Tracing Mg-rich fluids by Mg-O isotopes at slab-mantle interface in continental subduction zones: insights from the Mg-metasomatic rocks in both Western and Eastern Alps

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Introduction

The Mg-metasomatic rocks in both Western Alps (coesite-bearing whiteschist) and Eastern Alps (high pressure leucophyllite) are intriguing for their extreme Mg enrichment (e.g., Demény et al., 1997; Schertl and Schreyer, 2008; Ferrando, 2012). However, the origin of such Mg enrichment still remains to be resolved. If the Mg enrichment is caused by metasomatism of Mg-rich fluids, such samples are important to elucidate the fluid-rock interaction in continental subduction zones. To shed new light on this issue, we choose the typical samples of whiteschist from the Dora-Maira Massif in Western Alps, and leucophyllite from Rabenwald and Miesenbachtal in Austrian Eastern Alps as well as those from the Sopron-Fertorakos area in Hungarian Easteran Alps (Demény et al., 1997; Schertl and Schreyer, 2008). The country rocks of metagranite were also analyzed for comparison.

We performed a combined study of SIMS zircon U-Pb ages and O isotopes, and whole-rock Mg-O isotopes for the whiteschist and leucophyllite in Western Alps and Eastern Alps, respectively. The microbeam zircon U-Pb age and O isotope data comfirmed the protolith of the Mg-metasomatic rocks are similar to the country rock, i.e., metagranite. However, the Mg-O isotope compositions suggest two sources of Mg-rich fluids: one is extremely heavy in Mg isotopes, and the other is extremely low in Mg isotopes. Considering the Mg isotope systematics of terrestrial reservoirs, the former fluids were proposed to be derived from talc-rich serpentinites (Chen et al., 2016), whereas the latter fluids can be that has dissolved lots of magnesite. Therefore, this study shows that the fluids at slab-mantle interface can be complex, but can be traced with Mg-O isotopes combined with other petrological and geochemical constraints. Such fluids can greatly influence the geochemistry of crustal rocks in the subdution zones.

Analytical results

Zircon U-Pb dating for whiteschist in Western Alps yields two groups of ages at ~262 Ma and ~34 Ma, respectively (Fig. 1). The Permian ages occur in relict magmatic domains and are consistent with the protolith age of the country rock (metagranite). The Tertiary ages occur in coesite-bearing domains, consistent with the known ultrahigh-pressure metamorphic age. Whereas the relict magmatic domains show higher δ^{18}O values of ~9-11‰, the metamorphic domains exhibit lower δ^{18}O values of 5.8 to 6.8‰ (Fig. 1). The significant O isotope difference between the two types of domains suggests that the protolith of whiteschist underwent metasomatism by metamorphic fluids with relatively low δ^{18}O values. The δ^{26}Mg values for the whiteschist are mostly -0.07 to 0.72‰ (except two samples that are -0.46‰ and -0.26‰), considerably higher than the country rock with δ^{26}Mg of -0.54 to -0.11‰ (Fig. 2).

For the leucophyllites in Hungarian Eastern Alps, the metagranite to leucopyllite profile shows two trends of Mg isotope variations (Fig. 2): (1) the Mg isotopes become heavier toward the leucophyllite, from -1.30 ~ -0.64‰ in metagranite to -0.09 ~ 0.14‰ in leucophyllite; (2) the Mg isotopes become lighter toward the leucophyllite, from -0.29‰ in metagranite to -0.88‰ in leucophyllite. Similar features were found in Austrian Eastern Alps (Fig. 2).

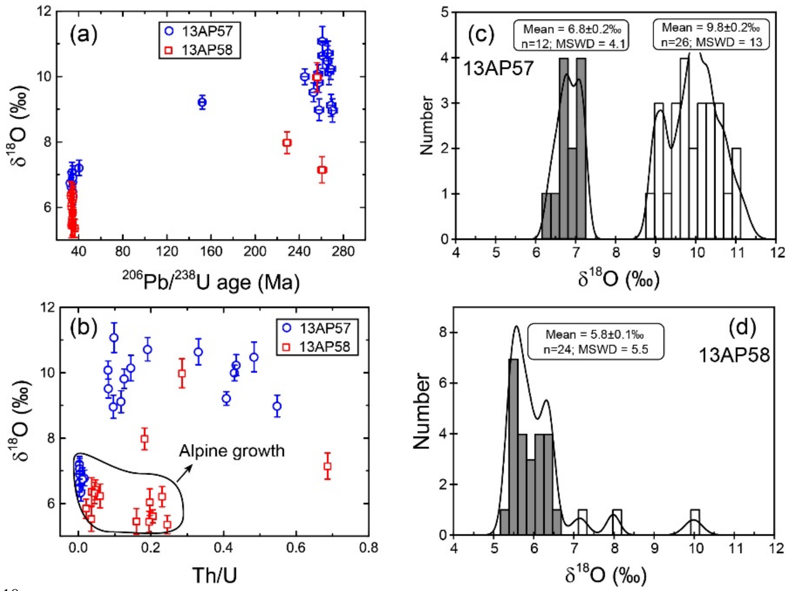

Figure 1: Zircon $\delta^{18}O$ values and their relations to U-Pb ages for whiteschist from Western Alps. The gray bars in panels c and d are metamorphic domains, others are relict magmatic domains. Data from Chen et al. (2016).

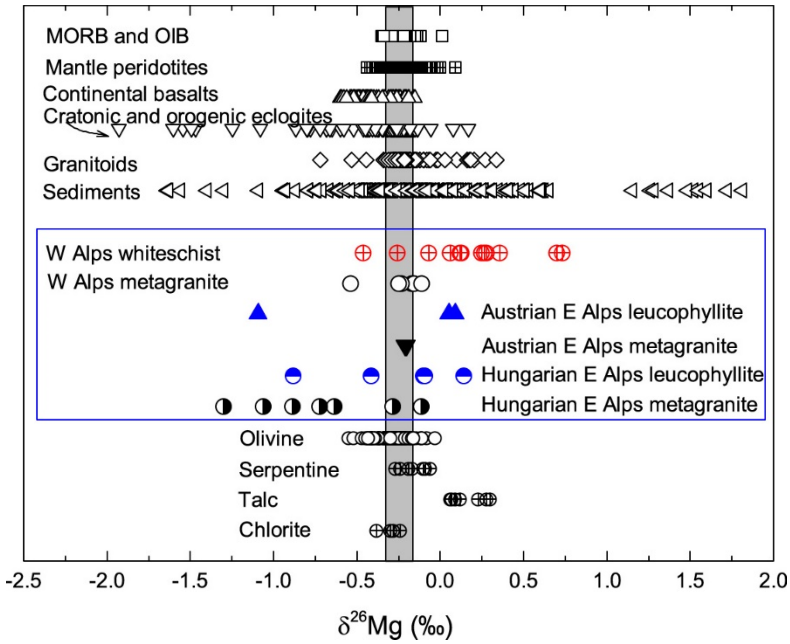

Figure 2: $\delta^{26}Mg$ values for whiteschist in Western Alps (Chen et al., 2016) and leucophyllite in Eastern Alps. The data for various reservoirs are summarized in Chen et al. (2016).

Discussion and conclusion

The similar zircon U-Pb age of ~262 Ma in both whiteschist and the country rock metagranite and the high $\delta^{18}O$ values of ~9-11‰ in such zircons, combined with previous petrological and geochemical studies, lend strong support that the protoliths of the whiteschist in Western Alps are similar to the country rocks of metagranite. The extremely heavy Mg isotopes in the whiteschist can not be interpreted by diffusion process (Chen et al., 2016). Although chemical weathering can result in variably heavy Mg isotopes for the residues, such a process is hard to explain the significantly lower $\delta^{18}O$ values in the metamorphic zircons, the extremely Mg-rich composition and the highly heterogeneous $\delta^{26}Mg$ values in the whiteschist. Considering previously reported mineral H-O isotopes and petrological results, we peopose that the protolith rocks experienced the metasomatism by a kind of Mg-rich fluids with heterogeneous but primarily heavy Mg isotope compositions during probably continental subduction. According to available Mg isotope data of rocks and minerals (Fig. 2), the fluids were possibly produced by devolatilization of talc-rich serpentinites at the slab-mantle interface in a subduction channel (Chen et al., 2016). This means the serpentinite dehydration in subdcution zones may greatly affect the geochemistry of the deeply subdcuted continental crust.

The leucophyllite in Eastern Alps has been documented to have a granitic protolith similar to the country rock (e.g., Demény et al., 1997). However, such a protolith have extremely low δ^{26}Mg values down to -1.30‰ (Fig. 2). Due to the insignificant Mg isotope change during silicate magma differentiation, and the only reservoir with such low δ^{26}Mg values are the carbonates (Teng, 2017), the protolith was possibly derived from partial melting of metasediments containing significant amounts of Mg-rich carbonates. The metagranite to leucopyllite profile shows two trends of Mg isotope variations. Two profiles in Hungarian Eastern Alps show that the Mg isotopes become heavier toward the leucophyllite, from -1.30 ~ -0.64‰ in metagranite to -0.09 ~ 0.14‰ in leucophyllite. This can be interpreted in a similar way to the whiteschist in Western Alps, i.e., the protolith experienced metasomatism by fluids with heavy Mg isotopes, probably derived from the talc-rich serpentinites. However, another profile in Hungarian Eastern Alps shows that the Mg isotopes become much lighter toward the leucophyllite, from -0.29‰ in metagranite to -0.88‰ in leucophyllite. In Austrian Eastern Alps, there is also one leucophyllite sample that shows an extremly low δ^{26}Mg value of -1.09‰ (Fig. 2). Whereas the Mg-enrichment in the leucophyllite suggests metasomatism by Mg-rich fluids, the extremely low δ^{26}Mg values of the leucophyllite require such fluids with extremely low δ^{26}Mg values. Considering the Mg isotope systematics in various reservoirs and the geological context for leucophyllite formation, it is possible that the metasomatic fluids have dissolved amounts of Mg-rich carbonates, probably magnesite, which can occur by carbonation of serpentinites (Beinlinch et al., 2014). This metasomatic process can also occur at the slab-mantle interface in a contintental subduction channel.

By Mg-O isotope analysis of Mg-metasomatic rocks metamorphosed at different ages and P-T conditions in Western Alps and Eastern Alps, we find extremely heavy and light Mg isotope compositions in such rocks. We propose that they reflect two types of Mg-rich fluids occurred at the slab-mantle interface in continental subduction channel: (a) derived from dehydration of talc-rich serpentinites; (b) derived from dissolution of magnesite produced by carbonation of serpentinites. This study shows that the fluid-rock interaction in the subduction channel can greatly influence the geochemical composition of crustal rocks within the channel.

References

Beinlich, A., Mavromatis, V., Austrheim, H., Oelkers, E.H., 2014. Inter-mineral Mg isotope fractionation during hydrothermal ultramafic rock alteration-Implications for the global Mg-cycle. Earth and Planetary Science Letters 392, 166-176.

Chen, Y.-X., Schertl, H.-P., Zheng, Y.-F., Huang, F., Zhou, K., Gong, Y.-Z., 2016. Mg-O isotopes trace the origin of Mg-rich fluids in the deeply subducted continental crust of Western Alps. Earth and Planetary Science Letters 456, 157-167.

Demény, A., Sharp, D.Z., Pfeifer, H.-R., 1997. Mg-metasomatism and formation conditions of Mg-chlorite-muscovite-quartzphyllites (leucophyllites) of the Eastern Alps (W. Hungary) and their relations to Alpine whiteschists. Contributions to Mineralogy and Petrology 128, 247-260.

Ferrando, S., 2012. Mg-metasomatism of metagranitoids from the Alps: genesis and possible tectonic scenarios. Terra Nova 24, 423-436.

Schertl, H.-P., Schreyer, W., 2008. Geochemistry of coesite-bearing "pyrope quartzite" and related rocks from the Dora-Maira Massif, Western Alps. European Journal of Mineralogy 20, 791-809.

Teng, F.-Z., 2017. Magnesium isotope geochemistry. Reviews in Mineralogy and Geochemistry 82, 219-287.