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^{18}O / ^{16}O and D / H Study of the Minerals from the Steinkogelschiefer and the Schwazer Augengneis (Salzburg / Tirol, Austria)

by *M. Satir*, H. Friedrichsen*** and *G. Morteani****

Abstract

^{18}O / ^{16}O- and D / H-ratios of 6 quartzes, 4 biotites, 3 muscovites, 2 phengites, 2 K-feldspars, 1 garnet and 2 ilmenites from the garnet-micaschists of the Steinkogelschiefer unit and of the Schwazer-Augengneise from the upper Trattenbach valley have been determined. Oxygen isotope fractionations yield a temperature of about 400 °C for the formation of the phengites in the Schwazer Augengneise. This phengites have been formed at an early low graded stage of the Hercynian metamorphism. They survived during further progress of metamorphism.

The maximum temperature of the Hercynian metamorphism is represented by the temperature of 560 °C which has been determined from O-isotope fractionation between quartz, muscovite, garnet, ilmenite, and biotite from the Steinkogelschiefer unit.

There is evidence from the H-isotopic composition of the micas that the minerals equilibrated with water of homogeneous isotopic composition during the Hercynian metamorphism.

During the Eoalpine phase no recrystallization and isotope reequilibration occurred.

Zusammenfassung

Es wurden die ^{18}O / ^{16}O- und die D / H-Verhältnisse von 6 Quarz-, 4 Biotit-, 3 Muscovit-, 2 Phengit-, 2 Kalifeldspat-, 1 Granat- und 2 Ilmenitkonzentraten aus den Granat-Glimmerschiefern der Steinkogelschiefereinheit und aus den Augengneisen des oberen Trattenbachtales bestimmt.

Die Fraktionierung der Sauerstoffisotope ergab für die Phengite aus den Schwazer Augengneisen eine Bildungstemperatur von ca. 400 °C. Die Phengite wurden in einer frühen niedrigtemperierten Phase der herzynischen Metamorphose gebildet. Sie blieben im weiteren Verlauf der Metamorphose unverändert erhalten.

Für die Minerale Quarz, Muscovit, Granat, Ilmenit und Biotit der Steinkogelschiefereinheit wurde aus der Sauerstoffisotopenfraktionierung die maximale herzynische Metamorphosetemperatur mit 560 °C bestimmt.

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Während der eoalpinen Phase kam es weder zu einer Rekristallisation der Minerale noch zu einer Neueinstellung des Sauerstoffisotopengleichgewichts.

Aus dem D/H-Verhältnis in den Glimmern kann geschlossen werden, dass die Minerale während der herzynischen Metamorphose mit einer in Bezug auf die Isotopenzusammensetzung homogenen fluiden Phase equilibrierten.

1. INTRODUCTION AND GEOLOGICAL SETTING

Many bodies of crystalline rocks occur along the border between the Innsbrucker Quarzphyllit and the Northern Grauwackenzone north of the Western Tauern Window (see lower part of Fig. 1). These bodies consist mainly of augengneisses. The augengneisses are known as Schwazer Augengneise or as Kellerjochgneise. Intensely folded garnet-biotite-muscovite-schists occur subordinately in a similar tectonic position. These garnet-mica-schists which are called Steinkogelschiefer form a body of 25 sq.km. north the village of Neukirchen am Grossvenediger (see Fig. 1).

According to TOLLMANN (1963,1977) the Steinkogelschiefer and the Kellerjochgneise belong to the middle Austroalpine unit. The «Innsbrucker Quarzphyllit» belongs to the lower, and the Grauwackenzone to the upper Austroalpine unit.

ACKERMAND and MORTEANI (1977) demonstrated from microscopic and geochemical investigations that the Steinkogelschiefer shows an older prograde metamorphism of amphibolite facies and a succeeding younger retrogressive metamorphism under greenschists facies conditions. The metamorphic grade of the underlying Innsbrucker Quarzphyllit and of the overlying rocks of the Grauwackenzone is lower than that of the Steinkogelschiefer. Some km east of the Steinkogelschiefer unit, pyrophyllite, chloritoide and stilpnomelane occur in the rocks of the Grauwackenzone (SCHRAMM, 1977). These minerals are typical of the greenschist facies. A similar metamorphic grade may be suggested for the rocks of the Innsbrucker Quarzphyllit. Until now, there have been no detailed studies on the metamorphic grade of the Innsbrucker Quarzphyllit.

According to SATIR and MORTEANI (1979) the age of the sediments from which the Steinkogelschiefer are derived is about 550 million years. The Rb-Sr-whole rock age of the garnet-mica-schists (Steinkogelschiefer) and of the Schwazer Augengneise indicate that these rocks have been intensely metamorphosed about 325 million years ago. This Hercynian metamorphism was the main mineral-forming event for the Steinkogelschiefer as well as for the Schwazer Augengneise (SATIR and MORTEANI, 1979). SATIR and MORTEANI (1979) deduced from the radiometric ages that Eoalpine metamorphism of these rocks occurred about 90 m.y. ago. During this metamorphic event a maximum temperature of about 350 °C was attained. This temperature was too low for

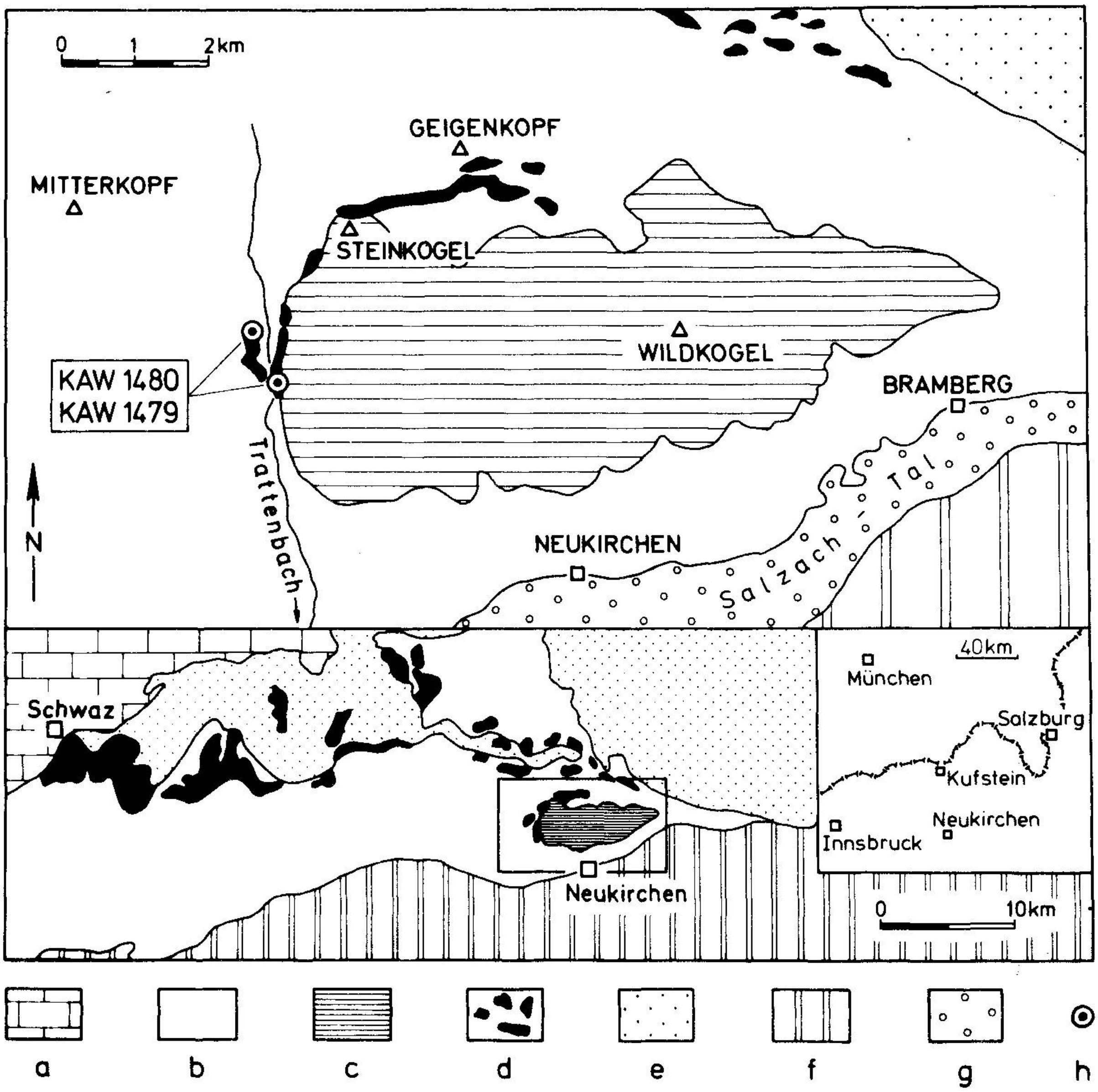

Fig. 1 Simplified geological map (after OHNESORGE, 1933) of the studied area, showing sample locations. In the lower part of the figure the position of the Schwazer Augengneise between the Innsbrucker Quarzphyllit and the Grauwackenzone is shown in a general sketch.
a = Nördliche Kalkalpen, b = Innsbrucker Quarzphyllit, c = Steinkogelschiefer unit, d = Schwazer Augengneise (Kellerjochgneise), e = Grauwackenzone, f = Penninic rocks of the Tauern Window, g = Alluvial gravels, h = sampling site.

mineral recrystallization in the Steinkogelschiefer. From radiometric data the amphibolite facies as well as the retrogressive metamorphism of greenschist facies (ACKERMAND and MORTEANI, 1977) are of Hercynian age (SATIR and MORTEANI, 1979).

In the upper Trattenbach valley, directly below the Steinkogelschiefer, some small bodies of augengneisses are found. These augengneisses, which belong to the Schwazer Augengneis unit, contain phengitic white micas. The phengite was formed during an early low grade event of the Hercynian metamorphism. Augengneisses which carry chlorite, however, show reactions between the phengite and the chlorite, forming muscovite, biotite and quartz (Satir and Morteani, 1978).

The main purpose of the present study was to determine:

(i) the degree of homogenization of the stable isotopes
(ii) the temperatures of the different metamorphic events, and
(iii) the influence of the low grade Eoalpine event on the oxygen isotopic composition of the Hercynian mineral parageneses.

2. EXPERIMENTAL METHODS

The samples used for isotope analysis were the same as those used in the age determinations published by Satir and Morteani (1979). The minerals were separated by magnetic separation and heavy liquid techniques. The purity of the concentrates was better than 99%, and was tested optically and by X-ray diffractometry. $^{18}O/^{16}O$-ratios of 6 quartz, 2 K-feldspar, 4 biotite, 3 muscovite, 2 phengite, 1 garnet and 2 ilmenite samples were analysed, as well as the H-isotope composition of the micas. The experimental methods adopted here are described by Hoernes and Friedrichsen (1974, 1978).

3. ISOTOPIC COMPOSITION OF THE ANALYSED MINERAL PHASE

The sites which have been sampled are shown in Fig. 1. Samples KAW 1475, KAW 1481, KAW 1482 and KAW 1484 are paragneisses of the Steinkogelschiefer unit. Samples KAW 1479 and KAW 1480 are Schwazer Augengneise. Samples KAW 1479 and KAW 1480 which are from the upper Trattenbach valley, occur near the border between the Steinkogelschiefer and the underlying Innsbrucker Quarzphyllit. Rb-Sr and K-Ar age determinations of all samples have been published by Satir and Morteani (1979). The results of the $\delta\,^{18}O$ stable isotope analysis are listed in Table 1.

The oxygen isotopic compositions of the analysed minerals from the Steinkogelschiefer and from the Schwazer Augengneise show only small variations. In Fig. 2 the $\delta\,^{18}O$ values of the analysed coexisting minerals from the Steinkogelschiefer and the Schwazer Augengneise are shown.

The δ D values of the biotites, muscovites and phengites and the calculated values of the coexisting fluid phase are also represented in Table 1. δ D values of -62 ± 8‰ have been obtained for the biotites and -37 ± 5‰ for the muscovites and phengites. The hydrogen isotopic composition of the white micas of both rock types is essentially identical. The H-isotopic composition of water-bearing mineral phases is controlled by the chemical composition (particularly

Tab. 1 $^{18}O/^{16}O$- and D/H-values of the minerals from the Steinkogelschiefer and the Schwazer Augengneise.

Sample-No. and Locality	Minerals	$\delta^{18}O$	δ D fluid	δ D solid	(A-B)	Δ (A-B)	T °C
KAW 1475	Quartz	+ 13.4			Qz - Bi	+ 6.10	492
Paragneiss,	Muscovite	+ 10.14	(-26.7)	-32.8	Qz - Mu	+ 3.26	514
Berger Alpe	Garnet	+ 8.75			Qz - Gr.	+ 4.65	538
N-Neukirchen	Biotite	+ 7.3	(-18.9)	-63.40	Bi - Mu	- 2.84	484
					Bi - Gr.	- 1.45	462
KAW 1481	Quartz	+ 12.8			Qz - Bi	+ 6.60	468
Paragneiss,	Muscovite	+ 9.91	(-30.2)	-36.3	Qz - Mu	+ 2.89	612
Wildkogel	Biotite	+ 6.2	(-11.9)	-56.7	Qz - Ilm.	+ 9.41	554
N-Neukirchen	Ilmenite	+ 3.39			Bi - Mu	- 3.71	436
					Mu - Ilm.	+ 6.52	536
KAW 1482	Quartz	+ 13.7			Qz - Bi	+ 6.24	484
Paragneiss,	Muscovite	+ 10.45	(-30.5)	-36.6	Qz - Mu	+ 3.25	516
0.3 km. south of	Biotite	+ 7.46	(-24.2)	-68.5	Qz - Ilm.	+ 9.20	565
Wildkogel	Ilmenite	+ 4.50			Bi - Mu	- 2.99	477
Neukirchen					Mu - Ilm.	+ 5.95	570
KAW 1484	Quartz	+ 12.8			Qz - Bi	+ 6.40	476
Paragneiss,	Biotite	+ 6.4	(- 8.5)	-53.5			
Bergs. Sessellift							
KAW 1479	Quartz	+ 12.9			Qz - Fsp	+ 2.60	346
Augengneiss,	K-Feldspar	+ 10.3			Qz - Ph	+ 3.92	404
Trattenbach valley	Phengite	+ 8.98	(-11.0)	-36.3	Fsp- Ph	+ 1.32	522
0.3 km. south of							
Sonntag Grund							
Alm							
KAW 1480	Quartz	+ 12.7			Qz - Fsp	+ 1.64	668
Augengneiss,	K-Feldspar	+ 11.06			Qz - Ph	+ 3.93	402
Trattenbach valley	Phengite	+ 8.77	(-16.5)	-41.7	Fsp- Ph	+ 2.29	270
0.6 km. NE of							
Steinbühel							

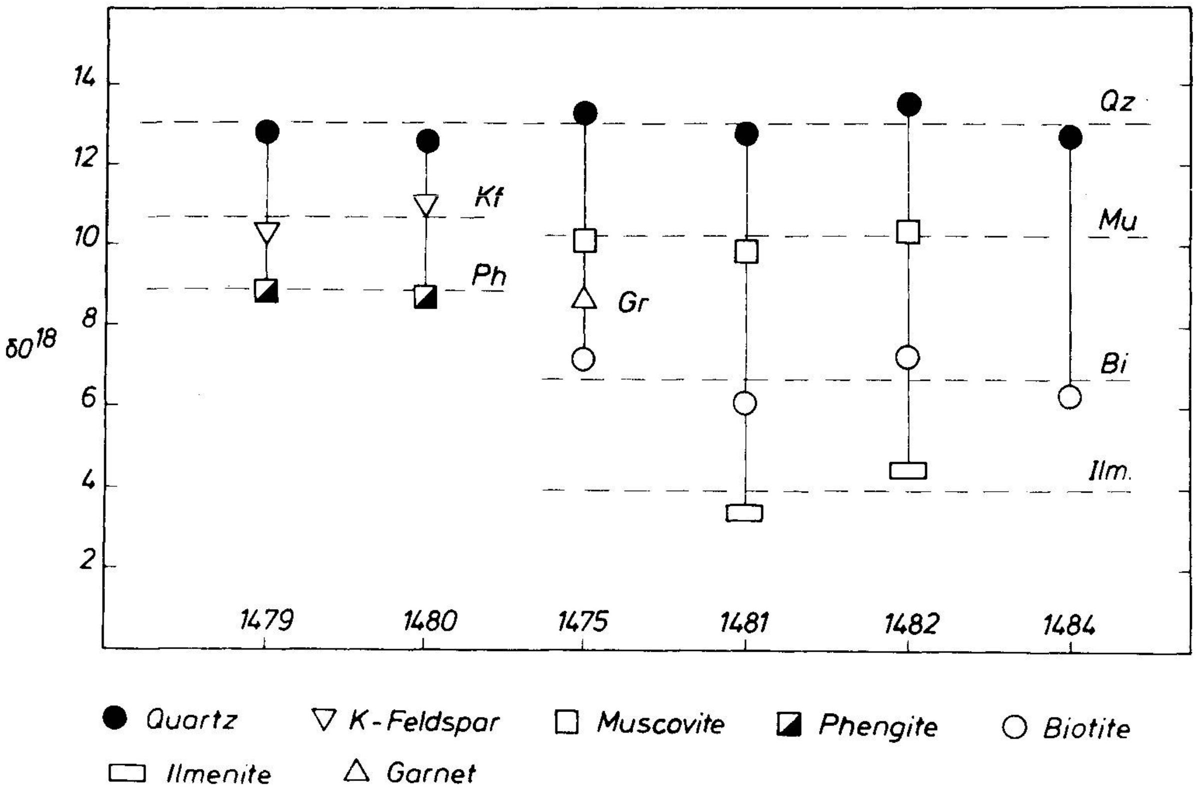

Fig. 2 δ ^{18}O-values of the coexisting minerals from the Schwazer Augengneise (KAW 1479, KAW 1480) and from the Steinkogelschiefer (KAW 1475, KAW 1481, KAW 1482, and KAW 1484).

the Al, Fe and Mg contents of the solid phase), the formation temperature, and the isotopic composition of the fluid phase coexisting with the solid phases during their crystallization or during later stages of metamorphism (SUZUOKI and EPSTEIN, 1976). If we calculate the H-isotopic composition of the fluid phase according to the method of SUZUOKI and EPSTEIN (1976), and using estimated values for the Al_2O_3, FeO and MgO contents of the micas, we obtain values of -10 to -15‰ (see Fig. 3).

The Schwazer Augengneise are orthogneisses. From Fig. 3 it can be seen that the δ D-values of the phengites in these rocks plot in the upper part of the field of metamorphic-H_2O as defined by TAYLOR (1974). This indicates that no trace of the magmatic origin of the Schwazer Augengneise remains. The same H-isotopic composition has been calculated by HOERNES and FRIEDRICHSEN (1978) for the metamorphic fluids of a pre-Alpine event in tectonically related rocks of the Ötztal-Stubai Alps. The δ D-values of the pre-Alpine biotites and muscovites of Ötztal-Stubai Alps are also virtually identical to those found in the present study.

SATIR and MORTEANI (1979) demonstrated that Sr-isotopes homogenized during Hercynian metamorphism in all studied rock samples. As this homogeni-

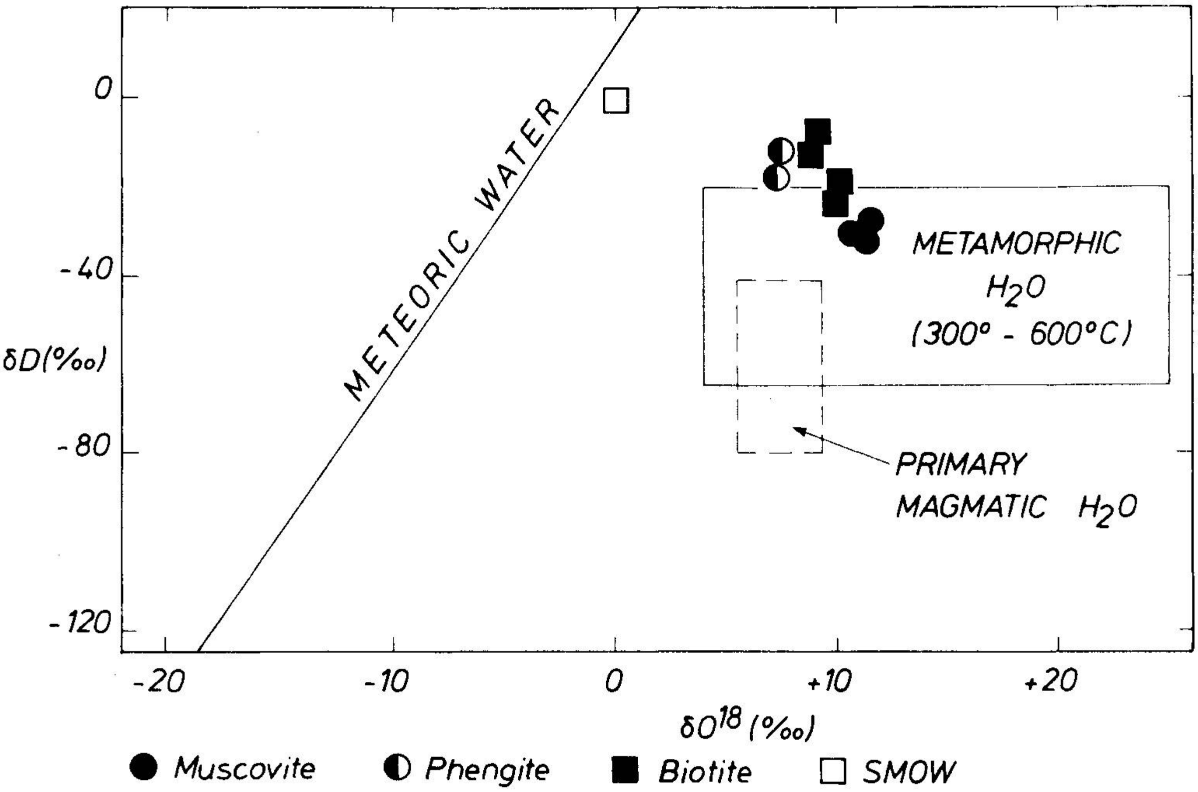

Fig. 3 Calculated isotopic composition of the water which equilibrated with micas. The isotopic composition of metamorphic and magmatic waters is taken from TAYLOR (1974).

zation requires the presence of a fluid phase, we can deduce the same age for the stable isotope homogenization. Hence, the mineral phases of the rocks investigated achieved not only Sr, but also O- and H-isotope homogenization during a metamorphic event of Hercynian age.

4. OXYGEN ISOTOPE FRACTIONATIONS

In Table 1 temperatures are presented which have been derived from oxygen isotope fractionations between the analysed minerals. The calibration curves used are discussed in detail by HOERNES and FRIEDRICHSEN (1978). The scatter of resulting O-isotope temperatures can be used to characterize the state of isotopic equilibrium since ideal O-isotopic equilibrium would yield temperatures from all thermometers. The limitations of this method, which result from the accuracy of the calibration curves, and an experimental error of ± 0.2‰ in the values of Δ (A-B), have been discussed in detail by HOERNES and FRIEDRICHSEN (1978).

Equilibrium conditions are closely approached in the sample KAW 1475. All mineral fractionations in this sample define an apparent temperature of 500 ± 38 °C (Table 1). Disequilibrium is probably represented by quartz-musco

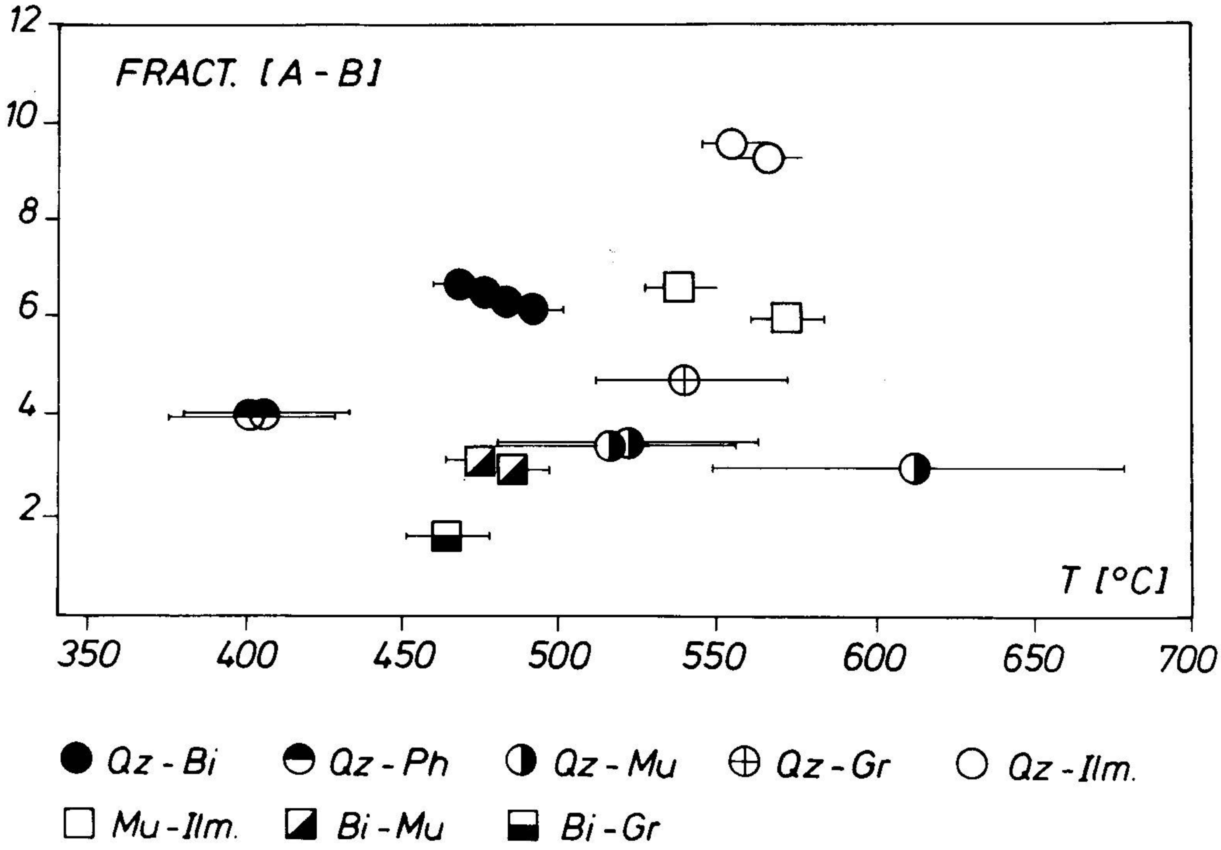

Fig. 4 δ ^{18}O-fractionations between mineral pairs plotted against the crystallization temperatures as deduced from the stable oxygen isotope data. The error bars result from the experimental error of ± 0.2‰.
Abbreviations: Qz = quartz, Bi = biotite, Ph = phengite, Mu = muscovite, Gr = garnet and Ilm = ilmenite.

vite in sample KAW 1481, and by quartz-K-feldspar and K-feldspar-phengite in samples KAW 1479 and KAW 1480.

The same thermometers show the tendency to yield similar temperatures in all samples. This is demonstrated in Fig. 4. The quartz-biotite fractionations, for example, define an apparent temperature of 480 ± 12 °C whereas the quartz-ilmenite fractionations yield higher temperatures around 560 °C.

5. OXYGEN ISOTOPE TEMPERATURES AND RADIOMETRIC AGE DETERMINATIONS

The temperature data will now be discussed in connection with petrological observations, and the Rb-Sr and K-Ar radiometric data of the micas obtained by Satir and Morteani (1979).

As pointed out by Satir and Morteani (1979) the temperatures during the Eoalpine event reached only 300 to 350 °C. The oxygen isotopic fractionations described above represent the temperature conditions of the Hercynian metamorphism. The relatively low quartz-phengite and quartz-biotite temperatures would represent the crystalization temperatures of phengite and biotite, respectively, during progressive Hercynian metamorphism (which reached maximum values of 550 to 560 °C, as suggested from quartz-ilmenite fractionations; for comparison see HOERNES and HOFFER, 1979).

These maximum temperatures of Hercynian metamorphism produced a complete Sr-isotope homogenization in the Steinkogelschiefer and Schwazer Augengneise, as indicated by similar Rb-Sr whole rock ages of 347 and 322 million years respectively (SATIR and MORTEANI, 1979). As mentioned above, a prograde reaction can often be observed in the Schwazer Augengneise, where early-formed phengites have reacted with chlorite to form biotite, muscovite and quartz (SATIR and MORTEANI, 1978). This prograde reaction has not occurred in samples KAW 1479 and KAW 1480 as no chlorite is available as a reactant in these samples. The white micas in the Schwazer Augengneise of the upper Trattenbach valley are therefore relict phengites formed during an early low temperature stage of the prograde Hercynian metamorphism. This is apparently the reason for the disequilibrium between quartz, K-feldspar and phengite in these two samples.

Muscovite and phengite are closed systems for radiogenic Sr isotopes at temperatures of below about 500 °C, and for Ar below about 350 °C (see JÄGER, 1962; WAGNER et al., 1977). Biotite, on the other hand, acts a closed system for radiogenic Sr and Ar isotopes at less than 300 °C.

The cooling ages of phengites in samples KAW 1479 and KAW 1480 are 273 and 260 million years respectively. The muscovite K-Ar ages, however, are 230 to 180 million years. These ages represent mixed ages resulting from a limited influence of the later Alpine metamorphism. This event is documented by Rb-Sr biotite ages of about 90 million years (SATIR and MORTEANI, 1979).

From the above radiometric data it can be concluded that the temperatures of the Alpine metamorphism in the Schwazer Augengneise as well as in the Steinkogelschiefer have not been higher than 350 °C. The low temperature Alpine event produced no recrystallization, and had no influence on the stable isotope composition of the minerals formed during the progressive phase of Hercynian metamorphism.

It appears to be a general rule that during retrogressive metamorphism there is no reequilibration of the stable isotopes of the mineral phases. HOERNES and HOFFER (1979) were able to show this in the case of the Damara Orogen in Namibia.

6. CONCLUSIONS

Oxygen isotope ratios of metamorphic minerals are fixed during the formation of the mineral. The temperatures derived from oxygen isotope fractionations can be interpreted as formation temperatures if the mineral pair under consideration formed under conditions of isotopic equilibrium (i.e. contemporaneously).

To change the specific $^{18}O/^{16}O$ ratio formed during progressive metamorphism, *a complete recrystallization* of the mineral is necessary. This has been observed not only in the present case but also by HOERNES and FRIEDRICHSEN (1978) and HOERNES and HOFFER (1979).

Initial radiogenic Sr- and Ar-isotopic values, on the other hand, can be modified due to the influence of fluid phases and/or temperature. This process does not require *a complete recrystallization* (see e.g. JÄGER, 1962).

If the temperature of metamorphism exceeds 500 °C then a cooling age can be obtained on the white micas by the Rb-Sr method. At metamorphic temperatures below 500 °C, the same method yields the formation age for the white micas. The blocking temperature of the K-Ar method for the white micas is about 350 °C. In the case of biotite, the blocking temperature for both the Rb-Sr and K-Ar methods is 300 °C. Therefore Rb-Sr and K-Ar ages for biotite are always cooling ages (JÄGER, 1962 and WAGNER et al., 1977).

This paper demonstrates that the combination of stable isotope and radiometric data allows investigation of the various phases of metamorphism in a particular area.

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References

ACKERMAND, D. and MORTEANI, G. (1977): Der Chemismus der Granate, Chlorite, Biotite und Turmaline in den Steinkogelschiefern (Land Salzburg, Österreich). Ein Beitrag zur geologischen Geschichte des Mittelostalpins. - N. Jb. Geol. Paländt. Abh. 154 (3), 367-385.

HOERNES, S. and FRIEDRICHSEN, H. (1974): Oxygen isotope studies on metamorphic rocks of the Western Hohe Tauern area (Austria). - Schweiz. Mineral. Petrol. Mitt. 54., 769-788.

HOERNES, S. and FRIEDRICHSEN, H. (1978): Oxygen and hydrogen isotope study of the polymetamorphic area of the northern Ötztal-Stubai Alps (Tyrol) - Contrib. Mineral. Petrol. 67, 305-315.

HOERNES, S. and HOFFER, E. (1969): Equilibrium Relations of Prograde Metamorphic Mineral Assemblages. A stable Isotope Study of Rocks of the Damara Orogen, From Namibia. - Contr. Mineral. Petrol. 68, 377-389.

JÄGER, E. (1962): Rb-Sr-age determinations on micas and total rocks from the Alps. - J. Geophys. Research, 67, 5293-5306.

OHNESORGE, TH. (1918): Rattenberg-Geologische Spezialkarte, der im Reichsrate vertretenen Königreiche und Länder der Österreichisch-Ungarischen Monarchie, neu aufgenommen und herausgegeben durch die k.k. Geologische Reichsanstalt, Wien, W. Müller, k.u.k. Hofbuchhandlung.

SATIR, M. and MORTEANI, G. (1978): P-T-conditions of the high-pressure Hercynian event in the Alps as deduced from petrological, Rb-Sr and $^{18}O/^{16}O$ data on phengites from Schwazer Augengneise (Eastern Alps, Austria). - Schweiz. Mineral. Petrol. Mitt. 58, 289-302.

SATIR, M. and MORTEANI, G. (1979): Kaledonische, herzynische und alpidische Ereignisse im Mittelostalpin nördlich der westlichen Hohen Tauern, abgeleitet aus petrographischen und geochronologischen Untersuchungen. - Geol. Rundschau, 68, 1, 1-40, Stuttgart.

SCHRAMM, J.M. (1977): Über die Verbreitung epi- und anchimetamorpher Sedimentgesteine in der Grauwackenzone und in den Nördlichen Kalkalpen (Österreich). Ein Zwischenbericht. - Geol. Paläont. Mitt. Innsbruck, Bd. 7, 3-20.

SUZUOKI, T. and EPSTEIN, S. (1976): Hydrogen fractionation between OH-bearing minerals and water. - Geochim. et Cosmochim. Acta. 40. 1229-1240.

TAYLOR, H.P. JR. (1974): The application of oxygen and hydrogen isotope studies to problems of hydrothermal alteration and ore deposition. - Econ. Geology, v. 69, p. 843.

TOLLMANN, A. (1963): Ostalpensynthese., 256 s., Wien (Deuticke).

TOLLMANN, A. (1977): Geologie von Österreich., Band I, Wien (Deuticke).

WAGNER, G.A., REIMER, G.M. and JÄGER, E. (1977): Cooling ages derived by apatite fission-track, mica Rb-Sr and K-Ar dating: The uplift and cooling history of the central Alps. - Mem. Ist. Geol. Mineral. Univ. Padova, 30, 1-27.

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