Isotopic geochemistry of the groundwater system in arid and semiarid areas and its significance: a case study in Shiyang River basin, Gansu province, northwest China

J.A. Shi · Q. Wang · G.J. Chen · G.Y. Wang · Z.N. Zhang

Abstract Shiyang River basin, located in the eastern part of Hexi Corridor in the middle Gansu province, NW China, is a typical arid to semiarid area. Within its drainage distance of merely 300 km, the groundwater system shows a gradual hydrochemical zonation from the upper reach to the lower reach, which is composed of hydrocarbonate, sulfate to chloride zones respectively. Variation in the saturation index (SI) of calcite and dolomite shows that, under arid to semiarid conditions, the drastic evaporation causes the groundwater quality to deteriorate in the lower reach. Isotopic compositions of H, O and He in the groundwater show that the groundwater recharge sources are mainly from meteoric water. δ^3He–^{3}He/^{20}Ne coordinates could clearly distinguish the water sources and mixing among them. In the Caiqi region, there is apparent mixing of the crevice water containing excess ^{4}He with the overlying groundwater, which also implies a much lower circulation rate of the groundwater. Fairly high ^{3}He/^{4}He ratios of the groundwaters collected from the adjacent area of hidden faults along Qilian Mountains show the eminent input of mantle-derived helium, indicating that these faults not only cut the crust deeply, but are currently active.

Keywords Arid and semiarid areas · Helium isotopic anomaly · Hydrochemical zonation · Northwest China · Saturation index

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Introduction

The mainland in northwest China is an ecologically fragile area, which is characterized by the features of arid to semiarid areas. These features include low and irregular rainfall, high temperature, drastic evaporation and eminent drought periods. Under such conditions, the distribution of annual precipitation and partitioning of surface water to groundwater vary from year to year. In addition, unplanned human activities, such as over-use of the groundwater, have led to serious consequences, for example, intense mineralization of downstream waters, a decrease in natural recharge to the groundwater, lowering of the regional water table, land desertification and salinization as well as degeneracy of vegetation. In recent years, strong dust-storm (also called the black storm) events frequently occur in four northwest provinces, including Gansu, Xinjiang, Ningxia and Inner Mongolia (Xu and others 1979; Iwasaka and others 1983; Cheng and others 1995), which is probably a warning from nature that more dangerous disasters are likely. If such a situation continues, the deterioration of the environment and ecosystem of this vast area is unavoidable.

Over the past decades, the Chinese government and scientists have carried out much research on the assessment, development, utilization and conservation of water resources in northwest China (Ma 1996; Zhang 1996; Zhou 1996). Shiyang River basin, located in the eastern part of the Hexi Corridor in the middle Gansu province, northwest China, has the typical climate features of the arid to semiarid inland. Research interests have been focused on aspects such as utilization survey, evolutionary prediction, reserve estimation and systematic assessment of natural water resources. Some reasonable allocation and utilization plans have been proposed (Liu and others 1998; Ye and others 1998). However, study of the hydrochemistry (especially isotopic geochemistry) of water resources is rather sparse, and efforts to use the geochemistry data available to solve particular problems are even fewer or non-existent. There are few investigations on the interaction and mechanism between surface water, groundwater and rock.

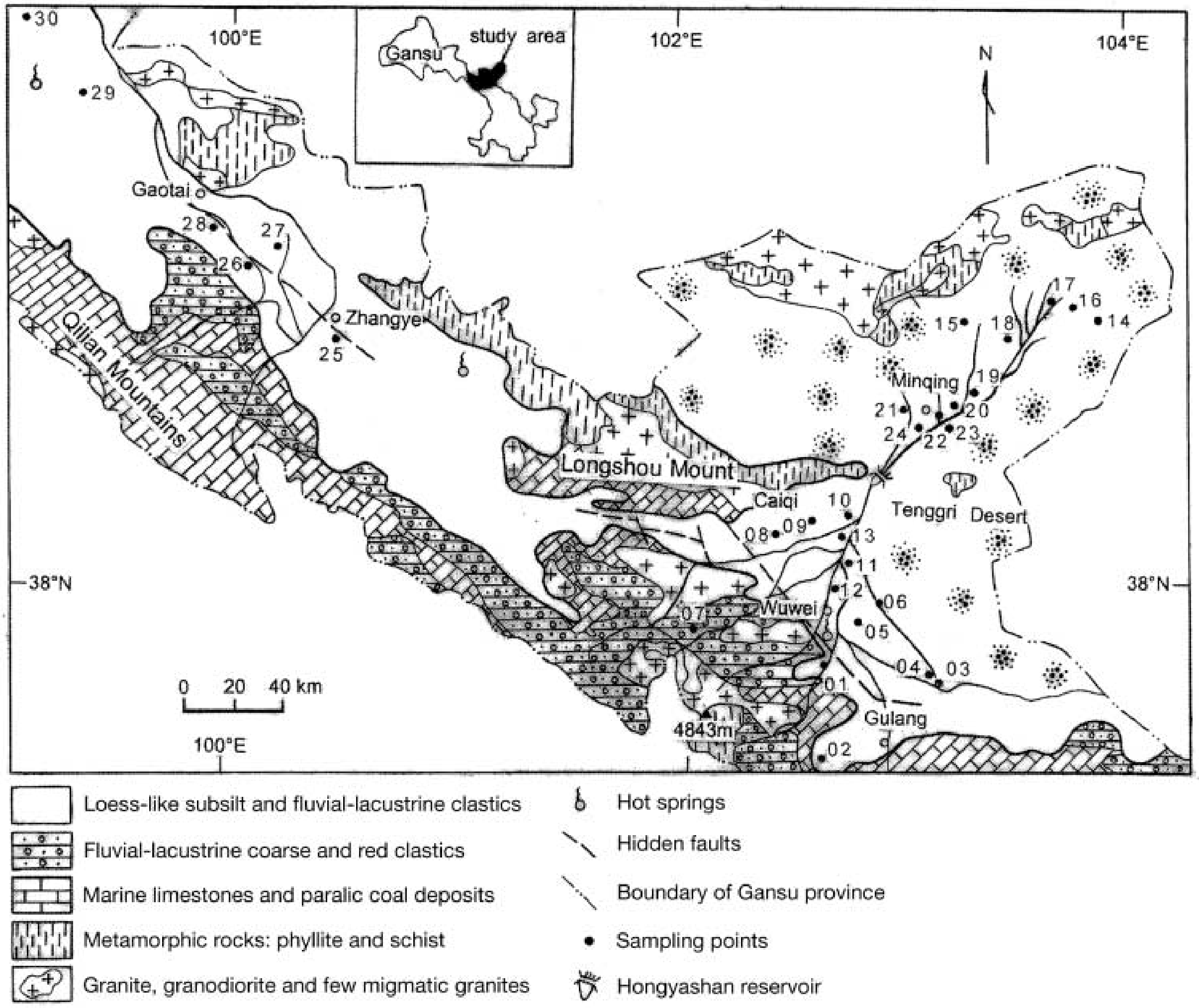
A river basin can be regarded as a whole ecosystem in which meteoric water, surface water and groundwater can transfer into each other to form a complete water cycle. Also, a close relationship exists between its water quantity and quality. This cycle controls the regional geochemical characteristics of the water environment. The groundwater system is one of the key links of the whole ecosystem, and any changes in the links will have a great impact on the whole system.

This study combined the systematic analysis of the hydrochemical types and features of the whole river basin with computer simulation and isotopic geochemical methods. The objective was to elucidate the controls of groundwater quality evolution, recharge, circulation and mixing processes and, furthermore, to explain the mechanism of these processes from the standpoint of environmental geochemistry. The results of the study may provide a theoretical basis for the government to make utilization strategies for water resources and development policies in northwest China in the new century.

Hydrology of the study area

Shiyang River basin is located in the eastern part of the Hexi Corridor, Gansu province, with a drainage area of 4.16×10^4 km^2.It originated from the Lenglongling glacier of the Qilian Mountains. Its total length is merely 300 km. It disappears in the Tenggeri desert (Fig. 1). The Qilian Mts. forms the southern part of the river basin. The elevation of the main peak, Lenglongling, reaches 4,832 m. Many modern glaciers are distributed above 4,500 m, occupying an area of ~64.8 km^2. The middle and northern part of the river basin is a plain that can be

Fig. 1
Location map of study area with simplified geological settings and sampling points



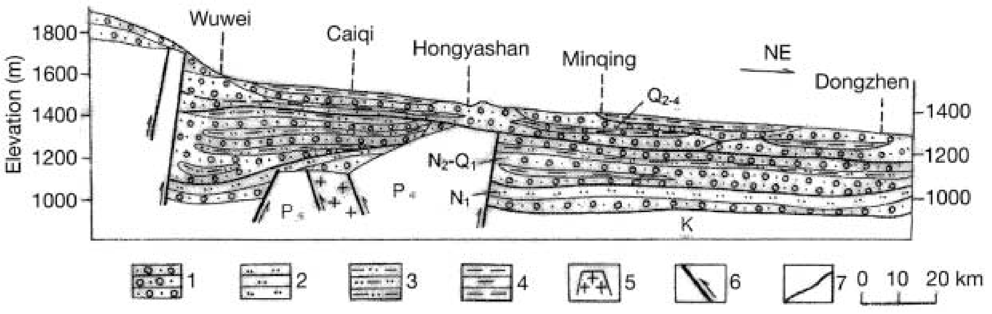


Fig. 2
Geological cross section of Shiyang River basin. *1* Gravel, pebble and coarse sand; *2* fine sands and silt; *3* sub silt; *4* clay; *5* granite; *6* faults; *7* stratum boundary

divided into two sub-basins, Wuwei and Mingqing sub-basins. The tail of Longshoushan Mountain, a branch of the Qilian Mts. separates them, where Hongyashan reservoir was built in the 1950s (Fig. 1). Consisting of Quaternary alluvial and pluvial sediments, Wuwei basin lies in a depression at the foot of the Qilian Mts. with an elevation ranging from 1,400–2,500 m. The loose Quaternary sediments filling the basin are of great thickness, which provide an ideal place for groundwater preservation. In terms of the hydrogeological characteristics, two geomorphologic units are recognized in Wuwei basin, a faulting-terrace zone and its sub-basin. The former is in the vicinity of Qilian Mts. and lies on the head of a pluvial fan. The aquifer there is composed of gravel and sand with a thickness of <50 m. Well-connected porosity of the aquifer provides a good conduit for groundwater flow, which is the basin's recharge region. The sub-basin is the enrichment zone of groundwater. As the grain size of the aquifer gradually decreases from south to north and the flow rate becomes slower, the hydraulic gradient becomes smaller. Along with the uplifting of the Quaternary basement, the burial depth of the aquifer becomes shallower, resulting in the springs of groundwater from the middle part of the Wuwei basin.

Minqing basin is mainly composed of Quaternary eolian and lacustrine deposits, with an elevation that ranges from 1,290–1,500 m. It borders the Wuwei basin to the south, Tenggeri desert to the east and north, and Longshoushan Mountain to the west. The loose Quaternary sediments (300–400 m in thickness) are well developed in this basin. Sand and silt constitute the aquifers, which are separated by the clay-dominant layers into 10 to 15 water-bearing zones (Fig. 2). Meanwhile, small gravel-pebble strips occur to the south of the basin.

Zonation of hydrochemical types

Based on long-term observation of groundwater hydrochemistry, the hydrochemical types show an obvious zonation from the upper to lower reaches. It changes from HCO_3^- through to SO_4^{2-} to Cl^- types (Fig. 3).

As shown in Fig. 3, HCO_3^-–Ca^{2+} or HCO_3^-–Ca^{2+}–Mg^{2+} water is mainly to the south of the basin where the recharge zone is located. Meteoric water can easily flow through the gravel and pebble aquifer, and groundwater is actively circulated. As a result, the water-rock reaction time is short, which leads to the formation of weakly mineralized hydrocarbonate water. From the south to the middle, the hydrochemical zone gradually transforms into a HCO_3^-–SO_4^{2-}–Ca^{2+}–Mg^{2+} or HCO_3^-–SO_4^{2-}–Ca^{2+}–Mg^{2+}–Na^+ type. To the north of the basin exists a discontinuous SO_4^{2-}–HCO_3^-–Ca^{2+}–Mg^{2+} zone or even SO_4^{2-}–Ca^{2+}–Mg^{2+} water. As a result of runoff leakage, a narrow HCO_3^-–Ca^{2+} or HCO_3^-–Ca^{2+}–Mg^{2+} zone occurs along the bank of Shiyang River. This kind of regional zonation is consistent with the flow direction of the groundwater. A hydrocarbonate (fresh water) zone is located in the south, hydrocarbonate–sulfate (fresh water) zone in the middle, sulfate–hydrocarbonate (sub-fresh water) zone in the north and a sulfate (saline water) zone in the northern margin of the basin.

From Hongyashan reservoir to the north, with a latitude ranging from 38°24′N to 38°38′N, the SO_4^{2-}–HCO_3^--type water is dominant, whereas a SO_4^{2-}–Cl^-–Na^+–Mg^{2+} zone occurs in the region from 38°38′N to 39°02′N .The northeastern part of the basin is the lowest reach of the river, the geochemistry of which is SO_4^{2-}–Cl^-–Na^+ and Cl^-–Na^+ (brine). The hydrochemical features of Mingqing basin are very complex because of the lower rate of groundwater flow, decrease in hydraulic gradient and shallower burial depth of the aquifer. In addition, the intense evaporation under arid climate causes a sharp increase in mineralization of groundwater, resulting in the large regional differentiation of hydrochemical types.

Both the Wuwei and Minqing basins show gradual hydrochemical zonation. In the upper reach, the mountainous crevice water and mountain front gravel–pebble facies form a hydrocarbonate zone. A sulfate zone occurs in the mountain front pluvial and lacustrine plain in the lower reach, which gradually transforms into a chloride zone in the desert and salty areas in the lower reach.

Sampling and methods

Oxygen and hydrogen samples were collected from the water-supplying wells within the Quaternary aquifer in Wuwei and Minqing basins in August 1997 and April 1998, respectively. All water samples were packed in plastic bottles, which were then sealed with wax. No air bubbles were allowed in the bottles to avoid exchange with

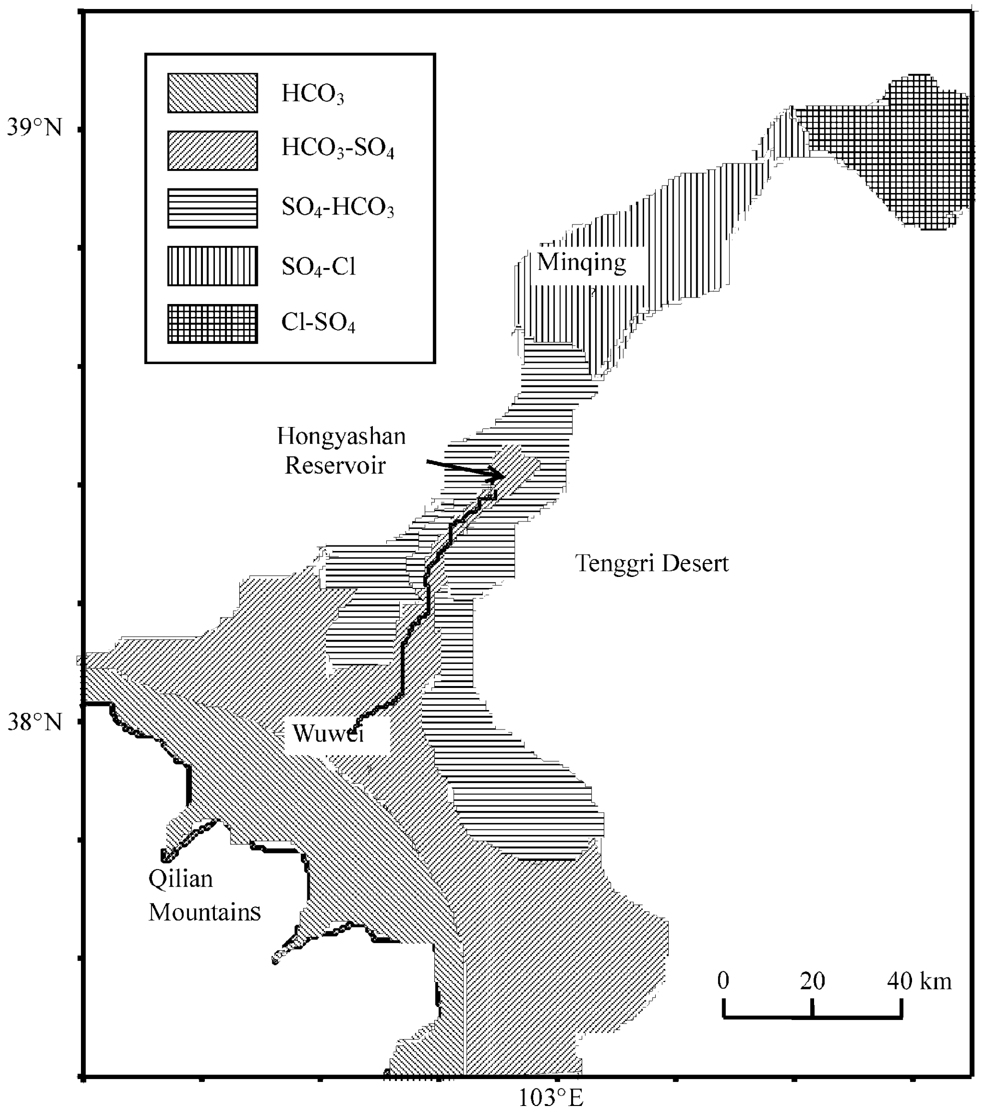


Fig. 3
Hydrochemical zones of the groundwater system in Shiyang River basin

carbon dioxide in the air. Deuterium (D) and oxygen-18 (O^{18}) were measured by MAT-252 mass spectrometry. Hydrogen samples were prepared by a zinc reduction method under temperatures of up to 700 °C, and ^{18}O samples by a H_2O–CO_2 equilibrium method. Here, SMOW (standard mean ocean water) was adopted as the criterion for measuring H and O isotopic compositions. Duplicate analyses of δD is within $\pm 1‰$ and $\delta^{18}O$ within $\pm 0.1‰$.

Helium samples were collected from the wells drilled in the Quaternary aquifer. In order to carry out comparison research, a few samples from the Heihe River basin (Fig. 1) were also gathered. To prevent air contamination and He leakage, special sodium-bearing glass bottles with lower He permeability were used in water sample collection. In the laboratory, all water samples were degassed under vacuum conditions to extract the gases, which were then pumped into a VG-5400 mass spectrometer through a gas purification apparatus. The air of Lanzhou city served as a working criterion with $^3He/^4He$ of 1.40×10^{-6} and $^4He/^{20}Ne$ of 0.318. $^3He/^4He$ of the groundwater can be expressed by δ^3He, which shows the He isotopic anomaly of groundwater in comparison with the air. δ^3He means $(R/Ra\text{-}1) \times 100\%$, in which R is the $^3He/^4He$ ratio of the measured sample, and Ra is the mean value of the atmospheric $^3He/^4He$, which is equal to 1.40×10^{-6}. Table 1 gives the analytical results of H, O and He isotopic compositions of the groundwater samples from the Shiyang and Heihe River basins.

Results and discussion

Hydrogen and oxygen are two widespread elements in nature. They have lower atomic orders and a much larger difference in isotopic ratio, that is, $\Delta A/A$ of H:D up to 100% and $^{16}O:^{18}O$ to 12.5%, where A is the mass number of the isotope and ΔA is the difference between the light and heavy isotope. The utmost isotopic fractionation can

Table 1
Isotopic composition of the groundwater samples from Shiyang and Heihe River basins. The samples W01 to W13 were collected from the upper reach of the Shiyang River, W14 to W24 from the lower reach of the Shiyang River and W25 to W30 from Heihe River. For their locations, see Fig. 1 where the sampling numbers are simplified

Sampling no.	Well depth (m)	$^3He/^4He$ ($\times 10^{-6}$)	δ^3He (%)	$^4He/^{20}Ne$ ($\times 10^{-7}$)	$\delta^{18}O$ (‰)	δD (‰)
W01	25	1.36 ± 0.04	−2.86		−6.9	−68.0
W02	7	1.50 ± 0.05	7.14		−7.1	−72.0
W03	180	1.36 ± 0.04	−2.86		−7.2	−79.0
W04	130	1.39 ± 0.04	−0.71	6.12	−7.3	−75.0
W05	70	3.20 ± 0.10	128.57	10.2	−7.5	−74.0
W06	75	1.50 ± 0.04	7.14	5.10	−6.6	−75.0
W07	4	1.29 ± 0.04	−7.86	4.77	−7.2	−70.0
W08	70	0.548 ± 0.016	−60.86	3.95	−6.6	−75.0
W09	70	0.428 ± 0.012	−69.43	4.84	−6.8	−79.0
W10	80	0.314 ± 0.01	−77.57	5.21	−6.9	−77.0
W11	27	1.55 ± 0.05	10.71		−7.2	−83.0
W12	20	2.42 ± 0.07	72.86	8.23	−7.5	−74.0
W13	280	0.0867 ± 0.0027	−93.81	23.8	−8.7	−87.0
W14	30	0.573 ± 0.015	−59.07	6.76	−7.2	−80.0
W15	60	1.19 ± 0.03	−15.00	5.12	−8.3	−77.0
W16	45	1.87 ± 0.04	33.57	7.29	−7.1	−76.0
W17	300	1.59 ± 0.04	13.57	5.41	−7.3	−75.0
W18	70	1.41 ± 0.04	0.71	6.77	−9.7	−96.0
W19	100	1.24 ± 0.04	−11.43	13.9	−9.5	−86.0
W20	80	1.75 ± 0.05	25.00		−6.9	−77.0
W21	80	1.50 ± 0.04	7.14	4.65	1.2	−73.0
W22	100	1.42 ± 0.04	1.43	4.97	−6.7	−81.0
W23	60	1.23 ± 0.04	−12.14	4.67	−7.4	−76.0
W24	100	1.35 ± 0.04	−3.57	4.73	−6.8	−73.0
W25	120	3.94 ± 0.1	181.43	13.0	−7.4	−75.0
W26	22	3.04 ± 0.08	117.14	12.0	−7.9	−72.0
W27	1	1.58 ± 0.04	12.86	7.43	−7.0	−79.0
W28	29	1.66 ± 0.04	18.57		−7.1	−68.0
W29	12	0.09 ± 0.003	−93.53	11.9	−6.9	−91.0
W30	60	1.53 ± 0.04	9.29	5.20	−7.6	−77.0

take place in natural status between their isotopes. In a natural water body the fractionation processes of H and O isotopes are also affected by physical and chemical factors. Therefore, they are sensitive isotopic tracers, and are widely applied in studying natural water circulation and movement of groundwater (Tolstinkin and others 1996).

After performing statistics of typical H and O isotopic values on rain from different regions in China, Zheng (1983) proposed a meteoric water line equation, $\delta D = 7.9\ \delta^{18}O + 8.2$ (Fig. 4). It shows a much larger deviation of H and O isotopic compositions from the meteoric water line. This is mainly because of the effect of local variations in rainfall (Dansgaard 1964). In addition, the poor coverage of vegetation in Shiyang River basin is another factor. During the recharge of meteoric water into groundwater, drastic evaporation can produce a much larger isotopic fractionation and cause deviation from the meteoric water line.

In the vicinity of Caiqi, the ^{18}O value is 9 units lighter than that in other areas by 2 units. This is because of the distribution of granite and metamorphic rocks (Fig. 1). When groundwater contacts with these rocks, water can exchange H and O isotopes with minerals in them. Such a water–rock equilibrium fractionation can reduce the content of ^{18}O in water. The representative reaction of O isotope can be expressed as follows:

$$0.5Si^{16}O_2 + H_2^{18}O = 0.5Si^{18}O_2 + H_2^{16}O, \ \alpha = 1.0492;$$

$$0.33C^{16}O_3^{2-} + H_2^{18}O = 0.33C^{18}O_3^{2-} + H_2^{16}O, \ \alpha = 1.0286$$

where *a* is the fractionation coefficient. At 25 °C, both reactions have much larger α, and the fractionation will enrich ^{18}O in the rock and ^{16}O in the water. The isotopic fractionation intensity and the water–rock system depend on the temperature, quantity ratio of water and rock, and reaction time. The water–rock equilibrium fractionation is very small during groundwater leakage. The slow groundwater circulation rate enables a full isotopic exchange between water and rock.

Distribution of δD and $\delta^{18}O$ values of surface water and groundwater has an obvious tendency for the $\delta^{18}O$ values to increase from the surface water to shallow and deep water, especially in those samples distributed at the margin of Minqing basin with well depth exceeding 200 m. Their average $\delta^{18}O$ values are much higher than that of

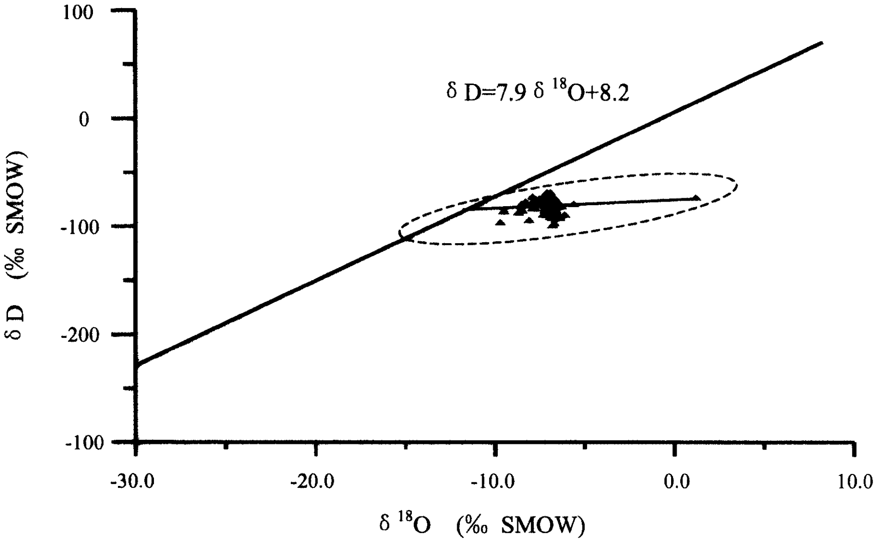


Fig. 4
Characteristics of H and O isotopic compositions of the groundwater in Shiyang River basin

the shallow and surface water of Wuwei basin Therefore, the groundwater around the Minqing desert margin has undergone very intense evaporation. In addition, the results of computer simulation on groundwater geochemistry have also confirmed this viewpoint. Groundwater continuously exchanges matter with various minerals and gases within the aquifer. As the exchange mainly takes the form of dissolution and precipitation of minerals, the saturation state of minerals in the water solution is the key factor to control in this exchange process. Through calculating the activity of various ions in groundwater, the saturation state of relative minerals can be stimulated. The saturation index (SI) is generally used to express the saturation state of the minerals. When SI is <1, the minerals will be dissolved. While SI is >1, they will deposit. Using the equilibrium coefficient method, the authors have developed a geochemical simulation program to calculate the SI indexes of calcite and dolomite in the groundwater of Shiyang River. Simulation results show that the calcite and dolomite reached oversaturation in April (dry season) in most areas of Wuwei basin, and in April and August (wet season) in all sampling wells in Mingqing basin (Fig. 5A, B).

Under normal conditions, both minerals rarely reach oversaturation at the same time because of the effect of isocation. There are two external factors that could make the two minerals precipitate simultaneously. One is the dissolution of gypsum in an aquifer. If enough gypsum is dissolved into the groundwater, the two minerals can be deposited at the same time. However, the concentration of $CaSO_4$ in shallow groundwater is very low. Few gypsum and anhydrite minerals are found in the shallow aquifer. The influence of this aspect can be eliminated. Drastic evaporation of groundwater is another possible factor. The annual mean evaporation of Wuwei and Minqing basin is higher than the rainfall, especially in winter and spring. In April, the calcite and dolomite of the groundwater in both basins are oversaturated. In July and August, because of the increase in crevice water recharge and rainfall, the two-carbonate minerals are in an unsaturated state in Wuwei basin. In contrast, both minerals in Mingqing basin are undersaturated throughout the year because the evaporation is much higher than rainfall under extremely dry climate conditions.

Hellium isotopic compositions of the groundwater are principally dependent on three aspects: the dissolved atmogenic helium, radiogenic helium released from water-bearing rock, and mantle-derived helium. In air-saturated surface water the ^{3}He/^{4}He ratio of the dissolved atmogenic helium is a constant of 1.399×10^{-6}. The concentration of atmospheric helium is mainly controlled by the temperature of meteoric water and the mean air pressure of the drainage area (Kamensky and others 1991). Most ^{4}He originates from the decaying products of the radioactive elements U and Th. Granite and metamorphic rocks rich in U and Th are the main origins of radiogenic ^{4}He. The input efficiency of He into water depends upon the concentration of U and Th, porosity, density and degassing efficiency of water-bearing rock and so on. Mantle-derived helium has a much higher ^{3}He/^{4}He ratio of $\sim10^{-5}$ and a narrow variation range (Wang 1989). The content of mantle-derived helium in groundwater is closely related to the tectonic activity; in particular, the deep fault-aided diffusion can prominently increase the content of mantle-derived helium in groundwater (Scholz and others 1973). Therefore, the ^{3}He/^{4}He ratio can be regarded as a sensitive indicator of a helium source. It can also be used as a stable tracer of groundwater in a basin, because it is slightly affected by temperature and salinity.

Hellium isotopic compositions of the groundwater in Shiyang and Heihe Rivers have a wide variation range from –93.8 to 181.4% (Table 1). The samples from other sources are close to the atmospheric He, ranging from -20 to $+20\%$. The ^{3}He/^{20}Ne ratios vary in a range from 4.65×10^{-7} to 7.43×10^{-7}, which is slightly higher than that of the air. Besides, the H and O stable isotopic com-

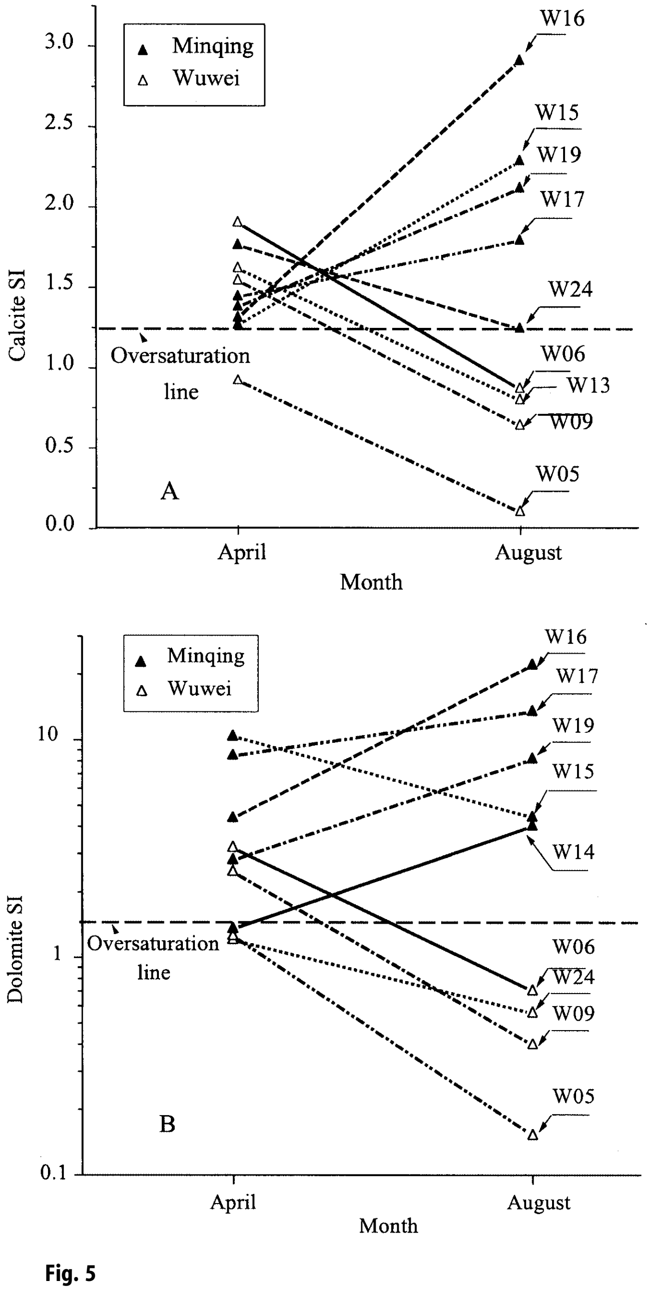


Fig. 5
Seasonal changes of SI indexes in the groundwater of Shiyang River. **A** Calcite; **B** dolomite

positions of these samples have a small variation range, with δD between -68 and -96‰ and δ^{18}O between -6.6 and 9.7‰.The means of δD and δ^{18}O are very close to that of the local meteoric water and glacial ablation water, implying that the meteoric water is the main recharge source of the Shiyang River.

As indicated in Table 1, the ^{3}He/^{4}He ratio of the groundwater in Caiqi, northeast of Wuwei basin, is lower than that of the atmospheric helium by 1 to 2 orders of magnitude, which implies that a significant amount of radiogenic helium has entered the groundwater. The gradually uplifting of the basement of Wuwei basin from south to north may lead to the fact that the depth of basement granite and metamorphic rocks is <300 m and the shallowest is only 100 m (Fig. 2). A large number of granite and metamorphic rock bodies are in this area (Fig. 1). To the south of the Qilian Mts. small- to medium-scale granite bodies of Caledonian rock exist , which is mainly composed of granodiorite, biotite granite, and Middle Cambrian metamorphic rocks. These well-fissured rocks contain abundant minerals rich in parent radioactive elements such as U and Th. The parent elements naturally decay to produce abundant excess ^{4}He in the crevice water. In addition, the grain sizes of the Pleistocene and Holocene aquifers become so small that they have greatly hindered the circulation of the groundwater. This causes an increase in mineralization, ranging from 1–5 g/l, and even >10 g/l in some of the water-supplying wells. Nearly stagnant groundwater prolongs the mixing time of the crevice water with the upper groundwater, and results in the apparent increase in ^{4}He in the groundwater.

Some inland salt lakes formed several hundreds years ago in the area of Dongzhen, the lower reach of Minqing County, and Gaotai county, and in the middle and lower reaches of the Heihe River (Fig. 1). Evaporates, including abundant dolomite, gypsum and anhydrite, are widely deposited in the Quaternary sediments. These chemical sediments tend to trap the ^{4}He isotopes derived from the decay of U and Th in adjacent basement rocks. The emitted ^{4}He is active enough to create damaged tracks in a host mineral, and ^{4}He is expected to escape easily along these tracks into crystal imperfections or grain boundaries (Ashkinadaze 1980). When these chemical sediments are dissolved into groundwater, the trapped ^{4}He will apparently elevate the concentration of ^{4}He in groundwater. The high mineralization of the groundwater in these areas, and the appearance of Cl–Na-type water demonstrate the existence of mixing between the fresh groundwater and brine water. Mixing is the principal reason why there is a helium isotopic anomaly in the groundwater. Apparent radiogenic ^{4}He accumulation in groundwater also implies a much slower circulation in the study area. In order to understand the origin of the groundwater, a ^{3}He/^{20}Ne-δ^{3}He coordinate is used. Twenty-four samples are plotted in Fig. 6, which shows a clear zonation of differently sourced groundwaters. Groundwaters from the fault zone at the front of Qilian Mts. contain relatively high δ^{3}He values and a narrow range of the ^{3}He/^{20}Ne ratio, which is indicative of the eminent input of mantle helium. e^{3}He values of the meteoric waters in the recharge zone range from -20 to $+20\%$, and the variation in ^{3}He/^{20}Ne ratios is much smaller. The mixing zone of crevice water and brine has z^{3}He values of $<-50\%$ with a relatively larger range of ^{3}He/^{20}Ne ratios.

The flux of mantle-derived ^{3}He is closely related to the tectonic activities (Li and Du 1998). A deep fault usually acts as an ideal conduit for mantle fluid migration upward and an active fault can greatly enhance the diffusion of noble gases to increase their concentration in the groundwater. In particular, the special physiochemical

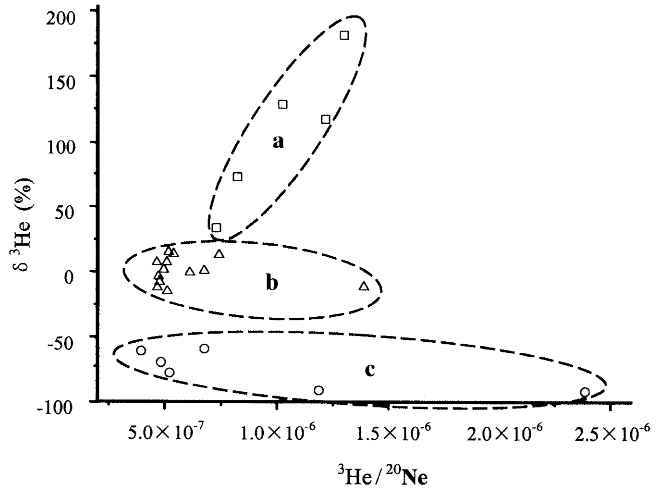


Fig. 6
Plot of δ^3He vs. ^{3}He/^{20}Ne of the groundwater in the study area. a: Groundwater in fault zone in the mountain front; b: recharge zone of meteoric water; c: mixing zone of the crevice water and brine

properties of helium enable it to migrate easily from the mantle to the crust with a strong capacity for diffusion and penetration. Thus, the variation of helium isotopes can provide important information on the activities of tectonics and seismicity.

A series of deep faults developed along the mountain front of Qilian Mts. These faults can be recognized on the Landsat TM image even though some of them are covered with Quaternary sediments. These faults stretch in a direction of NW to SE (Fig. 1). Having formed in the Mesozoic era, they were still active in the Cenozoic because of neotectonism in the Qinghai–Tibet plateau, and frequent earthquakes occurred in the last century in the study area (Guo and Qin 1999).

The high ^{3}He/^{4}He ratio (δ^3He ranging from 70 to 180%) of the groundwater samples collected from the adjacent area of these hidden faults proves the apparent contribution of mantle-derived helium in the vicinity of the fault zone. In addition, three hot springs along the fault zone (Fig. 1) provide evidence of these tectonic activities (Wang and others 1992).

Conclusions

Hydrochemical characteristics of the groundwater in Shiyang River basin show apparent zonation from the south to north. Hydrocarbonate-type water occurs in the gravel-pebble zone of the mount front, and sulfate-type water is mainly distributed in the alluvial, pluvial and lacustrine plain in the middle reach. Sulfate-chloride-type water appears in the marginal area of Tenggeri desert in the lower reach, and even chloride-type brine exists in some parts of the lower reach area. Computer simulation indicates that precipitation is the main factor that controls the groundwater hydrochemistry of Wuwei basin, whereas drastic evaporation influences the geochemistry of the Mingqing basin. Most of the groundwater isotopic compositions of O, H, and He are of meteoric water features, indicating that rainwater is the main recharge source to the groundwater system. Coarser aquifers distributed in the south of Wuwei basin enables rapid recharge into groundwater. In the middle-lower reaches, the recharge rate is much slower and it has a long circulation period. The formation of some of the groundwater is closely related to the mixing of the crevice water and brine. Occurrence of the helium isotopic anomaly in the adjacent area of the hidden fault zone along Qilian Mts. implies the existence of the apparent influx of mantle-derived ^{3}He, which indicates that the fault zone is still active.

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