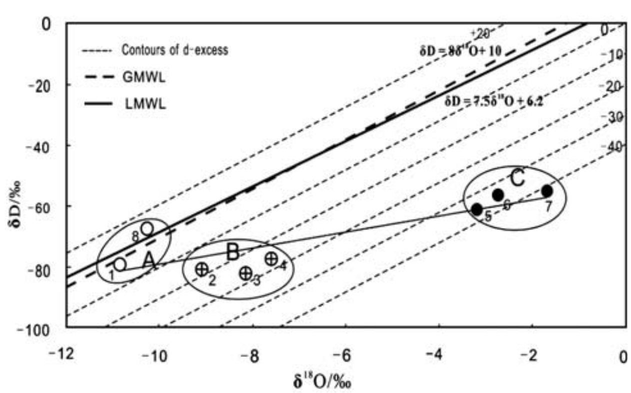

Fig. 3. Geothermal water $\delta D-\delta^{18}O$ relationship of Guanzhong basin.

D-excess can also be used to indicate oxygen drift degree. As D-excess decreases, oxygen drift increases. D-excess of geothermal water from samples 5–7 reaches up to −40‰, and lied at the end point of the $\delta^{18}O$ shift line (Fig. 3); while D-excess of samples 2–4 are between −20 and −5‰, and their drift degrees are closer toward the medium of the shift line. Samples 1 and 8 almost lie on the local meteoric water line (LMWL), and their drift degrees are the least altered.

According to the analysis of $\delta^{18}O$ distribution and D-excess, large-span drift of oxygen-18 in Gushi depression is indicative of variable recharge, formation, and environment of the geothermal water. The storage environment of samples 1 and 8 is open, retention time is short, and water–rock interaction is limited, hence the groundwater contribution in samples 1 and 8 has a closer relationship with a precipitation-type source. It therefore suggests a lixiviation genetic-type geothermal water mixed with modern circulating waters. The storage environments of samples 5–7 are close; the retention time is so long that water–rock interaction is significant. Connected with the geological structure and deposition history, the genetic type of the geothermal water for these samples may be of ancient dissolved filtered water or of the sedimentary origin geothermal water types. The remaining sample points of samples 2–4 lie towards the medium values between 5 and 7, and 1, 8 demonstrating a mix between a transition genetic type and a storage environment. Therefore, the characteristics of stable isotopes in thermal water of the Gushi depression can be divided into three groups A, B, and C groups. Groups A and C, respectively, represent the open and closed environment, slight and intense water–rock reaction, modern and ancient recharge water, infiltrating and connate genetic types. While group B represents a mixing of groups of A and C.

The tendency of the $\delta^{18}O$ evolution line in Fig. 3 is not horizontal, but shows the effects of hydrogen drift, moreover its slope is similar to the isotope drift slope of sedimentary water (Fig. 4) [6]. A comparison of Figs. 3 and 4 indicates that the latter shows the typical tendency of connate water; however from Fig. 3, samples 1, 2, 3, 4, and 8 almost do not demonstrate any significant hydrogen drift, this is indicative that their storage environment is somewhat open, which is representative of an oxidation environment. In contrast, the rest of the three samples (samples 5–7) show obvious hydrogen drift, resulting from a closed-reducing storage environment, possibly due to the presence of reducing gas such as H_2S and CH_4. These conclusions are coincidence with the oxygen drift, meanwhile

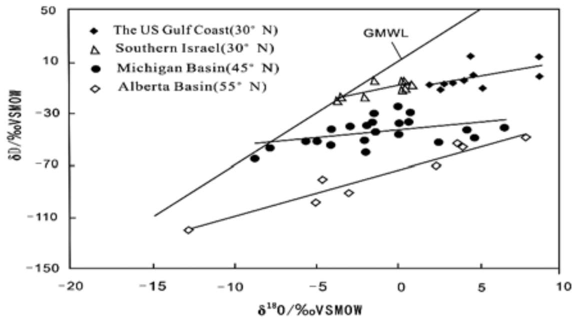

Fig. 4. The relationship between δD and δ^{18}O in some connate basins.

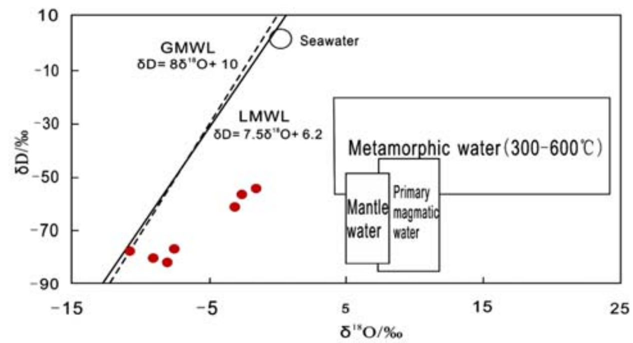

Fig. 7. Different origins water distribution of δ values.

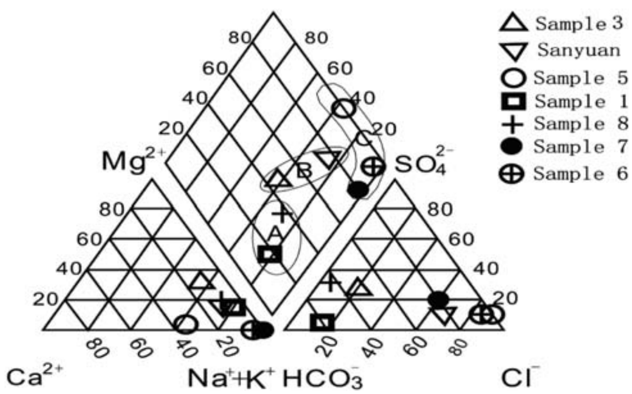

Fig. 5. Piper drawing of different geothermalwater samples.

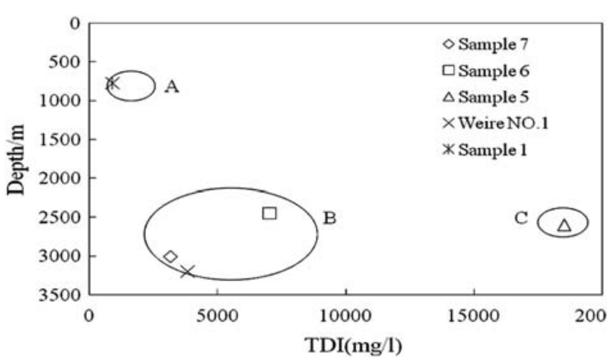

Fig. 6. Relationship between well's depth and TDI.

sedimentary evolution history of Gushi also supports these conclusions [7].

Fig. 5 shows the relative content of ions and chemical types of the geothermal water. The amount of Cl^- in groups A, B, and C shows a gradually increase in concentration. At the same time, the amount of Total Dissolved Ions (TDI) in groups A, B, and C has the same tendency, which is shown in Fig. 6.

5. Genetic type

Fig. 7 shows the δD vs. δ_{18}O distribution for groundwater of different origins. It can be seen that the δD and δ_{18}O values of the geothermal water in the Gushi depression fall outside of the δD and δ_{18}O values of metamorphic water, underlying magma water, and seawater. This is indicative that the origin and genesis of Gushi depression does not belong to these groups. Ancient or modern meteoric or sedimentary waters are possible sources for origin of the thermal water.

Helium isotope ratios ($^3He/^4He$) demonstrate their own characteristic features as a result of their origin from crust-derived, mantle or meteoric source $(1.1–1.4) \times 10^{-5}$, 2×10^{-8} and 1.4×10^{-6}, respectively). If we set the meteoric $^3He/^4He$ ratio (1.4×10^{-6}) as Ra, set the ratio of the sample as R, then $R/Ra < 1$ is the characteristic of shell source helium, and $R/Ra > 1$ is crust-derived helium joint. When $R/Ra > 4$, it indicates the existence of a large crustal derivation [11,12]. Geothermal water of the Gushi depression has R/Ra measured value of $(2.09–2.6) \times 10^{-8}$, which is less than 1 as a typical of a mantle source formation. This supports the conclusion of the Gushi depression geothermal water coming from the crust, and meteoric or connate waters are probable sources for thermal water in the study area.

The sulfate contribution of underground water has a variety of sources, including dissolved marine evaporates, continental gypsum, seawater intrusion, reduction sulfide mineral oxidation and oxidation of H_2S which is dissolved in water, atmospheric sulfate, etc. Various sources of sulfur contribute to the geochemical evolution process for groundwater, and they are an important part of groundwater salinization. An assessment of the sources of the geothermal water in the study area shown in (Fig. 8) can eliminate contributions from atmospheric sulfate, seawater sulfate, and the sulfate sources in geological time. The distribution of the geothermal water is closed to land evaporation rock, it is therefore concluded that the secondary sulfate formed by H_2S oxidation may be the source of sulfate ions in geothermal water of the study area. This supports the point that the geothermal water was formed in a closed reduction sedimentary environment, and that the sedimentary genetic type may be at least one of the genetic types of geothermal water in the study area.

The relationship between Na/Cl and Cl as well as Cl/Br and Cl of geothermal water is shown in Figs. 9 and 10. The break line represents the ratio of connate water from seawater. We can see that the Cl/Br of sample 5 is closed to the composition of connate seawater, Br was enriched, showing that Cl/Br was reduced and that the thermal reservoir was closed.

In summary, isotopic characteristics of the geothermal water in groups A–C are totally distinct reflecting their distinct origin and genesis. The isotopic composition of geothermal water in group A is exactly located

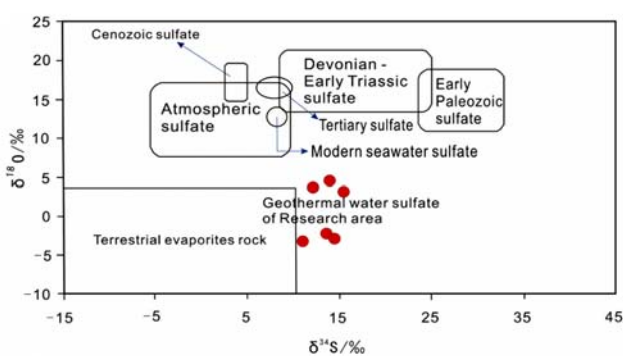

Fig. 8. δ^{34}S、δ^{18}O contradistinction of terrestrial, oceanic, and meterotic sulfate.

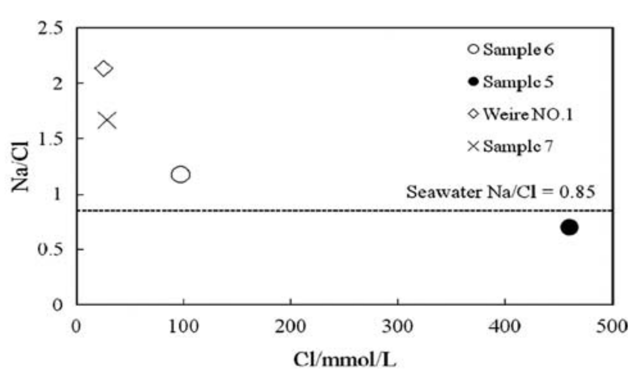

Fig. 9. Relationship between Na/Cl and Cl of geothermal water.

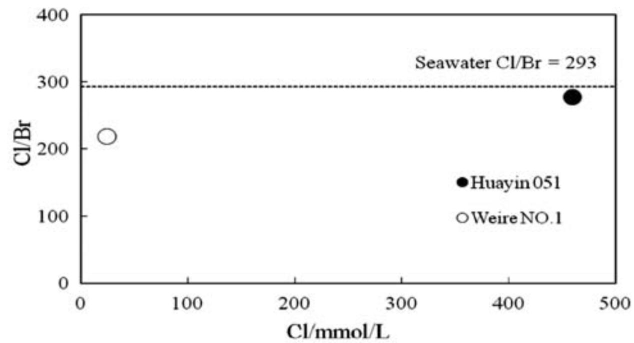

Fig. 10. Relationship between Cl/Br and Cl of geothermal water.

on the LMWL showing that the thermal water in group A is recharged by modern precipitation and it belongs to modern infiltration water. While the geothermal water in group C, represented by sample 5 is characterized by an obvious δ^{18}O shift and a slightly δD shift, which is a typical characteristic isotope features of connate water. Additionally, geochemical characterization of Na/Cl–Cl and Cl/Br–Cl ratios is similar to those of connate seawater, supporting the conclusions from the isotope study. It is also worth noting that quick sedimentation and long-term sedimentary-evolution history has offered appropriate geological condition for formation of connate water. All of the above discussion offers the evidence of possible genesis for residual connate water of geothermal water in Guanzhong basin. Group B is in the evolution process from group A to C, so water in group B has mixing characters of groups A and C, which is indicative of minor characteristics of connate water, and mainly characteristic of water desalted by meteoric water from cracked faults.

6. Conclusions

(1) Isotopic and hydrochemistry characteristics of geothermal water are completely distinct in Gushi depression. Among them, the storage environment of group A is of an open hydrologic cycle. Furthermore, the storage environment of group C is the most closed, groundwater alternatively extremely slow and water–rock reaction is extraordinarily efficient. While group B is a kind of transition water between groups A and C.

(2) Geothermal water in Gushi depression is recharged by ancient or modern precipitation, but not primary magmatic water, metamorphic water, seawater, or mantle water.

(3) The origin of geothermal water in the Gushi depression can be divided into three categories. The first category is recharged by ancient or modern precipitation, represented by group A. The second category is represented by group C, which is highly $\delta^{18}O$ shifted. The third, group B is a kind of mixed water with minor characteristics of connate water and major characteristics of desalted by latter meteoric water.

(4) Isotopic and geochemical characteristics of sample 5 are greatly similar to the connate water, it can speculated for connate water.

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