

Big difference in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of basalt and basin water: higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in plagioclase

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Abstract We analyzed the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of basaltic rocks and basin water in Xuyi, China, and found a big difference, which may challenge conventional wisdom on the contribution of basalt weathering in end-member analysis. Results of an in-house weathering experiment suggest that rainwater and dust are not responsible for the difference. By isolating the major minerals in basalt, we found that plagioclase has much higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than bulk basalt and basin water, which might explain the difference in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of basalt and basin water. We infer that low-temperature hydrothermal alteration increased the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of plagioclase. Future analyses of end-member contribution in a mixed-rock basin should take into account that basin water and plagioclase have higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than basaltic rocks.

Keywords Basalt · Weathering · $^{87}\text{Sr}/^{86}\text{Sr}$ · Plagioclase

1 Introduction

Strontium isotope analysis is an important tool for understanding weathering processes and the global carbon cycle. For example, $^{87}\text{Sr}/^{86}\text{Sr}$ analysis is often used to research the oceanic Sr isotope budget (Taylor and Lasaga 1999; Dessert et al. 2001; Allègre et al. 2010; Li and Elderfield 2013)

and for end-member analysis in ecosystem studies (Gosz et al. 1983; Capo et al. 1998; Pett-Ridge et al. 2009; Meek et al. 2016). That rocks and minerals have the same $^{87}\text{Sr}/^{86}\text{Sr}$ ratios as those of their weathering products is regularly assumed when calculating the contribution of different rocks/minerals to weathering solutions (Chung et al. 2009; Rengarajan et al. 2009).

It is generally recognized that basalt crystallizes rapidly, with a low degree of evolution and little magmatic differentiation; therefore, the Rb/Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios among different minerals in basalt should be similar. Similarly, the chemical weathering rate of basalt is very fast (Dessert et al. 2003), suggesting that there is no differentiation of Sr isotopes in the weathering processes. As a result, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of rivers should be similar to those of bedrock in basaltic basins.

However, we found that the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of river water were higher than those of basaltic rocks in Xuyi, China, which is a pure Cenozoic basalt area. Our research suggests that rainwater and dust are not the reason for the difference of ratios between basalt and basin water; rather, much higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in plagioclase than in bulk basalt might account for the difference.

2 Samples and methods

A total of 22 water samples were collected from 3 rivers, 2 reservoirs, a spring, and 2 wells in Xuyi, China during three periods: January, May, and June of 2015. All water samples were filtered through 0.22 μm Millipore filter, acidified to $\text{pH} < 2$ with ultrapure nitric acid, and stored at a temperature below 5 °C. Two fresh basaltic rock samples were collected and washed under ultrasonic wave to remove clay, then dissolved in an HF–HNO₃ mixture and

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analyzed for Sr isotope composition. A total of 3 kg of basalt were grinded to 2–5 mm and leached with pH = 3 hydrochloric acid. Leached solutions were collected for major element and strontium isotopic ratio analyses. About 150 pieces of plagioclase, quartz, Ca-montmorillonite, augite, and spinel crystals, as well as matrix, were selected from the broken and sieved basalt under binoscope by hand, and then dissolved in HF–HNO₃ mixture for Sr isotope analysis.

Major element and strontium concentrations in the water samples were measured in filtered and acidified water with an inductively coupled plasma atomic emission spectrometer (ICP-AES, iCAP-6300) in the Key Laboratory of Surficial Geochemistry, Ministry of Education, Nanjing University. Strontium in the solution was separated using Sr-Spec resin and isotopic ratios were determined on a Neptune Plus multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) also at the Key Laboratory of Surficial Geochemistry. ⁸⁷Sr/⁸⁶Sr was normalized to ⁸⁶Sr/⁸⁸Sr = 0.1194. Reproducibility and accuracy of strontium isotopic analyses were periodically checked by running the Standard Reference Material NBS 987, yielding a long-term mean ⁸⁷Sr/⁸⁶Sr value of 0.710265 ± 13 (2σ external standard deviation, n = 19). The international seawater standard IAPSO was used to verify the chemical procedure. Measurements of ten replicates yielded a mean ⁸⁷Sr/⁸⁶Sr value of 0.709194 ± 22 (2σ external standard deviation, n = 10). The analytical blank was <1 ng for strontium.

3 Results and discussion

The Sr isotope data for all samples have been plotted in Fig. 1 (detailed data are omitted in this paper). The ⁸⁷Sr/⁸⁶Sr ratios of field water—including river, reservoir, spring, and well water—ranged from 0.706255 to 0.707471

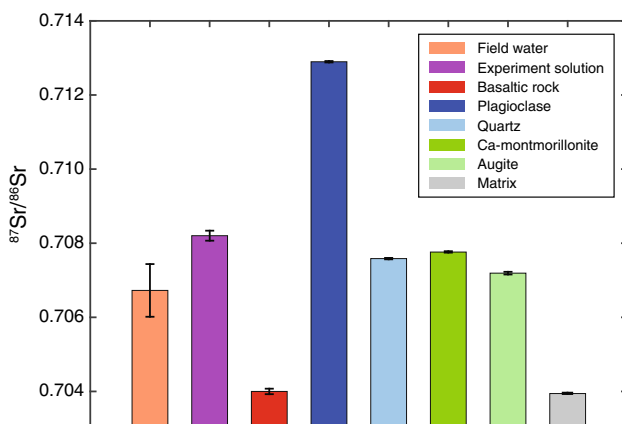


Fig. 1 Strontium isotope data of all samples

with a mean value of 0.706726 (n = 22). The ⁸⁷Sr/⁸⁶Sr ratios of the two fresh rock samples were 0.704052 and 0.703948 with a mean value of 0.704000—much lower than the field water. The ⁸⁷Sr/⁸⁶Sr ratios of the in-house weathering solution ranged from 0.708081 to 0.708339 with a mean value of 0.708203 (n = 17). The ⁸⁷Sr/⁸⁶Sr ratios of plagioclase, Ca-montmorillonite, quartz, augite, and matrix were 0.712897, 0.707761, 0.707585, 0.707192, and 0.703943, respectively. Spinel is insoluble in HF and HNO₃, and is dysgeogenous; therefore we did not measure its Sr isotopes. Plagioclase had the highest ⁸⁷Sr/⁸⁶Sr ratio; the other mineral samples had ⁸⁷Sr/⁸⁶Sr ratios similar to those of the field water samples. The matrix sample had a ⁸⁷Sr/⁸⁶Sr ratio very similar to that of the fresh basaltic rocks, which might suggest that matrix and whole rocks have the same composition.

The average ⁸⁷Sr/⁸⁶Sr ratio of field water (0.706726) was 0.002726 higher than that of fresh basaltic rocks (0.704000), a difference much larger than analysis error. It is generally recognized that rainwater and dust can have significant influence on a river's composition (Jin et al. 2011; Wu et al. 2013; Sherman et al. 2015; Clauer and Semhi 2016); therefore, higher ⁸⁷Sr/⁸⁶Sr ratios of field water might be due to dust and rainwater. However, the fact that the ⁸⁷Sr/⁸⁶Sr ratios of the in-house weathering solution (without rainwater or dust inputs) were higher than fresh basaltic rocks, suggests that dust and rainwater aren't the reason for the ⁸⁷Sr/⁸⁶Sr difference between basalt and basin water.

Among the selected four minerals (not considering matrix or spinel), plagioclase had the highest ⁸⁷Sr/⁸⁶Sr ratios. The ⁸⁷Sr/⁸⁶Sr ratios of the other three minerals were lower than those of the in-house weathering solutions; quartz, Ca-montmorillonite, and augite could not, therefore, have caused the high ⁸⁷Sr/⁸⁶Sr ratios of the in-house weathering solution. Mostly likely, plagioclase was primarily responsible for the high ⁸⁷Sr/⁸⁶Sr ratios of field water and of the in-house weathering solution, while quartz and Ca-montmorillonite more likely precipitated from the pore solution of basalt, which would explain the similar ⁸⁷Sr/⁸⁶Sr ratios among quartz, Ca-montmorillonite, and field water. The ⁸⁷Sr/⁸⁶Sr ratio of augite is close to that of field water, but lower than that of the in-house weathering solution, which might suggest that augite is not related to the difference of ⁸⁷Sr/⁸⁶Sr ratios between basalt and basin water.

While it is generally argued that the ⁸⁷Sr/⁸⁶Sr ratios of all minerals in basalt are similar as a result of the rock's rapid crystallization, this work shows that different minerals in basalt have different ⁸⁷Sr/⁸⁶Sr ratios. We have the opinion that plagioclase has suffered from low-temperature hydrothermal alteration, increasing the ⁸⁷Sr/⁸⁶Sr ratios of plagioclase and augite.

In the field of weathering research, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are widely used to analyze the end-member contribution of various sources. It is usually assumed that the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of basalt contribute to a weathering basin are equal to those of the basaltic rocks themselves (Chung et al. 2009; Rengarajan et al. 2009). Our work found that there is a big difference in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of basalt and basaltic basin water, which suggests that the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of the basaltic rocks do not represent the basalt end-member.

4 Conclusion

There is a big difference in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of basalt and basin water in Xuyi, China. Our work found that the high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of plagioclase, caused by low-temperature hydrothermal alteration, are the main reason for this difference. This finding tells us that when analyzing the end-member contribution in a mixed-rock basin including basalt, we should take this difference in account.

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