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A Preliminary Investigation on an Evaporating Experiment (25°C) for Qinghai Lake Water, China*

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ABSTRACT

Qinghai Lake is located in the north-eastern part of the Qinghai-Xizang (Tibet) Plateau, and is a typical continental brackish-water lake. The lake water is of a sodium sulphate sub-type with a salinity of 14.23‰ and clearly differs from seawater in chemical composition. It is saturated with $CaCO_3$. Aragonite is separated. Experimental results of evaporation show that hydromagnesite is first precipitated in the concentrated lake water, and then halite, thenardite, bloedite, picromerite, epsomite (sylvite) and carnallite. This salt-separating sequence and crystallization pathway is similar to that of other saline lakes of the Qinghai-Xizang Plateau, and differs from that of seawater. It is very important to illustrate the evolving tendency of Qinghai-Xizang Plateau salt lakes, as well as the formation of some salt deposits in continental lake basins.

INTRODUCTION

Qinghai Lake is located in an inter-montane rift-depression basin on the southern side of the Qilian mountains. Covering an area of 4340 km^2, it has an altitude of 3193.92 m above sea-level, and a maximum depth of up to 27 m. In the north-east there are many small lakes — Gahai and Haiyan Bay, etc. — separated or partially separated from the lake; in the east Erhai Lake is isolated from it. The external drainage is fairly well developed. The largest river — the Buha — is situated to the west of the lake and its total annual inflow into the lake makes up 67% of the total runoff. The annual average temperature is 0.9–2.7°C, and the annual evaporation is 3.8 times the annual precipitation. Thus this area has a high, cold, semi-arid prairie climate. Qinghai Lake began to be formed during the mid-Pleistocene (at least 0.5 Ma B.P.) (Yuan et al., 1990). The lacustrine sedimentation has developed since the Late Pleistocene and consists of a suite of dark calcareous muds enriched in inorganic materials with obvious fine lamination (Kelts et al., 1989; Huang et al., 1989).

Qinghai Lake water has a salinity of 14.23‰ and is of a sodium sulphate sub-type. It is a typical continental water-body (Table 1). The main chemical components of the water are cations $Na^+ > Mg^{2+} > K^+ > Ca^{2+}$ and anions $Cl^- > SO_4^{2-} > HCO_3^- + CO_3^{2-}$. Compared with seawater, there are obvious differences in chemical composition, characteristic coefficients and hydrochemical types. The waters of the salt lakes and lakes of the Qinghai-Xizang Plateau are characterized by high B and Li and low Br contents. In addition, they are high in $Mg\text{-}SO_4$ and low in Ca. At present, Qinghai Lake water is saturated with CaCO and aragonite is separating (Figs. 1 and 2). Hydromagnesite is distributed on the eastern bank of Haiyan Bay (Fig. 3).

The waters of the continental lake basins are mainly of two chemical types: sulphate and carbonate. Qinghai Lake is typical of the former. In order to discover the evolution process and salt-separating sequence of the water body, an evaporating experiment was carried out on a large volume of Qinghai Lake water. This experiment is important for illustrating the formation and evolution of the salt lakes on the Qinghai-Xizang Plateau as well as the formation of some salt deposits. However, little effort has been made, at home or abroad, to the study the evaporation of low concentration solutions.

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TABLE 1

Comparison of chemical composition between Qinghai Lake water and seawater (after Sun et al., 1992)

Location	Qinghai Lake	Seawater	South China Sea	Huanghai Sea	Haiyan Bay	Gahai Lake
Density (g/cm^3)	1.011		1.022	1.022	1.016	1.024
pH	9.15–9.30		7.52		8.94	9.02
Salinity (‰)	14.23	34.48	33.20	31.30	17.83	31.88
Main chemical components (‰):						
Na^+	3.93	10.56	10.20	9.67	5.02	9.46
K^+	0.16	0.38	0.39	0.33	0.20	0.44
Mg^{2+}	0.79	1.27	1.33	1.16	0.97	1.35
Ca^{2+}	0.01	0.40	0.39	0.37	0.01	0.01
Cl^-	5.79	18.98	18.44	17.15	7.42	13.37
SO_4^{2-}	2.35	2.65	2.61	2.37	2.91	6.04
HCO_3^-	0.68	0.14	0.15	0.13	0.58	0.53
CO_3^{2-}	0.52	–	–	–	0.71	0.68
Trace elements (ppm):						
B	11.7	4.6	4.3	4.3	14.8	24.7
Li	0.84	0.1	<1	0.17	1.13	2.10
Br	1.50	65	72	61	2.0	5.5
I	0.004	0.05	<0.01		0.005	0.011
Sr	0.04	8	9	7.8	0.05	0.07
Ba	0.02	0.006			0.03	0.02
P	0.503	0.001–0.06			0.95	1.20
Cu	0.016	0.001–0.025			0.03	0.024
Fe	0.067	0.003			0.09	0.10
Ni	0.092	0.0015–0.006			0.20	0.14
Mn	0.016	0.001			0.019	0.02
Ti	0.01	0.001–0.009			0.02	0.018
U	0.042	0.003			0.07	0.064
Zn	0.0021	0.009–0.021			0.014	0.004
Cr	0.124	0.001–0.0025			0.17	0.20
Si	0.925	0.01–4			1.32	2.04
Al	0.259	0.003–2.4			0.46	0.47
Characteristic coefficients:						
Na/K	24.56	27.79	25.69	29.30	25.48	21.50
Mg/K	4.94	3.34	3.41	3.52	4.90	3.07
Mg/Ca	79	3.18	3.41	3.52	96.5	135
$(K/\Sigma salt) \cdot 1000$	11.24	11.02	11.75	10.54	11.22	13.80
$Cl^-/\Sigma salt$	0.41	0.55	0.55	0.55	0.42	0.42
$SO_4^{2-}/\Sigma salt$	0.17	0.08	0.08	0.08	0.16	0.19
$(HCO_3^- + CO_3^{2-}/\Sigma salt) \cdot 100$	8.43	0.41	0.45	0.42	7.24	3.80
Hydrochemical type	Na_2SO_4-subtype	$MgSO_4$-subtype	$MgSO_4$-subtype	$MgSO_4$-subtype	Na_2SO_4-subtype	Na_2SO_4-subtype

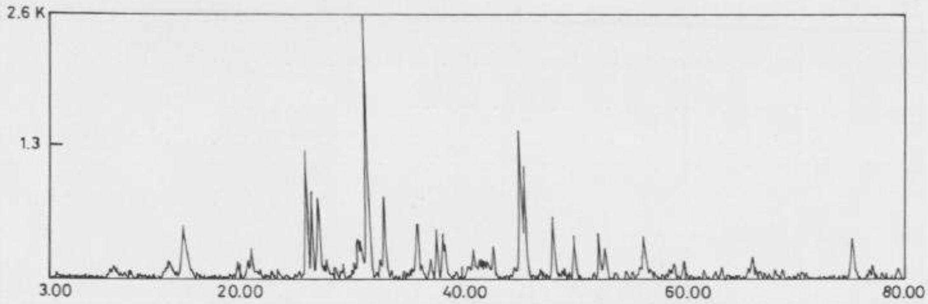


Fig. 1. X-ray powder analysis of aragonite (contained hydromagnesite) separated from Qinghai Lake water.

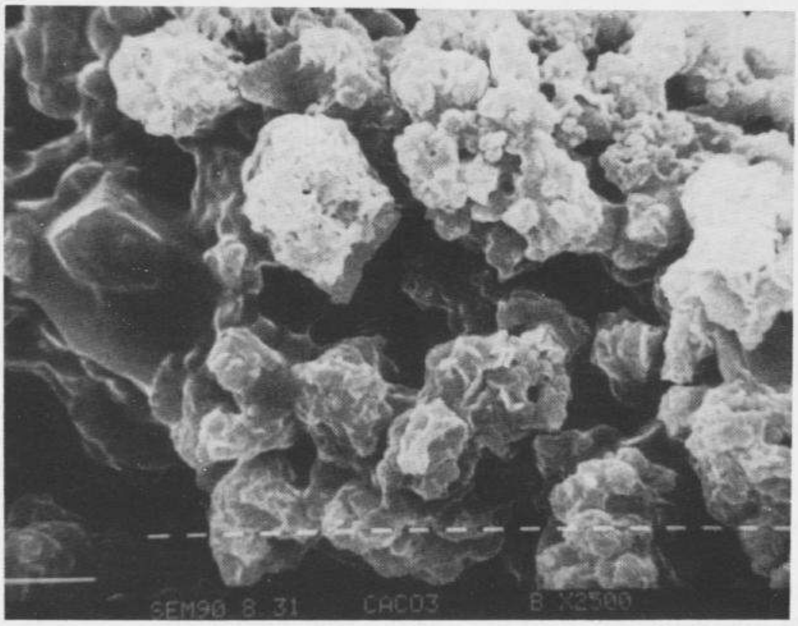


Fig. 2. SEM photograph of aragonite obtained from Qinghai Lake water.

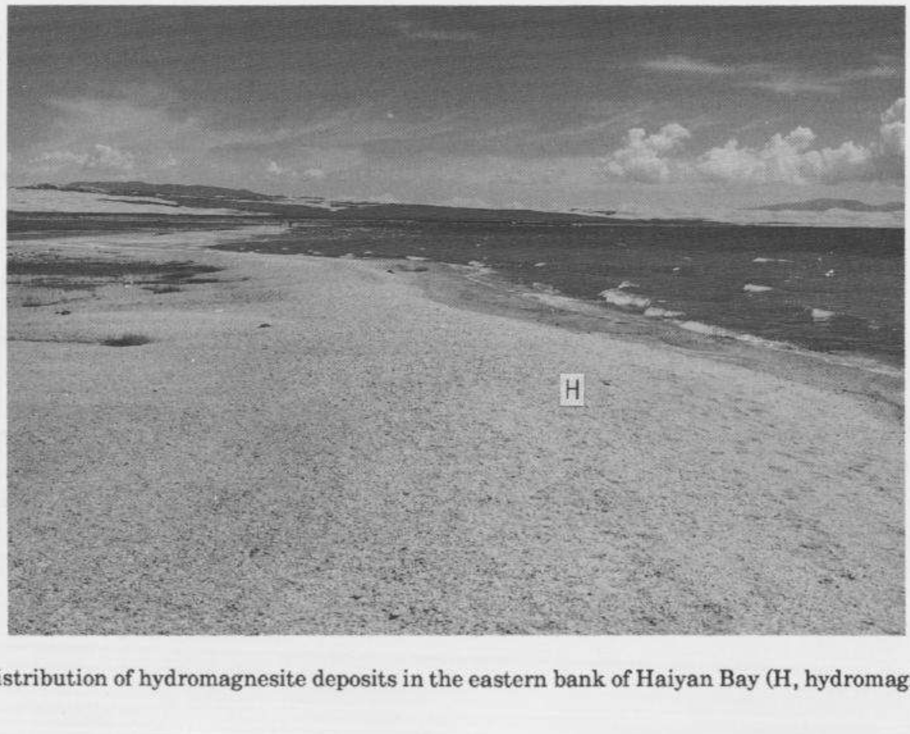


Fig. 3. Distribution of hydromagnesite deposits in the eastern bank of Haiyan Bay (H, hydromagnesite).

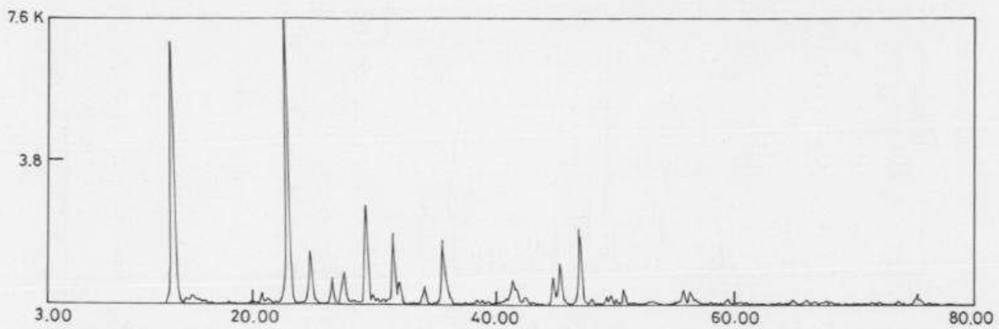


Fig. 4. X-ray powder analysis of nesquehonite obtained from the solar evaporating experiment for Qinghai Lake water.

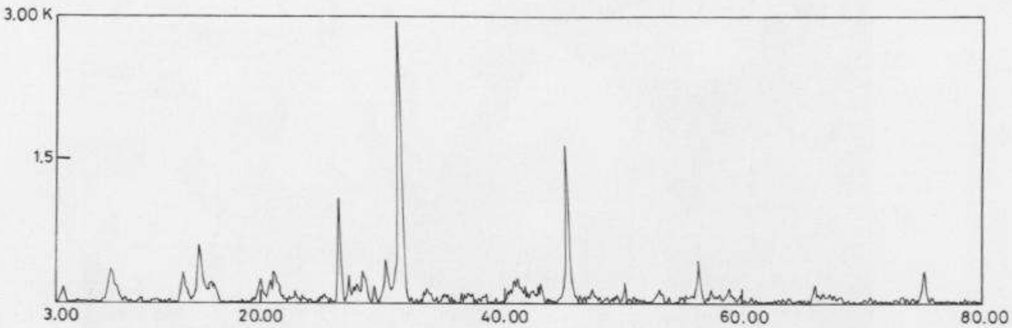


Fig. 5. X-ray powder analysis of hydromagnesite obtained from the solar evaporating experiment for Qinghai Lake water.

EVAPORATING EXPERIMENT

Experimental method

A water sample of approximately 0.75 m^3 was collected from Erlangjian on the southern bank of Qinghai Lake in April 1990. The solar evaporating experiment was then carried out in the field by the Xining laboratory on the large volume of lake water, from May to October of the same year, until the halite precipitation was separated from the mother liquid. In 1991 the evaporating experiment was carried out at 25°C in the laboratory using the brine of the separated halite, and finally ended at the carnallite precipitation stage. The solar evaporating experiment for Qinghai Lake water was carried out in plastic troughs (100x100x40 cm each) under sunlight. The isothermal evaporating experiment (25°C) for the lake water was carried out with an isothermal plant from the laboratory, putting the brine of separating halite into a glass trough which was heated with bulbs. The temperature was controlled by a contact temperature meter and a relay (precision ± 0.5°C). For the entire experiment we adopted the continuously separating method of liquid and solid phases.

Liquid phase samples obtained from the experiment were determined by chemical analysis and the AAS method (such as Na and Li elements). The solid samples were identified by chemical, microscope and X-ray powder analysis, and part by scanning electron microscopy.

EXPERIMENTAL RESULTS

Solar evaporating experiment on a large volume of Qinghai Lake water

The original lake water has a specific gravity of 1.010 and 17.07 g/l salinity. It is saturated with $CaCO_3$, and aragonite is separating. This is determined by X-ray powder analysis and scanning electron microscopy. As the evaporation and concentration progress, the salt-separating sequence was as follows (Table 2):

(a) When the specific gravity reached 1.015, and at a salinity of 22.21 g/l, nesquehonite began to precipitate (Fig. 4). At that time, the concentration of the mother liquid was similar to that of Haiyan Bay water (Table 1).

(b) Specific gravity reached 1.025 at a salinity of 33.94 g/l, hydromagnesite (containing a few calcites) began to precipitate (Figs. 5 and 6). At that time, the concentration of the liquid phase was similar to that of Gahai water (Table 1).

TABLE 2

The result of the natural evaporating experiment for Qinghai Lake water

Samples	S.G./t°C	Salinity (g/l)	pH	Chemical composition of liquid phase (g/l)												Index (M/100 M)			Solid phase
				Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	B_2O_3	Li (mg/l)	Br (mg/l)	I (ug/l)	$2K^+$	Mg^{2+}	SO_4^{2-}	
QE-OW	1.010	14.07	9.31	4.13	0.15	0.75	0.0	5.64	2.29	0.53	0.56	0.04	0.88	2.97	4.2	3.50	54.4	42.11	Aragonite
QE-1	1.015/17°C	22.21	9.27	6.40	0.25	1.15	0.01	9.21	3.7	0.83	0.67	0.06	1.3	4.5	6.5	3.4	53.05	43.5	Nesquehonite
QE-2	1.025/28°C	33.9	9.03	9.88	0.39	1.67	0.02	14.1	5.70	1.23	0.94	0.10	1.9	6.7	14.4	3.77	51.5	44.73	Hydromagnesite
QE-3	1.071/25°C	102.1	n.d.	31.7	1.27	4.07	0.05	44.9	17.9	1.16	1.09	0.31	5.4	19.4	53	4.39	45.2	50.4	Hydromagnesite
QE-4	1.237/17°C	352.5	n.d.	110.0	4.32	12.5	0.20	159.3	63.4	2.84		0.78	13.8	n.d.	90	4.50	41.80	53.7	Halite
QE-5	1.256/14°C	379.1	n.d.	120.0	4.68	13.4	0.18	170.1	68.16	2.54		0.86	14.5	n.d.	n.d.	4.55	41.75	53.75	Halite

TABLE 3

The result of the isothermal evaporating experiment (25°C) for Qinghai Lake concentration brine

Samples	S.G.	Salinity (g/l)	pH	Chemical composition of liquid phase (g/l)												Index (M/100 M)			Solid phase
				Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	B_2O_3	Li (mg/l)	Br (mg/l)	I (ug/l)	$2K^+$	Mg^{2+}	SO_4^{2-}	
QE-OW'	1.256	379.1	n.d.	120.0	4.68	13.42	0.18	170.1	68.16	2.54		0.8	14.5			4.55	41.7	53.75	Halite
QE-6	1.266	380.2	8.04	103.1	5.82	16.65	0.07	169.9	85.82	0.95	0.82	0.83	17.47	237	0.03	4.85	41.2	54.2	Halite + Thenardite + Hydro-glauberite (?)
QE-7	1.285	404.5	7.94	99.84	7.84	22.31	0.06	156.3	115.98	1.13	1.04	1.09	23.1	309	0.03	4.62	41.04	54.34	Halite + Thenardite + Bloedite
QE-8	1.303	403.8	8.00	94.72	9.94	25.21	0.02	153.7	117.6	1.06	1.53	1.33	43.1	370	0.04	5.40	42.7	51.9	Halite + Bloedite + Picromerite
QE-9	1.301	416.3	7.94	97.70	10.67	26.15	0.07	155.8	123.4	1.12	1.54	1.38	43.1	399	0.05	5.20	42.93	51.89	ditto
QE-10	1.306	416.8	7.87	84.50	12.7	29.63	0.06	151.8	135.04	1.13	1.98	1.73	52.8	483	0.05	5.63	43.7	50.7	ditto
QE-11	1.309	426.24	7.84	84.43	15.43	32.86	0.06	151.8	137.7	1.93	2.80	2.05	64.1	525	0.06	6.61	45.4	51.9	Halite + Bloedite + Picromerite + Epsomite
QE-12	1.346	436.7	7.24	46.7	31.8	55.7	0.04	164.2	138.3			5.07	160.5	562	n.d.	9.79	55.35	34.86	Halite + Epsomite + Carnallite
QE-E	1.350	446.9	8.52	15.0	31.37	84.83		216.3	99.40			9.42	425	1250	n.d.	8.11	70.8	21.06	Halite + Hyxahydrite + Epsomite + Carnallite

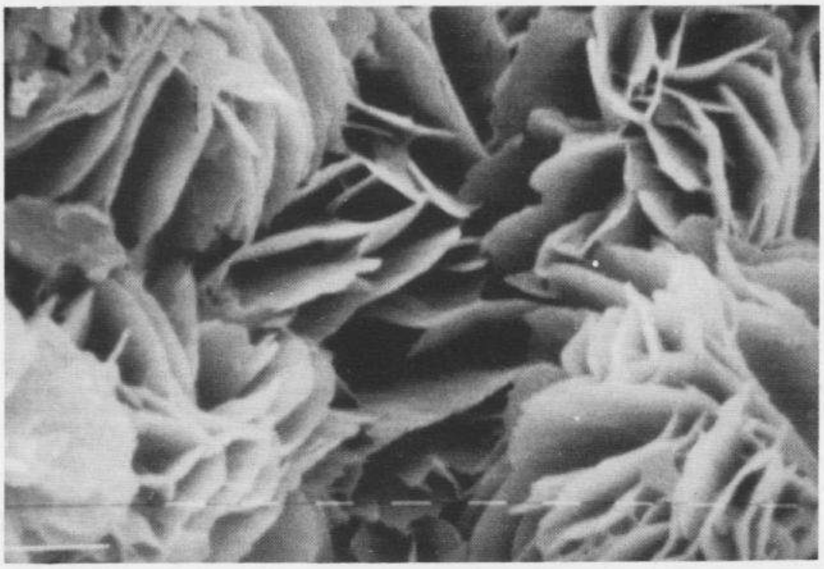


Fig. 6. SEM photograph of hydromagnesite obtained from the concentration brine of Qinghai Lake (x 7500).

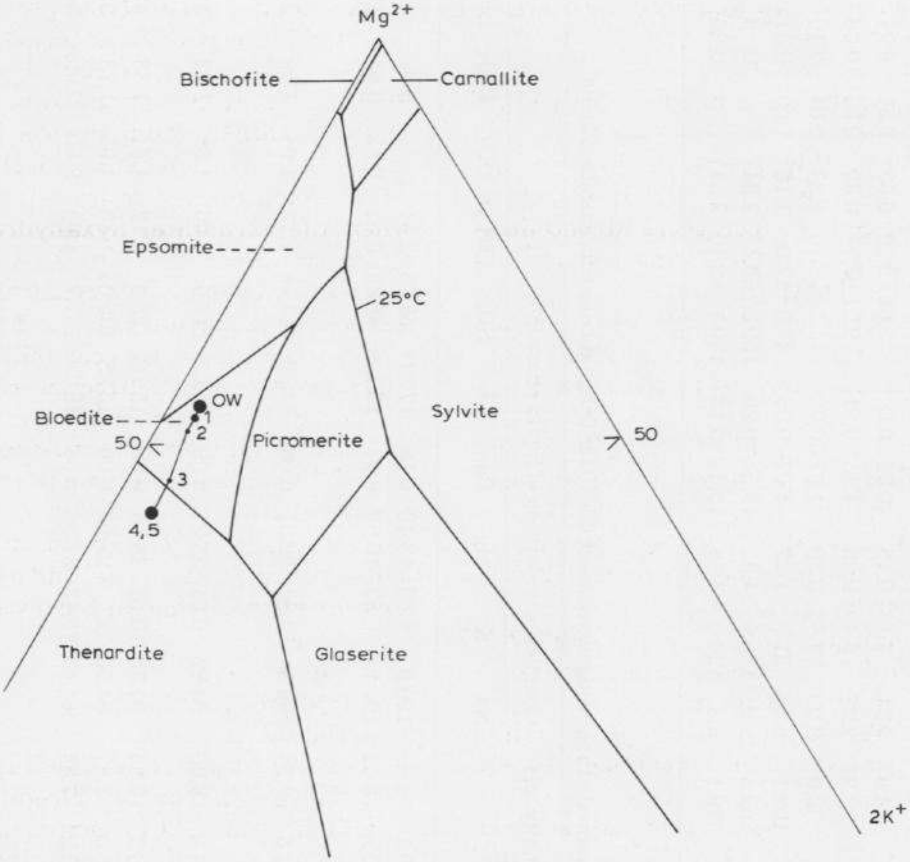


Fig. 7. The crystallization path of the solar evaporating experiment of Qinghai Lake water.

(c) At a specific gravity of 1.237 and a salinity of 352.52 g/l, halite began to precipitate.

With the evaporation and concentration of the lake water, the the chemical composition point of the original lake water is situated at the bloedite field of the metastable phase diagram (25°C) for Na^+, K^+, Mg^{2+}//Cl^-, SO_4^{2-}, H_2) system (Fig. 7), and then drops to the thenardite field with the separation of nesque-

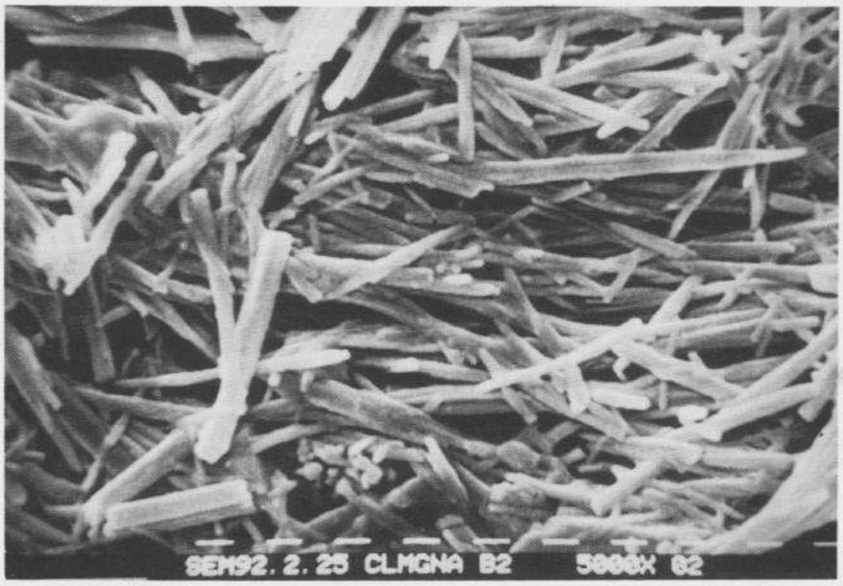


Fig. 8. Borate obtained from the final mother liquid of the evaporating experiment for Qinghai Lake water.

honite and hydromagnesite. This was the starting point for halite precipitation.

Isothermal evaporating experiment (25°C) for Qinghai Lake water

The original sample brine from the halite-separating stage with a specific gravity of 1.256 and a salinity of 379.07 g/l. With the evaporation and concentration of the brine, its salt-separating sequence is described as follows (Table 3):

(a) As the specific gravity of the brine reached 1.266, the salinity was 380.17 g/l and thenardite began to precipitate. Its mineral group was halite + thenardite.

(b) At S.G. 1.285, salinity 404.54 g/l, bloedite begins to separate. Its mineral group: halite + thenardite + bloedite.

(c) At S.G. 1.303, salinity 403.84 g/l, picromerite began to precipitate. Its mineral group: halite + bloedite + picromerite.

(d) At S.G. 1.309, salinity 426.34 g/l, epsomite began to precipitate. Its mineral group: halite + bloedite + picromerite + epsomite.

(e) At S.G. 1.346, salinity 436.66 g/l, carnallite began to precipitate. Its mineral group: halite + epsomite + carnallite.

(f) Finally, when the specific gravity reached 1.350 and salinity was 446.90 g/l the precipitated salts were halite + hyxahydrite + epsomite + carnallite. The remaining mother liquid, containing 9.42 g/l B_2O_3, was reserved for a month after which borate was precipitated (Fig. 8) (its name was undetermined).

In the experimental process. The original brine point was situated at the upper part of the thenardite field of the metastable phase diagram (25°C) for the Na^+, K^+, Mg^{2+}//Cl^-, SO_4^{2-}, H_2O system (Fig. 9). With evaporation and concentration, this point moved upwards, passing the bloedite field and entering the epsomite field. Finally it closed to the eutectic point of halite + epsomiite + picromerite + sylvite when the carnallite, hyxahydrite, epsomite and halite were separated (Fig. 9). Obviously the crystallization pathway was not consistent with that of the metastable phase diagram, because the component of the natural brine was complicated and its evaporation rate was rapid during the experimental process.

During the evaporating experiment process, the sylvite-separating stage should exist between points 11 and 12. Unfortunately we were unable to take the sample in time.

From the above, it can be concluded that the whole salt-separating sequence during evaporation and concentration of Qinghai Lake water is as follows:

a. Aragonite
b. Nesquehonite
c. Hydromagnesite
d. Halite
e. Halite + thenardite + hydroglauberite (?)
f. Halite + thenardite + bloedite
g. Halite + bloedite + picromerite + epsomite
h. Halite + bloedite + picromerite + epsomite
i. (Halite + picromerite + epsomite + sylvite)
j. (Halite + epsomite + sylvite + carnallite)
k. Halite + epsomite + carnallite
l. Halite + epsomite + hyxahydrite + carnallite

The whole crystallization path was also rather complicated. At first, the original point was situated

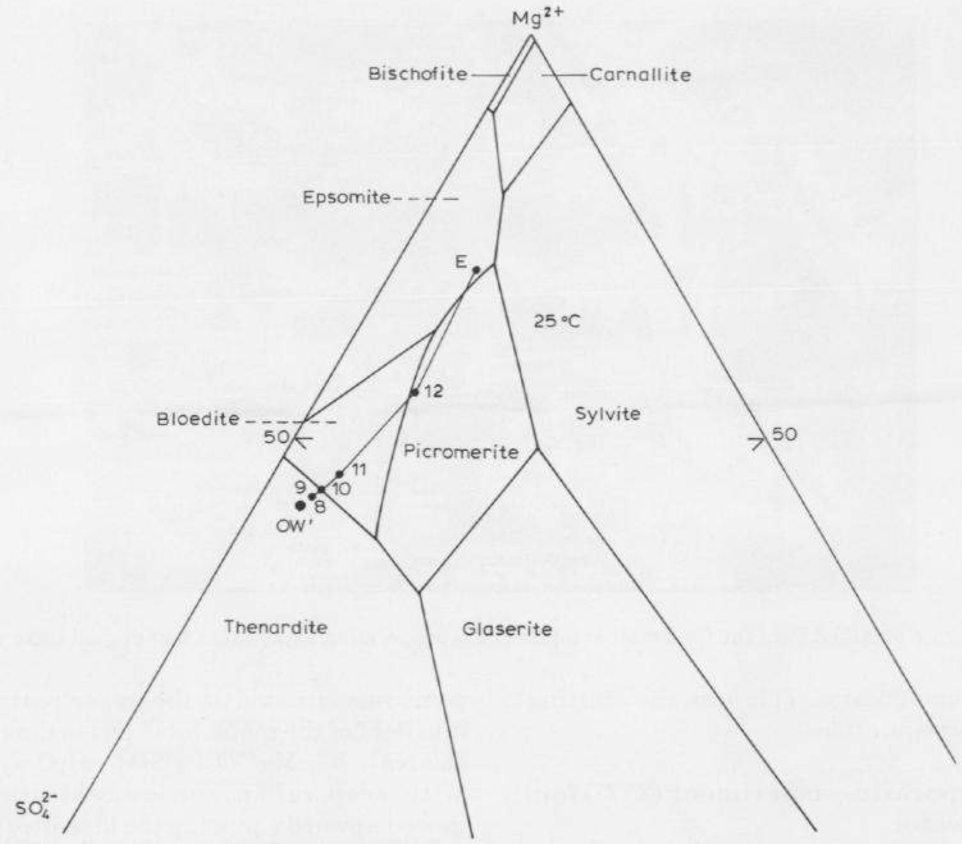


Fig. 9. The crystallization path of the isothermal evaporating experiment (25°C) for Qinghai Lake water.

at the bloedite field and then moved down to the thenardite field with the precipitation of nesquehonite and hydromagnesite, finally rising to the epsomite field passing through the bloedite field. That is, the final constituting point of the mother liquid still fell into the epsomite field of the metastable diagram for Na^+, K^+, Mg^{2+}, Cl^-, SO_4^{2-}, H_2O five-component system (Fig. 9).

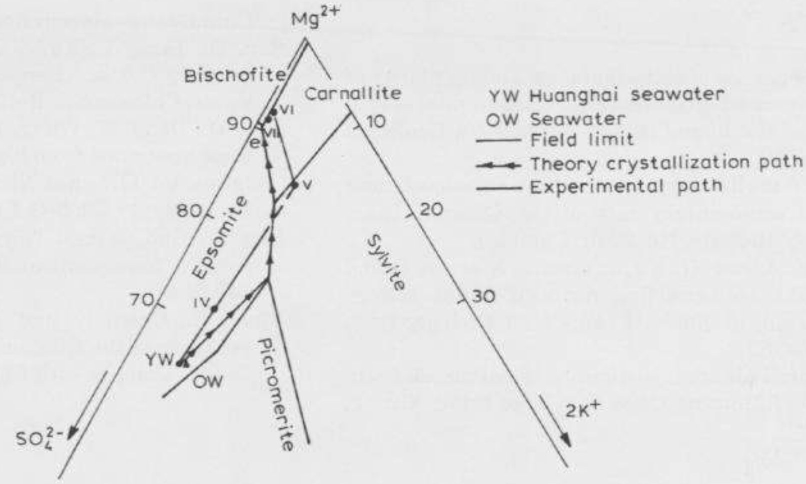
In addition, we have carried out the solar evaporating experiment for Gahai Lake water. The salt-separating sequence and crystallization path were similar to those of Qinghai Lake water.

In the above experimental process for Qinghai Lake water, further concentration in the mother liquid yielded the precipitation of various salts such as borate and lithium achieved at concentrations of 9.42 and 425 mg/l, respectively (Table 2). This sufficiently showed the characteristics rich in B and Li of the saline lakes on the Qinghai-Xiang (Tibet) Plateau of China.

DISCUSSION

1. The result of the evaporating experiment on Qinghai Lake water reflected the whole process of the evolution of the sulphate-type continental water-bodies. At the same time, it also revealed the future evolution route of Qinghai Lake under arid climatic conditions. At present hydromagnesite is depositing in the Haiyan Bay and Gahai Lake to the north-east of Qinghai Lake. This phenomenon shows that Qinghai Lake is slowly developing into a saline lake.

2. The salt-separating sequence and crystallization path in the process of evaporating experiment on Qinghai Lake water were similar to those of Zhacang Caka Salt Lake (Tibet) (Sun et al., 1984), and obviously different from those of seawater. According to the data of Chen (1983), the salt-separating sequence of the isothermal evaporating experiment at 25°C for Huanghai Sea water (China) was determined as follows: (a) aragonite, (b) gypsum, (c) halite + gypsum, (d) halite + epsomite, (e) halite + epsomite + sylvite, (f) Halite + epsomite + carnallite, and (g) halite + epsomite + carnallite + bischofite. Such a salt-separating sequence was obviously different from that of Qinghai Lake water. Although some of the same salts were precipitated, their separating condition from chemical composition of those water concentrated are also different, such as aragonite, halite and carnallite etc. (Table 2, Fig. 10).



Concentrating stage	Chemical composition (‰)							$M/2K^+ + Mg^{2+} + SO_4^{2-}$ = 100 M			Solid phase
	K^+	Na^+	Ca^{2+}	Mg^{2+}	HCO_3^-	SO_4^{2-}	Cl^-	$2K^+$	Mg^{2+}	SO_4^{2-}	
YW	0.33	9.56	0.37	1.16	0.13	2.36	17.11	5.5	62.8	31.6	
IV_2	12.56	32.74	0.19	45.82	—	65.53	146.60	5.9	69.0	25.0	Epsomite
V	18.96	8.93	0.15	67.58	—	55.32	185.45	7.2	83.2	16.8	Sylvite
VI	0.82	1.27	0.07	92.41	—	30.87	242.93	0.25	92.2	7.6	Carnallite
VII	0.52	1.26	—	92.59	—	35.85	238.25	0.20	91.1	8.7	Bischofite
OW*	0.38	10.56	0.40	1.27	0.14	2.65	18.98	5.8	62.2	31.3	

*OW — Seawater

Fig. 10. The crystallization path and salt-separating sequence of the isothermal evaporating experiment for Huanghai Sea water.

However, the crystallization path for Huanghai Sea water also differed greatly from that of Qinghai Lake water (Figs. 9 and 10). These differences result mainly from the differences in chemical composition between Qinghai Lake water and seawater. Thereby, such two kinds of salt-separating sequences lead to the appearance of two kinds of salt deposits in the normal marine and continental (including recent salt lakes) salt-forming basins.

3. Some salts precipitated at the early concentrating stage of the Qinghai Lake water also exist in those salt lakes on the Qinghai-Xizang Plateau. Hydromagnesite deposits are distributed widely there and the gypsum sediments are not developed in the lake, such as Zhacang Caka Salt Lake.

4. The mineral paragenetic groups related to thenardite, bloedite and picromerite separated in the concentration process of Qinghai Lake water can be found not only in those salt deposits of some salt lakes in Qaidam Basin, but also in some Tertiary salt-bearing basins of China, such as Dawenkou Basin (Shandong province), and Jianghan Basin (Hubei province).

5. The borate obtained from the final mother liquid of the experiment of Qinghai Lake water is similar to that of the concentrating brine from Daqaidam Salt Lake (Sun et al., 1982). It illustrated that the potash-separating stage brine was beneficial to the formation of borate. Therefore, borate can be found in the potash zone of many ancient salt deposits.

CONCLUSIONS

1. The result of the evaporation of Qinghai Lake water revealed the whole process of the evolution of sulphate-type water-body in continent, and also the further evolving pathway of Qinghai Lake was calculated under dry climate in the near future.

2. The result of that experiment found out the physico-chemical conditions of the precipitation of various salt deposits in the continental lake basins.

3. The appearance of high B-Li content in the final remained mother liquid also showed the characteristic of B-Li-rich of the salt lakes on Qinhai-Xizang (Tibet) Plateau.

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