



OPEN Lithium and brine geochemistry in the Qianjiang Formation of the Jiangnan Basin, central China

Xiaocan Yu¹, Chunlian Wang²✉, Hua Huang³, Jiuyi Wang² & Kai Yan²

The Li-enriched oilfield brine is a very important lithium resource. It has gained much attention and become the target of active Li surveys with the growing global demand for Li. However, only little is known about their feature and nature. In the study, hydrochemical data from 155 oil wells tapping the Eocene to Lower Oligocene Qianjiang Formation of the Jiangnan Basin, central China indicate that the brines are of the Na–Cl or Na–Ca–Cl type and are characterized by highly variable Li contents of 7.56 to 150 mg/L, with Mg/Li ratios less than 11.65. High Na/Cl and Cl/Br molar ratios indicate distinct contributions from halite dissolution. The Ca excess, Na deficit and Ca/Mg and Ca/Sr molar ratios in the brines imply multiple diagenetic processes, including halite dissolution, dolomitization, albitization and calcite or anhydrite cementation. The lithium contents of these brines have a weak relationship with the salinity and a negative correlation with Cl/Br ratios, possibly indicating that these Qianjiang oilfield brines have been diluted by secondary brines derived from halite dissolution. The spatial distribution patterns for Li and B concentrations of the brines are different from those for salinity and Br contents and show a geographic pattern, indicating that Li enrichment in the Qianjiang brines is likely connected with geothermal sources associated with volcanic activity.

The success of applications of Li batteries in electric and hybrid vehicles, in recent years, has spurred an increased interest in Li as a strategic resource, to the point that it has been served as one of the most critical metal minerals^{1,2}. The principle lithium resources include Li-rich hard rocks (pegmatites and volcanogenic clays) and continental brines³, among which the latter accounts for about 65% of the global lithium occurrences⁴. These Li-rich brines with average Li grades > 600 mg/L are distributed in the salt pans of the South American Altiplano-Puna^{5–7}, in the salt lakes of the Qinghai-Tibetan plateau^{8–10}, and in the Great Basin of the western USA^{11–13}.

As previously mentioned, the growing global demand for Li driven by its high electrochemical potential in emerging technologies and the rising price in the market greatly encourage the development of mining projects. As such, less-rich brine deposits such as oilfield brines and geothermal brines, with Li grades between 50 and 400 mg/L, gained much attention and became the target of active Li surveys throughout the world. Most petroliferous basins contain abundant Li-enriched oilfield brines¹⁴. The known oilfield brine deposits include those from the Jurassic Smackover Formation in the Gulf Coast Basin of America¹⁵, the Fox Creek area in the Alberta Basin of Canada¹⁶ and the Paleogene and Neogene formation in the western Qaidam Basin of China¹⁷.

The Jiangnan Basin is an important Late Cretaceous to Oligocene petroliferous basin in central China. Large quantities of Li-rich oilfield brines are stored in the Upper Eocene to Lower Oligocene Qianjiang Formation of the basin. The brine deposits at mean Li grades of 60.6 mg/L hold LiCl resources of ~ 4 Mt^{18,19}. Li enrichment in brines and evolution of brine hydrochemistry, however, remain unclear, except that potassium in these oilfield brines and reservoir characteristics have been reported by Yu et al.²⁰.

This paper presents the first broad hydrochemical data of oilfield brines from the Qianjiang Formation of the Jiangnan Basin, China and aims to investigate the water chemistry characteristics and temporal and spatial distribution of Li in brines and determine its potential enrichment mechanism. In addition, this study also offers an overview of the potential of unconventional Li survey and contributes to knowledge of the origin of Li-enriched oilfield brines in the continental petroliferous basins.

¹Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China. ²MNR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China. ³SINOPEC Jiangnan Oilfield Company, Qianjiang 433124, China. ✉email: wangchunlian312@163.com

Geological setting

The Jiangnan Basin is a Cretaceous–Oligocene rift basin in central China, associated with subduction and rollback of the palaeo-Pacific Plate^{21,22}. The basin underwent two salt-forming stages: Late Cretaceous to Early Eocene and Middle Eocene to Oligocene²³. The Middle Eocene to Late Oligocene Qianjiang Depression is the subsidence and deposition center of the basin (Fig. 1a). The depression, covering a total area of approximately 2500 km², is one of the most oil and gas rich regions in the Jiangnan Basin²⁵. It is bounded by the Qianbei fault to the northwest, the Yajiao–Xin’gou low uplift to the southwest, the Yuekou low uplift to the northeast, and the Tonghaikou uplift to the southeast (Fig. 1b). During the Middle Eocene to Early Oligocene, the intense faulting along the Qianbei fault led to the formation of a half-graben structural pattern that was deep in the northwest and shallow in the southeast. Thus, fan delta facies, transitional brackish to saline lake facies, and saline lake facies from northwest to southeast have been identified²⁶.

The Qianjiang Depression is superimposed on the basement of pre-Sinian metamorphic rocks, Sinian to Middle Triassic marine sedimentary rocks and Upper Triassic continental sedimentary rocks. Paleogene volcanic rocks are distributed in the northwest of the basin²⁷. The overlying basin strata, in ascending order, comprise the Upper Cretaceous Yuyang Formation, the Paleogene Shashi, Xin’gouzui, Jingsha, Qianjiang and Jinghezhen formations, and the Neogene Guanghuasi Formation (Fig. 1c). The Qianjiang Formation is a salt-bearing strata that yield abundant oil and gas resources, with a thickness of 4700 m in the depocenter. It is characterized by notable salt rhythmites and is composed of alternating halite, gypsum (or glauberite) and mudstone with siltstone

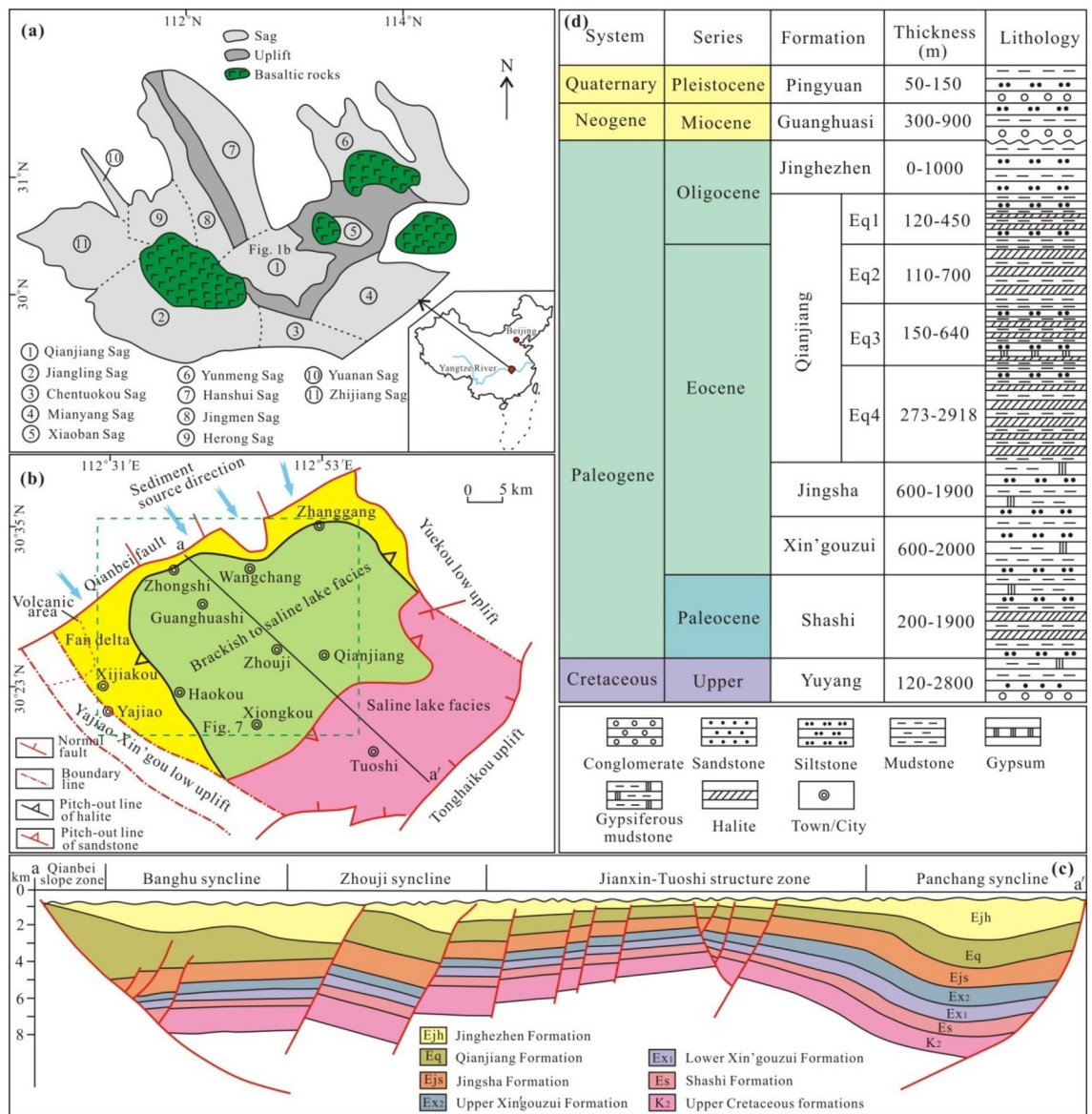


Figure 1. (a) Division of tectonic units of the Jiangnan Basin²⁴. (b) Sedimentary facies of the Qianjiang Formation of the Qianjiang Depression²⁴. (c) Interpreted seismic profiles of the Qianjiang Depression. The location of the seismic profile is shown in (b). (d) Stratigraphic column of the Qianjiang Depression²⁴.

and sandstone (Fig. 1d). The formation can be divided into four units from top to bottom: Eq1, Eq2, Eq3, and Eq4. Plenty of oilfield brines are produced in the sandstone reservoirs of the four stratigraphic intervals. The reservoirs are between 600 and 3900 m deep, with an average of 2200 m¹⁸.

Sampling and methods

The oilfield water samples were collected in June and July 2021 from 155 oil wells in the Yajiao, Xijiakou, Guan-guasi, Zhouji, Wangchang, Zhongshi, Zhanggang, Xiongzhou regions of the northern Qianjiang Depression. The ratio of water in the oil–water mixture is between 35% and 98%. The quantitative filter papers were used to separate the water from the oil at the sampling locations. Then, these water samples were filtered through 0.45 µm PTFE membrane filters and stored in the acid-washed HDPE bottles. Cation aliquots were acidified to pH < 2 with thermally distilled nitric acid and used for trace element analyses. Unacidified aliquots were used for anion analyses.

The main cations (K⁺, Na⁺, Ca²⁺, Mg²⁺, Li⁺, B³⁺, and Sr²⁺) of water samples were analyzed by inductively coupled plasma optical emission spectrometer (ICP-OES). Cl⁻, SO₄²⁻ and Br⁻ were measured by ion chromatography (IC). HCO₃⁻ and CO₃²⁻ were determined by 0.05 M HCl titration (AT). The analytical errors for ICP-OES, IC and AT were 2‰, 5‰ and 3‰, respectively. The contour diagrams of TDS, Br, Li, and B were performed using Surfer 12.0 software.

Results

The water chemistry data are given in the supplementary Table S1. The charge balance errors are less than 5.4% for all water samples. The brines are alkaline, with only a few acidic. They have total dissolved solids (TDS) ranging from 127 to 355 g/L. Based on the distribution pattern on a piper diagram, these brines can be classified as the Na–Cl or Na–Ca–Cl type (Fig. 2).

Na concentrations range from 46.10 to 132.90 g/L with a mean of 99.60 g/L. The K/Na molar ratios are less than 0.03. Most brine samples are characterized by Ca²⁺ > Mg²⁺. Cl contents range from 75.26 to 206.02 g/L with an average of 153.62 g/L. Concentrations of SO₄²⁻ and HCO₃⁻ are much lower than Cl⁻. The Na/Cl molar ratios are between 0.83 and 1.21, and the Cl/Br molar ratios are mostly between 478 and 2483 (Table S1). The Li concentration of the brines ranges between 7.56 and 150 mg/L, and the Mg/Li ratio is less than 11.65. These brines have high Br contents varying from 77.88 to 913 mg/L, with a mean of 329.51 mg/L. Boron concentrations range between 28 and 456.4 mg/L. The strontium contents show a large variation varying between 1.54 and 263.18 mg/L.

The brines from the Eq3 and Eq4 units have Li contents ranging from 9.98 to 150.00 mg/L, and are higher than the Eq1 and Eq2 waters which vary from 7.56 to 61.26 mg/L. B, Br, and Sr contents in each unit are relatively variable. Generally, the Eq3 and Eq4 waters have relatively high concentrations of Li, B, Sr, and Br.

Discussion

Chemical evolution process. The salinity of formation waters in the sedimentary basins can be attributed to evaporation and/or evaporite dissolution^{28,29}. Brines affected by halite dissolution have a Na/Cl molar ratio close to 1³⁰, which is higher than that of seawater (0.86). The brine samples from the Qianjiang Depression have Na/Cl molar ratios ranging from 0.83 to 1.21 (Fig. 3a), most of which are close to 1, indicating dominant contributions from halite dissolution, as evidenced by the high Cl/Br ratios³¹ (Figs. 3b, 4a).

The trends between Ca/Mg and Ca/Sr molar ratios (Fig. 4b) suggest dolomitization and calcite recrystallization processes^{29,33}, which are also supported by the mineralogical analysis of reservoir rocks in the study area²⁰.

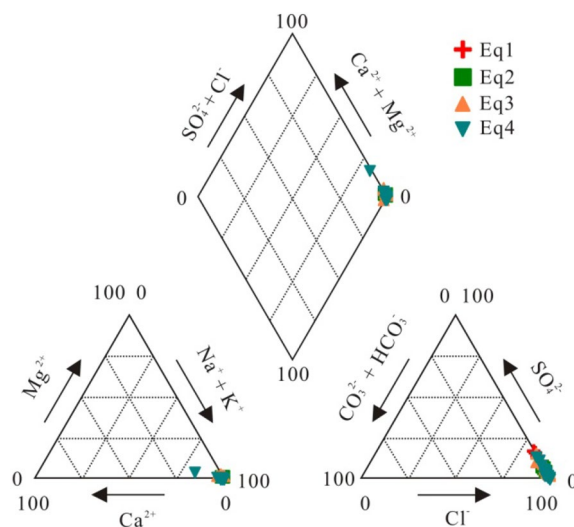


Figure 2. Piper diagram for oilfield brines in the Qianjiang Depression. The ratios plotted in the diagram are normality ratios.

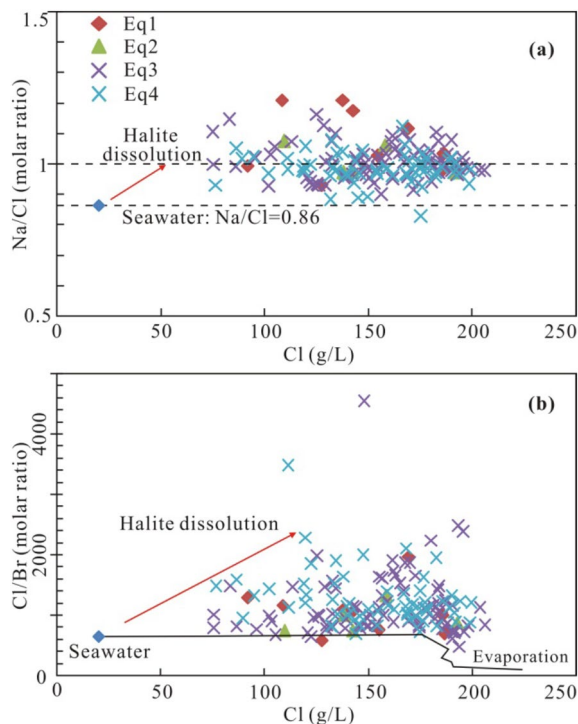


Figure 3. (a) Plot of Na/Cl molar ratios vs. Cl concentrations. (b) Plot of Cl/Br molar ratios vs. Cl concentrations in comparison to the seawater evaporation trajectory³¹.

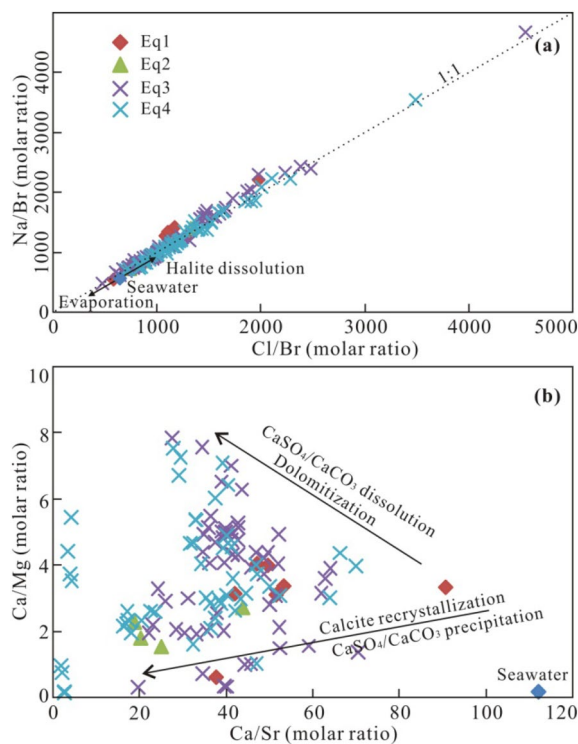


Figure 4. (a) Plot of Cl/Br vs. Na/Br molar ratios with trends for evaporating seawater and halite dissolution³². (b) Plot of Ca/Sr vs. Ca/Mg molar ratios with trends for calcite recrystallization and dolomitization processes³³.

The linear relationship between the excess Ca and the Na deficit relative to seawater reference ratios can be used to trace multiple water–rock interactions in sedimentary basins³⁴. Plotting of Ca excess and Na deficit of the Qianjiang brine samples shows multiple diagenetic processes (Fig. 5). Data for almost all samples are located near the trendline of halite dissolution, suggesting the origin affected by dissolution of halite and calcite or anhydrite cementation. Only one sample is plotted between the trendline of dissolution of CaSO_4 and CaCO_3 and dolomitization and the basal fluid line (albitization), indicating the influence of multiple water–rock interactions.

Spatial distribution pattern and origin of Li in brines. Variations in the grades of Li in the Qianjiang brines can be revealed by plotting Li contents against salinity and Cl/Br molar ratios. Figure 6a shows a weak correlation, which is incompatible with the fact that the residual brines have higher Li concentrations¹⁷. A negative correlation is shown in the Fig. 6b, indicating that Li concentrations of these brines are likely diluted by the mixing of the fluids derived from halite dissolution.

Based on the contour diagrams of Li, B and Br contents and TDS of these brines in the Qianjiang Depression, some spatial distribution patterns seem to be revealed. The high-salinity brines are mainly distributed in the Haokou, Zhongshi, Wangchang and Xiongkou areas (Fig. 7a). The high-bromine brines are located in the Haokou, Xiongkou and Qianjiang areas (Fig. 7b). The high-lithium brines are distributed between the Haokou and Zhongshi regions (Fig. 7c), whereas the high-boron brines are located between the Haokou and Zhongshi regions, followed by areas near Zhouji and Wangchang (Fig. 7d). So, the distribution patterns for TDS and Br

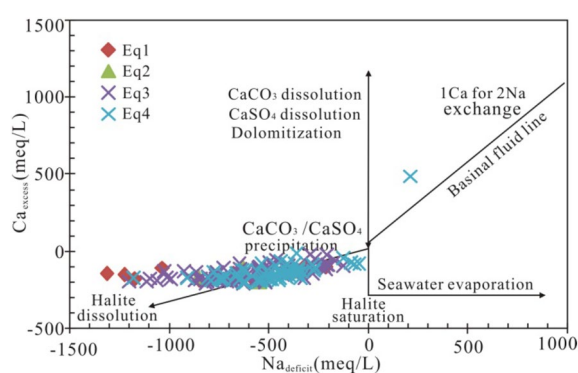


Figure 5. Plot of $\text{Na}_{\text{deficit}}$ vs. $\text{Ca}_{\text{excess}}$ for Eocene to Lower Oligocene oilfield brines³⁴. The basinal fluid line (BFL) means the theoretical trend for the albitization of primary seawater.

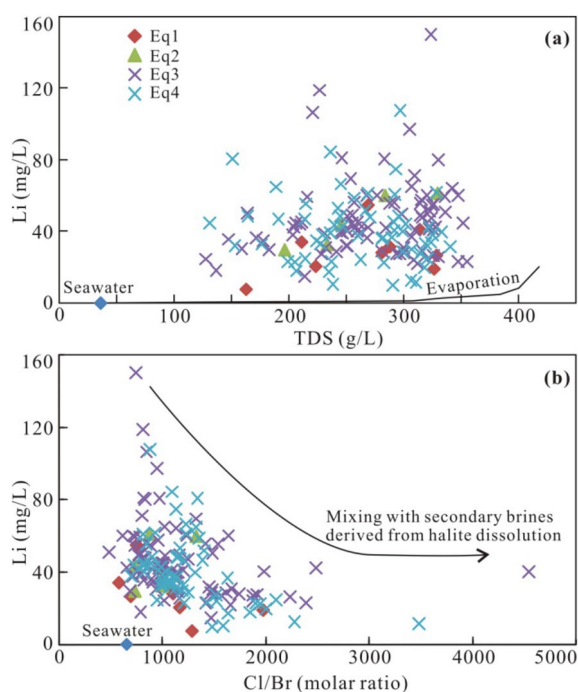


Figure 6. (a) Plot of TDS vs. Li concentrations in comparison to the seawater evaporation trajectory³¹. (b) Plot of Cl/Br molar ratios vs. Li concentrations.

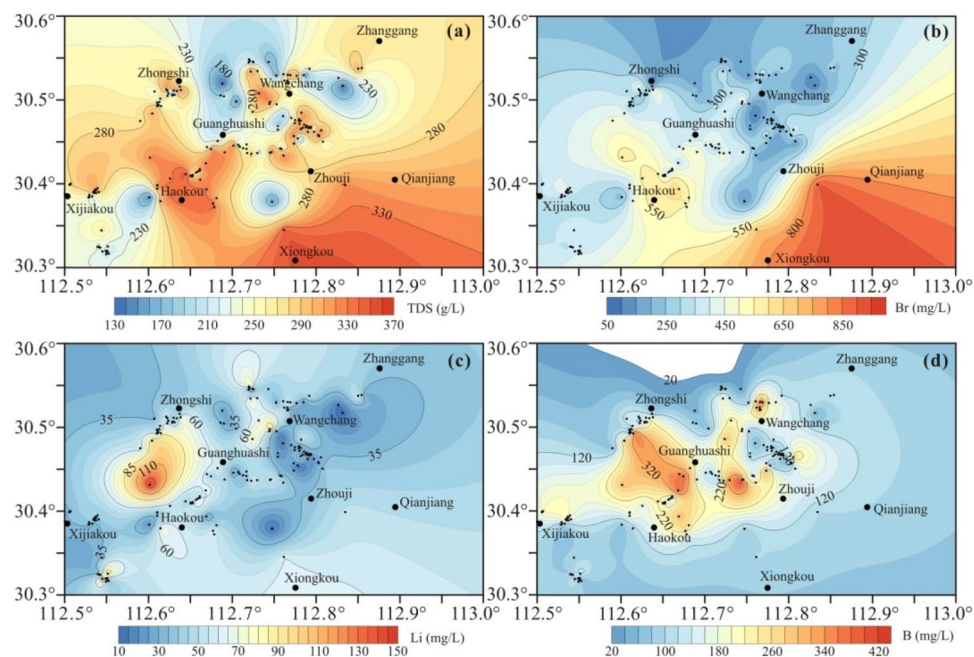


Figure 7. Contour diagrams of Li, B and Br concentrations and salinity of oilfield brines in the Qianjiang Depression. The area is shown in Fig. 1b.

contents show similar variation feature, while those for Li and B contents exhibit different characteristics and have the affinity to the volcanic rocks to the northwest of the study area. It is possible that Br enrichment is related to evapo-concentration while special material sources are required for the mineralization of Li and B.

Weathering of igneous rocks and hydrothermal supplies associated with volcanic activity have been suggested to interpret the sources of Li-enriched brines^{17,35–38}. The geographic distribution pattern for Li concentrations of these brines in the Qianjiang Depression, in combination with the widely developed volcanic rocks in the Jiangnan Basin, indicates that Li enrichment in brines is more likely to be associated with geothermal sources during volcanic activity^{39,40}.

Conclusions

This study reports the results of the hydrochemical analysis of oilfield brines from the Qianjiang Formation of the Jiangnan Basin, central China. The brines are of the Na–Cl or Na–Ca–Cl type and have Li contents ranging from 7.56 to 150 mg/L, with Mg/Li ratios less than 11.65.

High Na/Cl and Cl/Br molar ratios of these brines suggest contributions from halite dissolution. Plotting of Ca excess vs. Na deficit and Ca/Mg vs. Ca/Sr molar ratios indicates multiple diagenetic processes, including dolomitization, calcite or anhydrite cementation, halite dissolution and albitization. Variations in the grades of Li in brines have a weak correlation with the salinity. The Li contents of these brines may be diluted by the mixing of secondary fluids derived from halite dissolution. The spatial distribution for the concentrations of Li and B is different from those of TDS and Br and shows a geographic pattern, which is likely associated with geothermal supplies associated with volcanic activity.

Data availability

All data generated or analysed during this study are included in this published article and the supplementary information file (Table S1).

Received: 2 December 2022; Accepted: 11 March 2023

Published online: 17 March 2023

References

- Olivetti, E. A., Ceder, G., Gaustad, G. G. & Fu, X. Lithium-ion battery supply chain considerations: Analysis of potential bottlenecks in critical metals. *Joule* **1**, 229–243 (2017).
- Bibienne, T., Magnan, J. F., Rupp, A. & Laroche, N. From mine to mind and mobiles: Society's increasing dependence on lithium. *Elements* **16**, 265–270 (2020).
- Kesler, S. E. *et al.* Global lithium resources: Relative importance of pegmatite, brine and other deposits. *Ore Geol. Rev.* **48**, 55–69 (2012).
- Swain, B. Recovery and recycling of lithium: A review. *Sep. Purif. Technol.* **172**, 388–403 (2017).
- López-Steinmetz, R. L. Lithium- and boron-bearing brines in the Central Andes: Exploring hydrofacies on the eastern Puna plateau between 23° and 23°30' S. *Miner. Deposita* **52**, 35–50 (2017).
- López-Steinmetz, R. L. *et al.* Northern Puna Plateau-scale survey of Li brine-type deposits in the Andes of NW Argentina. *J. Geochem. Explor.* **190**, 26–38 (2018).

7. López-Steinmetz, R. L., Salvi, S., Sarchi, C., Santamans, C. & López-Steinmetz, L. C. Lithium and brine geochemistry in the Salars of the southern Puna, Andean Plateau of Argentina. *Econ. Geol.* **115**, 1079–1096 (2020).
8. Zheng, M. P. & Liu, X. F. Hydrochemistry of salt lakes of the Qinghai-Tibet Plateau. *China. Aquat. Geochem.* **15**, 293–320 (2009).
9. Li, Q. K. *et al.* Hydrochemistry and distribution and formation of lithium-rich brines in salt lake on the Qinghai-Tibetan Plateau. *Minerals* **9**, 528 (2019).
10. He, M. Y. *et al.* Sources and a proposal for comprehensive exploitation of lithium brine deposits in the Qaidam Basin on the northern Tibetan Plateau, China: Evidence from Li isotopes. *Ore Geol. Rev.* **117**, 103277 (2020).
11. Garrett, D. E. *Handbook of Lithium and Natural Calcium Chloride: Their Deposits, Processing, Uses and Properties* (Elsevier, 2004).
12. Munk, L. A. *et al.* Geochemistry of lithium-rich brines in Clayton Valley, Nevada, USA. In: *11th SGA Biennial Meeting*. 217–219 (2011).
13. Munk, L. A. *et al.* Lithium brines: A global perspective. *Rev. Econ. Geol.* **18**, 339–365 (2016).
14. Dugamin, E. J. *et al.* Groundwater in sedimentary basins as potential lithium resource: A global prospective study. *Sci. Rep.* **11**, 21091 (2021).
15. Collins, A. G. Lithium abundance in oilfield waters: Lithium resources and requirements by the year 2000. *U. S. Geol. Surv. Prof. Pap.* **1005**, 116–123 (1976).
16. Eccles, D. R. & Berhane, H. *Geological Introduction to Lithium Rich Water with Emphasis on the Fox Creek Area of west-Central Alberta (NTS 83F and 83K)* (Alberta Geological Survey Open File Report, 2011).
17. Li, J. S., Chen, F. K., Ling, Z. Y. & Li, T. W. Lithium sources in oilfield waters from the Qaidam Basin, Tibetan Plateau: Geochemical and Li isotopic evidence. *Ore Geol. Rev.* **139**, 104481 (2021).
18. Huang, H., Zhang, S. W. & Zhang, L. Y. Mineral characteristics and resources assessment of the deep brine in Qianjiang Formation, Jiangnan Depression. *J. Salt Lake Res.* **23**, 34–123 (2015).
19. Yu, X. C. *et al.* Genesis of lithium brine deposits in the Jiangnan Basin and progress in resource exploration: A review. *Earth Sci. Front.* **29**, 107–123 (2022).
20. Yu, X. C., Wang, C. L., Huang, H. & Wang, J. Y. Origin and evolution of deep-seated K-rich brine in Paleogene of Qianjiang Depression, Hubei Province. *Earth Sci.* **47**, 122–135 (2022).
21. Zhou, X. M., Sun, T., Shen, W. Z., Shu, L. S. & Niu, Y. L. Petrogenesis of Mesozoic granitoids and volcanic rocks in South China: A response to tectonic evolution. *Episodes* **29**, 26–33 (2006).
22. Li, S. Z. *et al.* Mesozoic tectono-magmatic response in the East Asian ocean continent connection zone to subduction of the Paleo-Pacific Plate. *Earth Sci. Rev.* **192**, 91–137 (2019).
23. Liu, Q. *et al.* *Mesozoic-Cenozoic Terrigenous Clastic-Chemical Rock Salt Deposits in China* (Science and Technology Press, 1987).
24. Huang, C. & Hinnov, L. Evolution of an Eocene–Oligocene saline lake depositional system and its controlling factors, Jiangnan Basin, China. *J. Earth Sci.* **25**, 959–976 (2014).
25. Zhang, Y. S., Yang, Y. Q., Qi, Z. X., Qiao, Y. D. & Yuan, H. R. Sedimentary characteristics and environments of the salt-bearing series of Qianjiang Formation of the Paleogene in Qianjiang Sag of Jiangnan Basin. *J. Palaeogeogr.* **5**, 29–35 (2003).
26. Fang, Z. X. Hydrocarbon exploration signification of intersalt sediments in Qianjiang Saline lake basin. *Acta Sedimentol. Sin.* **20**, 608–613 (2002).
27. Xu, L. X. *et al.* Chronology of Paleocene volcanic rocks in Jiangnan basin. *Oil Gas Geol.* **16**, 132–137 (1995).
28. Carpenter, A. B. Origin and chemical evolution of brines in sedimentary basins. *Okla. Geol. Surv. Circ.* **79**, 60–77 (1978).
29. Birkle, P., Garcia, M. B. & Padron, C. M. M. Origin and evolution of formation water at the Jujo-Tecominoacan oil reservoir, Gulf of Mexico: Part 1. Chemical evolution and water–rock interaction. *Appl. Geochem.* **24**, 543–554 (2009).
30. Bagheri, R. *et al.* Hydrochemical and isotopic ($\delta^{18}\text{O}$, $\delta^2\text{H}$, $^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{37}\text{Cl}$ and $\delta^{81}\text{Br}$) evidence for the origin of saline formation water in a gas reservoir. *Chem. Geol.* **384**, 62–75 (2014).
31. Fontes, J. C. & Matray, J. M. Geochemistry and origin of formation brines from the Paris Basin, France: 1. Brines associated with Triassic salts. *Chem. Geol.* **109**, 149–175 (1993).
32. Chi, G. & Savard, M. M. Sources of basinal and Mississippi Valley-type mineralizing brines: Mixing of evaporated seawater and halite-dissolution brine. *Chem. Geol.* **143**, 121–125 (1997).
33. McIntosh, J. C., Walter, L. M. & Martini, A. M. Extensive microbial modification of formation water geochemistry: Case study from a midcontinent sedimentary basin, United States. *Geol. Soc. Am. Bull.* **116**, 743–759 (2004).
34. Davisson, L. M. & Criss, R. E. Na–Ca–Cl relations in basinal fluids. *Geochim. Cosmochim. Acta* **60**, 2743–2752 (1996).
35. Hofstra, A. H., Todorov, T. I., Mercer, C. N., Adams, D. T. & Marsh, E. E. Silicate melt inclusion evidence for extreme pre-eruptive enrichment and post-eruptive depletion of lithium in silicic volcanic rocks of the western United States: Implications for the origin of lithium-rich brines. *Econ. Geol.* **108**, 1691–1701 (2013).
36. Araoka, D. *et al.* Lithium and strontium isotopic systematics in playas in Nevada, USA: Constraints on the origin of lithium. *Miner. Deposita* **49**, 371–379 (2013).
37. Orberger, B., Rojas, W., Millot, R. & Flehoc, C. Stable isotopes (Li, O, H) combined with brine chemistry: Powerful tracers for Li origins in Salar deposits from the Puna region, Argentina. *Proc. Earth Planet. Sci.* **13**, 307–311 (2015).
38. Yu, X. C., Liu, C. L., Wang, C. L., Zhao, J. X. & Wang, J. Y. Origin of geothermal waters from the Upper Cretaceous to Lower Eocene strata of the Jiangling Basin, South China: Constraints by multi-isotopic tracers and water–rock interactions. *Appl. Geochem.* **124**, 104810 (2021).
39. Pan, D. Y., Liu, C. L. & Xu, H. M. Characteristics and formation of potassium-bearing brine in the deeper strata in depression in Hubei Jiangling province. *Geol. Chem. Miner.* **33**, 65–72 (2011).
40. Yuan, X. Y., Hu, Y. F., Zhao, Y. J., Li, Q. & Liu, C. L. Contribution of hydrothermal processes to the enrichment of lithium in brines: Evidence from water–rock interacting experiments. *Aquat. Geochem.* **27**, 221–239 (2021).

Acknowledgements

The work was supported by the National Natural Science Foundation of China (Nos. U20A2092, 42002106), the Basic Scientific Research Business Expenses of Central Public Welfare Scientific Research (No. KK2005), and the China Geological Survey (No. DD20221684). We would like to thank Yancong Peng and Donghong Li for their help during the field sampling. We are grateful to reviewers for their critical and constructive review.

Author contributions

X.C.Y. prepared the original manuscript. C.L.W. and J.Y.W. revised the manuscript. H.H. and K.Y. processed the samples and conducted the experiments.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1038/s41598-023-31421-1>.

Correspondence and requests for materials should be addressed to C.W.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2023