^{36}Cl Age Study for Deep Geothermal Water of Guanzhong Basin

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Abstract. There are abundant geothermal water resources in the deep of Guanzhong Basin, whose origin and renewable ability has been the focus of academic circles .Previous research results of the environmental isotope hydrogeochemistry showed that there was small amount residual sedimentary water formed in the geological time in the deep geothermal water of study area, which was directly related to the sustainable development and utilization of geothermal resources. So this paper uses ^{36}Cl to study the age of deep groundwater. The results of ^{36}Cl age show that the biggest age of deep groundwater of Guanzhong Basin is 988.69~1123.98ka. Geothermal water with different tectonic units, different closed condition and different genetic types has different ^{36}Cl age.

Introduction

In the deep of Guanzhong Basin is rich in geothermal water resources, but the disorderly exploitation of geothermal water has led to a sharp decline of underground water level in recent years. Therefore, the origin of the deep geothermal water in the Guanzhong Basin has become the primary task of the sustainable development and utilization of geothermal resources. Qin Dajun believed the source of geothermal water in Xi'an for the Quaternary glacial precipitation in North Qinling Mountains[1]; Wang Runsan[2] believe that the geothermal water of Guanzhong basin in a closed state basically; Ma Zhiyuan[3~5] believed that the deep geothermal water in the Guanzhong Basin may exist residual sedimentary water； The study of ^{36}Cl dating in foreign countries started earlier, in 1983[6], the age of the core of the Saline Lake in the United States was determined by ^{36}Cl and prove the reliability of ^{36}Cl dating principle; this paper will use ^{36}Cl isotope dating method to study the deep geothermal water in the Guanzhong Basin, and provide evidence for the existence of residual sedimentary water and provides the evdience for the sustainable development of geothermal water resources in the research area.

General Situation

The study area is located in the central region of the Guanzhong Basin, an area of about 6000 Km^2 ，Northern study area is bounded by 10 km north of Weihe fault, south to Qinling piedmont fault, West bounded by the Yabai - Qishan fault and the East bounded is Chang'an - Lintong fault, It's mainly involves Xianli step-fault (Xianyang-liquan step-fault), Xi'an Sag and Gushi Sag three structural fault block. Geothermal wells in the study area mainly mined thermal reservoirs is Cenozoic Quaternary and Neogene strata, Respectively sanmen Formation of the lower Pleistocene of Quaternary（Q_p^1s），Zhangjiapo Formation of Neocene（N_2z），Lantian-Bahe Formation of Neocene（N_2l+bh），Gaoling Formation of the Miocene Neocene（$N_{1g}l$）. Among which, Lantian-Bahe Formation is the best of the reservoir condition and is also the main reservoir layer of devolpment and utilization currently, but also the main layer and fundamental purpose of this study.

Sampling and Testing

The groundwater samples and rock samples for the study mainly from Lantian-Baheheat reservoir,a total of 21 water samples were collected. Including Xi'an Sag 4, Xianli step-fault 7, Gushi Sag 3, Qinling piedmont shallow grouandwater 4, atmospheric precipitation 3. Isotope testing including δD, $\delta^{18}O$ and ^{36}Cl /Cl, where δD and $\delta^{18}O$ isotope samples measured by the In Chinese Academy of Geological Sciences and Institute of Environmental Geology Hydrogeology. $^{36}Cl/Cl$ are tested by China Institution of Atomic Energy. 10 rock samples were collected： Xi'an Sag 4， Xianli step-fault 4, Gushi Sag 2.

Relationship between ^{36}Cl and Cl^- 、 ^{18}O in groundwater

The relationship between $^{36}Cl/Cl$ and Cl^- can be used to determine the source of ^{36}Cl in groundwater. Figure 1 shows the relationship between Cl^- and $^{36}Cl/Cl$ in the study area is that the evolution of the atmospheric precipitation——shallow groundwater——deep groundwater in the recharge region to the occurrence region is gradually reduced With the increase of depth. Presents the process of gradual decay of ^{36}Cl is the main source of ^{36}Cl in deep geothermal water.

The value of ^{18}O in the Geothermal Water indicates the degree of exchange between the Geothermal Water and the surrounding rock, the greater the value, the greater the degree of exchange between the ground water and the surrounding rock. Figure 2 shows, drift of $\delta^{18}O$ in Gushi Sag is the most significant in the deep geothermal water, followed by East of Xianli step-fault,The drift of $\delta^{18}O$ in Xi'an Sag and west of Xianli step-fault is the least. With the increase of the drift of $\delta^{18}O$,the ratio of ^{36}Cl / Cl in Xi'an Sag, Xianli step-fault and Gushi Sag in deep geothermal water changed little ， It is indicated that the ^{36}Cl generated by underground has little contribution to the deep underground water of ^{36}Cl , and it also shows that the geothermal water in the three tectonic units has been formed in similar geological history.

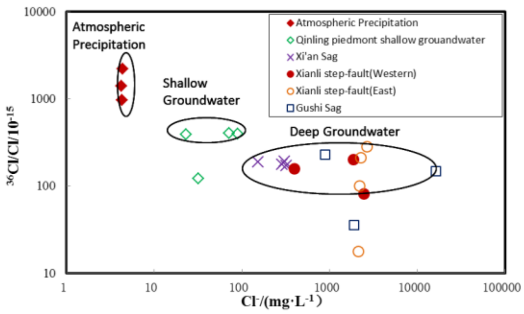

Fig.1 $^{36}Cl/Cl$ versus Cl^- from study area

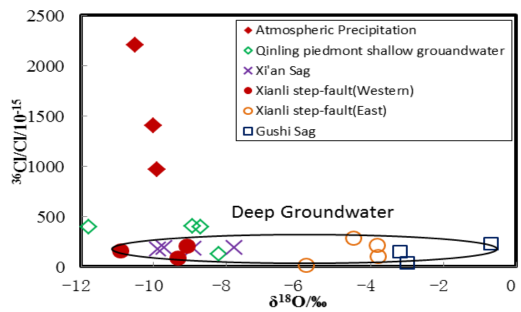

Fig.2 $^{36}Cl/Cl$ versus $\delta^{18}O$ from study area

Calculate the age of ^{36}Cl in groundwater

^{36}Cl decay may be described by a typical exponential equation. The change in the $^{36}Cl/Cl$ ratio with time is then described by[7]

$$R = R_0 e^{-\lambda t} + R_{se}(1 - e^{-\lambda t}) \qquad (1)$$

Where R is the measured $^{36}Cl/Cl$ ratio， R_0 is the initial $^{36}Cl/Cl$ value， λ is the decay constant for ^{36}Cl, R_{se} is the secular equilibrium of $^{36}Cl/Cl$. By equation (1) we can get the formula :

$$t = \frac{1}{\lambda}\ln\left[\frac{R_0 - R_{se}}{R - R_{se}}\right] \qquad (2)$$

In order to calculate the groundwater age, R_0 (initial $^{36}Cl/Cl$ value) must be known. We use equation (3) to calculate the $^{36}Cl/Cl$ value of the recharge area:

$$R_0 = \frac{A \cdot {}^{36}C_0}{N_a \cdot C_0 \cdot 10^{-3}} \qquad (3)$$

Where R_0 is atomic weight of ^{35}Cl（35.5）; N_a is Avogadro constant（6.02×10^{23}）; C_0 is atmospheric precipitation content of Cl^-; C_0 is ^{36}Cl concentration of atmospheric precipitation in the recharge area. We use equation（4）from Andrew and Kay to calculate the ^{36}Cl concentration of groundwater at the recharge area[8]:

$$^{36}C_0 = \frac{F \cdot 3.156 \cdot 10^7}{P} \cdot \frac{100}{100 - E} \qquad (4)$$

Where F is fallout rate; P is mean annual precipitation; E is evapotranspiration. The Guanzhong Basin located in the northern latitude of $33^{\circ}00'$~$35^{\circ}20'$ and the fallout rate in this area is 23 atoms / $m^2 \cdot s$; According to weather data provided by the meteorological department of Shaanxi Province for nearly 30 years, the average years of atmospheric precipitation (P) in the Guanzhong Basin is 586.91mm / a, evaporation percentage (E) is 80%;Cl^- content (C_0) of atmospheric precipitation is 1.92 mg / L. Put F, P, E into equation(4),get $^{36}C_0=6.184\times10^6$ atoms / L. Then put $^{36}C_0$ and C_0 into (3), can be calculated the atmospheric precipitation in the recharge area of $^{36}Cl/Cl$ value that is $R_0=189.93\times10^{-15}$.Because of the limitation of reservoir condition of deep geothermal water in the study area, the secular equilibrium ratio is obtained by using the method of calculation, and it can be calculated by the equation (5):

$$R_{se} = \frac{^{36}N}{^{35}N + ^{37}N} = \frac{\sigma\Phi}{\lambda} \cdot \frac{^{35}N}{^{35}N + ^{37}N} = 4.55 \times 10^{-10}\,\Phi \qquad (5)$$

Where Φ is neutron flux rate ;^{36}N is the number of atoms ^{36}Cl after irradiation neutron flux rate of Φ produced by ^{35}Cl. Atomic number of ^{36}N and Φ can be calculated by equation (6) 、(7):

$$^{36}N = \sigma^{35} N \Phi (1 - e^{-\lambda t}) / \lambda \qquad (6)$$

$$\Phi = P / \sigma_m \quad (cm^{-2} \cdot s^{-1}) \qquad (7)$$

Where σ is the transect of neutron capture reaction of ^{35}Cl（44.1barns） ;λ is the decay constant of ^{36}Cl（$2.3\times10^{-6}a^{-1}$）; P is the total of neutron production rate of rock; σ_m is the weighted average absorption cross section of rock. The total of neutron production rate of rock depends on the chemical composition of the rocks, and the sandstone and mudstone of P can be calculated respectively according to the equation (8) and (9):

$$P_{sandstone} = \rho(0.4764[U] + 1.04[U] + 0.48[Th]) \quad (neutrons \cdot cm^{-3} \cdot a^{-1}) \qquad (8)$$

$$P_{mudstone} = \rho(0.4764[U] + 0.99[U] + 0.46[Th]) \quad (neutrons \cdot cm^{-3} \cdot a^{-1}) \qquad (9)$$

Where $[U]$ and $[Th]$ is the content of U and Th in rocks respectively; ρ is the density of the rock. Accurate calculation the weighted average absorption cross section(σ_m) of rocks require full analysis of the data of rock composition, but generally you can get a better estimate based on 17 elements, the 17 elements respectively Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, Cl, Li, Cr, Co, Ni, Sm, Gd. σ_m can be calculated according to the equation (10)[9]:

$$\begin{aligned}\sigma_m &= \sum \sigma_i N_i \text{ moles} \cdot \text{barns} \cdot g^{-1} \\ &= 0.602 \times \rho \sum \sigma_i N_i \text{ atoms} \cdot cm^{-1}\end{aligned} \qquad (10)$$

Where N_i is element abundance of rocks; σ_i is neutron absorption cross section of each element .According to the study, R_0 = 189.93×10^{-15}, average of R_{se} in the sandstone and mudstone was 9.54×10^{-16}, the R_0 and R_{se} substituted into the equation (2), groundwater sample ages calculation results are shown in Table 1.

Table 1 Calculated ^{36}Cl age of groundwater sample

Numbe		1	2	3	4	5	6	7	8	9	10	11
Age of groundwater/ ka	Maximum		-	-	-	317.5	-		97.4	56.2	72.2	64.2
	Minimum	-	-	-	-	97.4	-	-	4.4	-	-	-
Number		12	13	14	15	16	17	18	19	20	21	
Age of Groundwater/ ka	Maximum	423.5	23.47	118.0	-	-	332.0	1123.9	142.8	809.7	-	
	Minimum	323.7	-	40.8	-	-	239.0	988.6	72.2	675.7	-	

Summary

Deep Groundwater in Guanzhong Basin, Wenre4 and Weire4 the ages of ^{36}Cl ranges 988.69 ~ 1123.98ka and 675.69 ~ 809.77ka. Although there are different degrees of mixing of groundwater in these two samples. However, the reservoir condition is relatively closed, and it still retains the characteristics of the sedimentary water in the geological history, and provides the evidence of the existence of sedimentary water in the depth of the Guanzhong Basin. So the calculated age is younger than actual age, the results of the ^{36}Cl dating should be regarded as the lower limit of the age of sedimentary water, the age of the original sedimentary water in the Guanzhong Basin is at least more than one million years.

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