Provenances and Controlling Factors of Solutes in Surface Runoff in the Tarim River Basin, Northwest China

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Abstract: Research addressing the spatial differences and evolution of river hydrochemistry can clarify the interaction between surface water-soluble substances and the environment, as well as reveal correlations between surface water quality and human activities. Here, by sampling surface runoff and taking regional geology as the background, we analyze the provenances and control factors of soluble substances in the Tarim River Basin. We found that: More than 80% of the soluble ions in surface water originated from rock weathering in the mountains. The Gibbs free energy between the ions showed that when the runoff flowed out of the mountain, the Ca²⁺ and HCO₃⁻ were almost saturated. The major ion concentration rose synchronously with the runoff migration. These findings indicate that the solute of surface water mainly originated from mountainous areas. Soluble substances had difficulty entering the river channel by erosion of the scarce surface runoff.

1. Introduction

Under the influence of climate change and human activities, the water quality had undergone qualitative changes in recent years in the Tarim Basin. At the end of the 1950s, the salinity of each section of the Tarim River was less than 1 g·L⁻¹, which was a typical freshwater river. However, in 2000, the salinity of the water system of Aksu River (Xidaqiao Hydrological Station)-Talimu River (Alar Hydrological Station) was between 248 and 13476 mg·L⁻¹, the average value was as high as 2.7 g·L⁻¹, and the rate of exceeding standard was 39% [1]. Therefore, many scholars had addressed the hydrochemistry of the Tarim River Basin. These studies focused on: (1) Water quality assessment and hydrochemical composition evolution of the main and tributaries of the Tarim River and Aksu River [2]; (2) Solute chemical composition characteristics and solute sources of typical tributaries [3]; and (3) Under the condition of emergency ecological water diversions, hydrochemical characteristics of groundwater and evaporative concentration effects were researched in the middle and lower reaches of the Tarim River [4]. There was a lack of systematic research on the provenances of soluble substances and controlling factors in the watershed.

Aiming at the differences in water chemical composition of rivers in mountainous areas and oasis areas under the influence of humans, the evolution process and controlling factors of water chemical compositions were analyzed based on regional geology, and the influence of human activities on the surface water quality of oasis was discussed in the Tarim Basin.
2. Materials and methods

2.1. Site description

Tarim River (74°~90°E, 35°~43°N) is China’s largest inland river, located in the belly of Eurasia. It is composed of 144 tributaries of nine sub-basins (The Aksu River, Kaidu River-Kongqi River, Dina River, and Weigan River-Kuqa River originate from the southern slope of the Tianshan Mountains; the Kashgar River, Yarkant River, Hotan River, Keriya River, and Qarqn River originate from the Kunlun Mountains/Pamirs Plateau). The surrounding Tianshan Mountains, Kunlun Mountains, Altun Mountains, and Pamir Plateau contribute to the circular distribution of regional landforms. What’s more, alpine glaciers are well-developed (Fig. 1), with areas and volumes of 19,77.65 km² and 2313.29 km³, respectively, accounting for 33.5% and 41.3% of China’s glaciers, resulting in an average of 41.5% and an increasing trend in the recharge rate of glacier meltwater to river runoff[5]. Gobi and deserts are widely distributed in the basin, with 20~80 mm of the annual precipitation and 1600~2200 mm of evaporation in the plain area[6]. However, because of the topography, the measured precipitation can reach more than 800 mm in mountainous areas [7].

![Fig. 1. Distribution of hydrochemical sampling sites in the main channel and tributaries of the Tarim River](image)

2.2. Sample collection and analysis

Given the characteristics of the development, utilization, and consumption of surface water in the Tarim River Basin, sampling was carried out near the hydrological station. In the runoff formation area, there were 19 and 12 runoff sampling points in Kunlun Mountains/Pamir Plateau (KMPP) and Tianshan Mountains (TM) areas, respectively. In the water resource utilization area, there were 3 and 8 sampling points in the oasis area of the Kunlun Mountains/Pamir Plateau Water System (OAKMPPWS) and the oasis area of Tianshan water system (OATWS). And there were 2 sampling points on the mainstream of Tarim River (MTR). Also, 6 samples of lakes/reservoirs in the oasis area of the Tianshan water system (LOATWS) were sampled. To reduce the error, the average of the 2 batches of data from Jul 14th to Aug 9th in 2016 and Jul 6th to Jul 27th in 2018 was used. The cations (Na⁺, K⁺, Mg²⁺, and Ca²⁺) were measured by Dinex-600 ion chromatography, and the anions (F⁻, Cl⁻, SO₄²⁻, and NO₃⁻) were measured by ICS-1500 ion chromatograph. The HCO₃⁻ was titrated with ZD-2 automatic potentiometric titrator. To more objectively reflect the hydrochemistry characteristics of the Tarim River Basin, we also collected the hydrochemical data of the meltwater at the end of the Kartamak Glacier [8], Qingbingtan Glacier No.72 [9], and the Koxkar Glacier [6], and some data of surface runoff obtained by Wu in the Tarim River Basin [10], (Fig. 1).
3. **Results**

3.1. **pH and TDS**

The pH of the surface water was between 6.80 and 8.90, with an average of 7.87 in the Tarim River Basin. TDS was between 115 and 5269 mg·L\(^{-1}\), with an average of 689.15 mg·L\(^{-1}\) (Table 1), which was significantly higher than 205.9 mg·L\(^{-1}\) in the Yangtze River Basin [11] and 453 mg·L\(^{-1}\) in the Yellow River Basin [12], and about 2.6-times higher than the TDS value of 266 mg·L\(^{-1}\) of Heihe, the second largest inland river in China’s Hexi Corridor [13], and also higher than the 388 mg·L\(^{-1}\) of the Nile River basin in the arid zone [14]. In the regional surface runoff, the average TDS in KMP and the TM areas were 437.55 mg·L\(^{-1}\) and 321.58 mg·L\(^{-1}\) respectively, which were only 33.21% and 44.75% of their corresponding oasis areas. The average value of TDS in the MTR was 1079.60 mg·L\(^{-1}\), which lay between the OAKMPPWS (1317.52 mg·L\(^{-1}\)) and OATWS (702.65 mg·L\(^{-1}\)) under human influence.

| Regional | F  | Cl  | NO\(_3\)- | SO\(_4^{2-}\) | HCO\(_3^{-}\) | Na\(^+\) | K\(^+\) | Mg\(^{2+}\) | Ca\(^{2+}\) | Si   | TDS (mg·L\(^{-1}\)) | pH  |
|----------|----|-----|----------|-----------|-----------|--------|-------|----------|--------|-----|----------------|------|
| TM       | 0.01 | 0.83 | 0.04 | 0.73 | 1.40 | 1.03 | 0.06 | 0.48 | 0.86 | 0.12 | 321.58 | 7.89 |
| KMP      | 0.01 | 1.05 | 0.02 | 1.14 | 1.94 | 1.50 | 0.06 | 0.55 | 1.32 | 0.09 | 437.55 | 7.91 |
| OATWS    | 0.04 | 2.79 | 0.02 | 1.31 | 4.04 | 3.97 | 0.11 | 1.28 | 1.18 | 0.09 | 702.65 | 7.85 |
| OAKMPPWS | 0.09 | 9.83 | 0.09 | 3.91 | 2.43 | 9.88 | 0.40 | 2.20 | 2.50 | 0.16 | 1317.52 | 8.09 |
| MTR      | 0.06 | 5.78 | 0.06 | 2.59 | 3.15 | 6.70 | 0.25 | 1.76 | 1.83 | 0.11 | 1079.60 | 7.76 |
| OATWS    | 0.02 | 1.89 | 0.01 | 1.61 | 1.23 | 2.08 | 0.11 | 1.04 | 0.90 | 2562.50 | 7.68 |
| LMTR     | 22.13 | 0.01 | 8.75 | 1.50 | 22.32 | 0.95 | 4.21 | 4.81 | 0.16 | 2562.50 | 7.68 |
| Whole basin | 0.02 | 3.44 | 0.04 | 1.80 | 2.22 | 3.89 | 0.15 | 1.09 | 1.45 | 0.13 | 689.15 | 7.87 |

3.2. **Hydrochemical compositions**

The Cl\(^{-}\) dominated the anion concentration in the Tarim River Basin, with an average concentration of 3.44 mmol·L\(^{-1}\), accounting for 45.75% of the total anions, followed by HCO\(_3^{-}\} and SO\(_4^{2-}\}, accounting for 29.51% and 23.99%, respectively. The proportions of NO\(_3^{-}\) and F\(^{-}\) were very small, only 0.48% and 0.22%, respectively (Table 1). This was different from the phenomenon that the world’s major rivers, including the Yangtze River and Yellow River basin in China, were dominated by HCO\(_3^{-}\} (1.79 mmol·L\(^{-1}\}, accounting for 49.71%) on average [14]. Among the cations, the Na\(^+\} concentration was 3.89 mmol·L\(^{-1}\}, accounting for 59.04% of the total cations, followed by Ca\(^{2+}\} and Mg\(^{2+}\}, which were 1.45 m mol·L\(^{-1}\} and 1.09m mol·L\(^{-1}\}, respectively. The K\(^+\} concentration (0.15 mmol·L\(^{-1}\}) was the smallest, accounting for only 2.34% of the total cations. The order was consistent with the order of the arithmetic average of the cation concentration of the world’s major rivers [14], but the total cation concentration of the former was 2.4-times the average of the latter.

In detail, because of the influence of regional geology and lithology, climatic conditions, and human activities, the anion composition of the surface water was very different in the Tarim River Basin. In the runoff from the KMP and the TM regions, the anion concentration of HCO\(_3^{-}\} was the highest, accounting for 46.77% and 46.37%, respectively, but the ratio of SO\(_4^{2-}\} to the total anion of the former was higher than that of Cl\(^{-}\}. Although the river water in the OAKMPPWS mainly originated from the KMP region, the anion evolved into Cl\(^{-}\} dominating, and its proportion of anion increased by about 1.4-times, while the proportion of HCO\(_3^{-}\}(14.86\%) decreased by nearly 70%. Compared with the runoff in the TM region, the anion concentration of OATWS increased by about 1.7-times. The proportions of HCO\(_3^{-}\}, NO\(_3^{-}\}, and F\(^{-}\} hardly changed, but the proportion of SO\(_4^{2-}\} decreased by 8.31%, and the corresponding Cl\(^{-}\} concentration increased by 6.43%. The total anion concentration in the MTR was 11.64 mmol·L\(^{-3}\}, which lay between the water bodies of the OAKMPPWS (16.34 mmol·L\(^{-3}\}) and the OATWS (8.20 mmol·L\(^{-3}\}). Although its replenishment mainly came from the runoff of the OATWS [5], the Cl\(^{-}\} concentration of the MTR had increased sharply due to the evaporation, human activities, and input of runoff from the OAKMPPWS. For cations, the concentration in the OATWS and LOATWS followed: Na\(^{+}\}>Mg\(^{2+}\}>Ca\(^{2+}\}>K\(^{+}\}, and all other regions follow: Na\(^{+}\}>Ca\(^{2+}\}>Mg\(^{2+}\}>K\(^{+}\} (Table 1). Therefore, the concentration of cations could vary greatly, but the composition changed little.
The total anion and cation concentrations in the LOATWS close to urban or agricultural irrigation areas are 4.76 mmol·L⁻¹ and 4.13 mmol·L⁻¹, respectively, which were only 58.05% and 63.15% of OATWS in the adjacent area on average. The relatively low concentration was due to the collection of river samples with high ion content in the lower reaches of the lakes/reservoirs, such as the samples at the end of the Weigan River (X15) and near the Tashidian villages (X18-19, TH20) of the Kongque River Basin. At the same time, affected by evapotranspiration crystallization, solute deposition, and human activities, the proportion of HCO₃⁻ in the LOATWS was 23.46% lower than that in the OATWS, while the proportion of Cl⁻ and SO₄²⁻ increases by 5.67% and 17.81%. The total concentrations of anions and cations in the LMTR were 32.39 mmol·L⁻¹ and 32.29 mmol·L⁻¹, respectively, which were 178.26% and 206.36% higher than the regional river runoff. This was because Daxihaizi Reservoir (No. TH15), and especially Taitma Lake (No.TH16), were located at the tail end of the river, and the intense evapotranspiration crystallization in the desert area had caused significant water salinization [15]. It should be noted that the water of LMTR was actually not related to the runoff of the mainstream of the Tahe River. This was due to the impact of climate change and a large amount of water diversion from industry and agriculture, the river section below the Daxihaizi Reservoir (No. TH15) had been dry for more than 10 years, and the Taitma Lake Oasis existed in name only since 1972.

4. Discussion

4.1. Hydrochemical erosion pattern

Based on the analysis of samples of lakes, rivers, and rainwater, Gibbs (1970) classified the ion sources in surface water into three categories: evaporation-crystallization, rock weathering, and atmospheric precipitation. The contributions of the three types of endmembers were distinguished by the ratio of TDS to Na⁺/(Na⁺+Ca²⁺) and Cl⁻/(Cl⁻+HCO₃⁻) [16].

The TDS of runoff samples in the KMPP region were between 115.00 and 878.62 mg·L⁻¹, the Cl⁻/(Cl⁻+HCO₃⁻) ratio was between 0.02 and 0.64 (average 0.28), and the ratio of Na⁺/(Na⁺+Ca²⁺) was between 0.00 and 0.61 (average 0.32). Similarly, the TDS of water samples in the TM region was between 157.30 and 561.50 mg·L⁻¹, the Cl⁻/(Cl⁻+HCO₃⁻) ratio was between 0.06 and 0.74 (average 0.36), and the ratio of Na⁺/(Na⁺+Ca²⁺) was between 0.15 and 0.61 (average 0.36). Therefore, the scattered points were mainly distributed in the left-center area of the Gibbs diagram (Fig. 2), indicating that rock weathering was the main hydrochemical process that controlled the water quality of the mountain runoff in the Tarim River Basin. Precipitation is mainly caused by water vapor being blocked by tall mountains and climbing in the Tianshan and Kunlun Mountains in the hinterland of Eurasia. The soluble matter in aerosols is mostly concentrated at a certain elevation near the ground [17], and the study area is far from the oasis area dominated by human activities. Therefore, the proportion of soluble substances derived from precipitation replenishment is less than 10% [6], which negates the main source of solutes in mountain runoff mainly comes from precipitation.
Fig. 2. Gibbs plot showing major processes affecting water chemistry in the Tarim River Basin.

In the OAKMPPWS, the TDS was between 304~5269 mg·L⁻¹, the ratios of the Cl⁻/(Cl⁻+HCO₃⁻) and Na⁺/(Na⁺+Ca²⁺) were between 0.25 and 0.93 and 0.19 and 0.81, respectively, and some of the scattered points were concentrated in the central area of the Gibbs diagram, indicating that the solute was mainly affected by rock weathering (Fig. 2), but the runoff at the end of the Qarqan River (TH1), Hotan River (TH6), and the Yarkand River (X52) were also significantly affected by evaporation or human activities. Similarly, while the solute was affected by rock weathering, it was also significantly affected by evapotranspiration crystallization in the OATWS, especially at the X19 sampling point at the end of the Kongqi River. Affected by the strong evapotranspiration in the plain area, the TDS, Cl⁻/(Cl⁻+HCO₃⁻), and Na⁺/(Na⁺+Ca²⁺) ratios of the MTR [TDS = 1080 mg·L⁻¹, Cl⁻/(Cl⁻+HCO₃⁻) = 0.68 and Na⁺/(Na⁺+Ca²⁺) = 0.63] and LMTR [TDS = 2563 mg·L⁻¹, Cl⁻/(Cl⁻+HCO₃⁻) = 0.87 and Na⁺/(Na⁺+Ca²⁺) = 0.67] were all significantly higher, which showed that their solutes were significantly affected by evapotranspiration crystallization (such as X29, X30, and TH16), but still partially retained the characteristics of the water quality of the recharge source area affected by rock weathering[16].

4.2. Evapotranspiration crystallization

In the piedmont and plain areas of the Tarim River Basin, although there were large amounts of brown calcium soil, desert soil [18], and the Paleogene-Neogene and Quaternary strata, including argillaceous sandstone, sandstone, mudstone, and other marine and terrestrial sedimentary strata [19], their influence on Ca²⁺ and HCO₃⁻ was not significant. This was reflected in the Gibbs free energies (ΔG) of sedimentary reaction equations 1 and 3 involved in the KMPP region, which were -0.34 and -1.31 (Table 2), both of which were less than 0, indicating that Ca²⁺, HCO₃⁻, and SO₄²⁻ were saturated when the runoff left the mountainous area, and the sedimentary reaction could occur and could continue to the OAKMPPWS, inhibiting the dissolution of carbonate rocks and sulfate rocks along the way. This suggests that the Ca²⁺, HCO₃⁻, and SO₄²⁻ in the runoff in the southern oasis area mainly came from the weathering of mountain rocks (Equation 7).

| Equation | Chemical equation | TM | KMPP | OATWS | LOATWS | OAKMPPWS | MTR |
|----------|------------------|----|------|-------|--------|-----------|-----|
| 1        | Ca²⁺+HCO₃⁻→CaCO₃↓+H⁺ | 0.11 | -0.34 | -0.62 | 0.44  | -1.07  | -0.61 |
| 2        | Mg²⁺+HCO₃⁻→MgCO₃↓+H⁺ | 5.01 | 4.74 | 3.91  | 4.94  | 3.58  | 3.99 |
| 3        | Ca²⁺+SO₄²⁻→CaSO₄↓ | -0.81 | -1.31 | -1.33 | -1.29 | -2.38 | -1.97 |
| 4        | Mg²⁺+SO₄²⁻→MgSO₄↓ | 14.92 | 14.60 | 14.03 | 14.03 | 13.10 | 13.46 |
| 5        | Ca²⁺+(OH)₂→Ca(OH)₂↓ | 8.91 | 8.65 | 8.79  | 9.17  | 8.05  | 8.66 |
| 6        | Mg²⁺+(OH)₂→Mg(OH)₂↓ | 1.29 | 1.20 | 0.79  | 1.14  | 0.17  | 0.73 |
The ΔG equation of ion chemical reaction is as follows (Equation 8):

\[ \Delta G = \left( \sum_i v_i G_i^{product} - \sum_i v_i G_i^{reactant} \right) + RT \ln \left( \frac{C^a}{C^b} \right) \]  

where \( G_i \) represents the standard free energy of formation, that is, the molar free energy of component \( i \) at 25°C and 1 atm; \( R \) represents the gas constant (1.987 \times 10^{-3} \text{ kcal mol}^{-1} \text{K}^{-1}); \( T \) is the thermodynamic temperature; \( A, B, C, \) and \( D \) represent the activity of the component, which can be replaced by the concentration value in a dilute solution; \( v_i \) represents the stoichiometric coefficient of each component, that is, \( a, b, c, \) and \( d \).

The ΔG of sedimentary reaction equations 1 and 3 involved in the runoff of TM region were 0.11 and -0.81, respectively, indicating that the deposition reaction of equation 4 could occur, \( SO_4^{2-} \) was in a saturated state, and \( Ca^{2+} \) and \( HCO_3^- \) were temporarily unsaturated. According to the inverse calculation of Equation 6, if the pH remained unchanged, the continuous reaction of Equation 7 would increase the concentration of \( Ca^{2+} \) and \( HCO_3^- \) by only 10.25%, then the ΔG of Equation 1 would become 0, indicating that in the runoff from the TM region, \( Ca^{2+} \) and \( HCO_3^- \) was also approaching saturation. Moreover, the suspended matter containing silicate rock from mountainous areas carried by runoff could continue to react. Thus, after the runoff flows out of the mountain, the impact of carbonate rocks and gypsum in marine and continental sediments in the plain area could also be ignored. After passing through the urban distribution area, affected by the strong evapotranspiration and crystallization in the desert/Gobi area, the ΔG of equations 1 and 3 were both negative and maintained to the MTR region. \( Ca^{2+}, HCO_3^-, \) and \( SO_4^{2-} \) were in a supersaturated state, forming \( CaCO_3 \) and \( CaSO_4 \) and then depositing, not only could cause river channel aggradation, but also leading to salinization of farmland for irrigation [20].

Furthermore, although the chemical reactions in Equations 2 and 4–6 could form slightly soluble or insoluble substances, their ΔG were all greater than 0, indicating that the sedimentary reactions of \( MgCO_3, MgSO_4, Ca(OH)_2, \) and \( Mg(OH)_2 \) in the rivers had not occurred yet in the Tarim Basin.

4.3. Contribution from different sources

To determine the contribution of the above ion sources, we used a forward model to quantify the cations from different sources in the Tarim River Basin. The model assumed that the chemical composition of the solute loaded in the river was the result of the mixing of different sources, and there was no exchange between cations [21].

4.3.1. Fractions of precipitation and ice melting-water input

Given that glacial meltwater dominated mountain runoff, and modern glaciers formed by precipitation in historical periods in the Tarim Basin, it was assumed that: (i) All F⁻ in surface runoff came from glacial meltwater/atmospheric precipitation; and (ii) The chemical composition of atmospheric precipitation was consistent with that of glacier meltwater. The atmospheric input part used the average molar ratios of the F⁻ of 21 glacier ice melt-water samples from the Koxkar Glacier in the study area: \( Na^+/F^- \) = 5.37, \( K^+/F^- \) = 1.12, \( Mg^{2+}/F^- \) = 7.09, \( Ca^{2+}/F^- \) = 37.15, \( Cl^-/F^- \) = 2.28, \( SO_4^{2-}/F^- \) = 2.27, \( HCO_3^-/F^- \) = 5.37 [6].

4.3.2. Fractions of human activity

We simply used the parameters of the human activities in the Yangtze and Yellow River Basins of China: \( NO_3^-/Na^+ \) = 2.27, \( Cl^-/Na^+ \) = 5, \( K^+/Na^+ \) = 1.4, \( Mg^{2+}/Na^+ \) = 0.2 and \( Ca^{2+}/Na^+ \) = 0.8[22].

4.3.3. Lithological fractions

Considering the special scenario of runoff replenishment sources in the Tarim Basin, it was assumed that: (i) \( Na^+ \) and \( K^+ \) elements corrected by precipitation, human activities, and evaporite came from
silicate weathering, and the corrected $\text{SO}_4^{2-}$ came from sulfide oxidation [23]. (ii) $\text{Ca}^{2+}_{\text{sil}} / \text{Na}^{+}_{\text{sil}} = 1$, $\text{Mg}^{2+}_{\text{sil}} / \text{Na}^{+}_{\text{sil}} = 0.6$ [14]; (iii) The chemical erosion reaction of silicate rock was preferentially driven by $\text{H}^+$ generated by sulfide oxidation. When sulfide oxidation produced insufficient $\text{H}^+$, it was driven by $\text{H}^+$ generated by atmospheric $\text{CO}_2$ dissolving in water, but there was no hydrolysis of silicate.

### 4.3.4. Model results

According to the forward model, the total dissolved cations in terms of ion equivalents were 12.50%, 0.47%, 36.10%, 14.26%, and 36.71% from precipitation/glacial meltwater, human activities, evaporative salt rock, silicate rock, and carbonate rock in the Tarim Basin, respectively (Fig 3).

The proportion of carbonate weathering replenishment in the KMPP and TM regions accounted for 41.69% and 42.86%, respectively. After reaching the oasis area, they decreased by 14.05% and 29.70%. When reaching the MTR region, the replenishment ratio (28.99%) of carbonatite carbonation was only two-thirds of the mountain runoff. This was the result of evapotranspiration crystallization that promoted the saturation of $\text{Ca}^{2+}$ and $\text{HCO}_3^-$, which not only inhibited carbonate erosion along the way, but also caused CaCO$_3$ sedimentation in runoff (see Section 4.2). For silicate rocks, the $\Delta G$ indicated that the $\text{Ca}^{2+}$ and $\text{HCO}_3^-$ of the runoff in the KMPP region had reached saturation (Table 2), which could inhibit the decomposition of Ca-feldspar to a certain extent. Moreover, although there was a lack of precipitation in the foothills and plains, there was still some precipitation that promoted the dissolution of evaporite in the Cenozoic loess and saline soil, causing the proportion of evaporite replenishment to rise from 17.46% in the KMPP region to 48.47% in the OAKMPPWS. These factors worked together to promote the rapid decrease in the proportion of silicate from 24.92% in mountainous areas to 4.05% in oasis areas. Conversely, in the northern part of the Tarim River, silicate replenishment increased from 17.92% in the TM region to 26.53% in OATWS.

![Fig 3. Diagram showing for each area of this study, the contribution as % of cationic concentrations in meq of the different reservoirs.](image)

### 5. Conclusion

Considering the regional geological conditions and the spatial distribution characteristics of precipitation, the water quality characteristics and solute sources in the runoff of the Tarim River Basin were analyzed.

1) In the runoff of the Tarim River Basin, more than 80% of the soluble ions came from rock weathering. Because of the sparse population and low degree of industrialization, the impact of human activities could be ignored. Affected by the distribution of precipitation and glacial meltwater, the solute replenishment ratio of precipitation/glacial meltwater showed a gradual decrease from the mountain to
the main stream. Similarly, because igneous rocks rich in silicate rocks were mainly distributed in high mountain areas where glaciers were developed, the proportion of silicate replenishment dropped significantly, while the proportion of evaporative salt rocks gradually increased because of the evapotranspiration crystallization.

2) When the runoff flowed out of the mountain, $\text{Ca}^{2+}$ and $\text{HCO}_3^-$ were almost saturated in the Tarim Basin. Moreover, affected by evaporation and concentration, the ion concentration increased synchronously, showing a good correlation in statistics. These indicated that the solute of surface water mainly originated from mountainous areas, and soluble substances, such as chlorides and sulfates of brown calcium soil and loess in the plains, had difficulty entering the river channel through the erosion of the scarce surface runoff.

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