Research Article

Evidence of the Uyunbulak Salt Lake Water Recharge in the Kumish Basin, Xinjiang, China, from Boron Isotopes

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The reserves of nitrate (NO$_3^-$) mineral resources in the Turpan-Hami Basin in Xinjiang rank second after those in the Atacama Desert in Chile, South America. Considerable attention has been devoted to nitrogen (N) sources of NO$_3^-$ deposits in recent years due to the increase in demand for NO$_3^-$ fertilizers in agriculture and chemical industries. However, although the potassium nitrate (KNO$_3$) deposits in the Uyunbulak salt lake in the Kumish basin, Xinjiang, China, have received increasing attention from numerous researchers in recent years, they all focused on the study of nitrate sources and agreed that the nitrate source in the Kumish basin is mainly atmospheric sedimentation. Studies on their water sources are scarce; for salt lake nitrate deposits, water supply also plays a crucial role in the genesis of the deposit. As a sensitive indicator, a boron isotope is often used to indicate water bodies from different sources. However, the presence of NO$_3^-$ ions in water will interfere with the determination of boron isotopes, so the research on boron isotopes in nitrate salt lakes has been hindered. In this study, the three-step ion exchange method published by Ma et al. (2020) was used to eliminate the influence of NO$_3^-$ ions in water on boron isotope determination, so as to reveal the water supply of Uyunbulak Salt Lake in Kumish basin by using boron isotopes which are more sensitive to water types. In this study, ice and snow meltwater, fissure water, groundwater, and surface water samples were collected from the Kumish basin and analyzed for the determination of boron (B) isotopic and hydrochemical compositions during the migration process of water bodies to reveal the recharge relationship between the water bodies from the northwestern margin of the basin and the study area. The obtained hydrochemical composition results showed a gradual increase in the salinity of the water body from 556 to 7372 mg/L from the northwestern to the southeastern parts of the basin, resulting in a gradual change in the hydrochemical facies type of Uyunbulak salt lake to NaCl. This finding suggested that the water body migrates from the northwestern to southeastern parts of the basin. The results of B isotope composition indicated two types of water bodies from different sources, namely, the ice and snow meltwater of the Southern part of the Tianshan Mountains and groundwater of the basin, exhibiting B isotope composition ranges of 26.66–27.26‰ and 12.75–15.19‰, respectively. These two types of water bodies are mixed at the Uzong spring (Q1). The ice and snow meltwater in the mixed water accounted for 46%, while the groundwater accounted for 54%. The mixed water continues to recharge the Uyunbulak Salt Lake in the southeastern part of the basin.

1. Introduction

The Kumish basin is an intermountain basin located in the southern part of the Tianshan orogenic belt, South Turpan-Hami Basin, Xinjiang, China. (Figure 1(a)) [1–5]. Indeed, the particular geological setting and extremely arid climatic conditions of the Kumish basin have resulted in the formation of rich potassium nitrate (KNO$_3$) deposits [6–8]. The Uyunbulak
salt lake is the lowest and largest playa in the Kumish basin, containing abundant KNO₃ resources [1]. The reserves of nitrate (NO₃⁻) mineral deposits in the Turpan-Hami Basin in Xinjiang rank second, just after those in the Atacama Desert in Chile, South America. Considerable attention has been devoted to the sources of NO₃⁻ deposits by several researchers in recent years due to the increase in demand for NO₃⁻ fertilizers in agriculture and chemical industries, more particularly to the KNO₃ deposits in the Uyunbulak salt lake in the Kumish basin, Xinjiang, China. Several researchers have conducted investigations on the formation process of the Kumish basin, sources of nitrate deposits, and metallogenic age. The obtained results of the formation process and salt-forming age of the Kumish basin were, in fact, relatively consistent. The research on nitrate sources is relatively mature, mainly including the following opinions: (1) NO₃⁻ is related to the capillary transport of groundwater evaporation [9]; (2) volcanic rocks, sub-volcanic rocks, and ancient volcanoes in the mining area are the main sources of NO₃⁻ [10, 11]; (3) NO₃⁻ is derived from metal-catalyzed photochemical reactions [12]; (4) NO₃⁻ can be derived from biological nitrification and nitrogen fixation processes in Jurassic coal measure strata [13, 14], (5) NO₃⁻ are associated with deep brines [15], and (6) NO₃⁻ is of atmospheric origin [16, 17]. The main view of atmospheric sedimentation as the source of nitrate in the nitrate deposit in the Kumish basin has been widely accepted by scholars. However, most of the abovementioned points of view were focused on the study of solid samples associated with nitrate-containing minerals. Li et al. [18] analyzed recharge water samples and soluble salts in the Kumish basin and revealed an enrichment of the Uyunbulak salt lake with K⁺, Na⁺, NO₃⁻, and other ore-forming ions from the northwestern part of the basin. Li et al. [19] showed a gradual migration pattern of Sr²⁺ in water and sediments of the Kumish from the northwestern to southeastern parts of the basin without investigating comprehensively the water migration process and water supply status. Since the origin of evaporite salt deposits is extremely dependent on water bodies and evaporation processes, it is necessary to assess the migration and replenishment of water in the basin. Boron (B) isotopes are reliable indicators that have been widely used to study the crust, mantle, and plate subduction evolution, to track the circulation of oceanic sediments and altered oceanic crust in the mantle in the subducted plates [20, 21] and to trace groundwater pollution [22–28]. B isotopic composition in groundwater is controlled by several factors, including B sources, the mixing process of water bodies from different sources, and the adsorption and fractionation of clay minerals, resulting in distinct characteristics in B isotopic composition between different water bodies. Therefore, B isotopes are good indicators for tracing water sources. In this study, ice meltwater, fracture water, groundwater, and surface water samples were collected from the northwestern edge of the Kumish basin to assess the migration pattern of water bodies in the Kumish basin using the B isotopes in combination with the characteristics of ion content changes during water migration, providing further evidence for the source of mineralized material of NO₃⁻ deposits in the basin.

![Geographical map of the study area. (a) Geographic location of the study area in China. (b) The geographic location of the water sampling sites.](image-url)
Table 1: Geographical locations of water sampling sites and water sample sources.

<table>
<thead>
<tr>
<th>Water sample source</th>
<th>Sample no</th>
<th>Altitude (m)</th>
<th>Longitude (E)</th>
<th>Latitude (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meltwater</td>
<td>K89</td>
<td>1929</td>
<td>87°26.62'23&quot;</td>
<td>42°30'22.09&quot;</td>
</tr>
<tr>
<td>Fissure water</td>
<td>K86</td>
<td>1764</td>
<td>87°32'4.08&quot;</td>
<td>42°30'35.14&quot;</td>
</tr>
<tr>
<td>Fissure water</td>
<td>K83</td>
<td>1706</td>
<td>87°34'12.23&quot;</td>
<td>42°30'19.00&quot;</td>
</tr>
<tr>
<td>Groundwater</td>
<td>J1</td>
<td>861</td>
<td>88°15'36.31&quot;</td>
<td>42°12'43.57&quot;</td>
</tr>
<tr>
<td>Groundwater</td>
<td>J2</td>
<td>814</td>
<td>88°21'35.71&quot;</td>
<td>42°10'9.35&quot;</td>
</tr>
<tr>
<td>Groundwater</td>
<td>X2</td>
<td>774</td>
<td>88°25'18.03&quot;</td>
<td>42°4'49.94&quot;</td>
</tr>
<tr>
<td>Groundwater</td>
<td>X3</td>
<td>756</td>
<td>88°29'45.83&quot;</td>
<td>42°01'38.61&quot;</td>
</tr>
<tr>
<td>Spring water</td>
<td>Q1</td>
<td>713</td>
<td>88°56'5.14&quot;</td>
<td>41°58'29.96&quot;</td>
</tr>
<tr>
<td>Brine</td>
<td>W54</td>
<td>696</td>
<td>89°20'38.68&quot;</td>
<td>41°50'18.10&quot;</td>
</tr>
</tbody>
</table>

Table 2: Results of the chemical analysis of the water samples in the study area.

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>HCO₃⁻ (mg/L)</th>
<th>NO₃⁻ (mg/L)</th>
<th>Cl⁻ (mg/L)</th>
<th>SO₄²⁻ (mg/L)</th>
<th>K⁺ (mg/L)</th>
<th>Na⁺ (mg/L)</th>
<th>Ca²⁺ (mg/L)</th>
<th>Mg²⁺ (mg/L)</th>
<th>TDS (mg/L)</th>
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</thead>
<tbody>
<tr>
<td>K89</td>
<td>185.1</td>
<td>15.6</td>
<td>64.6</td>
<td>144.5</td>
<td>3.4</td>
<td>38.7</td>
<td>75.5</td>
<td>28.3</td>
<td>555.7</td>
</tr>
<tr>
<td>K86</td>
<td>238.1</td>
<td>20.1</td>
<td>255.0</td>
<td>373.4</td>
<td>13.9</td>
<td>209.9</td>
<td>124.0</td>
<td>39.0</td>
<td>1273.3</td>
</tr>
<tr>
<td>K83</td>
<td>183.7</td>
<td>18.5</td>
<td>75.9</td>
<td>277.9</td>
<td>5.1</td>
<td>45.2</td>
<td>105.8</td>
<td>43.4</td>
<td>755.4</td>
</tr>
<tr>
<td>J1</td>
<td>149.9</td>
<td>23.9</td>
<td>307.1</td>
<td>499.8</td>
<td>7.6</td>
<td>274.0</td>
<td>129.6</td>
<td>35.9</td>
<td>1427.9</td>
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<tr>
<td>J2</td>
<td>59.4</td>
<td>38.2</td>
<td>894.2</td>
<td>788.3</td>
<td>11.1</td>
<td>588.8</td>
<td>207.5</td>
<td>77.6</td>
<td>2665.1</td>
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<tr>
<td>X2</td>
<td>87.7</td>
<td>40.8</td>
<td>628.0</td>
<td>541.1</td>
<td>19.3</td>
<td>484.4</td>
<td>89.6</td>
<td>53.5</td>
<td>1944.3</td>
</tr>
<tr>
<td>X3</td>
<td>83.2</td>
<td>22.8</td>
<td>369.1</td>
<td>546.7</td>
<td>11.6</td>
<td>312.7</td>
<td>112.1</td>
<td>44.8</td>
<td>1502.9</td>
</tr>
<tr>
<td>Q1</td>
<td>96.1</td>
<td>34.4</td>
<td>3229.0</td>
<td>1383.0</td>
<td>22.7</td>
<td>2075.0</td>
<td>388.1</td>
<td>144.7</td>
<td>7372.9</td>
</tr>
<tr>
<td>W54</td>
<td>121.1</td>
<td>158.1</td>
<td>178961.0</td>
<td>32740.0</td>
<td>3181.0</td>
<td>113165.0</td>
<td>317.8</td>
<td>8685.0</td>
<td>337329.0</td>
</tr>
</tbody>
</table>

2. Sampling and Methodology

2.1. Sample Collection. In this study, water samples were collected from the Kumish basin, including meltwater and fissure water, groundwater and surface water, and brine samples from the northwestern edge, the middle part, and the southeastern edge of the Kumish basin, respectively. The geographic location and coordinates of the sampling sites are indicated in Table 1 and Figure 1(b). These samples are distributed from the northwestern to the eastern parts of the basin.

2.2. Water Sample Analysis. The water samples need to be separated and purified by ion exchange resin before performing B isotope analysis. However, the presence of NO₃⁻ in the water samples can interfere with the determination of B isotopes. The conventional two-step ion exchange method cannot meet the sample pretreatment requirements [29–32]. Therefore, the three-step ion exchange method [33] was applied in the present study to successfully complete the pretreatment of the sample and effectively eliminate the interference of NO₃⁻ ions with B isotope determinations. The B isotope ratio (11B/10B) was determined using a Cs₂BO₂⁻-graphite [34] on a Triton thermal ionization mass spectrometer (Thermo Fisher Company). This mass spectrometer is indeed, equipped with a special dual Faraday cup system, allowing to achieve dual-acceptance determinations of 309 (Cs₂11BO₂⁻)/308 (Cs₂10BO₂⁻) ion masses. The B isotopic ratio (δ¹¹B) value was calculated in this study using the following formula:

$$\delta^{11}\text{B}(\%o) = 1000 \times \left(\frac{\text{11B}_{\text{sample}}}{\text{11B}_{\text{standard}}} - 1\right) \times \left(\text{11B}_{\text{standard}}\right)$$

(1)

where (11B/10B)sample is the B isotope ratio of the NIST SRM 951 standard and (11B/10B)standard is the B isotope ratio of the actual sample. The standard sample used is NIST SRM 951 H₃BO₃. The 11B/10B ratio of the standard sample determined in this study is 4.05624 ± 0.00002 (2σ, n = 3).

On the other hand, K⁺, Ca²⁺, Mg²⁺, and SO₄²⁻ contents in river water, groundwater, and brine samples were determined using an inductively coupled plasma spectrometer (ICP-OES) (Thermo Fisher Scientific). The detection limits of SO₄²⁻, K⁺, Mg²⁺, and Ca²⁺ were <0.1, ≤0.01, and ≤0.001 mg/L, respectively, whereas the Na⁺ and Cl⁻ concentrations were determined using the ion balance difference subtraction and Hg(NO₃)₂ volumetric titration methods, with determination errors of less than 2.0 and 1.0%, respectively. The B isotopic and hydrochemical analyses of water
samples were carried out at the testing center of the Qinghai Institute of Salt Lake, Chinese Academy of Sciences.

3. Results and Discussion

3.1. Chemical Composition of the Water Samples. The chemical compositions of the water samples in the Kumish basin are reported in Table 2.

According to the data reported in Table 2, a gradual decrease in altitude was observed from K89 to Q1. In addition, the results revealed increases in the concentrations of cations (K⁺, Ca²⁺, Na⁺, and Mg²⁺) and anions (Cl⁻ and SO₄²⁻) in the water body with decreasing altitude, among which Na⁺ and Cl⁻ ions exhibited the most prominent increases (Figure 2). This finding might be due to the presence of widespread quaternary chemical sediments in the Kumish basin, of which halite (NaCl) is the main mineral. The water body can dissolve and filter the salt substances in the stratum during the transport process, thereby gradually increasing the salt content in the water body with the migration distance. The K89 water sample was the original ice and snow melt water flowing into the basin through surface runoff from the southern part of east Tianshan Mountain, representing the water source of the study area. HCO₃⁻, SO₄²⁻, and Cl⁻ represented 49, 35, and 16% of the anion concentrations, respectively, whereas Ca²⁺ was the

![Figure 2: Changes in anions and cations concentrations with the transport process of water (a) cations and (b) anions.](image)
predominant cation, representing approximately 52%. On the other hand, the results showed increases in the contents of various ions with decreasing altitude. Among them, the contents of Cl– and Na+ ions showed the most considerable increase. The Cl– concentration in the Q1 water sample increased to approximately 69% at the Uzong Spring, while the HCO3– concentration decreased from the highest concentration to about 2%, whereas the Na+ concentration initially increased from 29 to 80%. The hydrochemical characteristics of the water body were close to those of the NaCl type brine water (W54) of Uyunbulak salt lake (Figure 3). In addition, the obtained results revealed an increase in the salinity from 556 to 7372 mg/L following the water migration to the Q1 location (Table 2).

3.2. Boron Isotope Analysis. The B isotope analysis results of the collected water samples are reported in Table 3.

It is worth noting that the W54 sample is a brine sample that has experienced an isotopic fractionation through the evaporation process, making it unsuitable for water source tracing.

According to the results reported in Table 3 and Figure 4, the δ11B values of samples K89, K86, K83, and J1 ranged between 26.66 and 27.26‰, suggesting similar B isotopic compositions (green area in Figure 4). For the convenience of description, the combination of K89, K86, K83, and J1 samples will be replaced by component 1 in the following sections, whereas the δ11B values of water samples J2, X2, and X3 ranged from 12.75 to 15.19‰, showing relatively B isotopic compositions (red area in Figure 4). The J2, X2, and X3 sample sequences will be replaced by component 2 in the following sections.

However, it should be mentioned that when B isotope composition is applied to trace the water sources, it is important to determine whether B isotopes are fractionated during the water transport process. Indeed, previous studies have shown that clay minerals have a strong adsorption effect on B [35–37]. Therefore, the influence of clay minerals on B isotopes in water is a factor that must be considered in water source tracing using B isotopes. Vengosh et al. [24] assessed groundwater pollution and successfully predicted the δ11B values of groundwater after being equilibrated with clay minerals in the Dan region. The B isotope composition in groundwater after adsorption onto clay minerals can be simulated according to Equation (2) [26] in order to determine whether the B isotope in groundwater is fractionated due to the clay adsorption.

\[
\delta_{11B_{gw}}^{11B} = \left[ \frac{\delta_{11B_{wz}}^{11B} + 1000}{\alpha - \alpha X + X} \right] - 1000, \tag{2}
\]

where \(\delta_{11B_{wz}}^{11B}\) denotes the \(\delta_{11B}^{11B}\) value of the mixed product of the water source and the Uzong spring, \(\alpha\) denotes the B isotope fractionation coefficient between dissolved and adsorbed B, and \(X\) denotes the remaining B fraction in the solution. \(X\) can be expressed as \(X = 1/(1 + K_d)\), and \(K_d\) denotes the partition coefficient of B in clay minerals.

Since B(OH)\(_3\) and B(OH)\(_4^-\) cannot be completely separated using the currently available methods, the \(\alpha\) value can only be estimated by theoretical calculations and

![Figure 3: Variations of anion and cation proportions in water with water migration ((a) cations and (b) anions).](image-url)

Table 3: Sample sources, B contents, and B isotopic composition in the water samples.

<table>
<thead>
<tr>
<th>Sample source</th>
<th>Sample no.</th>
<th>B content (mg/L)</th>
<th>(\delta_{11B}^{11B}) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meltwater</td>
<td>K89</td>
<td>0.24</td>
<td>26.66</td>
</tr>
<tr>
<td>Fissure water</td>
<td>K86</td>
<td>0.23</td>
<td>26.92</td>
</tr>
<tr>
<td>Fissure water</td>
<td>K83</td>
<td>0.21</td>
<td>27.26</td>
</tr>
<tr>
<td>Groundwater</td>
<td>J1</td>
<td>0.22</td>
<td>26.93</td>
</tr>
<tr>
<td>Groundwater</td>
<td>J2</td>
<td>0.27</td>
<td>15.19</td>
</tr>
<tr>
<td>Groundwater</td>
<td>X2</td>
<td>0.29</td>
<td>13.70</td>
</tr>
<tr>
<td>Groundwater</td>
<td>X3</td>
<td>0.25</td>
<td>12.76</td>
</tr>
<tr>
<td>Spring water</td>
<td>Q1</td>
<td>0.52</td>
<td>19.84</td>
</tr>
</tbody>
</table>
In this study, $\alpha$ was set to 0.981 [29] and 0.969 [35], while the $K_d$ value was set to 4.67 [25]. By applying Equation (2), the expected $\delta^{11}B$ value was calculated after the mixture between sample K89 and the Uzong spring water was equilibrated with clay minerals (curves B and C in Figure 5).

Figure 5: Relationship between the $\delta^{11}B$ values of the water samples and the altitude of the Kumish basin. The green and red areas in the figure indicate the boron isotopic composition ranges of component 1 and component 2, respectively.

Curve A in Figure 5 represents the $\delta^{11}B$ value of water after the ideal mixing of water in the northwestern margin of the Kumish basin and the Uzong spring without clay adsorption. Curves B and C illustrate the expected $\delta^{11}B$ values of the water samples from the northwestern margin of the Kumish basin and the mixed water samples from

Figure 4: Boron isotopic composition of water in the Kumish basin. The green and red areas in the figure indicate the boron isotopic composition ranges of component 1 and component 2, respectively.
the Uzong spring after reaching equilibrium with clay minerals at α values of 0.981 and 0.969, respectively. It can be observed from Figure 6 that the δ¹¹B value of component 2 was 10‰ lower than that of component 1. Previous studies have shown that clay minerals can easily adsorb ¹⁰B in the form of B(OH)₄⁻ [29]. In addition, Palmer et al. [35] showed a distribution coefficient of B in clay minerals of 4.67. Therefore, it can be concluded that the low δ¹¹B value of component 2 was not due to the fractionation of B in the water of component 1, suggesting that there were two types of groundwater in the basin characterized by different δ¹¹B values.

According to Figure 6, the δ¹¹B values of samples K86, K83, and J1 were plotted above the ideal mixing curve without being equal to the expected δ¹¹B values after the B adsorption onto clay minerals. This finding indicates that B isotopes in component 1 were not fractionated with clay minerals. On the other hand, the results in Figure 7 showed similar δ¹¹B values and B contents in component 1, demonstrating that component 1 did not exhibit any adsorption with clay minerals since the occurrence of clay mineral adsorption results in a decrease in B contents. The above-mentioned results indicated that samples K89, K86, K83, and J1 were derived from the same water source.

Similarly, Equation (2) was used in this study to evaluate whether B isotopic fractionation occurred with clay minerals during the water transport process from J2 to the Uzong spring.

Although the δ¹¹B values of samples X2 and X3 (Figure 8) were below the ideal mixing curve, the δ¹¹B values of samples X2 and X3 were relatively similar to that of sample J2. Similarly to component 1, the δ¹¹B values and B contents of component 2 suggested the lack of B isotope fractionation with clay minerals.

Indeed, K89, K86, K83, and J1 samples were derived from the same water source. The water body is transported from K89 to J1, from high-altitude (1929 m) to low-altitude (814 m) areas, respectively, without the occurrence of boron isotope fractionation during the water transport process. J2, X2, and X3 samples were derived from the same water source since the water body migrated from J2 to X3, with altitude values of 861 and 756 m, respectively, without any B isotope fractionation.

After mixing two solutions with different B isotopic compositions, the δ¹¹B value and B content of the mixed solution can be expressed according to the following equations:

\[
\delta^{11}B_{\text{mix}} = B_1 \times \frac{\delta^{11}B_1}{B_{\text{mix}}} + B_2 \times \frac{\delta^{11}B_2}{B_{\text{mix}}} \times \left(1 - \frac{1}{B_{\text{mix}}}\right),
\]

\[
B_{\text{mix}} = B_1 \times \left(1 - \frac{1}{B_{\text{mix}}}\right) + B_2 \times \left(1 - \frac{1}{B_{\text{mix}}}\right),
\]

where \(B_1\), \(B_2\), and \(B_{\text{mix}}\) denote the B concentrations of component 1, component 2, and mixed water, respectively; \(\delta^{11}B_1\), \(\delta^{11}B_2\), and \(\delta^{11}B_{\text{mix}}\) denote the δ¹¹B values of component 1, component 2, and mixed water, respectively; and \(F\) denotes the proportion of component 1.

**Figure 6:** Relationship between the δ¹¹B values and the altitude of water sampling sites in the northwestern margin of the Kumish basin, J1 and the Uzong spring water samples (Q1).
In the Kumish basin, the Uzong spring water is composed of water derived from component 1 and component 2 (Figure 9). Indeed, components 1 and 2 were transported independently before migrating to the Uzong spring without mixing with other water bodies.

3.3. Source of the Uyunbulak Salt Lake Recharge. The results of the hydrochemical composition of water samples in the Kumish basin suggested a migration of meltwater from the southern edge of East Tianshan Mountains in the northwestern part of the basin to the southeastern part of the basin.

![Figure 7: The relationship between boron isotopic composition and boron content in components 1 and 2.](image)

![Figure 8: Relationship between the $\delta^{11}B$ values and the altitude of the samples sampling sites (J1, X2, and X3) and the Uzong spring water samples.](image)
During the migration process, the salt substances in the dissolved strata increased the salinity of the water from 555.7 to 7372.9 mg/L, changing gradually the hydrochemical facies type of the Uyunbulak salt lake to NaCl. Although the chemical composition data of the water body can reveal the water body transport process from a high-altitude to low-altitude area, it cannot determine whether the groundwater in the study area is derived from two different water sources. The variation pattern of the B isotope is sensitive to the change in water compositions, thereby allowing accurate identification of the facies type of groundwater in the study area. The results of B isotopic composition revealed two different types

![Graph](image-url)
of groundwater in the Kumish basin, exhibiting different B isotope value ranges of 26.66–27.26‰ and 12.75–15.19‰. These two types of groundwater were mixed at the Uzong spring and continue to recharge the Uyunbulak salt lake.

3.4. Description of the Water Recharge. The B isotope composition can not only identify the groundwater recharge sources in this study but also determine the contributions of component 1 and component 2 to the Uzong spring water. As reported above, the Uzong Spring water sample consisted of components 1 and 2. The contributions of components 1 and 2 to the spring water in Uzong can be determined using the following formula:

\[
\delta^{11}B_{\text{mix}} = \delta^{11}B_1 \times F_1 + \delta^{11}B_2 \times F_2, \\
F_1 + F_2 = 1,
\]

where \(\delta^{11}B_{\text{mix}}\) denotes the mixed product of component 1 and component 2; \(\delta^{11}B_1\) and \(\delta^{11}B_2\) denote the \(\delta^{11}B\) values of component 1 and component 2, respectively; and \(F_1\) and \(F_2\) denote the proportions of component 1 and component 2 in the mixed product, respectively.

After mixing components 1 and 2, it can be observed from the \(\delta^{11}B\) values of Q1 that component 1 and component 2 accounted for approximately 46 and 54% of the B isotopic composition, respectively, in the Uzong Spring water (Figure 10).

4. Conclusions

According to the hydrochemical and B isotope analysis results of ice and snow melt water, fissure water, groundwater, and surface water samples from the northwestern part of the Kumish basin, the following conclusions are drawn:

1. There were two types of water with different B isotopic compositions in the Kumish basin. Among them, component 1 represented the ice and snow melt water and fissure water from the northwestern part of the basin, which is introduced into groundwater through the surface runoff and infiltration processes, whereas the source of groundwater for component 2 was uncertain. Therefore, further studies are required to determine the source of groundwater with component 2.

2. The Uzong spring water consisted of 46 and 54% of components 1 and 2, respectively. The mixed water body continues to recharge the study area.

3. According to the water’s chemical composition, the water body migrated from the northwestern to southeastern parts of the Kumish basin, with high-altitude and low-altitude areas, respectively. The salts were dissolved and filtered during the migration process, transporting the metallicogenic elements and facilitating the formation of the ore deposits.

Data Availability

All data are derived from our experimental results, which are shown in Tables 2 and 3 of the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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