Contrib. Mineral. Petrol. 70, 149–152 (1979)

Contributions to Mineralogy and Petrology

Oxygen and Hydrogen *Isotope Studies on* Minerals From *Alpine Fissures* and Their Gneissic Host Rocks, Western Tauern Window (Austria)

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Abstract. Fourteen cogenetic quartz-biotite pairs from gneissic wall rocks, and 22 quartz, 16 calcite, and 8 biotite samples and 1 sample of albite from fissure-filling veins in the Western Tauern Window were analyzed for their oxygen isotope composition. The $\delta^{18}O$ values show the following ranges: (a) quartz, +6.0 in fissure in amphibolite to +10.3 in fissures in granite gneisses; (b) biotite, +2.5 to +6.7; and (c) calcite, +7.0 to +8.9. The $\delta^{18}O$ value of albite is +7.1. Only a small variation in the hydrogen isotope composition of biotite was detected. δD values of 7 biotites from gneisses and fissure fillings varied from −54 to −59. There is no significant difference in the hydrogen isotope composition of fissure biotite and biotite from the host rock. This indicates that a common water source of probably deep-seated origin existed, with no detectable contribution from isotopically light meteoric water.

Oxygen isotope fractionations between coexisting quartz and biotite of 3.5 to 7.0‰ indicate equilibrium temperatures of 640° to 450° C, respectively, using the fractionation curve of Hoernes and Friedrichsen (1978). The highest temperatures of equilibration are for the rocks at the Alpenhauptkamm, i.e., the central part of the Tauern Window. Successively lower temperatures are found to the north and to the south of the Alpenhauptkamm along a traverse through Penninic units of the Tauern Window. The metamorphism of the host rocks and the filling of fissures has occurred at the same temperature in a given sample locality.

I. Introduction

The Penninic rocks of the Tauern Window consist of two main lithological-tectonic units, the Zentralgneis and the lower and upper Schieferhülle. The Zentralgneisses are mainly orthogneisses of granitic (Augen- und Flasergneis) to granodioritic (Metatonalit) composition with intercalated paragneisses. The lower and the upper Schieferhülle consist of imbricate sheets and nappes of calc-mica schists, gneisses, amphibolites, marbles, and phyllites (Morteani, 1974).

The Zentralgneisses, together with the main part of the lower Schieferhülle, are polymetamorphic rocks with an Alpine as well as a Hercynian and perhaps Caledonian metamorphic history. The rocks of the upper Schieferhülle which are of Mesozoic age show only the effects of the Alpine metamorphic phases.

Fissure-filling veins and most of the mineral equilibria in Penninic rocks of the studied area are a product of the Alpine metamorphism. The fissures were opened in an extensional phase during uplift and doming of the rock units. The fissures are filled mainly with quartz, carbonates, feldspars, and minor amounts of biotite and chlorite.

The $P-T$ conditions at the climax of the last Alpine metamorphism in the Tauern Window have been determined by several analytical methods:

(a) Morteani and Raase (1974) have mapped the plagioclase isograds and Raase and Morteani (1976) have mapped the structural stage of the K-feldspars.

(b). Hoernes (1973) determined a biotite isograd and several critical mineral reactions in pelitic rocks.

(c). Friedrichsen et al. (1973) and Hoernes and Friedrichsen (1974) have measured oxygen isotope fractionations between various mineral pairs. They have calculated 'paleo-isotherms' for the main phase of Alpine metamorphism from oxygen isotope temperatures and estimated confining pressure from pressure-critical mineral reactions.

All methods have yielded – within the analytical uncertainty – concordant data for the temperatures of the last metamorphic event. The rocks of the central part of the Western Tauern Window have been

0010-7999/79/0070/0149/$01.00

formed under the highest $P-T$ conditions, with temperatures higher than 600° C. To the north and to the south, rocks are exposed which show lower metamorphic temperatures (see inset in upper left corner of Fig. 1).

The main goal of this study has been to evaluate the temperatures of formation of the fissure-filling minerals and to relate these temperatures to the temperatures of formation of the host rocks. There is evidence that the fissures were filled after the main tectonic events (Luckscheiter and Morteani, 1979).

Previous studies on the chemical compositions of the fissure-filling carbonate phases by Hörmann and Morteani (1972), on partitioning of rare earth elements between these carbonates and host rocks by Lausch et al. (1973) and $^{18}O/^{16}O$ ratios (Schoell et al., 1975) all suggest a high temperature of formation for the carbonates. The carbonates in the fissures have exsolved ankeritic dolomite during the cooling period.

II. Experimental Methods

The mass spectrometric analyses were carried out with a 60°, 15 cm single focusing mass-spectrometer (McKinney et al., 1950). The analytical reproducibility for oxygen was better then $\pm 0.14^{0}/_{00}$ The reaction yields were 97 to 100%.

Hydrogen was extracted by complete combustion of the minerals at 1,400° to 1,500° C and was oxidized to H_2O with CuO. Uranium heated to 800° C was used to reduce the water to hydrogen, which was trapped on activated charcoal at liquid nitrogen temperature. D/H measurements were performed with a 15 cm radius mass spectrometer, and replicate analyses indicated an uncertainty of $\pm 1^{0}/_{00}$. All data are reported in the standard δ notation, relative to Standard Mean Ocean Water (SMOW).

The temperatures of mineral crystallization were derived from the quartz-biotite fractionation curve of Hoernes and Friedrichsen (1974).

III. Results and Discussion

A. Host Rock Data

Biotite and quartz of 14 samples of gneisses were analyzed for their oxygen isotope composition. Biotites from 4 samples of the lower Schieferhülle and the Zentralgneis were selected for D/H measurements. The δD values of the minerals from the Alpine fissures are given in Table 1 together with sample numbers and the formation temperatures determined from the $^{18}O/^{16}O$ data. (A complete list of all isotope data for the minerals from the country rock and the fissure minerals is available from the second author on request.) Metamorphic temperatures of the rocks are given in Fig. 1. These data provide detailed information on the temperatures of metamorphism in the area investigated and confirm the general pattern of the isotherms found by Hoernes and Friedrichsen (1974). Rather uniform δD values of $-57 \pm 3^{0}/_{00}$ for biotite are close to the accepted value of mantle hydrogen in biotites (e.g., Sheppard and Epstein, 1970). However, the isotopic composition of hydrogen in biotites of the upper Schieferhülle (Mesozoic cover) displays a large variation of from -60 to $-90^{0}/_{00}$ (Hoernes and Friedrichsen, unpublished data). The hydrogen isotope homogenization in the lower Schieferhülle occurred during the Hercynian metamorphic and/or magmatic events. A similar Hercynian homogenization was observed by Hoernes and Friedrichsen (1978) in the rocks of the Ötztal-Stubai Alps.

Table 1. Alpine fissure and host rock formation temperatures, as determined from $^{18}O/^{16}O$ data for coexisting biotite and quartz and δD values of the biotites. The sample localities can be found in Fig. 1 with the given formation temperature

Host rocks			Alpine fissures		
Sample number	Temperature °C	δD	Sample number	Temperature °C	δD
361	500	−58	C 6	522	−58
71.7	556	−59	C10	561	−54
71.130	550	−56	C26	590	−56
72.198	538	−56			

B. Fissure Mineral Data

Twenty-seven quartz samples, including 4 coexisting glassy and milky quartz pairs, 7 biotites, 1 albite, and 27 carbonates were analyzed. The results can be summarized as follows:

1. No large differences in isotopic compositions between minerals of the host rock and minerals of the fissures were observed; quartz from a fissure and quartz from the host rock do not differ in their $^{18}O/^{16}O$ ratios by more than 1%. No low $\delta^{18}O$ values which might have been a result of interaction with meteoric water were found. The similar hydrogen isotope composition of biotite from fissures and biotite from the host rocks ($\delta D = -56 \pm 2$) indicates a common source of water for both phases, and, as noted above, indicates its deep-seated origin without any contribution of isotopically light meteoric water.

2. Glassy and milky quartz originating from the same fissure show no difference in their $^{18}O/^{16}O$ ratios, although there is evidence from field observa-

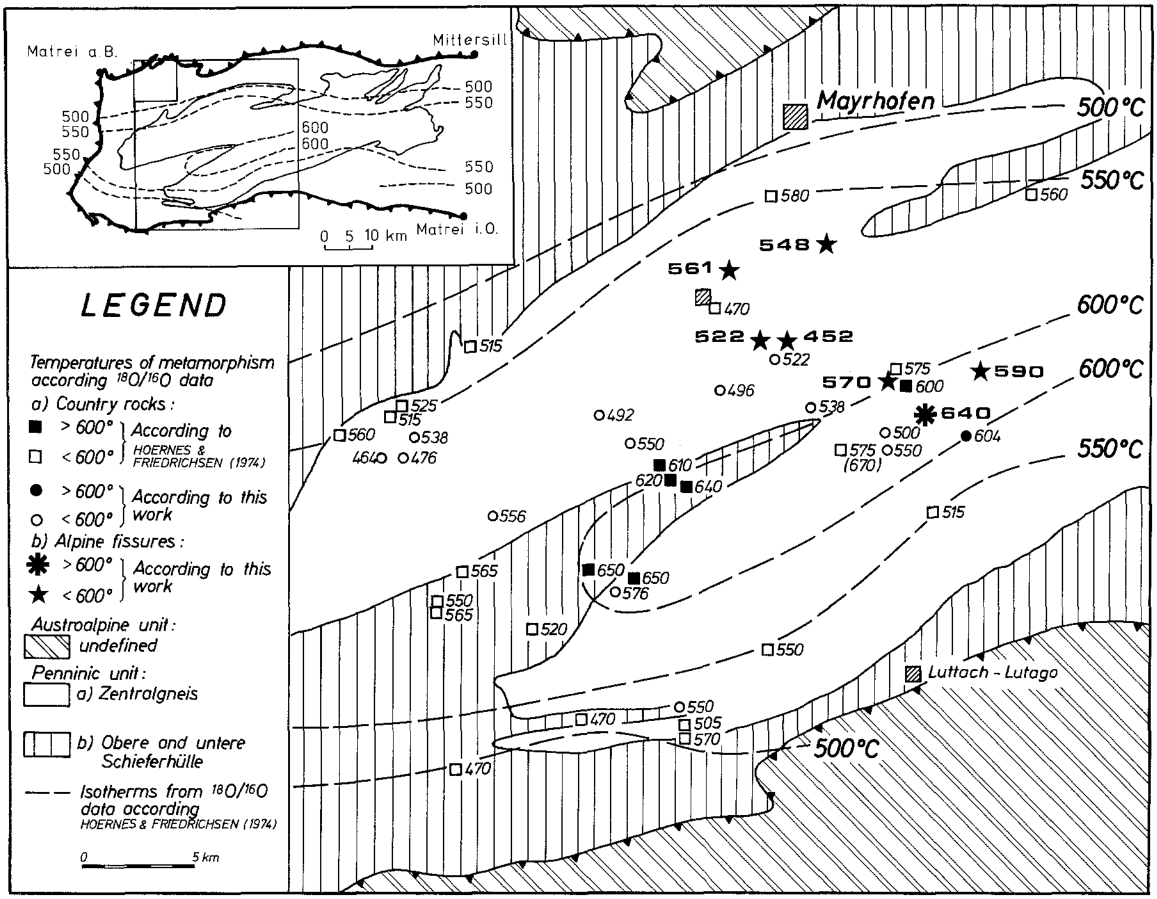

Fig. 1. Simplified geological map of the area studied with temperatures of formation of fissure minerals and host rocks as deduced from $^{18}O/^{16}O$ data

tions that milky quartz is older than glassy quartz. The milky color is caused by a dense population of fluid inclusions which were formed during syncrystalline deformation (Luckscheiter and Morteani, 1979).

3. Fissures containing quartz and biotites are rare. Hence, only seven coexisting quartz-biotite pairs were analyzed. Figure 1 shows that the temperature distribution during the formation of the fissure minerals and the formation of the minerals in the host rock were essentially identical. Since the fluid phase which existed during the formation of the fissure minerals and the host rock minerals had the same, and a rather uniform, isotopic composition, it can be concluded that the fissure minerals were formed at the temperature climax of the last Alpine metamorphic event.

Acknowledgement. We are grateful to Dr. B.E. Taylor for the critical reading of this paper.

The field work was supported by the Deutsche Forschungsgemeinschaft from the: Schwerpunktprogramm Geodynamik des mediterranen Raumes (Mo 232/2,3 and Fr 357/10-12-13).

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Received January 2, 1978; Accepted May 21, 1979