# SALT LAKES AND THEIR ORIGINS IN XINJIANG, CHINA*

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**Abstract**

This paper, based on field data and experimental results, gives an analysis and summary of the types and salt-forming characteristics of salt lakes in Xinjiang and the distribution and chemical compositions of their brines and groups of salt minerals. The evolution and substance origins of the salt lakes and their salt-forming regularities as seen from analyses of their paleogeographic environment and geological tectonics are also reported. This paper will serve as a reference for further investigation of the Xinjiang salt lakes, and as a guide for fuller utilization of their resources.

Xinjiang, broad in area, complicated in landform, and dry in climate, is one of the main inland salt regions in China. The salts here are abundant and complete in types and widely distributed. Among the deposits in the salt lakes there are mirabilites, halites, tronas, borates, nitrates formed by leaching, and highly-mineralized brines composed of Na, K, Mg, Cl, B, Li, U, Th and so on. These resources are basic raw materials widely used in the chemical and other industries, agriculture, national defence, etc.

Theories of evaporite sedimentation and thermal solution origins of salt-formation have been suggested. Based on the analyses of the ancient lake basins, their substance origins and paleoclimate changes in this area, the author proposes that although there were thermal solution origins (hot springs) in the formation of the salt lakes in Xinjiang, they were formed principally by evaporite sedimentation.

## I. DISTRIBUTION OF THE SALT LAKES

The Xinjiang salt lakes are distributed widely but not uniformly in the northwestern part of China (Fig. 1). They usually exist in groups in obvious zonations that can be divided into five salt lake areas on the basis of their geological structures and physiographic environment (Fig. 2). The main characters of each area are described in Table 1.

## II. THE SUBSTANCE COMPONENTS OF THE SALT LAKES

### 1. Mineral Constituents

Statistical data available show that excluding silicates and aluminate minerals, there are fifteen minerals in the salt lake evaporites of Xinjiang, among which are three carbonates, six sulfates, two borates, three chlorides, and one nitrate (Table 2). In the mineral assemblage of these salts, halite and mirabilite, which are precipitated broadly and are the thickest, constitute the main salt minerals in the salt lake areas in Xinjiang. Other salt minerals are not present in great quantity.

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**Table 1 The Main Characteristics of Salt Lake Areas In Xinjiang**

| Salt lake area / Features | I | II | III | IV | V |
|---|---|---|---|---|---|
| | Salt lake area of intermontane basin in Altay Mt. | Salt lake areas in Junggar basin | Salt lake areas in intermontane basin of Tianshan Mt. | Salt lake areas in Tarim basin | Salt lake areas in intermontane basin of Kunlun Mt. |
| Structure position | Altay geosyncline fold zone | Junggar depression | Tianshan geosyncline fold zone | Tarim platform | Kunlun geosyncline fold zone |
| Geographic environment | Arid, semi-arid desert region | Dry desert regions | | | Semi-arid desert regions |
| Lake basin properties | Depression basin | Depression eroded by rivers in fault basin | Fault basin | Depression eroded by rivers and deflation, fault basin | Depression basin |
| Dry index | 0.05—0.29 | 0.01—0.05 | 0.01—0.13 | 0.005—0.01 | 0.13—0.29 |
| Underground water types | $SO_4$ | $SO_4$-Cl | $SO_4$ | Cl-$SO_4$ | $HCO_3$-$SO_4$ |
| Salt deposits | Mainly halite | Mirabilite, halite | Mirabilite, halite, trona | Halite, mirabilite | Mirabilite, trona |
| Salt lake type | Mainly sulfate secondarily chloride | Sulfate | Mainly sulfate secondarily carbonate | Sulfate (chloride) | Sulfate (Carbonate) |
| Typical salt lake | Beishan | Ebinur Man Manas | Qijiaojing Aydingkol Barkol | Lop Nur Taitema Jiayiduobai | Kumukuli Shuoer |

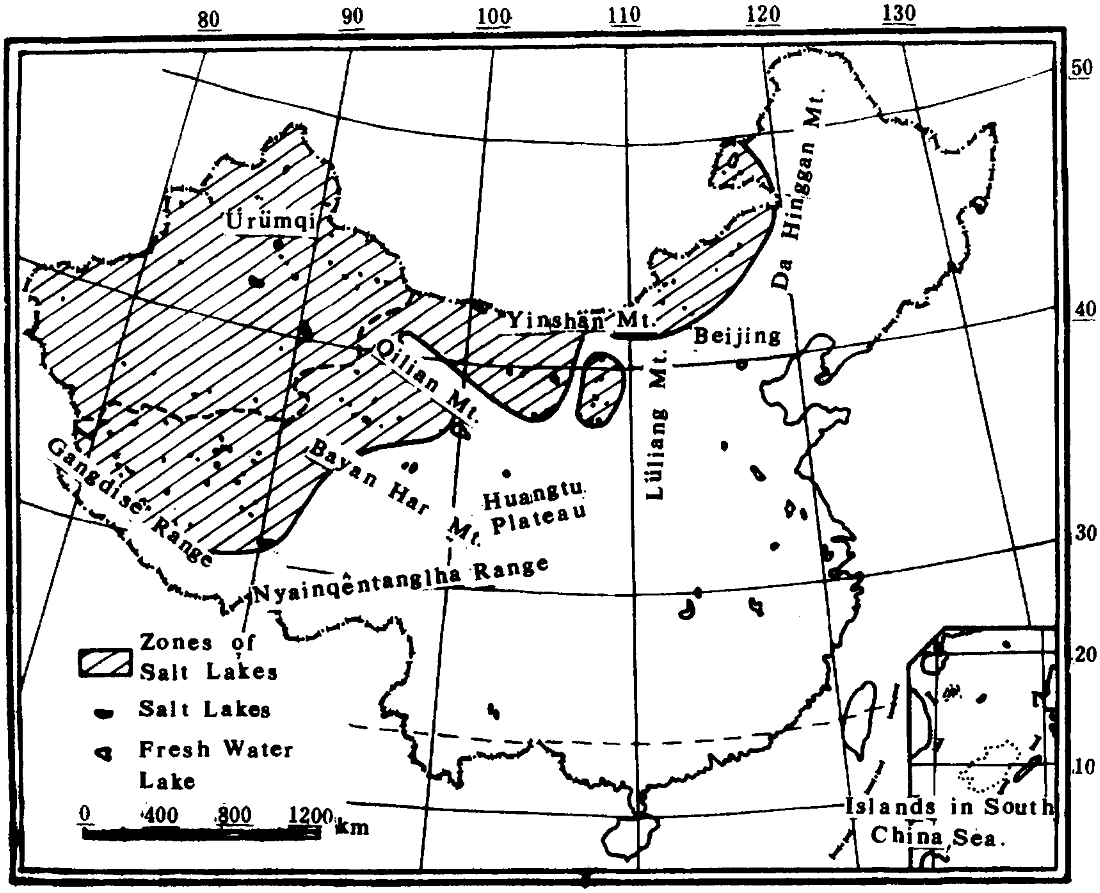


Fig. 1 Zones of salt lakes in China

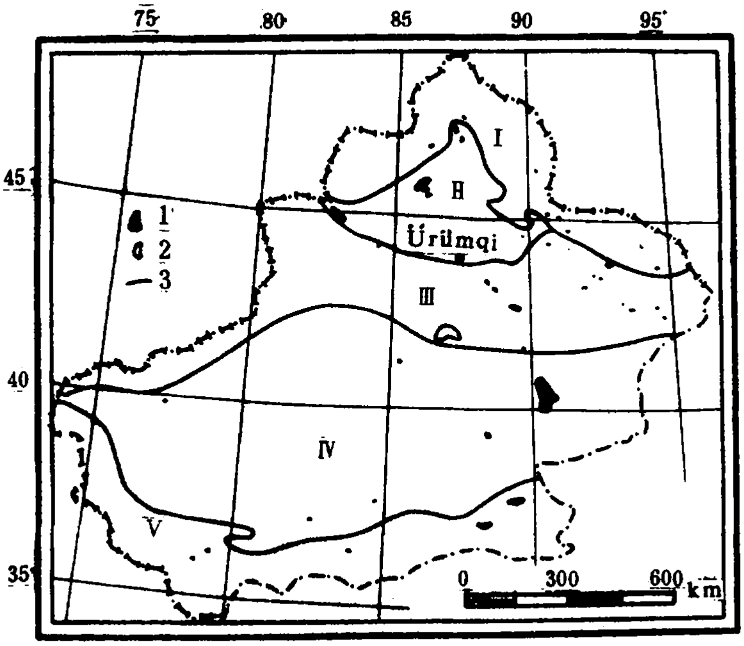


Fig. 2 Distribution of salt lakes over Xinjiang

1. Main salt lakes 2. Fresh water lakes 3. Borders of salt lake areas

I. Salt lake area in the intermontane basins in Altay Mt.

II. Salt lake area in Junggar Basin

III. Salt lake areas in the intermontane basins in Tianshan Mt.

**2. Brine Compositions**

The brines in the salt lakes of Xinjiang are divided into surface and interstitial brine types based on the conditions of salt–formation. There are surface brines in some saline lakes, such as Barkol Lake and the saline lake west of Dabancheng; some salt lakes have on surface brines, but only interstitial brines, for instance, the Qijiaojing salt lake and the Beishawo mirabilite lake, both of which have evolved into playas, or have been buried by sand.

Chemical analyses of the brines in the salt lakes in this region show that they consist chiefly of Na, K, Mg, Ca, Cl, $SO_4$, $HCO_3$, and $CO_3$ (except $H_2O$) which occupy 99% of the total dissolved salts in the brines of the salt lakes in this district (Table 3). These elements constitute the main

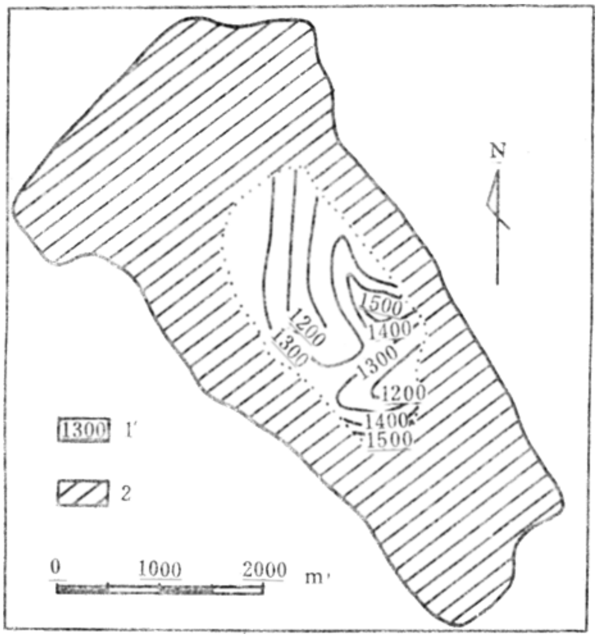


Fig. 3 Isoplethes of concentration of boron in the salt lake west of Dabancheng
1. Isoplethes of B concentration (mg/l)
2. Lacustrine sediments

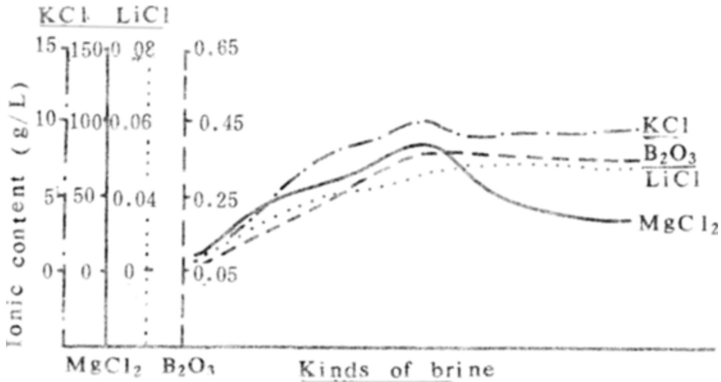


Fig. 4 Curves of K, Mg, B, Li concentrations in Ebinur Lake (data from Xinjiang Geological Bureau)

Table 2 Mineral Components in the Salt Lakes over Xinjiang

| Mineral components | | Types of salt lakes / Names of salt lakes | Taitema | Hongyanchi | Shuoer | Ebinur | Jiayiduobai | Moerlike | Lop Nur | Aydingkol | Barkol | Yiwu | Manas | North Barkol | East Dabancheng | Ulug | Tubu | West Dabancheng | Aqqikkol | Kezizhila | Heihu | Jiangbatawu | Beishan | Xiaoyanchi | Qingyanchi | Beishawo | Yongji | Badasong | Tala | Xiyanhu | Wuyongbuke | Qijiaojing | Huoyanshan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Hydrochemical types | Chloride | Sulfate | | | | | | | | | | | | | | Carbonate | | | Playas | | | | | | | | | | | | |
| Chloride | Carnallite | $KMgCl_3 \cdot 6H_2O$ | | | | | | | ○ | | | | | | | | | | | | | | | | | | | | | | | | |
| | Bischofite | $MgCl_2 \cdot 6H_2O$ | | | | ○ | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Halite | $NaCl$ | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ○ | | | ● | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● | |
| Sulfate | Gypsum | $CaSO_4 \cdot 2H_2O$ | | | | ○ | | | ○ | ○ | ○ | | | ○ | ○ | | | | | | | ○ | | | | | | | | | ○ | ○ | |
| | Syngenite | $K_2SO_4 \cdot CaSO_4 \cdot H_2O$ | | | | | | | | ○ | | | | | | | | | | | | | | | | | | | | | | | |
| | Bloedite | $Na_2SO_4 \cdot MgSO_4 \cdot 4H_2O$ | | | | ○ | | | | ○ | | | | | ○ | | | | | | | | | | | | | | | | | | |
| | Mirabilite | $Na_2SO_4 \cdot 10H_2O$ | ○ | | ● | ● | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | | | | ○ | ● | | | ● | ○ | ○ | | ○ | | ● | ○ |
| | Thenardite | $Na_2SO_4$ | | | | ○ | | | ○ | ● | ○ | | | ○ | ● | | | | | | | | | | | ○ | | | | | | ● | |
| | Glauberite | $Na_2SO_4 \cdot CaSO_4$ | | | | | | | | ○ | | | | | ○ | | | | | | | | | | | | | | | | | ○ | |
| Carbonate | Calcite | $CaCO_3$ | | | | | | | ○ | | | | | | ○ | | | ○ | | ○ | | | | | | | | | | | | | |
| | Trona | $NaH(CO_3)_2 \cdot 2H_2O$ | | | | | | | | | | | | | | | | ● | ● | ● | | | | | | | | | | | ○ | | |
| | Natron | $Na_2CO_3 \cdot 10H_2O$ | | | | | | | | | | | | | | | | | ○ | | | | | | | | | | | | | | |
| Borates | Pinnoite | $MgB_2O_4 \cdot 3H_2O$ | | | | | | | | | | | | | ○ | | | | | | | | | | | | | | | | | | |
| | Ulexite (?) | $NaCaB_5O_9 \cdot 8H_2O$ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Nitrate | Soda nitre | $NaNO_3$ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

● main minerals ○ secondary minerals

factors for classification of salt lake types and reflect the features of the salt lakes. The contents of rare and scattered elements such as B, Li, I, U, Th, etc., are very low in most salt lakes, but are quite high and accumulated in one or two salt lakes (Table 4). The saline lake west of Dabancheng (Fig. 3) contains the highest boron. Borates are even precipitated in the Shuoer salt lake. It is worth noting that the contents of U and Th are high in the interstitial brine of the Beishawo mirabilite lake, being several thousands and several tens of thousands times higher than those in seawater. They are also higher than those in similar salt lakes in China and abroad. Some salt lakes contain high amounts of potassium, which even appear in the minerals deposited in the last stage of salt lake development. Carnallite has crystalized out along the southern margin of Lop Nur Lake and there are deposits of syngenite in Aydingkol Lake. The brine in Ebinur lake contains $K^+$, $Mg^{2+}$, $B^{3+}$, $Li^+$, etc. (Fig. 4). This demonstrates that the concentrations of ions in brines are proportional to the mineralization of the brines.

The highly-mineralized brines in the Xinjiang salt lakes contain large amounts of dissolved salts with specific gravity of 1.200—1.230, and salinity of 70—200 g/l, with the highest being 494 g/l (in the Hongyanchi lake). Influenced by the natural environment, these brines are in different salt-forming stages. In terms of the classification system of mineralized lakes put forward by Valyashko, M.G.[8], the salt lakes in Xinjiang can be divided into three origin types: carbonate, sulfate, and chloride (Table 5). Of these the sulfate types and sodium sulfate subtypes are many, and widely distributed while the carbonate and chloride types are few.

## III. FORMING CONDITIONS OF THE SALT LAKES

Salt lakes are formed in the hypergene stage of the earth crust in the long-term interactions between the geographic environment and geological structure (especially new tectonic) and many other factors, such as the presence of closed or semi-closed landforms of stored water bodies, ancient lake basins, sufficient material origins of salt-forming elements, proper transporting conditions, and arid climates. Continuous investigations for many years reveal Xinjiang possesses the above-mentioned factors favorable for the formation and salt-formation of salt lakes.

### 1. Formation of the Salt Lake Basins

The salt lake basins in Xinjiang can be basically divided into structural and nonstructural basins on the basis of their origins.

Structural basins: the causative factors are inner agents, for instance, the formation of some large fault-depression or torsion depression basins were controlled or influenced by folds and rifts. The Tarim and Junggar basins along the two sides of Tianshan Mountain in Xinjiang, provided good landform environment for the formation of a number of secondary ancient lake basins. The statistics of more than fifty lakes show that their long axes NW-SE trends accord fundamentally with the trend of the Tianshan Mountains. They are obviously controlled by the zone of geosyncline-fold of the Tianshan Mountains. For example, Aydingkol Lake in the Turpan Basin, and the salt lakes (Fig. 5) in the western and eastern parts, respectively, of Dabancheng in the Chaiwopu depression, are all fault basins[2] that were formed by the influence of the synclinal fold along the north side of the Tianshan Mountains. The Ebinur Lake area in the southwestern part of the Junggar Basin is a fault basin[7] which was formed by the control of two groups of deep rifts in the northeastern and southwestern parts (extensions of the big Feiergan Rift). The Qijiaojing Lake Basin is more apparently controlled by structures and is a typical fault basin[1] (Fig. 6) with

Table 3 Chemical Compositions of Brines

| ...nes of lakes | Brine types \ Seawater | Salinity (g/l) | concentrations Na$^{+}$ | K$^{+}$ | Mg$^{2+}$ | Ca$^{2+}$ | B$^{3+}$ | Li$^{+}$ | U$^{6+}$ | Th$^{4+}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 35.00 | 10500.00 | 38.00 | 1350.00 | 400.00 | 4.60 | 0.17 | $3\times10^{-3}$ | $5\times10^{-3}$ |
| Ebinur | Surface | 91.80 | 28809.03 | | 2621.25 | 159.92 | | | | |
| | Interstitial | 403.00 | | | 16333.33 | | | | | |
| Qingyanchi | Interstitial | 234.00 | 51893.29 | | 3300.00 | 2230.05 | | | | |
| Xiaoyanchi | Interstitial | 362.92 | 106536.97 | | 994.93 | 1094.40 | | | | |
| Hongyanchi | Interstitial | 494.00 | | | | | 31.15 | 2.62 | | |
| Yongji | Interstitial | 430.00 | | | 12000.00 | | 220.60 | 5.89 | | |
| | Interstitial | 452.00 | 164684.00 | | 530.00 | 0.00 | 253.80–<br>1242.80 | 9.79<br>1.38 | 40.00 | 3.00 |
| Beishawo | Interstitial | | | 780.00 | | | 1110.13 | | 0.023 | 0.19 |
| | Interstitial | | 95656.40 | 655.00 | 7460.00 | 595.00 | 130.81 | | | |
| Aydingkol | Surface | 198.00 | 72834.16 | | 1254.42 | 617.03 | 49.73 | | | |
| Qijiaojing | Interstitial | 350.78 | 122842.38 | 1444.99 | 5028.77 | 190.18 | | | | |
| | Interstitial | 373.47 | 109647.18 | | 19526.41 | 0.00 | | | | |
| East Dabancheng | Surface | 351.56 | 115299.82 | 2520.91 | 6419.02 | 174.75 | | | | |
| Barkol | Surface | 212.57 | 58879.41 | | 11798.86 | 471.94 | 63.89 | | | |
| West Dabancheng | Surface | 275.54 | 101257.63 | 1927.82 | 52.65 | 6.07 | 1539.00 | | | |
| Yiwu | Surface | 342.34 | 101620.00 | | 18308.00 | 299.00 | 17.50 | | | |
| North Barkol | Surface | 148.51 | 47394.76 | | 4959.15 | 338.28 | 28.22 | | | |
| | Interstitial | 456.00 | 122834.34 | | 28900.95 | 0.00 | 137.02 | 8.00 | | |
| ...ubasenuoer | Surface | 200.00 | | 4205.00 | 147.00 | 116.00 | 272.20 | | | |
| Shulenuoer | Surface | | 6485.15 | 130.19 | 595.35 | 413.02 | | | | |
| ...iayiduobai Lake | Surface | 334.93 | 123424.99 | | 4364.22 | 178.56 | | | | |
| Lop Nur | Surface | | 1773.86 | 26.19 | 116.98 | 18.64 | | | | |
| Taitema | Surface | 151.00 | 44027.76 | | 3779.33 | 7044.06 | | | | |
| Manas | Surface | 167.00 | 49817.25 | | 2462.00 | 225.45 | | | | |

Table 4 A Comparison of the Ion Concentrations in Sea Water and in Brines of Salt Lakes

| Types \ Ions | U$^{6+}$ | Th$^{4+}$ | B$^{3+}$ | Li$^{+}$ | K$^{+}$ | I$^{-}$ |
|---|---|---|---|---|---|---|
| Sea water | 0.003 | 0.00005 | 4.6 | 0.17 | 380 | 0.06 |
| Salt lake brines* | 40 | 3 | 1100.78 | 1.17 | 780 | 5.24 |
| As multiples of sea water | 13300 | 60000 | 239.3 | 6.9 | 2.05 | 87 |

* Data from the Beishawo mirabilite

in the Salt Lakes over Xinjiang

| of ions (mg/l) | | | | | | Origins of the data |
|---|---|---|---|---|---|---|
| $Cl^-$ | $SO_4^{2}$ | $CO_3^{2-}$ | $HCO_3^-$ | $Br^-$ | $I^-$ | |
| 19000.00 | 2967.00 | 140.00 | 140.00 | 65.00 | 0.06 | Japanese Oceanic Society, 1971. Annual Table |
| 28913.41 | 32621.13 | 110.12 | 430.18 | 55.00 | 0.04 | |
| 179000.00 | 61333.33 | | | | | The Geological Department of Xinjiang Branch, Academia Sinica, 1960 |
| 118587.00 | 1993.00 | 427.00 | 130.81 | 6.69 | 1.41 | |
| 206917.25 | 457.73 | 45.12 | 106.40 | | | |
| 222000.00 | 1800.00 | | | | | |
| 174000.00 | 123000.00 | | | 50.00 | | |
| 20702.27 | 125636.11 | 120170.00 | 14.64 | | | |
| | | | | 29.72 | 5.24 | The Salt Lake Institute Academia Sinica, 1973 |
| 167830.00 | 3868.55 | | 427.00 | 6.69 | 1.41 | |
| 97508.25 | 25836.30 | 45.01 | 466.78 | 0.25 | 0.25 | 1971 |
| 181514.41 | 36649.18 | 0.00 | 150.10 | | | No.6 Geological Team of 1964 |
| 173571.23 | 69455.71 | 356.46 | 4.88 | | | Xinjiang Geological |
| 178587.77 | 50352.51 | 0.00 | 1063.54 | | | [illegible]reau |
| 81214.84 | 59522.01 | 206.28 | 726.36 | 45.00 | 1.20 | 1970 |
| 76119.80 | 67590.12 | 21291.25 | 7705.35 | | | 1964 |
| 177660.00 | 44083.00 | 251.00 | 37.00 | 55.00 | 0.04 | 1970 |
| 66081.64 | 29497.07 | 30.31 | 260.24 | 45.00 | 1.00 | The Xinjiang Comprehensive Investigation Team, Academia Sinica, 1957 |
| 183477.57 | 89842.84 | 379.86 | 148.88 | 120.00 | | |
| 93190.00 | 51480.00 | | | | | |
| 6353.89 | 7950.42 | 0.00 | 245.29 | | | |
| 183454.52 | 26800.97 | 0.00 | 210.51 | | | |
| 2423.49 | 600.89 | 0.00 | 169.02 | | | |
| 96265.76 | 9914.01 | 693.12 | 6437.40 | | | |
| 77296.26 | 9318.40 | 60.0h | 244.07 | | | Xinjiang Oil Administrative Bureau, 1957 |

Table 5 The Hydrochemical Types of the Brines in Xinjiang Salt Lakes

| ιes of lakes | Characteristic coefficients | | | | Hydrochemical types | |
|---|---|---|---|---|---|---|
| | $K_{n1}$ | $K_{n2}$ | $K_{n3}$ | $K_{n4}$ | | |
| t Dabancheng | 180.48 | 484.42 | 7476.20 | 2785.43 | Carbonate | |
| ιur | 0.01 | 3.11 | 86.46 | 1.34 | Sulfate | Subtype of $Na_2SO_4$ |
| asenur | 0.00 | 59.91 | 185.11 | 0.00 | | |
| enur | 0.06 | 2.44 | 8.23 | 0.20 | | |
| :ol | 0.02 | 1.25 | 35.39 | 0.52 | | |
| .h Barkol | 0.01 | 1.46 | 36.69 | 0.31 | | |
| ιojing | 0.01 | 1.81 | 80.60 | 0.26 | | |
| Dabancheng | 0.03 | 1.99 | 122.22 | 1.99 | | |
| duobai | 0.01 | 1.53 | 63.01 | 0.39 | | |
| gji | — | 2.59 | 256.07 | — | | |
| ingkol | 0.07 | 4.08 | 17.77 | 0.30 | | |
| Nur | 0.26 | 1.45 | 16.43 | 2.97 | | |
| as | 0.03 | 0.94 | 17.79 | 0.53 | | Subtype of $MgSO_4$ |
| u | 0.01 | 0.51 | 62.16 | 0.64 | | |
| ɡyanchi | 0.01 | 0.12 | 0.41 | 0.04 | Chloride | |
| ›yanchi | 0.04 | 0.11 | 0.26 | 0.09 | | |
| ema | 0.19 | 0.51 | 0.95 | 0.37 | | |

ιtified Cenozoic deposits. The basement of the lake basin and the surrounding ranges are nposed of a series of early Paleozoic volcanic clastic rocks, neutral–basic eruptive sea floor

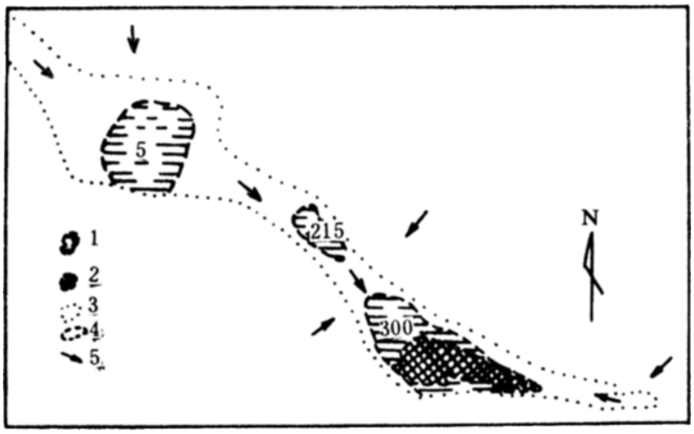


Fig.5 Sketch of the evolution of Chaiwopu ancient lake basin

1. Lake brines and their salinity (g/l)
2. Salt deposits
3. Borders of lake basin from the end of late Pleistocene to early Holocene
4. Borders of modern lake brines
5. Supplying directions of water

rocks, and normal marine sedimentary rocks. The Kumukuli basin, Baytik intermontane basin, and Barkol basin, are all structural origin basins. They are large in area and have evolved for a long time, and have formed some big salt lakes, such as Aydingkol, Ebinur, Kumukuli and other saline lakes.

Non–structural basins: they are basins, depressions and low lands formed by outside geological agents. The water–collecting basins and depressions belong to these kinds of basins which were formed by deflation, glaciation, erosion, or the accumulations of rivers and streams.

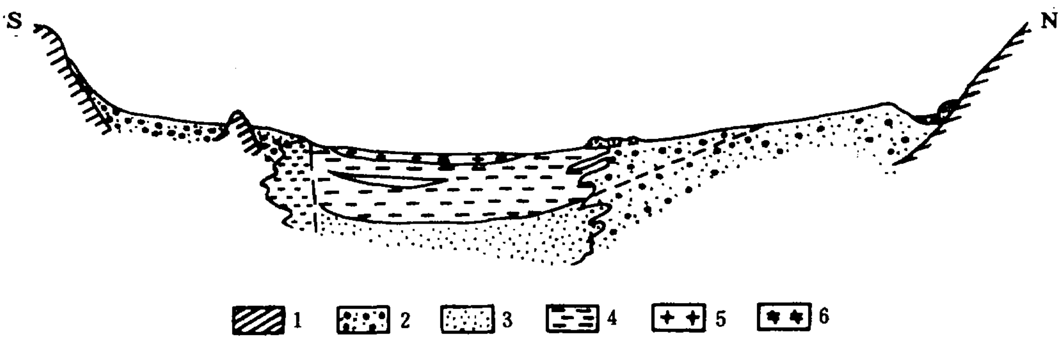


Fig. 6 Section of sediments in Qijiaojing salt lake (from Chen Taocheng)

1. Basic rock
2. Sand and gravel sediments
3. Sand sediment
4. Clay sediment
5. Halite
6. Mirabilite

These basins are usually wide and shallow, and have evolved only for a short time. They change easily, and often form small salt lakes or groups of lakes. For instance, the Manas, Ailikeηuoer, and Dabasongnuoer salt lakes were all formed by the course change and scouring action of the ancient Masas River. The course and other changes of rivers change the salt lakes sharply. For example, Lop Nur is a very unstable shifting lake[7]. Its subsidence centre has moved many times due to course and other changes of the Tarim River and its tributary, the Konqi River.

**2. Substance Origin of the Salts in the Salt Lakes**

The material origins of the salts in the Xinjiang salt lakes can be basically divided into three kinds: salts produced by a redissolution of ancient salts, by weathering of basic rock[7] and by cycling of natural waters.

Analyses of the paleogeography of the lithofacies show shallow marine or lagoon sediment structures of the early Miocene in Tertiary spread only in the Kashi–Kuqa depression. The whole of Xinjiang became an inland[1,3] in Miocene which formed red lacustrine clastic sedimentary structures extensively. In other words, the sea water of the ancient Mediterranean Sea had completely retreated from this region by the end of Tertiary, and the Quaternary inland lacustrine sediments had no direct relation with sea water. The various salt–forming elements are clearly not derived from the sea water.

The ancient salt deposits are the most widespread in the Xinjiang area of China. It is reported[3,5,6] that there are deposits of fossil salt sediments in the Cambrian, Devonian, Carboniferous, Jurassic, Cretaceous and Tertiary here. Among them, economically important carboniferous gypsum and Tertiary gypsum halite are thick and widely distributed. The well developed Tertiary evaporites indicate a long period of extensive precipitation of ancient salts in the district[3,6]. The salt bearing rock systems usually spread along the rims of the salt lake basins or near them, thereby providing directly the material origins of the salts for the salt lakes. For instance, gypsum–bearing rock systems are several hundred metres thick in the Kumukuli basin; gypsum deposits are widespread along the margin of the Turpan Basin, with a single layer of about 5 metres thick extending several kilometres discontinuously. The salt domes develop well, with salt layers more than one hundred metres thick extending tens of kilometres. The thickest is 127 m in the Aksu region of the Kuqa basin. Tertiary salt–bearing layers of various thicknesses spread in the Qijiaojing and Hami basins and other places. These salt–bearing rock systems supply salts for modern inland salt lakes. After the salts have been washed and leached by rain and ground water, the soluble ions of alkali metals and alkali earth metals, such as $Na^+$, $K^+$, $Mg^{2+}$, $Cl^-$, $SO_4^{2-}$, and so forth, are dissolved and then transported by surface water (water melted from ice and snow) or ground water into the salt lakes (Fig. 7). The salt sources are redissolved salts that often undergo a selective process of dissolution—precipitation—redissolution—reprecipitation, after which they are transported and moved many times. They are the most important direct substance origins of the salt–forming elements in the salt lakes of the region.

The salt lake basins are mostly surrounded by ranges of various rocks with different kinds of beds. Under the changeable natural conditions, the source rocks of the lake basins were strongly weathered physically and chemically. Soluble salts were carried to the lake regions by surface water (runoff) or ground water. This is another material origin of the salt–forming elements in the salt lakes here.

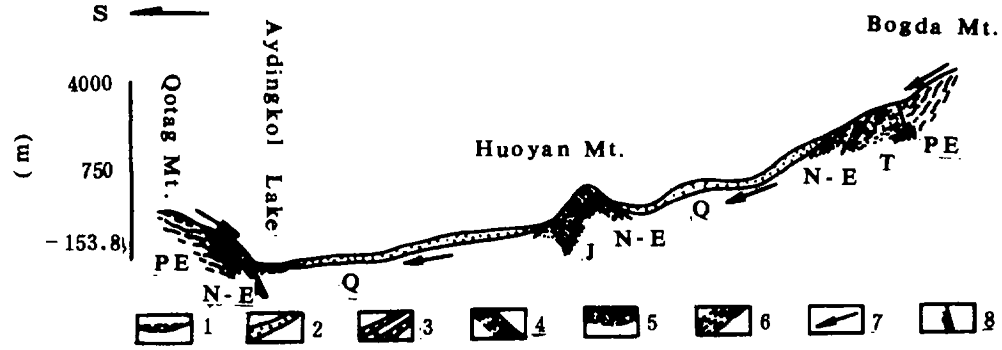


Fig. 7 A profile of Bogda–Qotag Mt. (from Xinjiang Oil Bureau)

1. Lacustrine sediment
2. Sand and gravel sediment
3. Salt–bearing rock systems
4. Coal–containing strata
5. Sandy shale
6. Basic rock
7. Supplying direction of water
8. Faults

Xinjiang is complicated in landform. It has many ice and snow covered peaks towering into the clouds, and basins and depressions below sea level. The cycles of ground water develop well. Its various springs (cold springs and hot springs) are very important sources of salts supplied to the salt lakes.

### 3. Paleoclimate and Salt–formation

An arid climate is an important factor that speeds up lake water evaporation and concentration and promotes salt–formation. The Xinjiang salt lakes were largely formed in Holocene of the late Quaternary. From analysis of data available, their salt–forming period was not very long. Their main salt deposits emerged from late Holocene up to the present. The ranges of the salt deposits were not so broad, and single cyclic sedimentation occurred in most salt lakes while multi–cyclic sedimentations emerged in some intermontane basins[1]. The vertical differentiation is clear in the salt deposits. From the bottom up there exist gypsum, mirabilite, and halite deposits. This is historic evidence of continuous Paleoclimate evolution from a humid to a dry climate. Generally speaking, under the inland arid climate, the humid environment is favorable for the accumulation of salt–forming elements whereas the arid environment is good for salt–formation.

Based on the analyses of the Xinjiang salt lakes' paleogeographic environment affected by the rising and faulting of the earth crust, two obvious paleoclimatic evolution cycles emerged during Quaternary, i.e. from a warm–humid to hot climate (from early Pleistocene to early Holocene) and from a wet to dry climate (in late Holocene up to today).

As the humid climate of Pliocene continued, freshwater lacustrine sand mudstones and conglomerate rocks were deposited in the beginning of early Pleistocene. This warm–humid climate was lasting and it became warm–dry only by early Holocene. The salification of the lake water started and the appearance of mirabilite and thenardite in some lake basins characterized the first climatic cycle. The Paleoclimate turned humid in the middle and late Holocene and lake water was relatively fresh. The occurence of sandy clay in lakes indicated the beginning of a new climatic

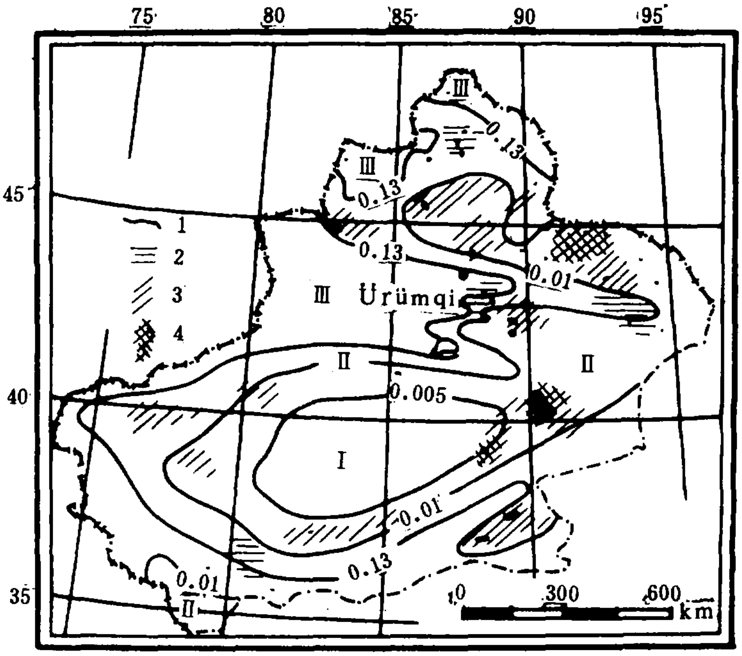


Fig. 8 Types of underground water and climatic zones in Xinjiang

1. Isopleth of dry index 2. Carbonate type

3. Sulfate type 4. Chloride type

I. Dry desert region II, Arid and semi–arid desert areas

III. Semi–arid desert–grassland region

cycle. The arid climate appeared over the whole of Xinjiang only in recent times (Fig. 8). Intense evaporation and concentration of the lake waters resulted in the existence over vast areas of salt-formations of mirabilites, halite, tronas, etc. that spread extensively in various dry basins over the whole of Xinjiang in the period.

## IV. CONCLUSION

The salt lakes that spread all over Xinjiang made the region one of the important salt lake zones in China. The lakes can be divided into carbonate, sulfate and chloride types according to origins (mainly sulfate types and sodium sulfate subtypes). The brines can be divided into surface and interstitial brines. They are highly-mineralized and have reached the stage of crystalizing out salts. There are carbonate, sulfate and chloride salts in the salt deposits, among which sulfates (such as mirabilites) and chlorides (such as halites) are widely distributed. The brines are principally composed of Na, K, Mg, Ca, Cl, $SO_4$, $HCO_3$, and $CO_2$. They also contain the rare and scattered elements B, Li, Th, I. It is evident that the above salts were formed by evaporation.

The Xinjiang salt lakes were formed not too long ago and the salt-forming period was quite short. Most of these salt lakes were formed from Holocene of the late Quaternary to the present. They are still in the stage of salt-formation. The differentiation of salt deposits is apparent and the sequence is clear.

The salt lake origins are chiefly structural. The new tectonic influence is particularly obvious, as shown by the many terraces along the lakeshores. The salt-forming elements of the salt lakes come from inland, and mainly from the redissolved salts of the Tertiary salt-bearing rock systems. Weathered rocks and natural water in the substance origion regions are the secondary sources. There are two cycles in Quaternary paleoclimate, i.e. from warm-humid to hot between early Pleistocene and early Holocene. (although the lake waters tended to be salified, most lake waters did not crystallize out salts; ) and from wet to dry from middle to late Holocene to the present. The lake waters are intensely evaporated and concentrated, and the salt-formation occurs over a very vast area. The regions with arid to semi-arid climate are the favorable zones for the formation of most salt lakes in Xinjiang.

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