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A Potassium-Argon Study of the Margin of the Tauernfenster at Döllach, Austria

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ABSTRACT

Twenty-one new potassium-argon ages on muscovites and biotites from localities across the edge of the Tauernfenster (Tauern Window) near Döllach, Carinthia, are used to supplement previously-published data in a discussion of the geological history of the area. Ages inside the Window cluster near 30 m.y.; outside the Window they lie near 78 m.y., but within 750 m horizontally of the edge, apparent ages rise as high as 174 m.y. Five conclusions are reached:

(1) the metamorphism of the Schieferhülle occurred at least 34 m.y. ago, and probably at a minimum of 78 m.y. ago;
(2) the western part of the Sonnblick gneiss massif was uplifted and cooled 5 to 10 m.y. before its eastern part;
(3) the edge of the Altkristallin sheet is the critical boundary of the area;
(4) the previously published view that the Altkristallin sheet moved and cooled 78 m.y. ago is confirmed; and
(5) at around 30 m.y. ago warm Window rocks rose vertically against cool Altkristallin rocks.

The anomalously high ages on muscovites from the thrust zone at the edge of the Window are best interpreted as being due to excess argon.

Introduction

This account of mineral potassium-argon ages is part of a series of studies being carried out in the Southeastern Tauern Window, Austrian Alps, by E. R. OXBURGH, the author and graduate students, with financial support for field studies from the Geological Survey of Austria, for which the author is most grateful. This paper is a direct follow-up of OXBURGH, LAMBERT, BAADSGAARD and SIMONS (1966), a similar study of the edge of the Window at localities east and north-east of Döllach (see inset on Fig. 1). Reference should be made to OXBURGH et al. (1966) and OXBURGH (1968, pp. 35–7) for reviews of the geological problems of this interesting area.

Döllach lies on the southern part of the Glocknerstrasse and is within the Geologische Karte der Sonnblickgruppe (EXNER, 1962). The principal features are the Altkristallin sheet, the Matreier zone, the Schieferhülle and the Zentralgneis (Fig. 1). The Altkristallin sheet, consisting of medium- to high-grade metamorphic rocks, corresponds to the upper Ostalpin or Austro-alpine nappes of other authors, and is known to have been formed as a metamorphic complex more than 300 m.y. ago (JÄGER, 1962; SCHMIDT, JÄGER, GRÜNENFELDER and GRÖGLER, 1967; MILLER, JÄGER and SCHMIDT, 1967 and HARRE, KREUZER, LENZ, MÜLLER, WENDT and SCHMIDT, 1968 and BREWER (personal communication). OXBURGH et al. (1966) suggested that it had been driven north and cooled 80–90 m.y. ago and possibly again at about 20 m.y. The

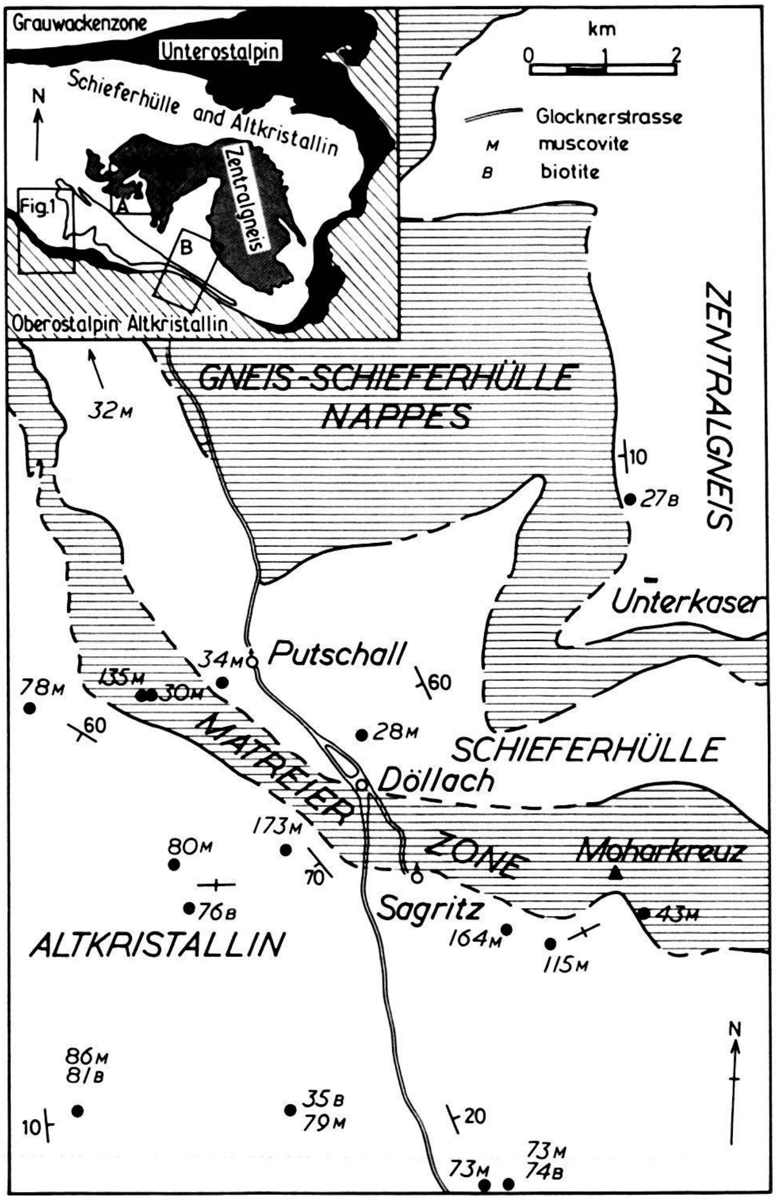

Fig. 1. An outline geological map of the Döllach area, based on the work of EXNER (1962). General dips and strikes of the main planar structure are indicated by conventional symbols. The main road through Döllach, leading to the Glocknerstrasse, is also shown, as are sample localities. The inset map shows the relationship of the area described to the areas studied by OXBURGH, LAMBERT, BAADSGAARD and SIMONS (1966), A indicating their Figure 3 and B indicating their Figure 2.

Matreier zone consists of thin, very low-grade metasediments of the orthoquartzite facies, highly differentiated, and is believed to include Triassic units containing dolomite and gypsum. As it is separated from the Variscan Zentralgneis by the later Mesozoic Schieferhülle and is of lower grade, it is identified as a separate nappe unit lying between the Altkristallin and the Schieferhülle proper. The latter unit also consists of highly differentiated thin low-grade metasediments: it is post-Lower Permian and was metamorphosed at least 22 m.y. ago to at least biotite-schist grade (OXBURGH et al, 1966). The Zentralgneis of the South-east Tauern consists of tonalites and other silicic igneous rocks formed during the late-Variscan 240 m.y. ago (LAMBERT, 1964; Ox-

BURGH, et al 1966; CLIFF 1968). No age-determinations are available on the Sonnblick Zentralgneisse, but they are so similar in all respects to the dated gneisses of the Hochalm massif that they are generally regarded as identical in origin, age and history. The Sonnblickgruppe is, however, unique in that at the western and southern margins of the block the gneisses are interfolded with the Schieferhülle in a series of exceptionally long and thin isoclines, while the main mass itself is attenuated into a 15 km long "tail" of 0.1 km width extending south-east along the Mölltal.

The only petrological complication in the Döllach area is the zone of phyllonite at the base of the Altkristallin, normally not more than 200 m thick. The rocks in this unit are mica-schists of low-grade appearance which pass upwards into normal Altkristallin rocks, and are in sharp contact with normal Matreier zone rocks downwards. No obvious discordance or tectonic break can be seen in this area, but exposure of the soft-weathering phyllonites is poor across the wooded Möll valley at Döllach. In the vicinity of the Moharkreuz (specimens 3053 and 3055) the phyllonites are vertical or dipping north-east and in close contact in a wooded area with quartzites (3054), but in the next exposures west, at the Gartlbach, the phyllonites (3044) are interfolded (?thrust) with dolomite of the Matreier zone, dipping 70° south. In the Gradenbach, further west, poor exposures show a 45°–60° southwest dip of the contact. These variations over a 6 km length do not suggest that the contact of the Altkristallin sheet with the Schieferhülle is that of a simple sub-horizontally-thrust mass against a basement.

The potassium-argon ages

The analyses of the minerals are set out on Table 1, including data from within the Tauern Window, and Table 2 for data from the Altkristallin. The minerals were separated using a combination of electromagnetic and super-panning techniques by Mrs. J. Crisford, and analysed by either the Reynolds all-glass mass spectrometer (J. Simon's analyses) or an MS10 (R. Goodwin's analyses), in each case using metered Ar^{38} as internal standard. The potassium analyses were made by routine flame photometry.

The pattern of ages is the same as that found near Obervellach (OXBURGH et al, 1966) but some high individual ages occur and, in general, the ages from within the Window are higher than those in the Obervellach area. If the age of 37 m.y. from the Obervellach area is excluded, as it must be, the figure now being known to be erroneously high, there is no overlap of age range at all. Accepting the uplift/cooling hypothesis of interpretation of potassium-argon ages leads to the conclusions that:

(1) the metamorphism of the Schieferhülle, the formation of the Sonnblick massif and of its attendant isoclines antedated 34 m.y. (the apparent age of 3036) or perhaps 42 m.y. if the age of 3054 (Table 1) is accepted at its face value;

(2) the western part of the Sonnblick massif was uplifted and cooled some 5 or 10 m.y. before its eastern part and also the Hochalm massif. The spreads of ages obtained at both Obervellach and Döllach prevent a closer estimate, while the data from Böckstein (OXBURGH et al, 1966, Fig. 3) do not assist in clarification.

The Altkristallin data (Table 2 and Fig. 2) produces the same plateau of ages at 78 m.y. at 2 to 5 km from the edge of the Window in the Altkristallin at Obervellach

Table 1. Potassium-argon analyses of minerals from within the Tauern Window near Döllach.

Sample number	Mineral	Rock unit	Analyst	K%	Ar^{40} cc/gm STP $\times 10^{-5}$	% radiogenic Ar^{40}	Age
3062	Biotite	Zentralgneis	1	6.55	0.703	70	26.7 ± 0.6
3036	Muscovite	Schieferhülle	1	6.47	0.895	64	34.4 ± 0.8
3056	Muscovite	Schieferhülle	2	5.69	0.627	61	27.5 ± 1.0
3058	Muscovite	Schieferhülle	1	5.95	0.765	60	31.9 ± 0.8
3063	Muscovite	Zentralgneis	2	8.22	0.980	77	29.7 ± 1.1
3037	Muscovite	Matreier zone, black slate	2	5.61	0.664	62	29.5 ± 1.0
3038	Muscovite	Matreier zone, marble	2	5.38	2.99	76	135 ± 5
3054	Muscovite	Matreier zone, muscovite-quartzite	2	7.15	1.28	81	42.5 ± 1.5

Analysts: 1. J. Simons; 2. R. Goodwin

Table 2. Potassium-argon analyses of minerals from the "Altkristallin" thrust-sheet near Döllach.

Sample number	Mineral	Rock type	Analyst	K%	Ar^{40} cc/gm STP $\times 10^{-5}$	% radiogenic Ar^{40}	Age
3042	Muscovite	Two-mica-gneiss	1	5.89	1.91	83	80 ± 2
3043	Muscovite	Two-mica-gneiss	2	7.27	2.24	83	76 ± 2
3044	Muscovite	Phyllonite	2	6.51	4.70	96	173 ± 6
3045	Muscovite	Muscovite-gneiss	1	6.21	1.98	86	78 ± 2
3046	Biotite	Two-mica-gneiss	1	6.51	2.14	85	81 ± 2
3046	Muscovite	Two-mica-gneiss	1	8.73	3.08	97	86 ± 2
3049	Biotite	Two-mica-schist	2	7.57	1.06	79	35 ± 1
3049	Muscovite	Two-mica-schist	2	8.18	2.64	84	79 ± 2
3053	Muscovite	Phyllonite?	2	5.21	3.55	93	164 ± 4
3055	Muscovite	Phyllonite	1	5.62	2.65	91	115 ± 2
3059	Biotite	Two-mica-gneiss	1	6.92	2.09	89	74 ± 2
3059	Muscovite	Two-mica-gneiss	1	6.88	2.05	86	73 ± 2
3061	Muscovite	Two-mica-gneiss	2	8.96	2.67	85	73 ± 2

Analyst: 1. J. Simons; 2. R. Goodwin.

(Oxburgh et al, 1966, Fig. 5) and is interpreted in the same manner. The data give us conclusion

(3) that it is the edge of the Altkristallin sheet which is the principal break in the age pattern in this region, and conclusion

(4) that the Altkristallin sheet moved and cooled at or near 78 m.y. ago.

The one low figure, 35 m.y. from 3049 biotite, is presumably an isolated example of out-gassing of mica in the Altkristallin during the movements within the Window (see conclusion (1) above). There is no petrographic indication of any reason for the outgassing of this particular biotite.

The age pattern at the edge of the Altkristallin sheet is, however, quite different from that at Obervellach, due possibly to differences in exposure and sampling. The phyllonite muscovite ages of 115, 164 and 173 m.y., and the Matreier zone ages of 30,

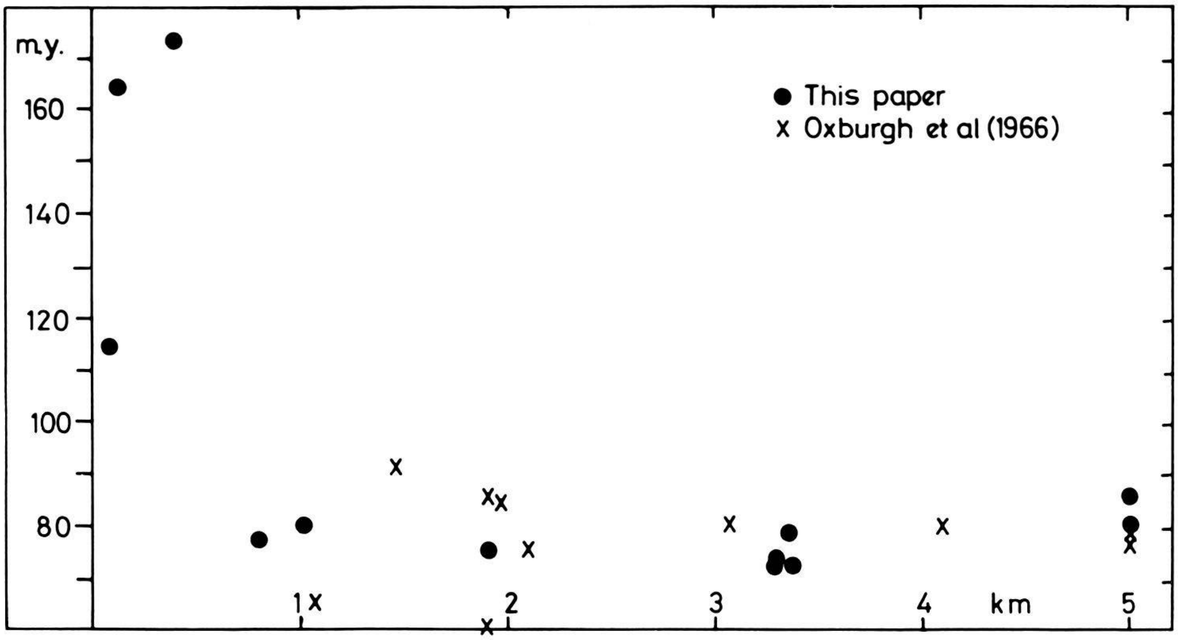

Fig. 2. Mineral ages from the Altkristallin sheet plotted against horizontal distance from its edge. Biotites and muscovites are not distinguished, but in the Döllach area there are no systematic differences between their apparent ages.

42 and 135 m.y. create as yet inexplicable problems. The four 100+ m.y. ages are from low-K muscovites of a variety of grain sizes in rocks of two distinct lithologies. The low K values are not exceptional in this group, however, and are typical of phengitic muscovites from low-grade rocks. Such micas usually have low occupancy of the interlayer site, and high Na and high Fe contents, leading to low weight percentages of K. Although no-one has suggested an actual case of excess argon in muscovite, it is the author's preferred solution at the moment, as the geological setting is certainly one in which high argon pressures might have been created. There is no obvious alternative to this conclusion. The apparent age of the Matreier zone marble is near the Jurassic-Cretaceous boundary, an unlikely age for metamorphism of part of a sedimentary series which is believed to extend well into the Cretaceous. It is equally difficult to see how genuine high ages in the phyllonites could be preserved while the thrust sheet itself above was being outgassed. In any case, the phyllonite is only found along the edge of the thrust sheet (Exner, 1962) and minerals in it were presumably formed or recrystallised at the time of thrusting 78 m.y. ago.

The relationship of the Window to the Altkristallin

In Oxburgh et al. (1966), two possible explanations of the curious age pattern of this district were advanced:

(a) that warm Tauern rocks rose vertically against cool Altkristallin rocks about 20 m.y. ago; or

(b) that cool Altkristallin rocks were thrust over warm Tauern rocks a little earlier than 20 m.y. ago, followed by some uplift of the area, to cool the Tauern rocks and freeze the ages.

The disparity of cooling ages between the Obervellach and Döllach districts, conclusion (2) above, seems to rule out the second of the preceding suggestions and modifies the first to read as conclusion (5) of this paper:

(5) that warm Tauern rocks rose vertically against cool Altkristallin rocks about 30 m.y. ago in the western part of the Sonnblick massif, and at about 20 m.y. ago in the Hochalm massif.

Given this conclusion, the question of the excess argon can be considered further. If the phyllonite zone came into existence at least 78 m.y. ago during the thrusting and outgassing of the presumed passive Altkristallin block above, it is reasonable to suggest that the biotite-grade metamorphism of the phyllonites and Schieferhülle also occurred at that time. From then until 35 m.y. ago we have no record of any events in this area, but from 35 m.y. to about 27 m.y. uplift and cooling of the Sonnblick massif occurred, with closure of mica argon systems. Thus, for some 50 m.y. argon was being steadily expelled from the Zentralgneis, the Schieferhülle and the Matreier zone, presumably migrating upwards. If volatiles escaping from the warm complex beneath became trapped by the cool Altkristallin sheet at their mutual interface, it is not too difficult to imagine high argon pressures arising, leading to high argon contents of the muscovites immediately prior to their "freezing" at about 30 m.y. ago.

It is unfortunate that time did not permit of separation of the scarce biotite from the phyllonites and its analysis before publication of this paper, to test this possibility further. However, such analyses will be made and reported together with other analyses from very closed spaced sampling localities across this geological boundary at other places along its length. Another problem which requires pursuit is the unity and history of the Altkristallin sheet, in view of the differences between the data in this paper and that from supposedly similar tectonic units further east (FLÜGEL, 1964) and further west (SCHMIDT et al., 1967; MILLER et al., 1967 and HARRE et al., 1968). The coincidence, however, of the Rb-Sr mineral ages of 80 m.y. from the Schneeberger Zug (SCHMIDT et al., 1967), the Rb-Sr mineral age of 77 m.y. from the Brenner Mesozoikum (MILLER et al., 1967, $Rb^{87}\lambda = 1.47 \cdot 10^{-11}y^{-1}$) with the potassium-argon ages from the Altkristallin discussed above confirm the importance of the 78–80 m.y. event in the Alps.

The author wishes to acknowledge, with many thanks, the work of J. SIMONS and R. GOODWIN, who provided all the analyses, and discussion with E. R. OXBURGH and M. J. BREWER on these and allied problems. He is particularly indebted to M. J. BREWER for discussions on the question of excess argon, on which BREWER has extensive unpublished data from analyses of Altkristallin rocks further east.[1])

APPENDIX

Localities and descriptions of analysed samples.

Zentralgneis and Schieferhülle of the Tauern Window, Döllach area.

3062. Zentralgneis outcrop south-west of Schralkaser, Gr. Zirknitztal, immediately by house, approximately 5.5 km north-east of Döllach.

Biotite-granodiorite-gneiss with corroded remnants of orthoclase-microperthite and oligoclase (1.5 mm) in a banded base of 0.2 mm quartz and 0.05 mm albite-microcline-quartz-chlorite-muscovite-

[1]) Meanwhile, the data on excess argon in micas referred to has been published (BREWER, 1969).

epidote. 10% biotite occurs in 0.5 mm grains arranged in elongate clusters. Plagioclase is full of muscovite and epidote. Biotite is partly or totally chloritised adjacent to microcrystalline areas.

3063. Zentralgneis in "Gneiss Lamella No. 1" at 2100 m., Gr. Zirknitztal, 0.6 km northwest of Schralkaser.

Polymetamorphic schistose gneiss, rich in muscovite and quartz (1 mm and smaller). Porphyroblasts of 1 mm untwinned microcline are developing in quartz-rich bands, and contain resorbed muscovite and garnet. Biotite, epidote and calcite occur in significant quantity, with accessory sphene, apatite and oxide.

3036. Muscovite-quartzite of Schieferhülle; upper part of new cliff exposure, as last.

A quartzite with 0.1 mm granular quartz partly in equilibrium texture, with 5% muscovite up to 0.2 × 0.02 mm lying in two principal schistosity planes intersecting at 30°; there is considerable evidence that one schistosity is developing at the expense of the other. Accessory calcite, epidote and tourmaline.

3056. Calc-phyllite of Schieferhülle, 1180 m, on road from Döllach to Zirknitz, 0.6 km north of Döllach village centre.

A fissile muscovite-chlorite-calcite-quartz schist, with one schistosity plane. Muscovite not deformed, in flakes 0.3 × 0.02 mm.

3058. Impure marble in Schieferhülle, on roadside 200 m northwest of Rasthaus Schoneck, Glocknerstrasse.

Calcite (0.5 mm) 60%, quartz 30%, muscovite (0.8 × 0.1 mm) 10% with accessory oxide and graphite: schistosity weak-wide range of orientations of muscovite.

Unterostalpin of Matreier zone

3037. Black "slate", south side of path, 450 m southeast of Berchtold, Gradenbach, 3.1 km west-north-west of Döllach.

80% calcite and quartz (0.5 mm) with laminae of muscovite, chlorite and graphite, maximum size 0.1 × 0.01 mm.

3038. Impure marble, south side of path, 400 m south-south-east of Berchtold, Gradenbach. 3.2 km west-north-west of Döllach and 700 m within Tauern Window.

An 0.5 aggregate of 75% calcite, 20% quartz and 5% muscovite, with graphite, oxide and sphene.

3054. Muscovite-quartzite, at 2040 m, 0.7 km south-east of Mohar Kreuz, east of Sagritz.

20% muscovite (0.2 mm maximum length) lying in marked shear zones, but within these zones, disorientated. 20% 2 mm porphyroblasts of calcite in one band of the rock. Remainder of quartz with lesser microcline and traces of chlorite and oxide. The quartz is of a wide range of grain sizes and shows sign of intense deformation.

Altkristallin

3042. Muscovite-biotite-gneiss, 2140 m on eastern corner of ridge 0.4 km east of Gartlkopf, west-south-west of Döllach.

Of metasedimentary type: quartz 70%, biotite and muscovite 15% and a few resorbed garnets, with chlorite-muscovite reaction borders. Quartz highly strained, with curved strain-lamellae.

3043. Muscovite-biotite-gneiss, 1880 m. in Gartlbach 1.1 km south-east of Gartlkopf.

Similar to 3042, but cataclasis of quartz developing and garnet pseudomorphed by chlorite; accessory oxide and epidote.

3044. Phyllonite, at 1380 m, about 800 m south of Ranach, Gartlbach, and 1.4 km south-west of Döllach.

A muscovite-biotite-quartz-microcline-epidote-schist, with about 70% quartz. Muscovite generally in one schistosity plane, maximum grain size 0.1 × 0.01 mm but about 1% of the muscovite occurs as 0.3 mm porphyroblasts growing oblique to the schistosity.

3045. Muscovite-gneiss, 1490 m in Gradenbach, 300 m. north-east of point where the Nossberger Weg crosses stream, 4.6 km west-north-west of Döllach.

Of metasedimentary type: 50% quartz, 30% muscovite (up to 1 mm), 15% biotite and 5% garnet altering to chlorite and biotite: accessory oxide and apatite. Texture complex—a pronounced strain-slip cleavage is present, earlier than the alteration of the garnets.

3046. Muscovite-biotite-gneiss, 1580 m in Wangenitztal, 100 m west of bridge at 1540 m, 6.0 km south-west of Döllach.

15% of 1 mm muscovite and 2% 0.5 mm biotite, well-oriented in one schistosity plane, are set in a granular groundmass of 0.3 mm quartz, microcline and oligoclase. Resorbed garnets occur rarely; also subhedral 2 mm porphyroblasts of microline. The texture clearly demonstrates multi-stage metamorphism, but the micas do not differ in mode of occurrence from one another.

3049. Mica-schist, 700 m east fot the water-mill at 1430 m in Wangenitztal, 4.5 km at 192° from Döllach.

A typical muscovite-biotite-garnet-oligoclase-quartz schist of medium-grade type. Muscovite and biotite each form about 15% of the rock and occur as 1–2 mm flakes in a multi-schistose pattern. No chloritisation of either biotite or garnet.

3053. Phyllonite, at 1700 m on path to Mohar Kreuz from Sagritz, 2.6 km south-east of Döllach.

Originally very like 3049, this rock contains 30% muscovite and 10% chlorite in a quartz-rich groundmass, with remains of chloritised garnets. Of the muscovite, 20% is in the form of bent 1 mm crystals residual from the previous history of the rock, but 80% is in 0.1 × 0.01 mm flakes, clustering around the primary muscovite, or associated with chlorite of similar habit (replacing biotite), or distributed irregularly through the 0.1 mm quartz groundmass. No biotite is preserved.

3055. Phyllonite, at 1960 m on Mohar Kreuz, 200 m north of top of "Material-Bahn" on path to Sagritz, 3.2 km south-east of Döllach.

A multiple schistosity rock containing 0.5 mm crystals of muscovite, biotite and chlorite, all equally defining the schistosities, and showing no signs of mutual replacement. The biotite is orange-brown and forms about 2% of the rock: chlorite is colourless and forms 5%, while muscovite forms about 15% of the rock. Quartz is present in a wide range of grain sizes, showing signs of severe deformation. Microcline occurs as a lesser component of the quartz-rich groundmass, and as porphyroblasts to 1 mm. Garnets form about 1% of the rock, being 0.25 mm across and ranging in shape from euhedral to anhedral.

3059. Biotite-gneiss, at 1300 m on new road, 200 m north-west of Klabisch, 5.7 km south-south-east of Döllach.

A biotite-garnet-quartz-oligoclase gneiss with traces of muscovite and oxide. The biotite is generally irregular and rounded, but forms some 20% of the rock. Garnet, forming less than 1% of the rocks, is resorbed and clearly unstable.

3061. Muscovite-biotite-gneiss, at 1130 m, lowest exposure on new road from Mortschach to Klabisch, 500 m west of Klabisch and 5.5 km south-south-east of Döllach.

A muscovite-biotite-garnet-microcline-oligoclase-quartz gneiss with most of the biotite pseudomorphed by chlorite.

Features of the petrography of the five rocks containing muscovites with anomalously high ages

The Matreier zone rocks 3038 and 3054 are in no way exceptional. 3038 is a normal marble with every appearance of a single progressive metamorphism, the muscovite being confined to, and lying within, thin parting planes. 3054 has suffered more apparent deformation, resulting in segregation of minerals into bands, but there is no suggestion of anything unusual. The muscovite seems to be all of the same generation.

The Altkristallin phyllonite rocks are more varied. 3053 and 3055 may represent partially-retrogressed garnet-mica schists of different bulk chemical composition. Apart from the variation in garnet habit in 3055, it shows little sign of chemical disequilibrium, but 3053 is clearly in a disequilibrium state, particularly in so far as it contains two generations of muscovite. 3044 is chemically close to 3055, but has the appearance of a mono-metamorphic muscovite-chlorite schist.

There are, therefore, no common or general features of these rocks as far as the white mica is concerned, except that all occur within 750 m horizontally (and therefore about 600 m structurally) from the edge of the Tauern Window.

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