Application of Environmental Isotopes to Study the Origin and Recharge Mechanism of Geothermal Water

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Abstract. To study the recharge mechanism of groundwater, it is necessary to determine the source of recharge water, the location of recharge area, recharge period, recharge channel and recharge rate. The study of groundwater recharge by using environmental isotopes is based on the change of isotopic composition of water with space and time. On the one hand, the isotopic composition is not affected by physical and chemical processes and remains basically unchanged during the migration from the heat source to the sampling point. Therefore, it is suitable for labeling or tracer; On the other hand, they are very sensitive to temperature change, water rock interaction, steam emission, mixed dilution of water from different sources and surface evaporation. Therefore, they are suitable as geological indicators of these processes.

Keywords: Environmental isotopes · Geothermal water · Origin and supply mechanism

1 Introduction

Most of the heat energy in the geothermal system is stored in the rock mass, but the heat energy transmission is not only through heat conduction, but also mainly through the convective circulation of water (liquid water and steam). Therefore, geothermal water is the main object of geothermal field exploration and development. In recent 30 years, the scale of geothermal water exploitation and drilling depth in China are increasing day by day, which requires scientific evaluation of geothermal water resources. One of the important topics is to establish a geothermal water mathematical model or simulation model in line with the actual conditions of geothermal field. Therefore, it is necessary to establish and correct the scientific theory and means of the model.

Since the early 1960s, the International Atomic Energy Agency began to operate the global atmospheric precipitation monitoring network (GNIP), which promoted the birth of isotopic hydrology and provided theories and methods for studying the natural water

M. A. Jan and F. Khan (Eds.): BigIoT-EDU 2022, LNICST 465, pp. 243–248, 2023.
https://doi.org/10.1007/978-3-031-23950-2_27

cycle and evaluating the age of groundwater from the nuclear level. China has also operated the China atmospheric precipitation isotope monitoring network (CNIP) since 1985 to study the temporal and spatial distribution and environmental effects of atmospheric precipitation in China (Wang Dongsheng, 1993), which provides background data and basic theory for the application of environmental isotopes in all scientific fields related to natural water in China [1].

Therefore, environmental isotopes have been increasingly applied in the exploration and development of geothermal water in China. A series of studies have been carried out on the origin, recharge and chronology of geothermal water, and an attempt has been made to correct the conceptual model of geothermal water by using environmental isotopes (Wang et al., 2001). The study of geothermal water recharge mechanism and chronology is the basis of applying environmental isotopes to correct the conceptual model of geothermal water. This paper focuses on the theory, method and latest progress of the application of environmental isotopes in the study of geothermal water recharge mechanism.

2 Related Work

2.1 Origin of Geothermal Water

The origin of geothermal water can be atmospheric precipitation, river water, lake water, etc., collectively referred to as "atmospheric water"; it can be water buried in the formation, such as formation water, syngenetic water, etc., collectively referred to as "sealed water" At first, it was thought that magma was the common origin of heat, water and solute. Later, geothermal water was found by comparing the isotopic composition of geothermal water and regional atmospheric precipitation δ The H value tends to be close to the local atmospheric water (Craig, 1963), indicating that the geothermal water mainly originates from the atmospheric water, because the surrounding rock is usually poor in hydrogen, and the geothermal water is very weak during its migration from the heat source to the sampling point δ It is inconvenient to keep the H value basically. At the same time, it is found that the ^{18}O value of geothermal water is greater than that of local atmospheric water in varying degrees. The experiment shows that this is the relationship between water and surrounding rock under high temperature conditions δ ^{18}O values are usually about + 10%) as a result of isotopic exchange. The increase of ^{18}O values of many geothermal waters relative to local atmospheric precipitation is increasing δ The D-^{18}O diagram shows a nearly parallel drift, which indicates that there is little composition of geothermal water from magma with uniform isotopic composition. Of course, the possibility of magmatic water participating in atmospheric water recycling is not ruled out [2].

Through the comparative study of hydrogen and oxygen isotopes of atmospheric precipitation and geothermal water, China's geothermal water is divided into cyclic geothermal water and sealed geothermal water. Cyclic geothermal water occurs in the deep aquifer outside the fold system and large artesian basin, which is mainly controlled by hydrostatic pressure and geostatic pressure. Cyclic geothermal water has isotopic composition and hydrogeochemistry similar to modern atmospheric precipitation

Genetic coefficient, geothermal water points are distributed along the global atmospheric drawdown line, as shown in Fig. 1.

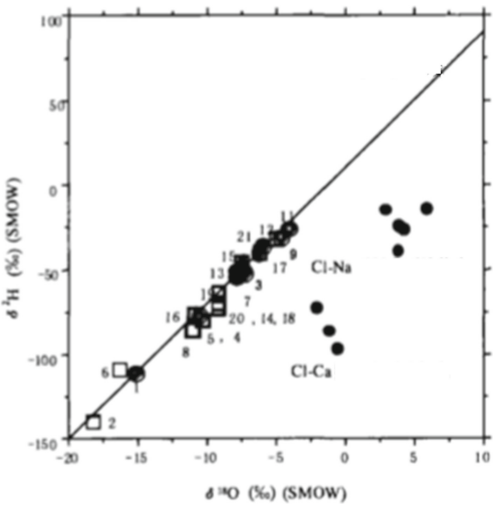

Fig. 1. Hydrogen oxygen isotopic composition diagram of geothermal water and atmospheric precipitation

2.2 Application Principle of Environmental Isotopes

The so-called environmental isotopes refer to those stable isotopes and radioisotopes that exist in the environment and whose concentration is not controlled by the researcher during the research project, which are different from those manually put in quantitatively under the control of the researcher.

In recent 40 years, environmental isotopes have been applied to large geothermal fields in the world. At present, they have become a common means of geothermal development. Among them, the application of stable isotopes has two aspects: on the one hand, the isotopes of some elements, such as the stable isotope atmosphere of hydrogen, due to the lack of hydrogen in the surrounding rock, the migration of deuterium from the heat source to the sampling point is not affected by physical and chemical processes, and the concentration remains basically unchanged, which is suitable for marking or tracing the origin of water molecules; On the other hand, the isotopes of some elements, such as oxygen isotope ^{18}O, are very sensitive to temperature change, water rock interaction, steam emission, mixing and dilution of water from different sources, and surface evaporation due to the oxygen enrichment of surrounding rock [3]. It is suitable to be used as a geological indicator of these processes.

In the hydrological cycle, when the physical state of water (gaseous liquid solid) changes, the fractionation intensity of the isosteric cords of hydrogen and oxygen in water molecules is inversely proportional to the ambient temperature, which is related to factors such as latitude, elevation and season. Therefore, the mass number difference of stable

isotopes of hydrogen and oxygen in water molecules can be used to mark the formation environment of water. Tritium and ‘C are the most commonly used radioisotopes in geothermal investigation. They can be used to determine the age of geothermal water or to find out the share of recent atmospheric precipitation. On the basis of monitoring the isotopic background value of regional and urban atmospheric precipitation, combined with the labeling or tracing of stable isotopes in water molecules and the timing of radioisotopes in water solutes and solvents, it is helpful to reveal the origin and recharge mechanism of groundwater (including geothermal water) and eliminate the multi solution of single application of hydrogeochemical and hydrogeological methods.

3 Study on Groundwater Recharge

Groundwater recharge refers to the process that the aquifer or aquifer system obtains water from the outside. It has a wide range of supply sources, including atmospheric precipitation infiltration supply, surface water (rivers, lakes, oceans, etc.), irrigation water return supply, overflow supply and artificial recharge supply. According to the recharge source of groundwater, lerneretal (1990) defined three main recharge mechanisms, as shown in Fig. 2: direct recharge, and groundwater recharge by direct infiltration in a large range of precipitation; Indirect recharge: the leakage of surface water supplies groundwater; Localized recharge: ponding infiltration in small depressions, and three recharge mechanisms can exist at the same time. These three recharge mechanisms recharge groundwater through the downward infiltration of precipitation into the soil, and the infiltration of precipitation into the soil and through the soil matrix is a complex process.

Generally speaking, there are two main infiltration modes after precipitation enters the soil: piston flow and preferential flow. In the piston flow, the soil water moves in the form of stratification, and the new water discharges the old water in the form of horizontal push from top to bottom, so that the soil water is pushed down. In the preferential flow, the new water may bypass the old water existing in the soil matrix through shortcuts (such as vertical cracks, megaspores, rotten plant roots and earthworm holes), so as to migrate faster to the deeper soil layer. Among the three recharge mechanisms, these two different water infiltration modes can exist at the same time, and the differences of infiltration modes can be reflected from the properties of soil water. For example, two different infiltration types will produce different soil water isotope profile distribution characteristics, and then the infiltration type can be determined, that is, the infiltration mode of water in soil can be determined.

Mastering the groundwater recharge mechanism can provide basic information for water resources management. Therefore, since the mid-1980s, the international hydrogeological community has paid attention to the quantitative study of groundwater recharge, and the study of groundwater recharge has entered the peak. The methods of quantitative research on groundwater recharge have gradually become richer, and the application of methods has changed from one method to multiple methods. However, different research methods have their applicability and limitations. It is very important to select appropriate methods, especially for areas with thick unsaturated or water storage, the hydrological process is very complex, and the selection of groundwater recharge research methods is very key.

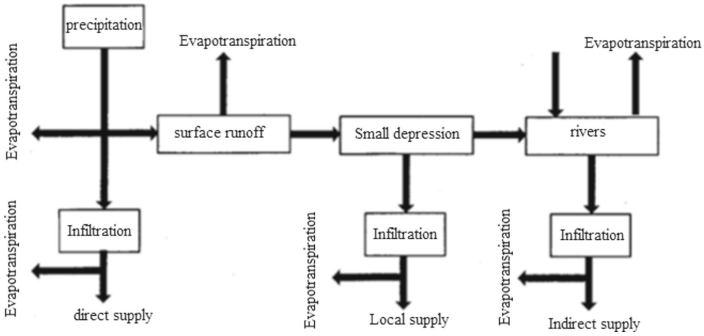

Fig. 2. Groundwater recharge mechanism

4 Application of Environmental Tracer in Groundwater Recharge

(1) Hydrogen and oxygen stable isotope
Environmental isotopes widely exist in various water bodies in nature. In the process of conversion between different water bodies, isotopes have different contents in different water bodies due to their fractionation effect. Using the difference of isotopic contents, we can study the mutual transformation formula and amount of different water bodies. The change of stable isotopic composition in nature is very small, so it is generally used internationally δ Value to represent the isotopic content. δ Value refers to the thousandth difference between the stable isotope ratio (R) in the sample and the isotope ratio of standard water sample, i.e.:

$$\delta = \frac{R_{sample} - R_{reference}}{R_{reference}} \times 1000\% \tag{1}$$

When δ ^{18}O and δ When D is positive, it means that the sample is enriched with ^{18}O and D than smow standard (standard average seawater); When it is negative, it indicates that the two isotopes in the sample are poorer than those in smow standard. For different water bodies δ ^{18}O and δ The difference and correlation of D value can reveal the source of precipitation water vapor, the way of precipitation supplying groundwater, the way of soil water transport and the transformation relationship of different water bodies.

(2) Conservation of chlorine
The conservation of chlorine was proposed by briksson and khunakasem in 1969. It was originally used to study the groundwater recharge in the coastal plain of Israel. The basic principle is that the chlorine element of rainfall and groundwater is conserved. After measuring the chlorine element content of rainfall and groundwater, the recharge of groundwater can be calculated. Namely:

$$\overline{P} \times \overline{C}_p = \overline{R}_t \times \overline{C}_{gw} \tag{2}$$

Chloride mass balance (CMB) can directly obtain the rate of direct infiltration recharge of precipitation at spatial points. It is the main method for the study of

groundwater recharge in thousands of arid and semi-arid areas. Chlorine conservation can be used in both saturated and unsaturated zones. Using this method, rainfall data of a hydrological year are usually collected, and the average value of chlorine in precipitation is calculated by rainfall weighted algorithm. The average value of chlorine in groundwater can be obtained by arithmetic average value. The use of this method must meet the following four preconditions: the chlorine in groundwater comes from atmospheric precipitation; In the groundwater system, chlorine is stable without any chemical reaction; The total amount of chlorine does not change with time [4]; There is no cycle of chlorine in the aquifer. Therefore, the mass conservation method of chlorine has limitations. If there is a soluble substance containing chlorine in the formation (such as salt rock, etc.), or when the wind transports the salt from another system to the study area, the chlorine conservation method is not applicable. Soil chloride ion sampling shall be conducted in areas with little impact of human activities as far as possible to avoid the impact of human input of chloride ions (such as non irrigated wasteland). When there is human input of chloride ions (such as irrigation), the chloride ions input from irrigation must be taken into account in the chloride ion mass balance to improve the accuracy of evaluation.

5 Conclusion

On the basis of monitoring the isotopic background value of regional atmospheric precipitation, combined with the labeling or tracing of stable isotopes in water molecules and the timing of radioisotopes in water solutes and solvents, it is helpful to reveal the origin and recharge mechanism of groundwater (including geothermal water) and eliminate the multi solution of single application of hydrogeochemical and hydrogeological methods. Taking deuterium as the main marker of the origin of geothermal water, through the comparative study of environmental isotopes and hydrogeochemistry between geothermal water and atmospheric water, magmatic water or formation water in North China Plain, it is found that cyclic geothermal water has isotopic composition and hydrogeochemical genetic coefficient similar to modern atmospheric precipitation, indicating that it mainly originates from atmospheric water, Chronological studies show that circulating geothermal water is usually not supplied by modern times, and its main supply period is the cold and wet period of late Pleistocene, while sealed geothermal water is ancient water with an age of hundreds of millions of years, and its origin is related to the dehydration of gypsum or the dehydration and exhaust of upper mantle.

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