



Short Communications (Research Advances)

Discovery of bauxite-type helium source rock in Jinzhong basin, central North China and its resource potential evaluation

Qiao Zhang^a, Jun-lin Zhou^{a,*}, Yu-hong Li^a, Ya-zhuo Niu^a, Wang Guo^a, Shang-wei Ma^a, Yun-peng Zhang^a, Shao-hua Hu^b, Yu Ding^b^a Key Laboratory for the Study of Focused Magmatism and Giant Ore Deposits, Xi'an Center, China Geological Survey (Geoscience Innovation Center of Northwest China), Xi'an 710119, China^b Shanxi provincial third institute of geological engineering investigation, Jinzhong 030620, China

1. Objective

Among globally known industrial helium-enriched natural gas reservoirs, associated helium is dominantly crust-derived helium (⁴He), which is generated by the radioactive decay of uranium (U) and thorium (Th) in crustal rocks. These rocks with old ages are also defined as helium source rocks. Published accumulation models for helium have revealed that granite is the main and effective helium source rock in the crust (Li YH et al., 2018). Besides, bauxite, with generally high concentrations of radioactive elements (U and Th), has recently been proposed to be a premium helium source rock (Li JY et al., 2022). However, it has remained poorly studied and evaluated whether bauxite is an effective and more premium source rock than others for helium resources. The Jinzhong basin, located on the east of Ordos basin (Fig. 1a), has superb helium-enriched gas indications (Li JY et al., 2022). As the lowest part of the Lower Carboniferous Benxi Formation, Xiaoyi-type bauxites are widely scattered in the western part of the basin (Fig. 1b), which provides an ideal target. This paper focuses on the concentrations of uranium (U) and thorium (Th), helium-generation rate with Xiaoyi-type bauxites and diverse types of rocks in the western part of Jinzhong basin, including granites, metamorphic and sedimentary rocks. Then, a comprehensive comparison will be conducted to evaluate the effectiveness and helium-generation intensity of bauxite, together with granites in the adjacent Weihe basin as the main helium source rock.

First author: E-mail address: hotrock2012zq@163.com (Qiao Zhang).* Corresponding author: E-mail address: zjunlin@mail.cgs.gov.cn (Jun-lin Zhou).Literary editor: Xi-jie Chen
doi:10.31035/cg2023037

2096-5192/© 2023 China Geology Editorial Office.

2. Methods

Based on geological surveys and data from shallow drill holes, 100 samples were collected from bauxites in the Late Carboniferous Benxi Formation, other diverse types of sedimentary rocks, Paleoproterozoic basement metamorphic rocks and granites around the western part of Jinzhong basin (Fig. 1b). Radioactive elements (U and Th) analysis was conducted in the Institute of Uranium Deposit, No. 203, Nuclear Industry, Xi'an. Samples were decomposed by nitric acid, hydrofluoric acid and perchloric acid and then heated into a solution. The laser uranium analyzer with nitrogen molecular laser was used to measure the fluorescence intensity in the solution, and the uranium content in the sample was calculated. After a series of processes such as decomposition, filtration, precipitation and extraction, the content of thorium in hydrochloric acid was determined by spectrophotometry. The determination method and detailed process for uranium and thorium refer to national nuclear industry standards EJ/T 550-2000 and EJ/T 814-94, respectively.

3. Results

The results from 100 samples show distinctive concentrations of U and Th, with three groups (Table 1). Firstly, the Paleoproterozoic granites show relatively high concentrations of Th at 29.2×10^{-6} – 92.3×10^{-6} (average in 55.1×10^{-6}), but low concentrations of U (generally below 8×10^{-6} , average in 6.5×10^{-6}). Secondly, the ore-bearing series of bauxites have both high concentrations of U (most above 10×10^{-6} , average in 18.1×10^{-6}) and Th (most above 20×10^{-6} , average in 51.9×10^{-6}). Apart from the two types of rocks, other rocks in different positions, including sandstone, siltstone, mudstone, schist, gneiss, limestone, and dolomite, show similar features with the concentrations of U varying

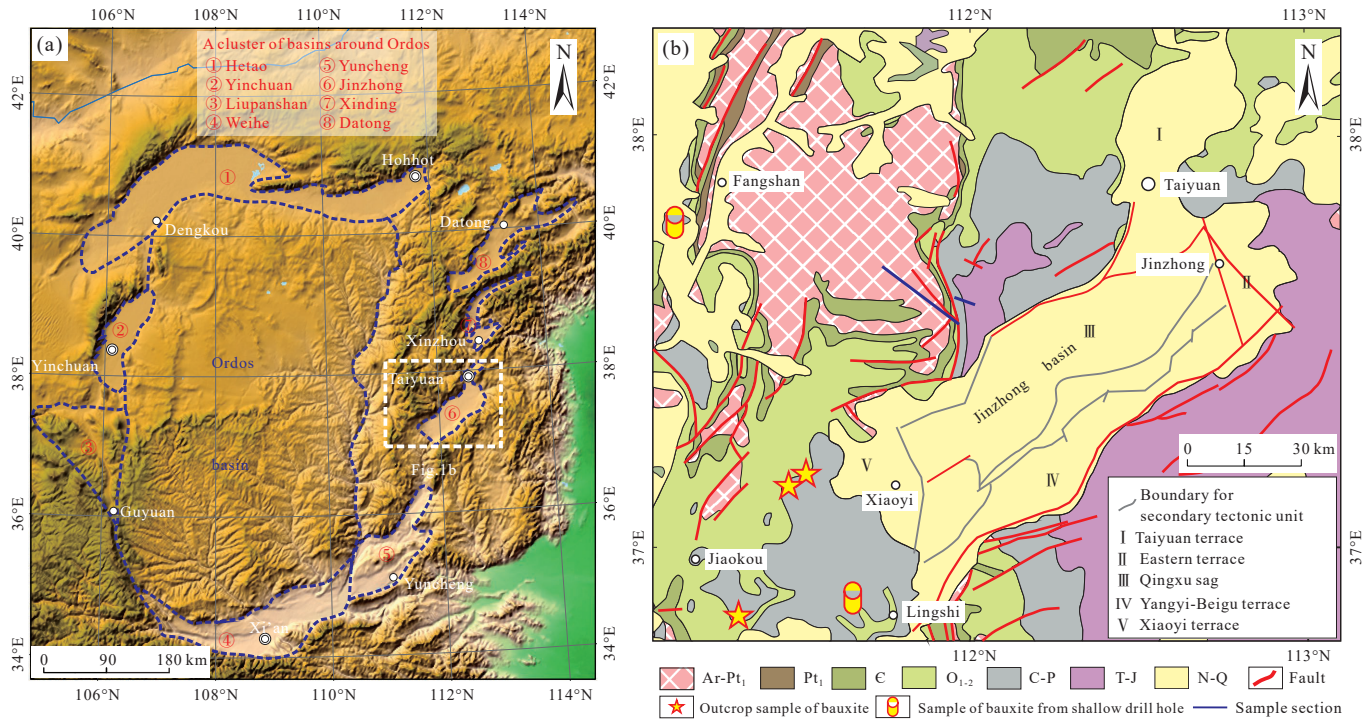


Fig. 1. Distribution map (a) of Ordos, Jinzhong and adjacent basins; geological sketch (b) of Jinzhong basin, Shanxi and its secondary tectonic unit, showing representative sampling locations.

Table 1. The contents of helium-produced elements (U, Th) and helium generation rates and volumes in different rocks of Jinzhong and Weihe basins.

Location	Sample source	Sample number	The average content of helium-produced elements		Helium-generated rate/(cm ³ /g·a)	Helium generation volume per mass since formed/(cm ³ /g)
			U/10 ⁻⁶	Th/10 ⁻⁶		
Jinzhong basin	Bauxites from Benxi Fm.	30	18.1	51.9	3.72×10 ⁻¹²	1.12×10 ⁻³ (300 Ma)
	Paleoproterozoic granites	23	6.5	55.1	2.40×10 ⁻¹²	4.8×10 ⁻³ (2000 Ma)
	Other sedimentary and metamorphic rocks	47	6.2	11.6	1.10×10 ⁻¹²	
Weihe basin	Granites in southern basin*	146	5.1	17.9	1.14×10 ⁻¹²	2.29×10 ⁻⁴ (200 Ma)

The formula for helium generation is based on Brown AA (2010), $\text{He (STP cc He/g rk)} = (1.22 \times 10^{-13} \times \text{U} (10^{-6}) + 0.292 \times 10^{-13} \times \text{Th} (10^{-6})) \times \text{T, y (STP = 0}^\circ\text{C, 0.1 MPa)}$, data with "*" refer from previous data.

from 2.7×10^{-6} (the average value of the upper crust) to 10×10^{-6} , the contents of Th around the average value (10.5×10^{-6}) of the upper crust. The former two rocks are much higher than those in granites located on the south of Weihe basin (Th- 17.9×10^{-6} , U- 5.1×10^{-6} , Table 1).

Helium-produced elements U and Th are enriched in crustal rocks. Research has confirmed that granite is an effective helium source rock. In contrast, hydrocarbon source rocks, such as shale, hot shale, and mudstone, are proven to be not helium source rocks, on account of hydrocarbon gases generated from them diluting helium from them to sub-economic levels (Brown AA, 2010). Bauxite is commonly enriched in uranium (U) revealed by gamma spectrometry log and recent radioactive analysis. Our results analyzed above are presented to support that bauxite has the greatest potential for helium generation. Notably, recent studies reported that associated gases from geothermal wells in Jinzhong basin have rarely high concentrations (8.5%–18.86%) of helium, compared with those (0.1%–9.226%) in Weihe basin (Li YH

et al., 2018; Li JY et al., 2022), which argues for bauxite as the main helium source rock. Moreover, bauxite can serve as a good gas reservoir, rather than hydrocarbon source rock. Therefore, bauxite can be a premium and effective helium source rock.

Based on the calculation formula proposed by Brown AA (2010), the helium generation rates of bauxites in Jinzhong basin have the highest values ($3.7 \times 10^{-12} \text{ cm}^3/\text{g}\cdot\text{a}$) on average similar to that in hot shale (Fig. 2), which argues for the conclusion mentioned above. Together with the Paleoproterozoic granites in the west of the basin, the average value of the two is two-three times than that of granites from the southern Weihe basin (Table 1), which is demonstrated as one of the regions with the greatest helium resource potential (Li YH et al., 2018). Considering the forming age and thickness, bauxites are superior to granites from the southern Weihe basin in helium generation volume per mass, which are second only to Paleoproterozoic granites in the western part of Jinzhong basin (Table 1). Consequently, bauxite could be a

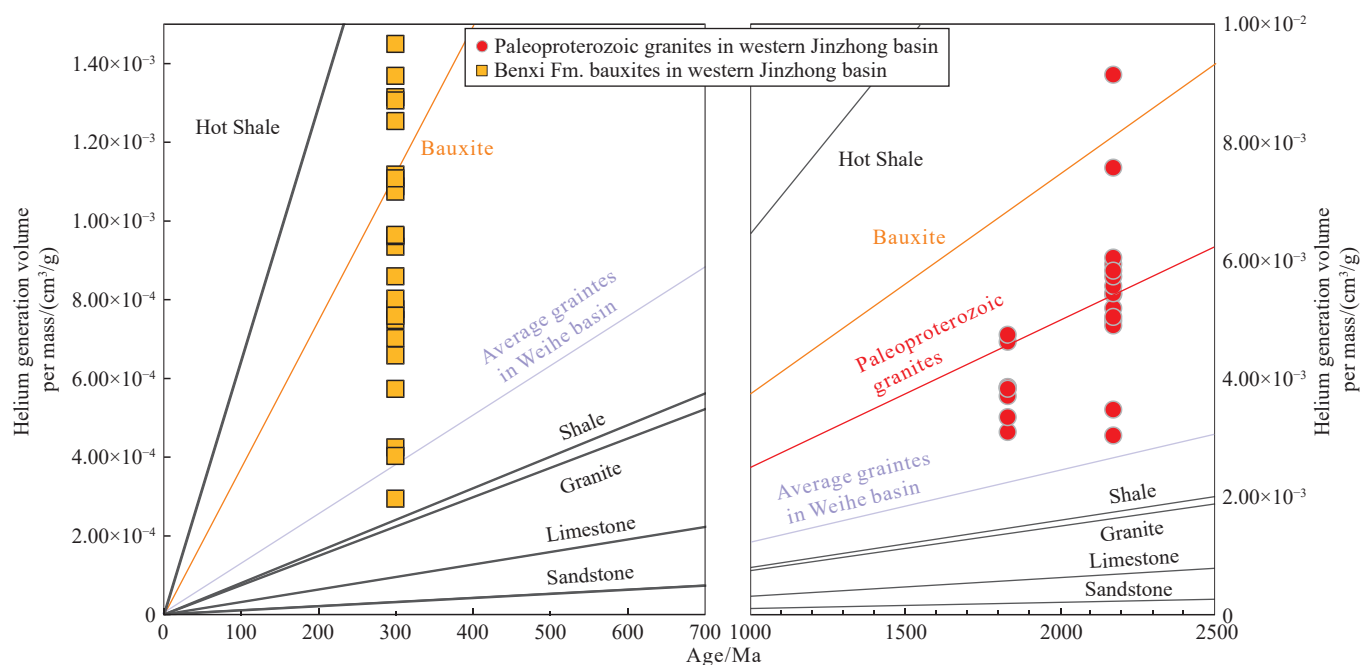


Fig. 2. Diagram for helium generation volume per mass (cm^3/g) with ages.

premium source rock with the highest helium-generation intensity among helium source rocks. On account of rarely high concentrations (8.5%–18.86%) of helium and the accumulation conditions of helium-enriched gas in Jinzhong basin, “Shanxi-type” helium accumulation model has been newly proposed and bauxite is viewed as a crucial helium source rock with carrier gas originating from overlying coal measure strata (Li JY et al., 2022), which is enhanced by synthetical evaluation of this study. This model will provide positive guidance on helium resources of the Greater North China Basin with similar accumulation conditions for helium-enriched gas and premium helium source rock (bauxite). In conclusion, high concentrations of helium-generated elements and superb helium-generation intensity have facilitated the great helium resource prospect for bauxite, which will play crucial roles in the theoretical knowledge and practical exploitation of domestic and overseas helium.

4. Conclusion

Bauxites in the Late Carboniferous Benxi Formation, western Jinzhong basin, show high concentrations of two helium-generated elements uranium and thorium. By comparison, it is concluded that bauxite can be a premium and effective helium source rock with the highest helium-generation intensity. It can make a significant contribution to the supplement of helium source rocks in published helium accumulation models with granites as the main helium source rocks. As a consequence, bauxite has great potential for helium resource and deeply exploitation of bauxite on gas and helium need to be highlighted.

CRedit authorship contribution statement

Qiao Zhang, Jun-lin Zhou, Yu-hong Li and Ya-zhuo Niu

conceived of the presented idea and prepared the manuscript. Qiao Zhang, Wang Guo, Shang-wei Ma, Yun-peng Zhang, Shao-Hua Hu, Yu Ding conducted the field work and collected the samples. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgement

The research is supported by China Geological Survey Project (DD20221665, DD20230026, DD20230268, DD20230314) and National Key Research and Development Program (2021YFA0719003). The authors are grateful to Hai-hong Xu and Ming-wei Zhu for supports in the fieldwork and two anonymous reviewers for their constructive comments and suggestions.

References

- Brown AA. 2010. Formation of High Helium Gases: A Guide for Explorationists. AAPG Convention, New Orleans, Louisiana, USA, 1–5.
- Li JY, Li YH, Hu SH, Zhou JL, Chen GC, Zhang SQ. 2022. “Shanxi-type” helium accumulation model and its essentiality. *Journal of Xi’an University of Science and Technology*, 2022, 42(3), 529–536 (in Chinese with English abstract). doi: [10.13800/j.cnki.xakjdx.2022.0316](https://doi.org/10.13800/j.cnki.xakjdx.2022.0316).
- Li YH, Zhou JL, Zhang W, Han W, Wang XY, Chen GC, Yuan BQ, Li ZC, Zhang L, Ma QF, Li YH, Zhang JG, Ren ZL, Zhang Q, Jiang T, Guo W, Zhang YP, Zhang WL, Wang L, Li JC, Gong ZQ, Qiao SH, He ZY. 2018. Helium Accumulation Conditions and Resource Prospect in Weihe Basin. Beijing, Geological Publishing House, 1–289 (in Chinese).