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Research Advances

Discovery of the Ca-Cl type brine in deep aquifers and implications for the shallow giant glauberite deposits in the Lop Nur playa, Tarim Basin, NW China

Hua Zhang[a,*], Peng-cheng Jiao[a], Cheng-lin Liu[a,*], Hui Yan[b], Fan-kai Zhang[b], Wen-xue Li[b], Yong-mei Yu[b], Lu-sha Wang[b], Yu-fei Hu[a], Li-cheng Wang[a], Li-jian Shen[a]

[a] *Ministry of Natural Resources Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing* 100037, *China*
[b] *State Development and Investment Corporation, Xinjiang Luobupo Potash Co., LTD, Hami* 839000, *China*

1. Objective

Lop Nur is currently one of the world's largest playa and located in the easternmost of the Tarim Basin, northwestern China. It developed unique giant glauberite deposits during the Quaternary, of which analogue with such a scale deposit is rarely seen around the world. Moreover, potassium-rich brine hosted in these glauberite intercrystalline contains a resource of KCl up to 0.25×10^9 t, supporting the operation of the global largest plant for K_2SO_4 fertilizer in Lop Nur. It was generally thought that salt materials such as K^+, SO_2^{4-}, and Ca^{2+} for glauberite deposits and the related potassium-rich brine in Lop Nur mainly originate from river water in the Tarim Basin, due to Lop Nur served as a terminal lake of the basin during the Quaternary (Fig. 1). However, thermodynamic simulation and evaporation experiment using river water of the Tarim Basin failed to generate such a large amount of glauberite deposits as modern observed. The authors' previous studies predicted that to form such a scale of glauberite deposits extra Ca-enriched fluids are required, however, direct evidence for this hypothesis is still not obtained. During 2017, the authors conducted a 1200 m deep drilling project (Well LDK02) in Lop Nur and revealed Ca-Cl type of brine in deep aquifers of clastic reservoirs. For the first time, this contribution presents the chemical composition of the deep Ca-Cl brine of Lop Nur that chemically distinct from the shallow brine hosted in glauberite intercrystalline and surrounding river inflows. The discovery of the deep Ca-Cl brine proves the hypothesis and provides new perspectives for understanding the formation of giant glauberite deposits of Lop Nur and hydrological circulation of brine in the eastern Tarim Basin.

2. Methods

The Well LDK02 is located in the northwest of Luobei Sag, the northern Lop Nur (Fig. 1). It 's hydro-geological drilling with reaming and corresponding casings at intervals of 0–501 m, 501–803 m, and 803–1200 m, respectively. The Well LDK02 recovered continuous 1200 m long core sediments, mainly including the salt sequence of 0–297.24 m, medium-fine clastic sediments of 297.24–538.19 m, medium-coarse clastic sediments of 538.19–802.91 m, and dominated coarse clastic sediments of 802.91–1200.00 m, respectively. A pumping test for four aimed aquifers was conducted separately to avoid mixing with each other.

Forty brine samples from clastic reservoirs (500–1200 m) and 17 brine samples from evaporite reservoirs (0–210.62 m) were collected with different stratigraphic depths. K^+, Ca^{2+}, Na^+, Mg^{2+}, Cl^-, and SO_4^{2-} of brine samples were detected by Inductively Coupled Plasms and Atomic Emission Spectrometry (ICP-AES, SPECTRO, German; RSD<1%), and HCO_3^- was measured by hydrochloric acid titration with phenolphthalein and a mixed solution of methylene blue and methyl red as indicators. All analysis was conducted in the Ministry of Natural Resources Key Laboratory of Metallogeny and Mineral Assessment. The hydrochemical type of brine is classified using ion mass and equivalent concentration.

3. Results

The major elements composition of brine from Well LDK02 are shown in Table 1.

* Corresponding author: *E-mail address*: zhang.hua@email.cgs.gov.cn (Hua Zhang); liuchengl@263.net (Cheng-lin Liu).

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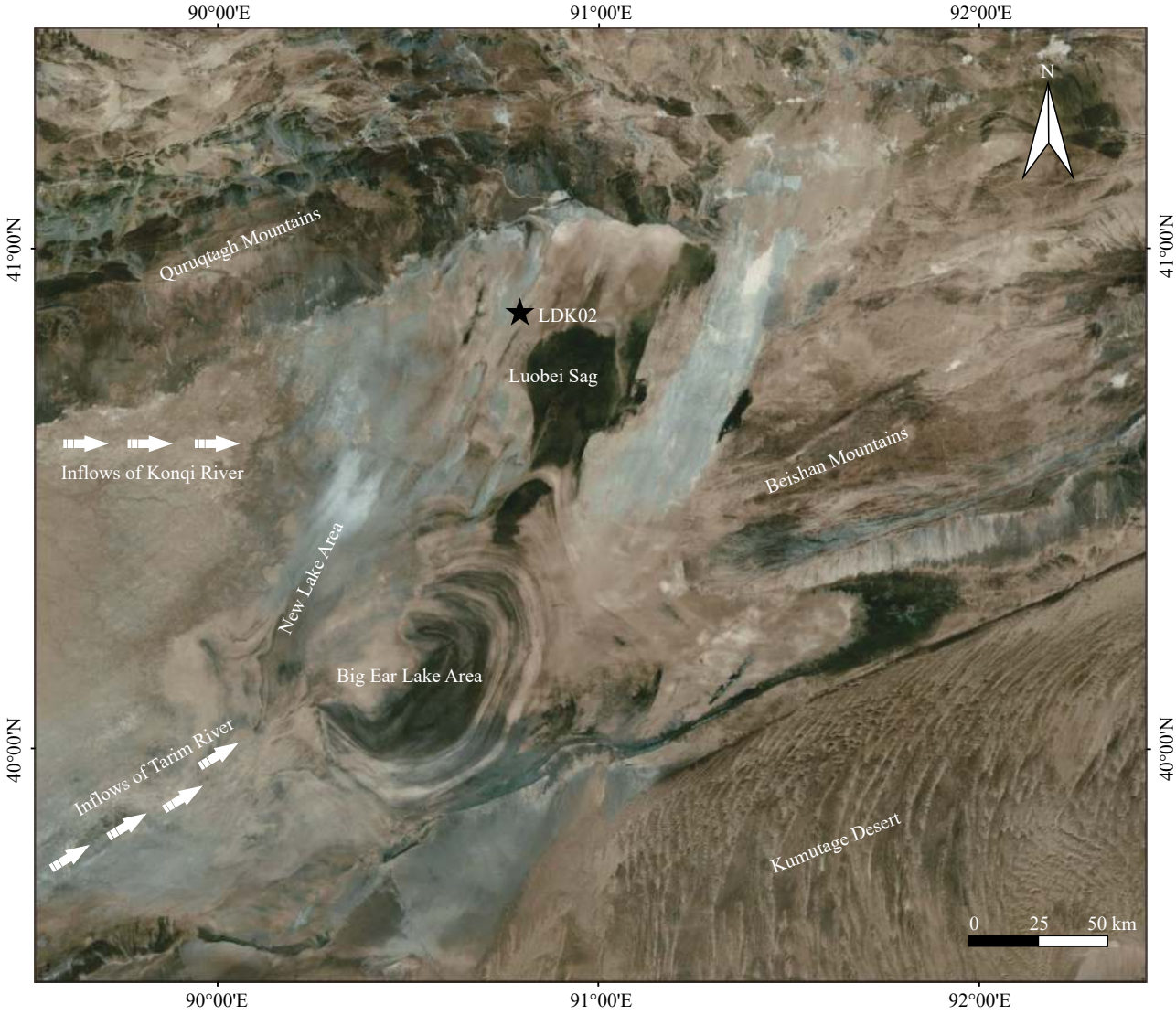

Fig. 1. Location of Well LDK02 in Playa Lop Nur, Tarim Basin, NW China.

Table 1. Mean content of major element of brine from Well LDK02 in the Lop Nur playa, Tarim Basin, NW China (g/L).

Depth intervals	Sample Number	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	Water Type
0–200 m	17	8.98	110.10	0.12	16.84	182.59	65.32	0.18	SO_4 type
500–800 m	20	4.02	87.70	4.36	6.75	167.46	3.00	0.13	Ca-Cl type
800–1200 m	20	0.27	54.25	8.34	3.62	107.18	1.95	0.16	

The shallow brine from 0–200 m is dominated by cation of Na^+, Mg^{2+}, and K^+ and anion of Cl^- and SO_4^{2-}, with very little Ca^{2+} (107.35–127.15 mg/L). The brine within 500–800 m stratigraphic interval yields a salinity range of 260.82–280.26 g/L, with higher Ca^{2+} (3.03–4.97 g/L) and lower Mg^{2+} and SO_4^{2-} in concentration. The 800–1200 m brine yields a salinity range of 168.32–181.01 g/L, with the highest concentration of Ca^{2+} (7.91–8.47 g/L) and lowest of SO_4^{2-} and Mg^{2+} compared with the overlying brine.

4. Conclusion

The obtained deep brine (500–1200 m) from Well LDK02 have Ca^{2+} equivalents > SO_4^{2-}+ HCO_3^-+CO_3^{2-} equivalents. This type of brine is called Ca-Cl type brine and is observed in some modern salt lakes such as the Qarhan Salt Lake in Qaidam Basin (Lowenstein TK et al., 1989). The discovery of the Ca-Cl type brine affirms the authors' predictions that there must have brine resource from deep aquifers of Lop Nur (Liu CL et al., 2006) and an additional large amount of Ca^{2+} are necessary indeed, to form such a large amount of glauberite sediments as observed (Liu CL et al. 2006; Li RQ et al., 2020).

Therefore, it suggests that the new-found Ca-Cl type brine has fed the saline lake along fault zones and thus provided extra Ca^{2+} source for the formation of giant glauberite deposit and extra K^+ source as well for the super-large brine potash deposits in Lop Nur (Fig. 2). These deep brine can reach the

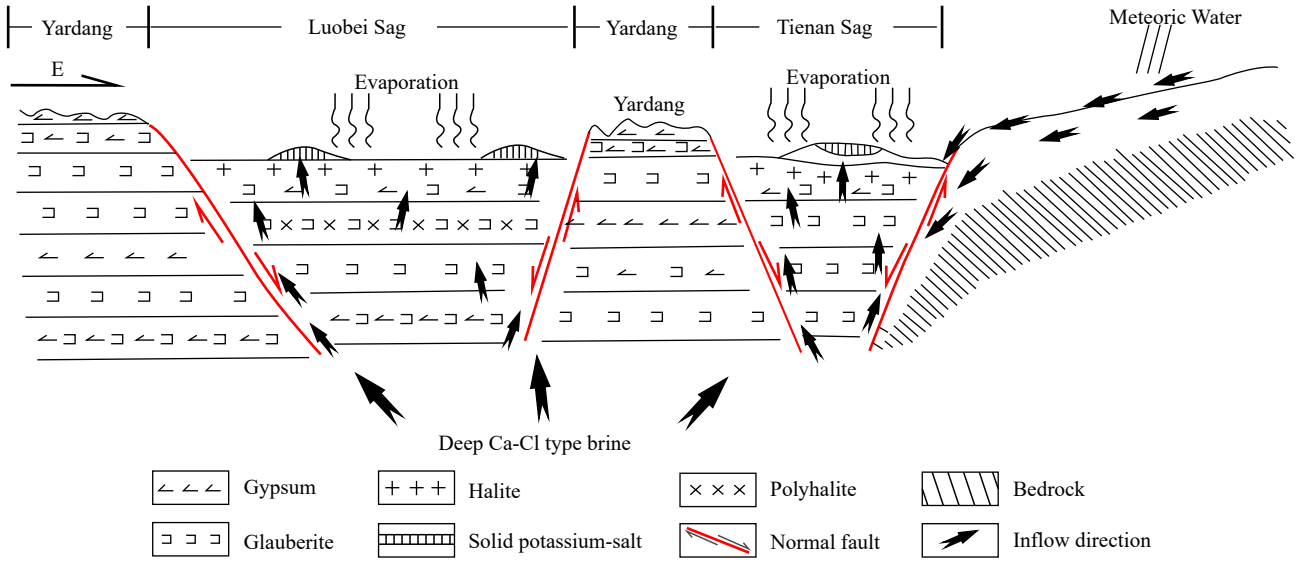

Fig. 2. Schematic discharge of deep Ca-Cl brine in Lop Nur, Tarim Basin, NW China (modified from Liu CL et al., 2003).

surface by convection-driven circulation associated with thermal anomalies or by tectonic-driven circulation.

CRediT authorship contribution statement

Hua Zhang and Cheng-lin Liu conceived of the presented idea. Cheng-lin Liu, Peng-cheng Jiao developed the theory. Hua Zhang, Peng-cheng Jiao, Hui Yan, Fan-kai Zhang, Wen-xue Li, Yu-fei Hu, Li-jian Shen, Li-cheng Wang, Lu-sha Wang, Yong-mei Yu collected and analyzed the samples. Hua Zhang wrote the original draft. Cheng-lin Liu and Peng-cheng Jiao reviewed and edited the manuscript. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflict of interest.

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