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Groundwater Formation Mechanism in Beishan Area, Northwest China—A Potential Site for China's High-Level Radioactive Waste Repository

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China is now facing the challenge of how to safely dispose of high level radioactive waste (HLW). At present, deep geological disposal scheme is widely accepted for HLW disposal in the world. The basic concept of deep geological disposal is to place prepared and packaged radioactive waste in excavated tunnels in geological formations. This concept relies on a series of barriers, natural and engineered, to store the waste for thousands of years and to minimize the amount of radioactive material that may eventually be transported from the repository to the human environments.

Groundwater is the primary medium by which radionuclides could be transported from a repository to the human environments. Therefore, the primary functions of the barriers are to keep water away from the waste as long as possible, and to limit the amount of water that finally contact the waste, and to slow the release of radionuclides from the waste, and to reduce the concentrations of radionuclides in groundwater. Where and when radionuclides will finally reach the biosphere depends mainly on the groundwater flow directions and flow rate. So that, the hydrogeological research plays an very important role in the sitting and site characterization for a potential site of a HLW disposal repository.

Hydrogeological studies will focus on how groundwater moves through a site and how it could affect a repository. Therefore, groundwater formation must be the principal hydrogeological problem in the site characterization for a potential site of a HLW disposal repository. Beishan area is located in the rocky gobi desert region in northern part of Hexi Corridor, with dry climate, little precipitation, few or no inhabitants, and no prospects of economic development. The granite that is widely distributed in this area is the best host rock for the HLW disposal repository. During the last several years, hydrogeological investigations have been carried out in this area. Based on the synthetic analysis of hydrogeology, groundwater chemistry, isotopes ,dynamic characteristics of groundwater level and so on, the groundwater formation mechanism in Beishan preselected area of HLW disposal repository is discussed in this paper.

1 General Situation of the Study Area

The study area is located in the northwest of Gansu Province, and is attributed to a low-mountain hill area. Topography shows high south and low north. The southern area is a low-mountain one and constitutes a NWW-trending insequent arranged mountain terrain composed of Huayaoshan-Zhangfanshan-Batannanshan with intensely dissected topography. The elevation range is 1670～1834m above sea level and the relative difference in elevation is about 165m. The northern area comprises hill area composed of rocky desert with little difference in elevation. The rocky desert consists mainly of granite and is located at the same elevational surface (1700m a.s.l). Muddy desert forms two trains of NE-striking depressions. The eastern Jiujing-Bantan depression is the main water-catchment area in the region. Valleys and canyons are developed in the region. These are NE- and EW-trending linear valleys controlled by faults without perennial surface water and obvious terraces. EW-trending valleys are developed at the northern margin and in the central-south part of the region. The NE-trending valleys are relatively small and attributed to subsidiary drainage. Surface water appears only in the rainy season in valleys and it become dry soon after raining.

The climate in the study area belongs to the continental mid-Asia desert climate. Summer is seriously hot with the highest temperature reaching 37.3℃ and the winter is terribly cold with the lowest temperature of -28.3℃. The

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yearly average temperature is 4～6℃ and the daily temperature difference may reach 20～25℃. July to August is rainy season. The rainfall is small and not homogeneously distributed. Powerful rainfall results in mountain torrents. Snowfall usually begins in October. Frozen period lasts from November to March of the second year. The yearly rainfall is only from 60mm to 120mm, but the yearly evaporation reaches 3130.9mm.

The study area is a gobi-desert area with only several families of herdsmen engaged in husbandry of sheep and camels. No important mineral resources have been found in the study area up to now. Basically there is no prospect of economic development. That is one of the main reasons why the area has been chosen as a potential site for China's HLW disposal repository.

2 Hydrogeological Condition

In general, Beishan area is very poor in groundwater resources. The pumping tests in the area here shows that the outflow rates for most of the boreholes are less than 50m3/d. Based on the topography, lithology, and geological structure, The groundwater in Beishan area is grouped into three categories. (1) the upland rocky fissure unit, (2) the valley and depression pore-fissure unit and (3) the basin pore-fissure unit. The upland rocky fissure groundwater is the most prevalent in this area.

The hydrogeological characteristic of each unit is described as following.

(1) Upland rocky fissure groundwater: It is the most important groundwater type in Beishan rarea and is mainly phreatic water occurring in weathering and structural fissures. The groundwater recharge relies primarily on the precipitation infiltration, with the discharge occurring mostly through evaporation and lateral outflows into the fracture water-bearing zone, intermontane, and valley depression as a result of underground runoff. The present water level in the pre-selected area is about 12m～65m below the surface. Water content is controlled by the topography and geomorphologic landscape.

(2) Valley and depression pore-fissure groundwater: In Beishan area the valley and depression are generally coincident with the fault zone. That is, they are often developed on the bases of fractures and faults, so that the amount of this kind of water is commonly more abundant than that of the others. The water table is shallower, with the depth of 2 m to 8m below the surface. The water is mainly recharged by the infiltration of rainfall and temporary water flood and the main discharge relies on the evaporation and runoff towards the basin and the Hexi Corridor.

(3) Basin pore-fissure groundwater: This kind of groundwater is mainly distributed in basins in the north and the northeast of the area. The basins are mainly composed of Jurassic, Tertiary and Quaternary age formations. This kind of groundwater gets its recharge from the lateral inflows. The amount of basin groundwater depends mainly on conditions of basin scale, lithology of aquifer, and structure. In general, the water head is close to the surface. In some areas, the groundwater becomes artesian.

3 Groundwater Formation Mechanism

As has been mentioned above, for a HLW repository site the hydrogeological studies will focus on how grongdwater moves through the site and how it could affect a repository. Beishan area is in the northern part of Hexi Corridor where is very little rainfall, most of which evaporates. Approximately only 60mm to 120mm of rain falls on the area in a year. That means the groundwater resources must be very poor in the area. But according to the results of borehole drilling and testing as well as regional hydrogeological investigation in the area (up to now 19 boreholes have been drilled for project of HLW repository in the area), the groundwater distributed almost everywhere. How and where does the groundwater come from? In the last several years, we did a lot of research and investigation work to get evidences trying to answer the question. Based on the results of research and investigation work, we recognized that the groundwater is mainly recharged from the infiltration of rainfall in the area. The evidences are shown as following.

3.1 Evidence from groundwater long-term monitoring

Long-term monitoring of groundwater in the area was conducted from 2004. Up to now, more than 10 boreholes and shallow wells have been monitored in order to know the dynamic characteristics of groundwater level. The results show that the variation range of groundwater level in shallow observation wells was more than 1.5m (belongs to mix dynamic type of infiltration, evaporation and runoff) and indicate a closer relation between shallow groundwater and precipitation. For the shallow boreholes (at depth above 150m), the variation range of groundwater level was generally less than 1m (belongs to mix dynamic type of weak infiltration, evaporation and runoff) which shown the relation between groundwater in this depth and precipitation was not very close. For the deep boreholes (at depth above 600m), the variation range of groundwater level was mostly less than 0.5m (belongs to mix dynamic type of weak infiltration and weak runoff) which shown the relation between deep groundwater and precipitation was not very obvious. From above evidence, we can recognize the groundwater is mainly recharged from precipitation in the study area.

3.2 Evidence from in-situ seepage test

In-situ seepage test plays an important place in calculation parameters of aeration zone and then analyzing the relationship between groundwater and precipitation because of its accuracy, convenient and low cost. From 2009 to 2012, we carried out the in-situ seepage test in study area for different geomorphologic types such as valley, depression and clinoform. The calculated filtration coefficients are shown in Table 1. It can be seen that the mean filtration coefficient for valley is the biggest one with value of 4.0×10^{-5} m/s in three kinds of geomorphologic types. The mean filtration coefficient for depression is the smallest one with value of 0.769×10^{-5} m/s. From the values of filtration coefficients in three kinds of geomorphologic types, we can recognize that the groundwater is mainly recharged by precipitation infiltration through valley sediment in the study area. Actually, although the precipitation is small, powerful rainfall is generally formed and results in valley flood in the study area. According to our observation in last several years, the continuance time of valley flood was seldom more than 3 hours and most of floodwater disappeared through seepage in the area.

Table 1 calculated filtration coefficients from in-situ seepage test

Geomorphic type	test number	filtration coefficient （m/s）	Mean filtration coefficient（m/s）
valley	32	$1.9\times10^{-5}\sim9.77\times10^{-5}$	4.0×10^{-5}
clinoform	14	$7.57\times10^{-6}\sim2.4\times10^{-5}$	1.6×10^{-5}
depression	9	$2.05\times10^{-6}\sim1.73\times10^{-5}$	0.769×10^{-5}

3.3 Evidence from hydrogen and oxygen isotopes of groundwater

During last several years, we have carried out much research on isotope hydrology to understand the formation of groundwater in this area. Many groundwater samples were collected and analyzed for δ^{18}O, ^{2}H and ^{3}H isotopes. From analyzed results, we can see that the δ^{2}H values of shallow groundwater generally lie in the range -26.3‰～-86.8 ‰ and the δ^{18}O values are mostly in the range of -2.7‰～-10.4 ‰. For the deep groundwater, the δ^{2}H values are mainly in the range of -62.8‰～-73.1‰, and the δ^{18}O values generally lie in the range of -8.0‰～-8.90‰. For the surface water, δ^{2}H values arnge from -51.2‰ to -78.0‰, and δ^{18}Ovalues are from -6.9‰ to -10.47‰.

From the plot of δ^{2}H versus δ^{18}O, it can be found that stable hydrogen and oxygen isotopic compositions in Beishan groundwater fall on a line very similar to that of world meteoric water line, indicating that both shallow and deep groundwater are of meteoric origin. But the difference of stable isotopic content between shallow groundwater and deep groundwater is very clear. That is shallow groundwater is abundant in heavy isotopes, while deep groundwater is lacking in heavy isotopes. This is an indication that the two waters do not have a common origin yet both are “normal” groundwater and fall on a line very similar to that of world meteoric water line. It is known that some ancient waters have heavy isotope content lower than that for recent local recharge area. So the difference is, almost certainly, a reflection of cooler recharge conditions that existed during the infiltration of the deeper waters. From the above discussion, it can be concluded that the shallow groundwater with higher δ^{2}H and δ^{18}O is mainly recharged by recent and local precipitation, and the deep groundwater with lower δ^{2}H and lower δ^{18}O may be originated from regional precipitation at higher elevation, or may be from the precipitation during the geological history period with lower temperature.

3.4 Evidence from other aspects

Generally, hydrogeochemical characteristic can be used to deduce the groundwater origin. According to our research on groundwater chemistry in the area, the concentrations of TDS in groundwater generally increase along the flow path. In the groundwater recharge area, the TDS are generally less than 1g/l; while those in the groundwater discharge area are greater than 3g/l, with the highest value reaching 80g/l. That is enough to prove that lixiviation and evaporation are the basic pattern forming the groundwater chemistry in the area. Lixiviation occurs mainly in recharge areas with higher elevation, with evaporation occurring over the discharge areas at lower elevation.

Noble gases have decisive advantages for application as tracers in groundwater research because of their chemical inertness. From 2009 to 1011, we carried out the research on noble gases and their isotopes in the area. The noble gas isotopes such as ^{4}He, ^{20}Ne, ^{40}Ar, ^{3}He/^{4}He, ^{40}Ar/^{36}Ar, ^{4}He /^{20}Ne, ^{4}He /^{40}Ar were measured and analyzed for both shallow and deep groundwater. Based on obtained data, the cycle characteristics of different aquifer systems were analyzed. The evidences from noble gases and their isotopes also indicate that the groundwater is mainly of meteoric origin in the area.

Key words: Groundwater formation; hydrogeological condition; isotope; noble gas; groundwater