Chemical and Isotopic Characterization of Inland Waters around Desert Area in Xinjiang, NW China

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Abstract

For seeking the origin of water and the hydrologic cycle, we investigated the major ion concentration of inland waters in and around desert area in Xinjiang, NW China. Concentrations of a short-lived radioactive isotope, tritium, two stable isotope species, oxygen-18 and deuterium (D), and isotopic compositions of strontium are also measured. The chemical and isotopic composition of the waters from these areas have regional characteristics which mean that the geological feature of their water-head and drainage areas control the chemistry of inland waters.

Hydrogen and oxygen isotope compositions show that river waters are not directly recharged by rain water, but by glacier and/or frozen ground melt, therefore the seasonal variation of isotopic compositions is not so conspicuous as that of precipitation. The results of tritium concentration of waters also suggest that glacier and/or frozen ground melt are important source of water flow of the basins in Xinjiang.

Introduction

The desert area in Xinjiang is mostly located in inland basins such as Tarim Basin, Zhungar Basin and Turpan Basin. Annual precipitation rate at desert area is small, therefore precipitation and glacier discharge at the surrounding mountain areas are major water sources for the basins. Surface flows, as well as subsurface ones from mountain ranges, irrigate oases distributing around the desert periphery, and go underground in the desert area.

Geochemical studies of water give important information for a better understanding of the influence of geological and climatic condition to a hydrologic system. From 1990 to 1994 we investigated the desert area in Xinjiang, NW China and collected inland water samples, including river waters, lake waters, ground waters (Okada and Yabuki, 1991; Okada et al., 1992, 1994a, 1994b, 1995). In this paper we review the results of major ion chemistry of inland waters under arid condition. Isotopic compositions of strontium, concentration of a short-lived radioactive isotope, tritium and two stable isotope species, oxygen-18 and deuterium (D) of the water samples, are also reported and discussed (Yabuki et al., 1993; Yabuki et al., 1996a; Yabuki et al., 1996b).

Geographical features of investigated areas

1. Tarim Basin is the largest enclosed interior basin in China, surrounded by world-famous high altitude ranges, Tianshan, Pamir, Kunlun and Arjin Mountains. Some of the peaks reach higher than 7000 m above sea level. Only the northeast of the basin is opened and leads to the Hexi Corridor, Gansu Province, but no river comes out from the basin. Taklimakan Desert, the largest sand desert in

China, occupies most part of the Basin. Annual precipitation at the central desert area is less than 10 mm and around desert periphery is 60 to 80 mm and evaporation rate is 2000 to 3000. The basin slopes from southwest to northeast to the lowest point, Lop Nur. Rivers from surrounding mountain ranges, such as Akesu River, Kashigar River, Yercheng River, Hetian River and Keliya River, finally join to Tarim River, the largest river in Tarim Basin which runs from the west to the east. Tarim river as well as Kongque River at eastern part and Cherchen River at the south-eastern part becomes underground stream toward the lowest point, Lop Nur.

2. Zhungar Basin in northern Xinjiang is surrounded by Tianshan and Altay Mountains. The center of the basin is occypied by Gurbantenggut Desert, the second largest sand desert in China. The basin is opened toward the north-west, and moist currents come from this direction. Therefore the climate of Zhungar Basin is relatively moderate comparing with other desert areas in Xinjiang. The annual precipitation amounts to 200 mm at the northern foot of Tianshan Mountains and 100 mm even in the desert area.

3. Turpan Basin constitutes an intermontane basin found within the eastern Tianshan Mountain Ranges. The north of the basin is flanked by Mt. Bogeda with 5445 m height. Huoyanshan Mountains at the northern part of the basin divide the basin into two parts. The lowest area of the basin is Aidinghu Lake which located southern part of the basin with -154 m below sea level.
Turpan Basin is known as one of the most dried and high-temperature region in China, with less than 20 mm of annual precipitation and 3000 mm evaporation. The melted snow and glacier water at the mountain region and precipitation rushed out from the outlet of the mountain valley, then disappear into desert, therefore, it formed the aquifers that rich in dynamic storage of ground water.

Samples

Water samples including river waters, ground waters, soil waters and lake waters are collected by the field investigations executed every year in October from 1990 to 1994. Sampling location maps are shown in Fig. 1. As sampling area covers wide range, we divide sampling areas as follows:
1. Northern and eastern parts of Tarim Basin: Including Akesu, Kuche, Luntai and Kuerla and Yuli, Tieganlike and Alagan. The area is consist of fluvial fans and alluvial-fluvial plains of southern foot of Tianshan Mountains, river basins of Tarim River, Kongque River and Bositenghu Lake.
2. Southern part of Tarim Basin: Northern foot of Arjin mountains and Kunlun Mountains, Ruoqiang, Qiemo, Minfeng, Yutian and Hetian, including river basin of Cherchen River, Keliya River and Hetian River.
3. Western and south-western parts of Tarim Basin: So called Kashigar Delta between South Tianshan Mountains and West Kunlun Mountains, including Yerchen River and Kashigar River basins.
4. Pamir: The Pamir Plateau, located in the western part of Tarim Basin, is 4000 m hight on average. Some peaks are higher than 7000 m above sea level.
5. South-western part of Zhungar Basin
6. Turpan Basin

Analysis

1. Temperature, pH and electric conductivity of the samples are measured at sampling sites with portable pH and SC meters. HCO_3 and CO_3 content are determined by titration.
Major cations, K, Na, Ca and Mg and Strontium concentration are determined by inductively coupled plasma spectrometer (Japan Jarrell-Ash, ICAP-575 II). Anions such as Cl, SO_4 and NO_3 are measured using ion chromatography (Shimadzu, HIC-6A). \
2. Tritium concentration: The measurements of tritium concentration are carried out using liquid scintillation counter (Packard, TRI-CARB 2260). Detection limit is 0.2Bq/L (50ml water, 2000 minutes).

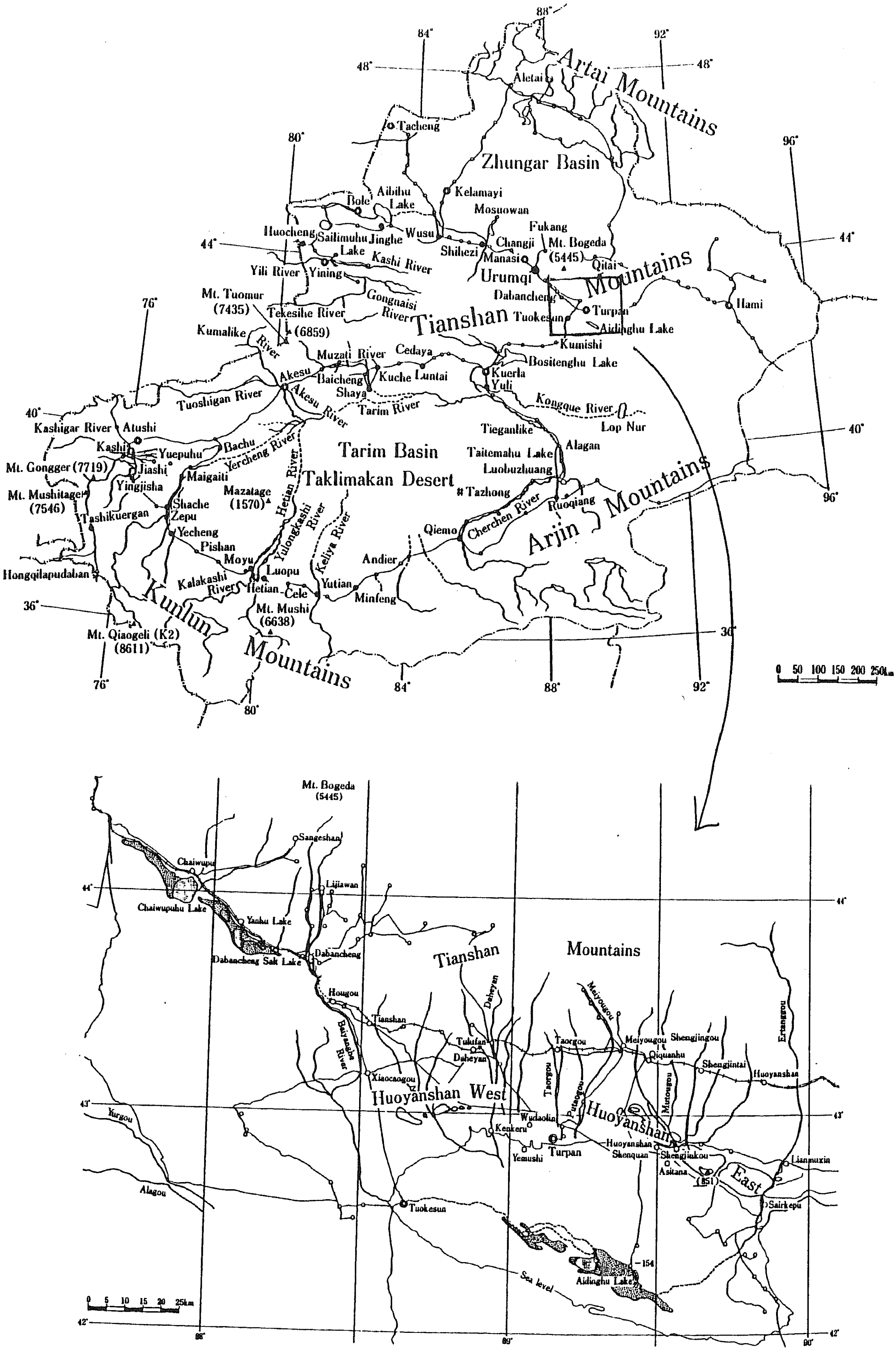


Fig. 1 Maps of Xinjiang (upper) and Turpan Basin (lower) showing the sampling locations

3. Hydrogen and oxygen isotopes: For measurements of deuterium and oxygen isotope composition, water samples are decomposed into hydrogen and oxygen gases. Hydrogen gas can be collected by water-metal zinc reaction at 420 °C for 6 hours. In the case of oxygen, isotope exchange between water and carbon dioxide is used. Prepared gas samples are analyzed by Niel type double inlet mass spectrometer (Finigan Mat Delta-E). Measured values are expressed as δ value, permil deviation from a reference, defined by the following formula.

$\delta = 10^3 (R - R_0) / R_0$ (‰)

Here R and R_0 are isotope ratios of the sample and the standard, respectively.

4. Strontium isotopic composition: Filtered water samples are directly passed through a cation exchange resin (AG 50W-X8 Resin, Bio-Rad) column in HCl media to separate strontium from other major elements. The isotopic composition of Sr was determined by using a thermal ionization mass spectrometer (VG Elemental VG54).

Results and discussion

1. Chemical types of inland waters

According to Piper (1944), chemical type of water can be plotted on tri-linear diagram as the function of major cation (Ca-Mg-(Na+K)) and major anion (HCO_3-Cl-SO_4) concentration as shown on Fig.2. Piper diagram is useful to discuss the environmental condition and chemical characteristics of water samples. Water belongs to the area I is (Ca-HCO_3) type, river water and shallow ground water belong to this category. Area II is Na-HCO_3 type, fresh ground waters usually show this type. Area III is Ca-SO_4 or Mg-SO_4 type of the waters under special geological environment. Waters belong to Type IV, Na-SO_4 and Na-Cl type is saline water.

Fig.2A Waters from Zhungar Basin, and Akesu River belong to Ca-HCO_3 type while Tarim River belong to Na-Cl type. The results suggest that Tarim River is strongly affected by saline soil of river drainage. Bositenghu Lake and Kongque River show Na-SO_4, but waters from lower reaches-desert area show Na-Cl type.

Fig. 2B Waters from southern part of Tarim Basin belong to Na-Cl type, not only desert area but also ground waters and river waters of Kunlun Mountain area. It is suggested that salt layer in Kunlun Mountains provide Na and Cl ions to water systems . Waters from Pamir belong to Ca-HCO_3 type.

Fig. 2C and 2D. In Turpan Basin, most of water comes from Bogeda Mountains. Waters belong to Tianshan Mountains show Ca-HCO_3 at upper reaches and after they passed Huoyanshan Mountains they change their chemical type to Na-SO_4 because of sodium sulfate enriched layer in Huoyanshan Mountains. Waters from desert area show Na-Cl type. Karez is a method to exploit and utilize the ground water in arid region. Through the subsurface tunnels, the groundwater could flow out itself to the ground surface. Karez water from Wudaolin shows Na- Ca-HCO_3 type, same as spring waters at the foot of Huoyanshan Mountains, while the well waters show $NaSO_4$ type, which shows Karez keep their water quality better than teh well water.

2. Correlation between major soluble ions

(Na+K)-Cl: Most of river waters in Xinjiang, concentration ratios of (Na+K)/Cl are more than unity. This means that sulfate and carbonate ions also contribute to valance with sodium and potassium ions. Especially in Turpan Basin, sodium ion is provided as Na_2SO_4 that widely spread at the central area of the basin. Correspond to excess (Na+K)/Cl ratio of river waters of lower reaches from Turpan Basin, (Ca+Mg)/SO_4 ratios at lower reaches show less than unity, and other waters of lower reaches are equal unity, which suggest, that the river waters are strongly affected drainage soil salt characteristics. While, at upper reaches, cation concentrations exceed Cl and sulfate concentration. The results suggest that at the upper reaches, sodium, potassium, calcium and magnesium are derived not only from evaporites but also from carbonate or silicate rocks. At the upper reaches in Turpan Basin, (Ca+Mg)/HCO_3 ratio is nearly equal to unity, which suggest that main sources of these ions are carbonate rocks.

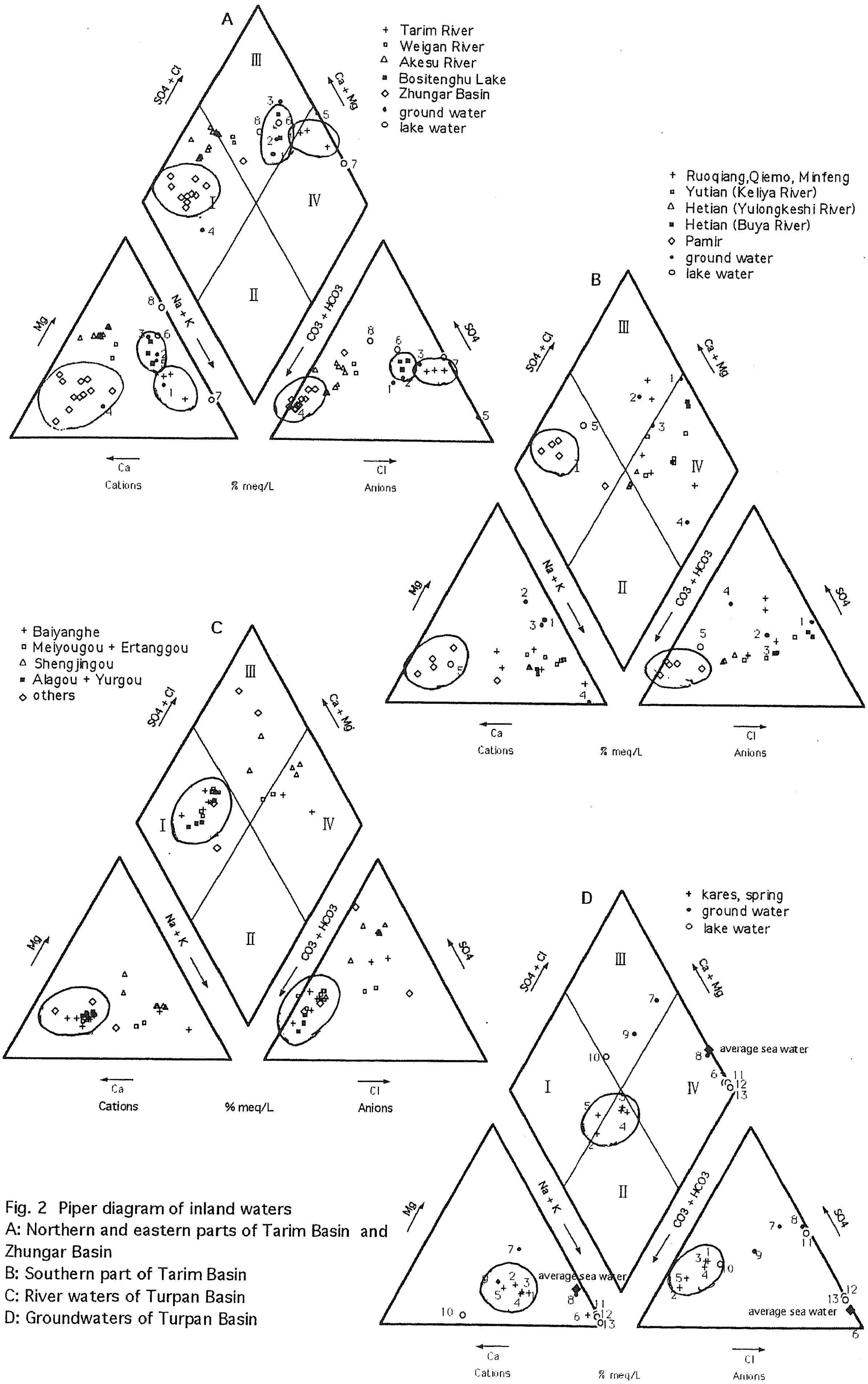
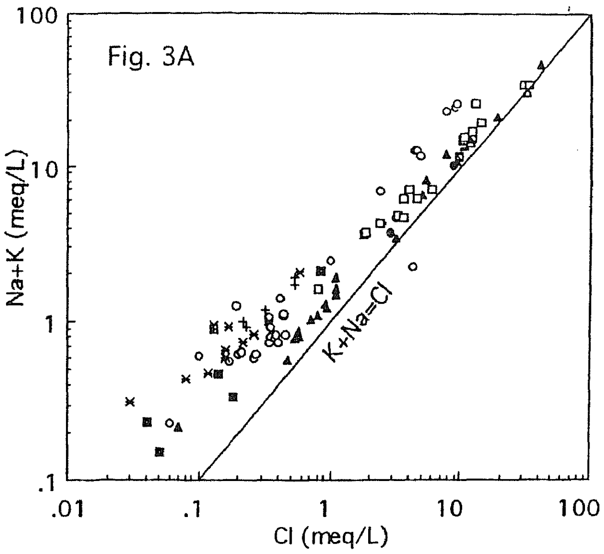


Fig. 2 Piper diagram of inland waters
A: Northern and eastern parts of Tarim Basin and Zhungar Basin
B: Southern part of Tarim Basin
C: River waters of Turpan Basin
D: Groundwaters of Turpan Basin



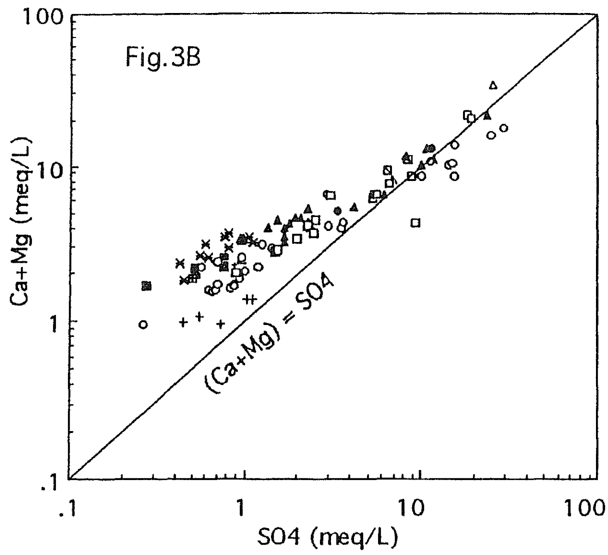
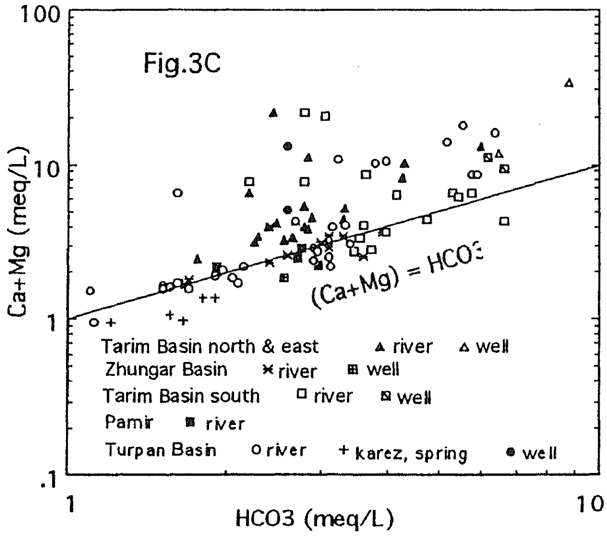


Fig.3 Correlation between major soluble ions
A: (Na+K)-Cl
B: (Ca+Mg)-SO4
C: (Ca+Mg)-CO3



3. Variation of strontium isotopic composition

Variation of strontium isotopic compositions of waters are shown in Fig. 4. It has conspicuous regional characteristics. $^{87}Sr/^{86}Sr$ ratios of waters from Turpan Basin have the lowest value (0.7069 - 0.7097), while increasingly higher values are found in the Zhungar Basin (0.7083-0.7104), northern and eastern parts of the Tarim Basin (0.7102-0.7113) and western and southern part of Tarim Basin (0.7104 - 0.7137). Each region has relatively constant strontium isotopic composition. Such regional uniformity suggests that strontium is mainly derived from evaporite minerals in sedimentary rocks in the mountain area and from salt deposits in the lower drainage. It is known that low strontium isotopic composition comes from carbonate rocks, and strontium of high isotopic composition is caused by igneous or metamorphic rocks. The source of strontium of low isotopic composition in Turpan Basin is considered to be carbonate rock in Bogeda Mountain.

In southern Tarim Basin, the variation of strontium isotopic composition is larger than that of other regions (0.7104-0.7126). Especially, $^{87}Sr/^{86}Sr$ ratios of Yulongkashi River are highest, 0.7130 - 0.7137. The high $^{87}Sr/^{86}Sr$ ratios could be due to the local sources, some igneous or metamorphic rocks in high mountain ranges of Kunlun Mountains.

Tritium concentration

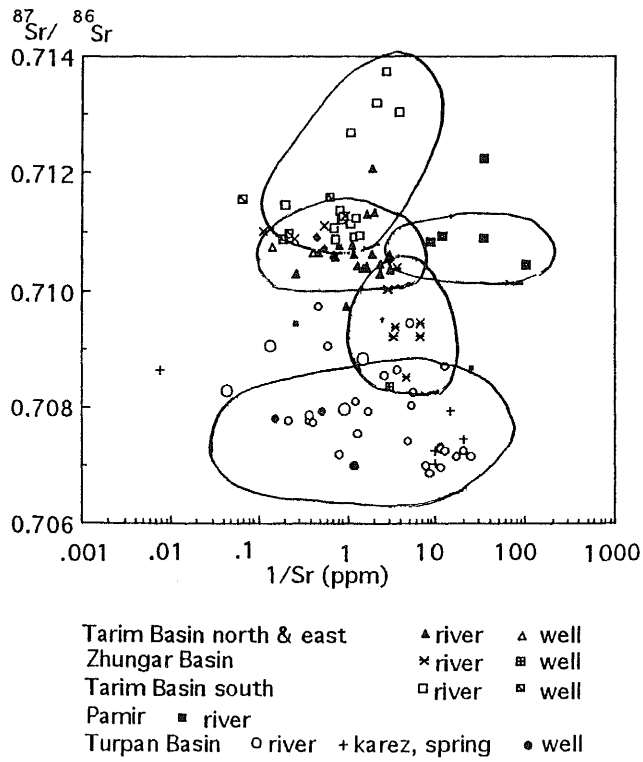


Fig. 4 Variation of strontium isotopic composition

4 Tritium concentrations in inland waters around desert areas in Xinjiang are classified into three groups.
4-1. Waters of nearly zero tritium concentration: Ground water, including well water and spring water. They belong to fossil waters or cycled waters with long residence time.
4-2. Waters of high tritium concentration, more than 5 to 17 Bq/L: River waters and lake waters at mountain areas. The results indicate that these waters are affected by glacier melts of high tritium concentration.
4-3. Waters, tritium concentration of which are between groups 1 and 2,: River waters and some ground waters at low altitude areas. They are possibly mixtures of both groups.

5. Deuterium and ^{18}O contents of inland waters

Regional distribution of the hydrogen and oxygen isotopic ratios are shown in Fig. 5 and Fig. 6, which show that river waters from Pamir Plateau have light isotopic ratios, then increasingly higher values are found in the Zhungar Basin, Turpan Basin and Tarim Basin. The isotopic compositions of river waters from the Turpan Basin are within the extent of those from Tarim Basin. Comparing with meteoric waters in Tarim Basin, δD values of inland waters are neither consistent with winter nor summer precipitation. The results suggest that river waters are not directly recharged by rain water, but recharged by glacier and/or frozen ground melt.

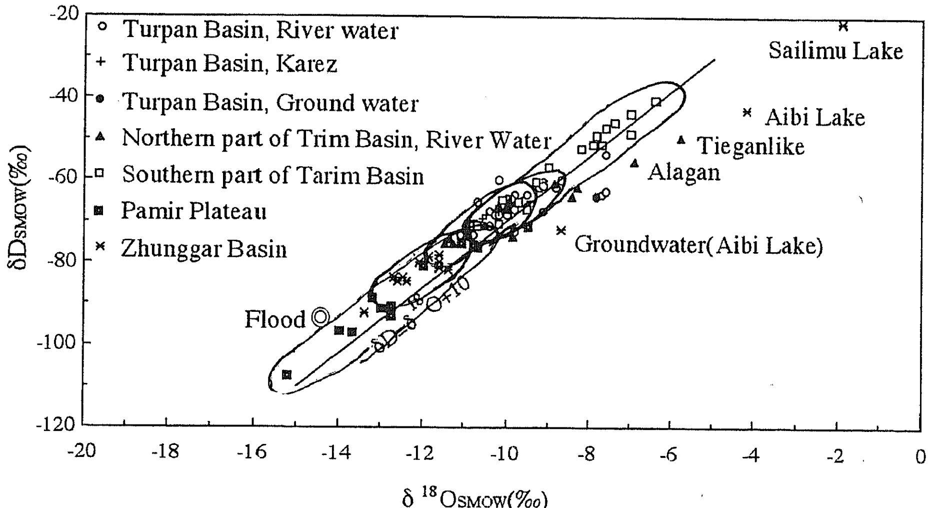


Fig. 5 δD vs. $\delta^{18}O$ of inland waters around desert areas in Xinjiang.
Data of northern part of Tarim Basin are from Wushiki et al., 1993

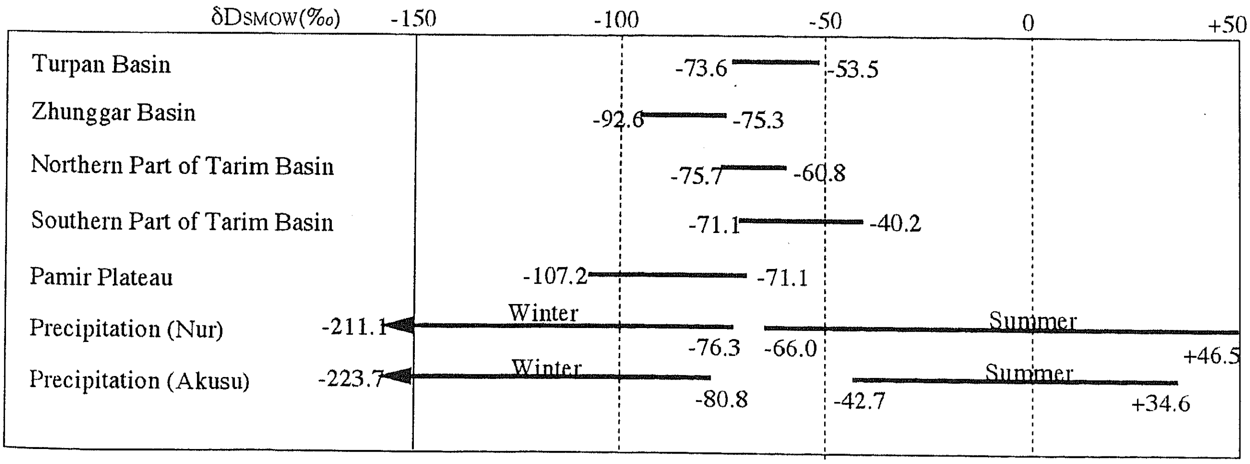


Fig. 6 δDSMOW(‰) of inland waters around desert areas in Xinjiang.
Data of northern part of Tarim Basin and precipitation are from Wushiki et al . (1993)

Conclusion

1. River waters in Xinjiang show Ca-HCO_3 type at upper reaches and change into Na-SO_4 and Na-Cl types reflecting soil properties around river drainage.

This result is consistent with the correlation between soluble major ions, i.e.. at the upper reaches, HCO_3 ions show good correlation with Ca+Mg ion, while at the lower reaches, Ca+Mg correlate with SO_4 ion

2. Strontium isotopic compositions have conspicuous regional variation. Each region has relatively constant isotopic composition. Such regional uniformity suggests that strontium is derived from evaporite minerals in sedimentary rocks in the mountain area and from salt deposits in the lower drainage.

3. Hydrogen and oxygen isotope composition show that river waters are not directly recharged by rain water, but by glacier and/or frozen ground melt, therefore the seasonal variation of isotopic composition is not so conspicuous as that of precipitation. The results of tritium concentration of waters also suggest that glacier and/or frozen ground melt are important source of water flow of the basins in Xinjiang.

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