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Distribution of pre-Alpine and Alpine Metamorphism of the Southern Ötztal Mass and the Scarl Unit, based on K/Ar Age Determinations

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With 6 Figures, 3 Tables and 1 Plate

Content

1) The Alpine Metamorphism of the Permoscythian

a) Geology

The following study is mainly concerned with Permoscythian rocks of the Central Alps, in particular with the area of the Mauls – Penser Joch, the Engadine Dolomites and the Jaggl-window as well as with Lower Austroalpine lenses north of Sterzing and south of Steinach/Brenner, respectively.

The detailed field work by H. ALBER (details not published; see "Geologischer Tiefbau der Ostalpen", Jahresbericht 1976) shows that the Permomesozoic series of the Mauls – Penser Joch, some tens of m in thickness, consist of a strongly compressed, steep syncline which is folded deeply into the crystalline basement. Lithologically, one can distinguish a clastic, coarse- to medium-grained lower part with numerous layers of quartz-conglomerates and just a few pelitic beds and a higher part which constists mainly of fine-grained metapelites. Clastic porphyroid components appear to occur frequently within the upper part of the coarse-clastic sequence.

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Concerning the structures, one can trace, on principle, two different directions of B-axes along the entire extension of the Permomesozoic of the Mauls – Penser Joch, which can also be partly observed in the neighbouring crystalline rocks: older, steeply plunging (0–40°) B-axes and, parallel to these structures, mineral elongations and an elongation of detrital components. A second, younger group is characterized by microfolds and lineations; it dips to the west with a flat-to-steep angle, and with a large variation in dip values.

During the folding process of this Permomesozoic sequence the underlying crystalline rocks were, in part, intensely phyllonitized and mylonitized.

The structure of the basal part ("Unterbau") of the Engadine Dolomites in the area of Sta. Maria / Ofen Pass is controlled by a large updoming of the Verrucano ("Münstertaler Verrucanokuppel"; STAUB 1937, HESS 1953). The geologic situation of the Scarl Unit was already studied in detail by SPITZ & DYHRENFURTH (1914), later by HESS (1953), SCHMID (1973), DÖSSEGGER (1974) and others.

The mainly coarse- to medium-grained clastic metasediments of the Münstertaler Verrucano locally attain thicknesses of up to more than 500 m. Within the light-grey/light-green or pink, often strongly foliated metasediments we frequently find violet slate components and, in other cases, quartz pebbles of a few cm in size in conglomeratic layers.

The Permoscythian of the Jaggl (up to 150 m thick) is very similar to the Münstertaler Verrucano in the basal parts. The amount of clastic K-feldspar is remarkable within some beds. Higher up we note a grading of the coarse-clastic metasediments towards finer-grained green schists ("Wechselschichten", RICHTER & ZINKERNAGEL 1975) with a continuously increasing content of carbonate. According to our field investigations, the Jaggl-metasediments form, together with their crystalline basement, the orthogneiss of Plawenn, an eastern continuation of the Rojen window, i. e. a tectonic window of the Scarl Unit within the crystalline rocks of the Ötztal mass (THÖNI 1973).

The investigated Permoscythian rocks of the upper Eisacktal and the Silltal belong to the Lower Austroalpine Unit and form thin lenses, tectonically intercalated between the Austroalpine crystalline mass at the top and the Schieferhülle of the Tauern Window at the base. They consist of light or greenish-white, very fine-grained metaquartzites to quartzite-schists, partly very similar to the "Semmeringquarzit".

b) Petrography and Metamorphism

Thin section analysis has shown that most of the investigated samples consist mainly of quartz and white mica. The feldspar content increases to about 20 vol-% (mainly clastic microcline-perthites in feldspathic metasandstones) only in a few samples of the Jaggl-Permoscythian; in most cases it is far below

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e. Strongly kinked biotite in a paragneiss of the western Ötztal mass. The minerals do not show any secondary alterations (sample T 598); parallel Nic.

f. Retrograde alteration of biotite to chlorite in a micaschist south of Laas (sample T 683). The biotite porphyroblast fringes out along the rims and shows an intense intergrowth with secondarily-formed chlorite; crossed Nic.

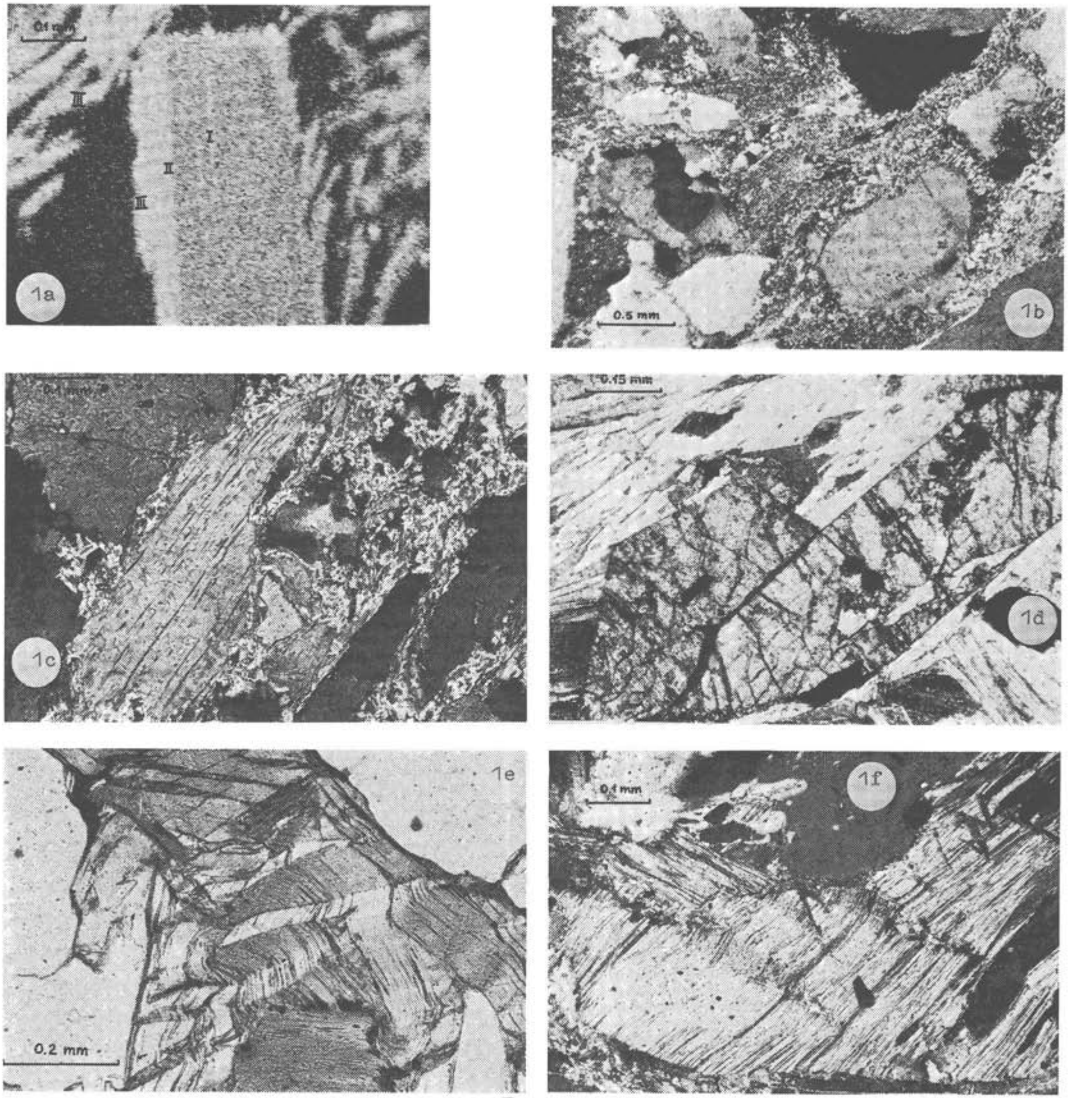


Fig. 1:

a. Element distribution of Fe (FeK_{α}-radiation) in a white mica of an orthogneiss of Plawenn. Dark areas = quartz + feldspar. From the grey central part of the coarse-grained white mica we note a sudden jump to light parts of the rim, with a notable increased Fe-concentration (see analysis, p. 147).

b. Texture of coarse-grained Verrucano of the Jaggl-area (sample No. WAP 292, see Fig. 5) with coarse quartz components and fine-grained cement of quartz and newly-formed muscovite; crossed Nic.

c. Newly-formed fine-grained phengite along the rims of coarse-flaky pre-Alpine white mica as well as intergranular in a strongly tectonized orthogneiss of the Münstertal (sample T 564); crossed Nic.

d. Idiomorphic, cataclastically deformed, non-diaphthoritic staurolite from a mica-rich paragneiss of the western Ötztal crystalline mass (sample T 595, Rojental); parallel Nic.

10 vol-% and some of this is also represented by newly-formed albite. Newly-formed chlorite is present as a minor constituent (2–15%) in approximately 30% of 80 samples investigated; pyrophyllite has been identified in two Verrucano samples of the Münstertal (south of Sta. Maria) by X-ray analysis. Furthermore, in one sample of the Münstertal-Verrucano (T 486), as well as in one specimen of the Penser Joch-Permoscythian, the beginning of biotite-growth was observed.

The metamorphic influence is clearly visible in all the samples investigated; on the other hand, primary sedimentary textures are still very readily recognizable. Within the quartz grains, as well as within the white mica, one may often distinguish coarse-grained detrital components from finer-grained newly-formed or recrystallized parts. Coarse-clastic quartz components often still show undulatory extinction; at the same time, however, a continuous decomposition of large grains to domains of subgrains can be observed. Polygonization within quartz-fabrics with a pronounced intergranular interfingering of the subgrains is frequent in quartzitic layers which are poor in phyllosilicates. Finer detrital quartz components begin to recrystallize in small intergranular wedges or at the boundary-contact of coarse grains. Distinct fine-grained polygonal quartz-textures without undulatory extinction of the single grains and showing typical large-angle grain-boundaries and smooth intergranular contacts are restricted to parts of very fine-grained matrix. Coarse quartz pebbles often show spine-like indentations of fine-flaky, newly-formed white mica. The average grain size of the newly-formed potassic white micas is fairly constant 0,02 mm or smaller. The coarse-scaly, obviously detrital white micas often show a rim of recrystallized or newly-formed muscovite/phengite. The fairly frequent occurrence of resorption-tubes in quartz demonstrates that the contamination of the sediments with porphyry material was notable in parts of the Penser Joch-Permoscythian, as well as in the Münstertal/Jaggl-area.

For the separation of the different grain sizes which were to be analysed, 100–200 g of each sample were crushed and then pulverized for 30 sec in an agate grinding-mill. From this still partly coarse-grained powder the grain sizes $< 2\mu$, $2–6\mu$, $6–11\mu$ and, in some cases, even coarser classes were separated by sedimentation in distilled water.

X-ray analyses showed that all investigated samples of the grain size $< 2\mu$ are composed mainly of potassic white mica and, in a smaller amount, of quartz (Tab. 1). With the method of MAXWELL & HOWER (1965) for the qualitative determination of the mica-polymorphs, only the modification 2M could be found in 23 investigated samples ($< 2\mu$). DT-analyses from 29 samples yielded quartz contents between 7 and 12% within the grain size $< 2\mu$. Samples very rich in quartz have not been analysed by this method. Apart from white mica and quartz, the X-ray diffractograms of 60 samples of the same grain size showed small amounts of chlorite (18 samples), pyrophyllite (2), albite (6), K-feldspar (10), calcite and dolomite (1). The K-contents give additional information about the purity of these mica-concentrates.

Electron microprobe analyses of 27 samples (melted glass fragments of the $< 2\mu$-grain size) showed distinctly higher (FeO + MgO)-contents for the white micas of the frequently dark-grey schists of the Penser Joch-area (3–7% FeO, 1,5–4% MgO) than for those of the green/grey-violet metasedi-

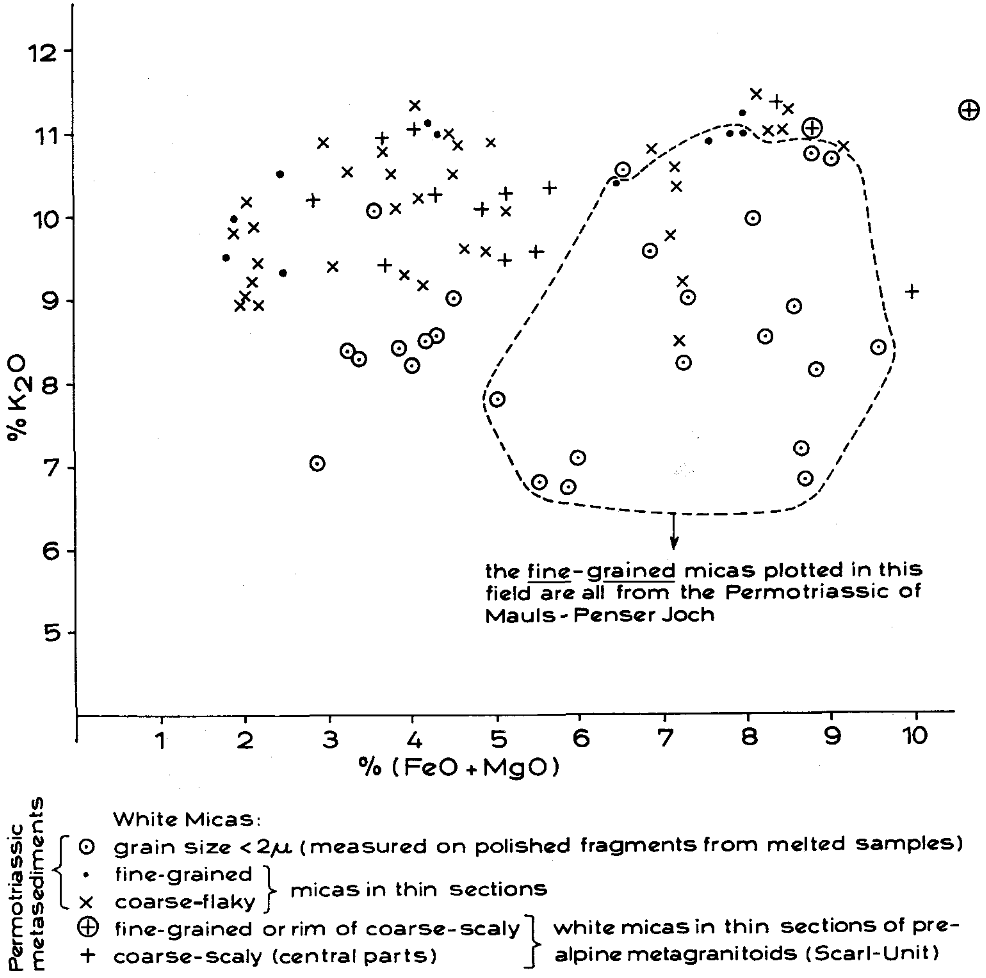


Fig. 2

ments of the Engadine Dolomites and the Upper Vinschgau (1,5–5% FeO, 1–2% MgO; see Fig. 2). It should be emphasized that the absolute (FeO+MgO)-values of the pure white micas are in most cases probably slightly higher than shown in Fig. 2, because of the varied contamination of these mineral concentrates with quartz (and in some cases with small amounts of other minerals).

44 samples (32 of which are from the metasediments of the Scarl Unit) of the $<2\mu$-grain size were analysed with regard to their muscovite/phengite composition; for this a GUINIER de Wolff Camera II was used. If we accept the boundary-line muscovite/phengite by CIPRIANI et al. (1968) at a value of $b_0 = 9{,}025$ Å, 30 out of the 44 samples analysed represent muscovites, but only 14 phengites (Fig. 3). The lattice parameter of a value of 9,025 Å corresponds to a (FeO+MgO)-content of approximately 3,3% (cf. GRAESER & NIGGLI

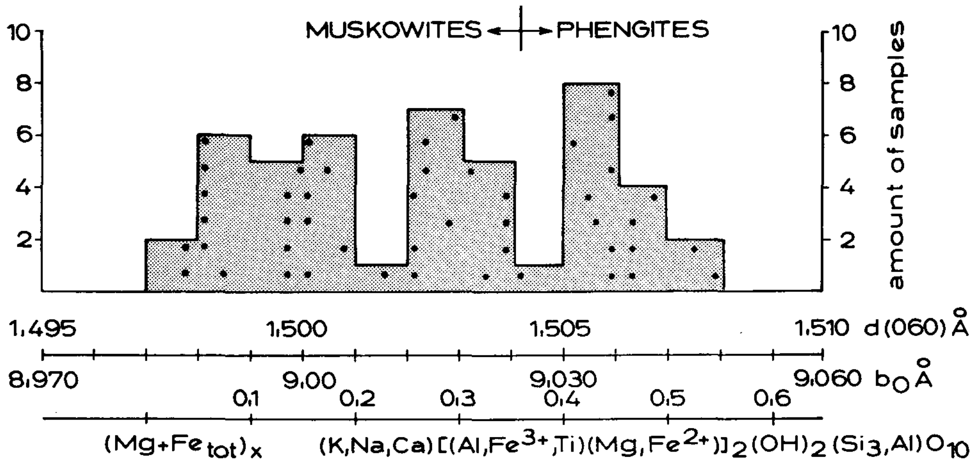


Fig. 3: Histogram showing the white micas formed during Alpine metamorphism in the boundary-field muscovite/phengite (cf. CIPRIANI et al., 1968). All samples belong to the grain size <2μ from Permoscythian rocks (mainly Scarl Unit). Analysing method: GUINIER Camera, FeKα-radiation.

1966). As it is not possible to distinguish between FeO and Fe_2O_3 by this method, it is therefore not possible to calculate the amount of ferrimuscovite within the analysed micas. The first determinations of FeO/Fe_2O_3-ratios in 7 samples of the Münstertal show Fe_2O_3-contents between 30 and 70% in Fe_{tot} (method after WILSON 1955). So a notable proportion of Fe^{3+} is confirmed at least for the pink-violet metasediments of the Scarl Unit. Direct proof of the presence of other Fe-minerals (hematite!) which could considerably vitiate the values of the newly-formed white micas under study, could not be supplied by X-ray or GUINIER Camera techniques. Mineralogical and petrographic investigations of the material under discussion will be continued.

We can summarize as follows. Phengite is less frequent in the Münstertal than in the Jaggl-area but here and there this mineral occurs in fine-grained, green (but chlorite-free) schists with only small contents of coarse-detrital components. In the Münstertal Permoscythian the paragenesis quartz + muscovite + chlorite is more widespread than the paragenesis quartz + phengite (cf. also Tab. 1). Within the greenish-grey/dark-grey schists of the Penser Joch Permoscythian on the other hand, phengite is widespread. In all the samples investigated phengitic composition of the white micas is thus combined with a special lithology. This supports the argument that the bulk chemistry of the rock was most probably the decisive factor, whether phengite or muscovite was formed (but bulk chemistry analyses were not carried out). Since, in the Jaggl, and especially in the Penser Joch-metasediments, the phengite contents are markedly higher than in the Münstertal, one may likewise assume, on the other hand, slightly increasing pressure-conditions from west to east (southeast) with probably equal temperatures during metamorphism.

As thin section analysis by microprobe technique has shown, the composition of the coarse-detrital white micas in the Permoscythian rocks varies considerably within a small scale (thin section). Some of these minerals represent phengites, if we accept the boundary-line phengite/muscovite at an Al^{IV}-substitution of 10% by Si (BERAN 1969). These results find a plausible correspondence and explanation in the mica-analyses from the crystalline rocks of the Scarl Unit (Fig. 2; p. 147).

These data do not agree with the results of SASSI (1972, p. 110); this author points out that all newly-formed white micas from this wider Austroalpine area under discussion, in particular also Jaggl and Piz Lat-metasediments) represent phengites; meanwhile the pre-Alpine ones are, without exception, muscovites and thus the product of a metamorphism with fairly low pressures. Furthermore, no marked interruption in the b_0-values between 9,005 Å and 9,025 Å (cf. Fig. 3) could be found. In any case, it is not possible to fix the distribution of Alpine metamorphism in the area investigated only by taking into consideration the occurrence of muscovite and phengite.

c) Geochronological Results from the Permoscythian

The 56 K/Ar values (Tab. 3, No. 1–56) published here were obtained, with a few exceptions, from samples of the grain size $< 2\mu$ of the epimetamorphic Permoscythian of the Central Alps and, in part, of the Northern Calcareous Alps.

In the Engadine Dolomites the data can be classified in two groups. 10 out of 14 values from north of the line Taufers i. M. – Sta. Maria belong to the time interval of 85–95 m.y., three values are higher than 95 m.y., one value is lower than 85 m.y. To the same time interval (84–92 m.y.) belong 10 mica ages of the Jaggl-metasediments. Nine samples of the Permoscythian south of Sta. Maria/Münstertal yielded younger ages, between 74 and 86 m.y. Within the same time interval one sample of the Verrucano of Stilfs may be placed as well as one sample from sericite-phyllites (presumably Verrucano) between Eyrs and Spondinig/Vinschgau (Tab. 3, No. 44), which are tectonically intercalated along the continuation of the Schlinig thrust east of the Upper Vinschgau (THÖNI, 1980a).

The 5 K/Ar values from the basal parts of the Northern Calcareous Alps (Verrucano of Flirsch, Permoscythian north of Arlberg Pass), on the other hand, show an abnormal age distribution between 65 and 91 m.y.

The Permoscythian of the Mauls–Penser Joch yielded Late Alpine ages between 15 and 22 m.y. (12 values). Most of these data were published earlier (see FRANK et al. 1977). Here four more analyses are being added to that group.

Similarily young ages of around 14 m.y. are given by two sericite-quartzites from Lower Austroalpine lenses north of Sterzing; meanwhile, four samples from quartzose schists of the same tectonic unit north of the Brenner Pass yield higher and markedly varying ages between 20 and 32 m.y.

Finally, two ages of 12 m.y. of the westernmost Tauern-Schieferhülle (Sterzing) and one value of 32 m.y. from the "Ladiser Quarzit" near Prutz are listed.

Tab. 1: Mineral composition of the analysed samples from the Phermoscythian (grain size $< 2\mu$; X-ray diagrams)

Sample No.	White mica (muscovite/ phengite)	Quartz (partly DT-analyses)	Albite/ Plagioclase	K-feldspar	Chlorite	Pyrophyllite	Other minerals	% K $< 2\mu$
WAP 274	××	×	+		×			4,88
WAP 275	×××	+	+		+	+		6,25
WAP 276	×××	×(12%)	+		+	×		6,52
WAP 277	×××	×(10,5%)	+		+			6,47
WAP 278	×××	+			+			7,78
WAP 279	×××	×(10,5%)						7,01
WAP 280	×××	×(10,5%)			+			7,09
WAP 281	×××	×(11%)			+			7,45
WAP 282	×××	×(9,5%)			+			6,48
WAP 283	×××	+			+			7,78
WAP 284	×××	+	+		+			7,06
WAP 285	×××	×(10,5%)			+			6,47
WAP 286	×××	×(12%)						6,84
WAP 287	×××	+						7,03
WAP 288	×××	×(9,5%)						7,05
WAP 289	×××	+			+			6,82
WAP 290	×××	×	+	+				7,20
WAP 291	×××	×(12%)		+				7,35
WAP 292	×××	×						7,10
WAP 294	×××	+(7%)						7,99
WAP 295	××	×			+			5,25
WAP 296	×××	×			+			6,96
WAP 297	×××	××						5,35
WAP 298	×××	×		+				7,02
WAP 299	×××	××		+				4,80
WAP 300	×××	×						6,27
WAP 302	×××	×		+				7,72
WAP 304	×××	××						4,90
WAP 307	×××	+						7,95
WAP 308	×××	+						6,86
WAP 309	×××	+						6,79
WAP 311	×××	+						7,45
WAP 312	×××	×		+				5,76
WAP 314	×××	×		+				6,82
WAP 315	×××	×		+				6,05
WAP 316	×××	×		+				5,81
WAP 468	×××	×						5,86
WAP 469	×××	×						6,26
WAP 471	×××	×			××			3,80
WAP 472	×	×			××	calcite + dolomite		2,77
WAP 485	×××	×						6,02
WAP 509	×××	+			××			4,94
WAP 511	×××	+			+			6,94
WAP 534	×××	×						7,44
WAP 537	×××	+						7,61
WAP 547	×××	+						7,75
WAP 548	×××	+						7,20

Symbols: ××× = very high content, ×× = high content, × = low content, + = detected (few %)

2) Alpine Metamorphism of pre-Alpine Crystalline Rocks

a) Crystalline Rocks of the Scarl Unit

a1) Textures

The crystalline basement of the Scarl-metasediments, the Münstertal orthogneisses and the augengneiss of Plawenn respectively, show a selective tectonization and locally varying alteration of their primary pre-Alpine textures by Alpine metamorphism. The biotite-poor orthogneisses of Plawenn, the crystalline basis of the Jaggl-metasediments, generally occur as strongly tectonized augengneiss. Coarse-grained two-mica-metagranites with unoriented metamagmatic textures are distributed in the area of Piz Sesvenna. Strongly foliated augengneisses can be observed, for instance, at the road-outcrops from Fuldera to Lü.

Like the metasediments, the quartz material shows, in part, intense recrystallisation in fine-grained polygonal textures and/or strong intergranular interfingering. The plagioclases are partly unmixed. Remarkable diaphthoresis by chloritization of biotite, preferably along the crystallographic basal faces, was observed in coarse-grained metagranites of the upper Val Sesvenna. The coarse pre-Alpine white micas normally show, particularly in strongly foliated parts, a rim of fine-grained muscovite/phengite (Fig. 1c). Fine-grained white micas also grow within recrystallized quartz. Moreover, in two specially investigated cases, microprobe analyses showed that the cores (Fig. 1a, I) of some coarse-scaly white micas change into a rim with an abruptly enhanced Fe-content and a noticeably lower Al-content (Fig. 1a, II, Tab. 2). These chemical differences are not visible, when the thin sections are analysed microscopically.

	rim	of the mica	core
SiO_2	49,7		49,8
TiO_2	0,39		0,66
Al_2O_3	25,3		30,6
Cr_2O_3	0,01		0,01
FeO (Fe_{tot})	9,1		4,2
MnO	0,05		0,03
MgO	1,37		1,27
CaO	0,05		0,01
Na_2O	0,04		0,4
K_2O	8,80		9,60
Total	94,81		96,64
Cations (11 O)	6,929		6,922
$H_2O\pm$	non det.		non det.

Tab. 2: EMP-analysis of rim and core of the white mica shown in Fig. 1a.

A possible explanation is that these pre-Alpine micas were not changed, either structurally or chemically, in their central parts, during the weak Alpine metamorphism; at the same time, part of the rim-zones were chemically redistributed without changes in their morphology; only the outermost parts (optically recognizable as a fine-scaly heap, cf. Fig. 1c) really recrystallized (Fig. 1a, III).

It should also be pointed out that the (FeO + MgO)-contents of the central parts of these micas reach values which correspond, at the least, to a slightly phengitic composition (cf. p. 145).

a2) K/Ar Mica Ages

Two biotites with small amounts of chlorite from the Sesvenna granitegneisses revealed slightly rejuvenated ages ("Mischalter"); meanwhile one pure biotite still shows a Late Hercynian age of 272,1 ± 8,3 m.y. (Tab. 3, No. 77, 80, 81).

To approximately the same group belong two biotites of the Silvretta crystalline rocks from the tectonic contact zone to the Engadine Window (Tab. 3, No. 78, 79).

Two white micas from strongly tectonized orthogneisses (Tab. 3, No. 58, 59) of the Scarl Unit yielded Hercynian ages.

b) Crystalline Rocks of the Ötztal Mass

b1) Textures

As regards the northwestern part of the Ötztal mass, pre-Alpine textures have hardly changed within the metamorphic rocks. A characteristic feature for this zone is a locally strong (late- to postmetamorphic) tectonization of the textures (partly cataclasis, kinking; see Fig. 1d, e). But it is still unclear whether we are dealing with pre-Alpine or Alpine tectonics. In any case, diaphthoresis, for instance, of staurolite, garnet or biotite are almost entirely lacking. Transverse chlorites, which in some cases most probably represent late, Alpine formations, have however been observed in some areas.

Farther east-southeast in the same tectonic unit we reach a zone which is distinguished by an increasing and partly intense retrograde alteration of the Hercynian mineral parageneses. Chloritization of garnet, alteration of staurolite to sericite, chlorite and chloritoid, and chloritization of biotite (Fig. 1f) are the most remarkable features of this area. Some aspects of the diaphthoritic character of these rocks may be observed macroscopically.

But only far to the southeast, in the "thermal high" of the Schneeberger Zug (Monteneve), partly amphibolite-facies-conditions were reached again during Alpine metamorphism (see results by FRANK, HOINKES, MAURACHER, PURTSCHELLER, next volume) and the entire pre-Alpine mineral parageneses thus recrystallized.

b2) K/Ar Mica Ages

These observations are, in general, clearly reflected in the arrangement of the mineral ages in three different zones (see Plate 1).

In the northwestern part of the Ötztal crystalline rocks white micas, as well as biotites, yield Hercynian ages. Out of 13 analyses, 9 biotites range from 283 to 297 m.y., two samples have values higher than 300 m.y. while, two values are below 280 m.y. The potassic white micas gave ages of between 300 and 315 m.y. (Tab. 3, No. 58–76).

From the "zone of biotite-mixed ages" 9 biotite-concentrates were analysed; these yielded theoretical model ages of between 135 and 245 m.y.

On the other hand, three biotite ages of this zone are much higher than 300 m.y. Obviously, we are dealing here with ^{40}Ar-excess and the numbers of these model ages have no geochronologic meaning (Tab. 3, No. 88–90).

In the southeastern area, the "zone of Alpine biotite cooling ages", 5 biotites yielded ages of between 72,5 and 85,8 m.y.; biotites from the same zone, with varying contaminations of chlorite, gave partly higher ages (Tab. 3, No. 91–98).

A white mica from the northern border of this zone has a strongly rejuvenated age of 173 ± 5,3 m.y. White micas are more resistent to rejuvenation than biotites and show no excess argon (cf. THÖNI 1980a).

3) Degree and Evolution of Alpine Metamorphism in the Area Investigated. Interpretation of the Age Data

The mica ages between (roughly) 75 and 95 m.y. are Upper Cretaceous (Turonian-Middle-Senonian) and reflect, generally speaking, the Early Alpine thermal events within the Permomesozoic sedimentary cover. The thrusting of the Upper Austroalpine rock-pile over the tectonic units of the Central Alps is accepted by many authors as one of the most important factors in the origin of this metamorphism. During this process the isotherms have been updomed, partly as a result of strong tectonic compression: the lower parts of the overthrusting unit were affected, only slightly, by metamorphism.

In principle, the K/Ar mica ages from the basal parts of the Northern Calcareous Alps (Tab. 3, No. 1–5) reflect this event but show an unusually wide distribution. At present no definitive explanation can be given because only a few data are available. In any case, we must probably reckon with late- to postmetamorphic (Tertiary) movements in these strongly tectonized basal parts of the Upper Austroalpine Unit, by means of which local ^{40}Ar-loss and thus rejuvenation of the micas formed during Early Alpine metamorphism could have been partly caused.

The separation into two age-groups in the Engadine Dolomites and in the Jaggl-area is justified. But here too we find single analyses which do not agree very well. Since the southern, younger group shows, on the average, the same values as those which were found for biotites of the southern Ötztal crystalline mass (Schneeberger Zug) by the Rb/Sr-method (SATIR 1975), the explanation that the data under discussion represent cooling ages may be plausible.

Also applying to the northern, older group in the Engadine Dolomites are the data of the Jaggl-metasediments. Whether in this case we are dealing with formation ages, i.e. whether the time of (roughly) 90 ± 5 m.y. represents the peak of the Early Alpine metamorphism in this area, is still unclear but in any case it is a possible explanation. This problem will possibly be solved by using the Rb/Sr-small-scale-isochron-method (unpublished data).

The two relatively high age values from the Val Sesvenna may point to a weakening metamorphism towards the north. This explanation, however, is not

Table 3: K/Ar Age Data of the Analysed Samples

A) White Micas from Permoscythian Rocks (grain size < 2μ)

No.	Lab. No. No. of sample	Sample description Locality	Analysed mineral Grain size	% K	$^{40}Ar_{rad}$ $cm^3 \cdot 10^{-6}$ NTP/g	% rad	Age m.y.	Notes
1	WAP 547 T 740	Sericite-schist 1 km N Arlberg Pass	White mica <2μ	7,75	22,178	95,28	72,1±2,3	sample coll. W. RESCH (Innsbruck)
2	WAP 548 T 741	Sericite-schist 1 km N Arlberg Pass	White mica <2μ	7,20	23,567	92,74	82,3±2,7	
3	WAP 66 V 2	Verrucano near Flirsch/Stanzertal	White mica <2μ	5,03	18,197	66,76	90,7±4,1	sample preparation W. FRANK
4	WAP 67 V 3	Verrucano near Flirsch/Stanzertal	White mica <2μ	5,36	13,784	93,58	65,–±2,1	
5	WAP 69 V 5	Verrucano near Flirsch/Stanzertal	White mica <2μ	7,32	21,02	89,90	72,6±2,4	
6	WAP 388 F 3	Sericite-Qu-schist Ladiser Burgfels/Prutz	White mica <2μ	7,63	9,706	82,25	32,4±1,2	
7	WAP 290 T 514	Coarse-grained Qu-Ser-schist + feldspar Hengst/Jaggl	White mica <2μ	7,20	26,261	86,97	91,5±3,2	
8	WAP 291 T 518	Green fine-grained Qu-Ser-schist Hengst/Jaggl	White mica <2μ	7,35	24,746	86,49	84,6±2,9	
9	WAP 292 T 519	Coarse-grained Verrucano Hengst/Jaggl	White mica <2μ	7,10	25,742	82,68	90,9±3,3	see Fig. 5
10	WAP 292 T 519	»	Total rock	1,822	7,578	27,77	103,9±11,2	
11	WAP 294 T 524	Fine-grained phengite-schist (Scythian) Pleißkopf/S Jaggl	White mica <2μ	7,99	29,063	90,73	91,2±3,–	
12	WAP 294 T 524	»	Total rock	5,15	21,012	74,51	102,–±4,1	
13	WAP 295 T 525	Coarse-grained Verrucano Pleißkopf/S Jaggl	White mica <2μ	5,25	17,52	71,78	83,9±3,5	

14	WAP 300 T 544	Coarse-grained Verrucano E St. Valentin/SW Jaggl	White mica <2μ	6,27	21,365	88,30	85,6±2,9	
15	WAP 302 T 546	Green Verrucano Hengst/Jaggl	White mica <2μ	7,72	24,576	89,15	80,1±2,7	
16	WAP 304 T 549	Coarse-clastic Verrucano Hengst/Jaggl	White mica <2μ	4,90	17,017	72,52	87,2±3,6	
17	WAP 314 T 572	Qu-sericite-schist + K-feldspar Langtaufers/NE Jaggl	White mica <2μ	6,82	24,052	89,26	88,5±3,–	samples from the same outcrop (ca. 2 m²)
18	WAP 315 T 573	»	White mica <2μ	6,05	21,785	84,40	90,3±3,2	
19	WAP 316 T 574	»	White mica <2μ	5,81	20,668	83,80	89,3±3,2	
20	WAP 334 T 727	Dark fine-grained carbonaceous schist 700 m SE Alp Sesvenna	White mica <2μ	7,44	34,627	92,82	115,9±3,7	
21	WAP 537 T 730	Green fine-grained sericite-schist Val Sesvenna/3 km E Scarl	White mica <2μ	7,61	30,192	95,28	99,3±3,1	
22	WAP 307 T 555	Green fine-grained phengite-schist Punt la Drosa	White mica <2μ	7,95	26,88	93,65	85,–±2,7	
23	WAP 308 T 556	Green fine-grained phengite-schist 2 km SW Il Fuorn	White mica <2μ	6,86	24,452	94,07	89,4±2,9	samples from the same outcrop (ca. 1 m²)
24	WAP 309 T 557	»	White mica <2μ	6,79	24,125	93,21	89,1±2,9	
25	WAP 311 T 561	Medium-grained Verrucano Alp Buffalora/ 3 km WNW Ofen Pass	White mica <2μ	7,45	27,226	92,19	91,6±3,–	
26	WAP 284 T 500	Coarse-grained Verrucano Cierfs/Münstertal	White mica <2μ	7,06	26,617	92,92	94,5±3,–	samples from the same outcrop (ca. 10 m²)
27	WAP 285 T 501	Coarse-grained Verrucano Cierfs/Münstertal	White mica <2μ	6,47	25,256	92,71	97,7±3,2	
28	WAP 286 T 502	Fine-grained, green Verrucano 1 km N Cierfs/Münstertal	White mica <2μ	6,84	24,389	88,84	89,5±3,–	
29	WAP 287 T 503	Light-green Verrucano 800 m ESE Cierfs	White mica <2μ	7,03	24,478	90,55	87,4±2,9	samples from the same outcrop (road-outcrop, ca. 3 m²)
30	WAP 288 T 504	Violet coarse-grained Verrucano 800 m ESE Cierfs	White mica <2μ	7,05	24,954	90,20	88,8±3,–	
31	WAP 289 T 505	Violet coarse-grained Verrucano 800 m ESE Cierfs	White mica <2μ	6,82	23,647	84,90	87,1±3,1	

No.	Lab. No. No. of sample	Sample description Locality	Analysed mineral Grain size	% K	$^{40}Ar_{rad}$ $cm^3 \cdot 10^{-6}$ NTP/g	% rad	Age m.y.	Notes
32	WAP 511 T 702	Medium-grained Verrucano Prasüras/WNW Valcava, Münstertal	White mica $<2\mu$	6,94	23,442	92,17	84,6 ± 2,8	
33	WAP 274 T 481	Red-violet clastic Permoscythian Road to Umbrail Pass/ S Sta Maria, m 1860	White mica $<2\mu$	4,88	15,066	83,01	77,7 ± 2,8	5 samples of an outcrop of ca. 50 m^2
34	WAP 275 T 483	„	White mica $<2\mu$	6,25	18,271	58,63	73,7 ± 3,8	
35	WAP 276 T 484	„	White mica $<2\mu$	6,52	21,0587	82,86	81,2 ± 2,9	
36	WAP 277 T 485	„	White mica $<2\mu$	6,47	20,897	86,39	81,2 ± 2,8	
37	WAP 278 T 486	„	White mica $<2\mu$	7,78	23,29	83,10	75,4 ± 2,7	
38	WAP 279 T 491	Folded Qu-sericite-schist with coarse Qu-pebbles Road to Umbrail Pass/ S Sta Maria, at Hotel "Alpenrose"	White mica $<2\mu$	7,01	24,163	82,51	86,5 ± 3,1	5 samples from the same outcrop of ca. 100 m^2 probably later tectonic overprinting
39	WAP 280 T 493	„	White mica $<2\mu$	7,09	23,612	87,98	83,7 ± 2,9	
40	WAP 281 T 494	„	White mica $<2\mu$	7,45	22,924	86,54	77,5 ± 2,7	
41	WAP 282 T 495	„	White mica $<2\mu$	6,48	23,759	88,91	91,9 ± 3,1	
42	WAP 283 T 496	„	White mica $<2\mu$	7,78	24,611	87,39	79,6 ± 2,7	
43	WAP 312 T 567	Green Verrucano Avigna-Tal/N Taufers i. M.	White mica $<2\mu$	5,76	16,84	64,28	73,7 ± 3,4	
44	WAP 509 T 700	Mus-Chl-schist near Stilfs	White mica $<2\mu$	4,94	16,25	74,59	82,7 ± 3,3	
45	WAP 485 T 658	Sericite-phyllite between Spondinig and Eyrs/ Vinschgau (road-outcrop)	White mica $<2\mu$	6,02	18,934	70,32	79,1 ± 3,4	Stratigraphic position problematic (? Verrucano)

46	WAP 296 T 536	Greenish fine-grained quartzitic schist Road-outcrop N Nößlacher Joch	White mica <2µ	6,96	8,789	54,59	32,2±1,8	4 samples from the same outcrop (ca. 100 m^2) Lower Austro-alpine Unit
47	WAP 297 T 537	»	White mica <2µ	5,35	4,824	47,22	23,–±1,5	
48	WAP 298 T 538	»	White mica <2µ	7,02	5,577	42,96	20,3±1,4	
49	WAP 299 T 539	»	White mica <2µ	4,80	4,837	46,46	25,7±1,7	
50	WAP 468 T 607	Sericite-quartzite ca. 700 m N Sterzing (road-outcrop)	White mica <2µ	5,86	3,085	24,52	13,5±1,65	Lower Austro-alpine Unit (?) Permoscythian
51	WAP 469 T 608	»	White mica <2µ	6,26	3,555	46,92	14,5±0,9	
52	WAP 471 T 610	Dark-grey, slightly carbonaceous phylllite Railway station Sterzing	White mica <2µ	3,80	1,773	47,126	12,–±0,8	Penninic rocks of the Schieferhülle
53	WAP 472 T 611	Dark Chl-Mus-schist Railway station Sterzing	White mica <2µ	2,77	1,261	29,29	11,7±1,2	
54	WAP 243 A 419	Grey phengite-schist Brennerstraße E Welfenstein	White mica <2µ	8,03	5,288	61,92	16,9±0,8	Samples from the Permoscythian of Mauls — Penser Joch
55	WAP 244 A 420	Grey phengite-quartzite Brennerstraße E Welfenstein	White mica <2µ	6,70	4,511	56,78	17,2±0,9	
56	WAP 224 A 338	Grey-green quartzitic schist Maulser Berg, E Brennerstraße	White mica <2µ	7,02	5,271	61,67	19,2±0,9	(for other data see FRANK et al. 1977)
57	WAP 271 A 353	Green phengite-quartzite ENE Rötenspitze	White mica <2µ	3,65	5,219	50,02	36,4±2,2	

B) Minerals from pre-Alpine Crystalline Rocks

58	WAP 564 T 562	Strongly foliated muscovite-granite-gneiss Road to Lü/Münstertal	White mica 0,45—0,15 mm	9,08	115,192	97,29	299,9±9,2	
59	WAP 460 T 591	Muscovite-granite-gneiss Plawenn	White mica 0,45—0,15	8,65	113,156	98,68	308,5±9,4	
60	WAP 293 T 520	Muscovite-metagranite 1 km E Jaggl	White mica 0,43—0,25	8,60	114,303	97,94	313,1±9,6	

No.	Lab. No. No. of sample	Sample description Locality	Analysed mineral Grain size	% K	$^{40}Ar_{rad}$ $cm^3 \cdot 10^{-6}$ NTP/g	% rad	Age m.y.	Notes
61	WAP 461 T 592	Biotite-plagioclase-gneiss Langtaufers/Laröth	White mica 0,45—0,15	8,09	107,106	98,93	311,9±9,5	
62	WAP 467 T 602	Staurolite-gneiss Langtaufers/Freibrunn	White mica 0,45—0,15	7,49	99,057	93,15	311,6±10,–	
63	WAP 494 T 667	Paragneiss + Chl 1,5 km NNE Obergurgl	White mica >0,15	6,71	47,342	97,25	172,9±5,3	
64	WAP 483 T 656	"Gneissphyllite" near St. Anton/Arlberg	Biotite + chlorite 0,43—0,15	4,29	51,659	97,21	285,8±8,8	
65	WAP 497 T 672	Fine-grained paragneiss 1 km NW Ötz	Biotite 0,45—0,15	7,21	86,299	98,60	284,2±8,6	
66	WAP 476 T 633	Biotite-plagioclase-gneiss near Mittelberg/Pitztal	Biotite 0,45—0,15	7,04	83,85	98,45	283,–±8,6	
67	WAP 451 T 576	Tonalitic gneiss In Pedroß/NE Reschen	Biotite >0,15	7,94	102,498	98,66	304,8±9,3	
68	WAP 472 T 577	Paragneiss Langtaufers/1 km N Kaproner Alm	Biotite 0,45—0,15	6,62	82,247	99,02	294,2±8,9	
69	WAP 453 T 578	»	Biotite 0,45—0,15	6,58	75,92	99,40	274,8±8,3	sample slightly weathered
70	WAP 455 T 581	Biotite-plagioclase-gneiss Langtaufers/Rossell	Biotite 0,45—0,15	6,41	77,448	98,74	286,7±8,7	
71	WAP 461 T 592	Biotite-plagioclase-gneiss Langtaufers/Laröth	Biotite 0,45—0,15	6,99	87,806	98,91	297,2±9,–	see No. 61
72	WAP 462 T 593	2-mica-paragneiss Rojen/Grion Tal	Biotite 0,45—0,15	7,20	87,724	99,38	289,–±8,7	
73	WAP 463 T 595	Biotite-micaschist Hinterrojen/Fallung	Biotite 0,45—0,15	7,16	94,251	99,26	310,3±9,4	
74	WAP 465 T 600	Biotite-gneiss Langtaufers/Valbanair	Biotite 0,45—0,15	6,99	84,641	99,08	287,3±8,7	
75	WAP 466 T 601	Staurolite-micaschist Langtaufers/Weißkugelmoräne	Biotite 0,45—0,15	6,92	80,342	97,87	276,3±8,5	sample slightly weathered

76	WAP 467 T 602	Staurolite-gneiss Langtaufers/Freibrunn	Biotite 0,45—0,15	7,50	94,342	99,04	297,6±9,–	see No. 62
77	WAP 473 T 612	Biotite-granite-gneiss Avignatal/N Taufers i. M.	Biotite 0,45—0,15	6,82	77,858	98,79	272,1±8,3	
78	WAP 479 T 647	Fine-grained paragneiss Fimbertal/Steinige Bleis	Biotite 0,45—0,15	7,70	52,652	94,65	167,8±5,3	
79	WAP 541 T 734	Paragneiss between Giarscun and Lavin/ Unterengadin	Biotite (+ chlorite) 0,43—0,15	5,88	41,363	97,52	172,4±5,3	
80	WAP 474 T 613	Fine-grained biotite-gneiss Avignatal/N Taufers i. M.	Biotite 0,45—0,15	5,86	54,153	97,61	223,3±6,9	
81	WAP 538 T 731	Meta-granite Val Sesvenna	Biotite + chlorite	5,05	47,342	98,32	226,3±6,9	
82	WAP 459 T 590	Fine-grained paragneiss Road to Matsch	Biotite 0,45—0,15	6,13	51,775	98,19	205,1±6,3	
83	WAP 496 T 669	Augengneiss 5 km S Umhausen/Ötztal	Biotite >0,15	6,94	37,677	97,06	134,5±4,2	
84	WAP 543 T 736	Biotite-micaschist Matsch/Kartatsch	Biotite 0,45—0,15	5,95	47,78	95,35	195,6±6,2	
85	WAP 506 T 684	Micaschist Laaser Tal/near Angelus Ferner	Biotite 0,43—0,074	6,37	61,307	88,08	232,–±7,9	
86	WAP 487 T 661	Biotite-micaschist Allitzer Alm/Strimmtal N Laas	Biotite >0,15	6,48	66,235	97,08	245,4±7,6	
87	WAP 495 T 668	Biotite-plagioclase-gneiss 1,5 km NW Zwieselstein/Ötztal	Biotite + chlorite 0,43—0,15	5,12	35,339	96,07	169,1±5,3	
88	WAP 478 T 635	Biotiteporphyroblast-gneiss Hintere Matscher Alm via Salurnspitz	Biotite 0,45—0,15	7,13	257,42	98,23	749,1±22,9	^{40}Ar-excess
89	WAP 477 T 634	Biotite-plagioclase-gneiss Hintere Matscher Alm	Biotite (+ chlorite) 0,43—0,15	5,83	91,046	97,24	362,7±11,2	^{40}Ar-excess
90	WAP 513 T 704	Paragneiss Graue Wand N Kurzras/Schnals	Biotite 0,45—0,15	6,99	143,1	98,01	462,–±14,1	^{40}Ar-excess
91	WAP 522 T 715	Paragneiss 3,5 km NE Talstation Stubaier Gletscherbahn/Stubaital	Biotite (+ chlorite) 0,43—0,15	5,01	18,91	79,25	94,6±3,6	

No.	Lab. No. No. of sample	Sample description Locality	Analysed mineral Grain size	% K	$^{40}Ar_{rad}$ $cm^3 \cdot 10^{-6}$ NTP/g	% rad	Age m.y.	Notes
92	WAP 494 T 667	Paragneiss + Chl 1,5 km NNE Obergurgl	Biotite (+ chlorite) >0,15	5,32	19,026	86,95	89,7±3,1	see No. 63
93	WAP 519 T 711	Mica-rich paragneiss Oberhaushof N Goldrain Vinschgauer Sonnenberg	Biotite 0,43—0,15	6,92	23,634	95,36	85,8±2,7	
94	WAP 489 T 662	Biotite-granite-gneiss Burgfelsen Kastelbell/Vinschgau	Biotite >0,15	7,02	21,236	76,64	76,1±3,–	
95	WAP 491 T 664	Fine-grained paragneiss + Chl 300 m W Naturns/Vinschgau	Biotite + chlorite 0,43—0,15	5,51	30,394	94,52	136,6±4,3	
96	WAP 492 T 665	Garnet-micaschist ca. 4 km N Moos/Passeier Timmelsjochstraße	Biotite >0,15	7,32	21,693	95,72	74,7±2,3	
97	WAP 524 T 717	2-mica-paragneiss + Chl Töll/Meran (Staatsstraße)	Biotite + chlorite 0,43—0,15	4,01	11,908	79,53	74,8±2,8	
98	WAP 523 T 716	Mica-rich paragneiss St. Leonhard/Passeier	Biotite 0,43—0,15	7,42	23,119	95,28	78,4±2,7	

For methodical data and analysis technique see FRANK et al., 1977, p. 2.

Calculation values used:

$\lambda^{40}K_{\beta^-} = 4,962 \times 10^{-10} y^{-1}$

$\lambda^{40}K_{e\,1+2} = 0,581 \times 10^{-10} y^{-1}$

$^{40}K = 0,01167$ K; atomic percent

$^{40}Ar/^{36}Ar_{air} = 295,5$

$$\text{error} = \pm \frac{\text{age} \times 3}{\%\ \text{rad}}$$

very evident as in the southern part of the Silvretta crystalline mass we still find ^{40}Ar-loss in biotites (Plate 1; cf. also GRAUERT 1969); thus we can expect a similar intensive Alpine metamorphism in the southern Silvretta as in the crystalline rocks of the Scarl Unit. On the other hand, it is not clear whether this biotite rejuvenation in the vicinity of the Engadine Window and of the late structure of the Engadine Lineament has its origin in Cretaceous or in Tertiary tectonic/metamorphic events. Of course, the metamorphic evolution of the Engadine Window cannot be interpreted at the moment on the basis of only one age value (Tab. 3, No. 6). Considering the Alpine metamorphic zonation south and north of the Engadine Lineament, we have to reckon not only with the lateral movement, but also with considerable vertical displacements of the two areas.

A more plausible explanation at the time for the two values mentioned (Tab. 3, No. 20, 21) would be a weakening metamorphism from bottom to top of the rock pile. Still higher age values should be found in higher stratigraphic/tectonic levels, if this interpretation is suitable.

No evident explanation could be found for single non-fitting points, without conducting protracted control-analyses (Tab. 3, No. 15, 41, 43).

It has been repeatedly shown that the contamination of the grain size $<2\mu$ by detrital material (such as detrital muscovite, K-feldspar) must be slight, using the described separation-method, and that the falsification of the true metamorphic ages of the Alpine micas is therefore insignificant and most probably is within the limits of error. Normally samples with no or only small amounts of detrital micas have been selected for the separation of the different grain sizes. The effect of pulverization of coarse-detrital components was reduced further by using only a short time (30 sec) for the grinding of the crushed samples.

In some cases, however, samples with considerable amounts of detrital mica have been taken for this purpose. Analyses of different samples from the same outcrop show that the ^{40}Ar-loss during metamorphism was fairly perfect in the cm-m-scale. The samples No. 17–19 (Tab. 3), for example, were collected within an area of 2 square metres. The K/Ar age values of the $<2\mu$-grain size of these samples range, within the limits of error, between 88,5 and 90,3 m.y. All three samples show detrital white mica and K-feldspar contents of 5–10% (thin section). The X-ray diagrams of the dated samples still show small amounts of K-feldspar. The three age values are not only concordant with each other but also show a good fit with those of other samples of the wider area, which are composed only of quartz and white mica and the thin sections of which show fine-grained textures only of newly-formed phengite and quartz (Tab. 3, No. 11, 23, 24).

In order to check the influence of detrital components for this dating method, a coarse-grained Verrucano from the Jaggl-area was intentionally treated in the manner described and four different grain sizes and the total of this rock sample were analysed (Fig. 5, Fig. 1b). The samples yielded a K/Ar-isochron of 87,7 ± 2,5 m.y. The grain size $<2\mu$ of this sample has a model age of 90,9 ± 3,3 m.y. and thus the two values overlap still within the limits of error. The relatively small amount of inherited ^{40}Ar of 1,45 $cm^3 \times 10^{-6}$ for white micas

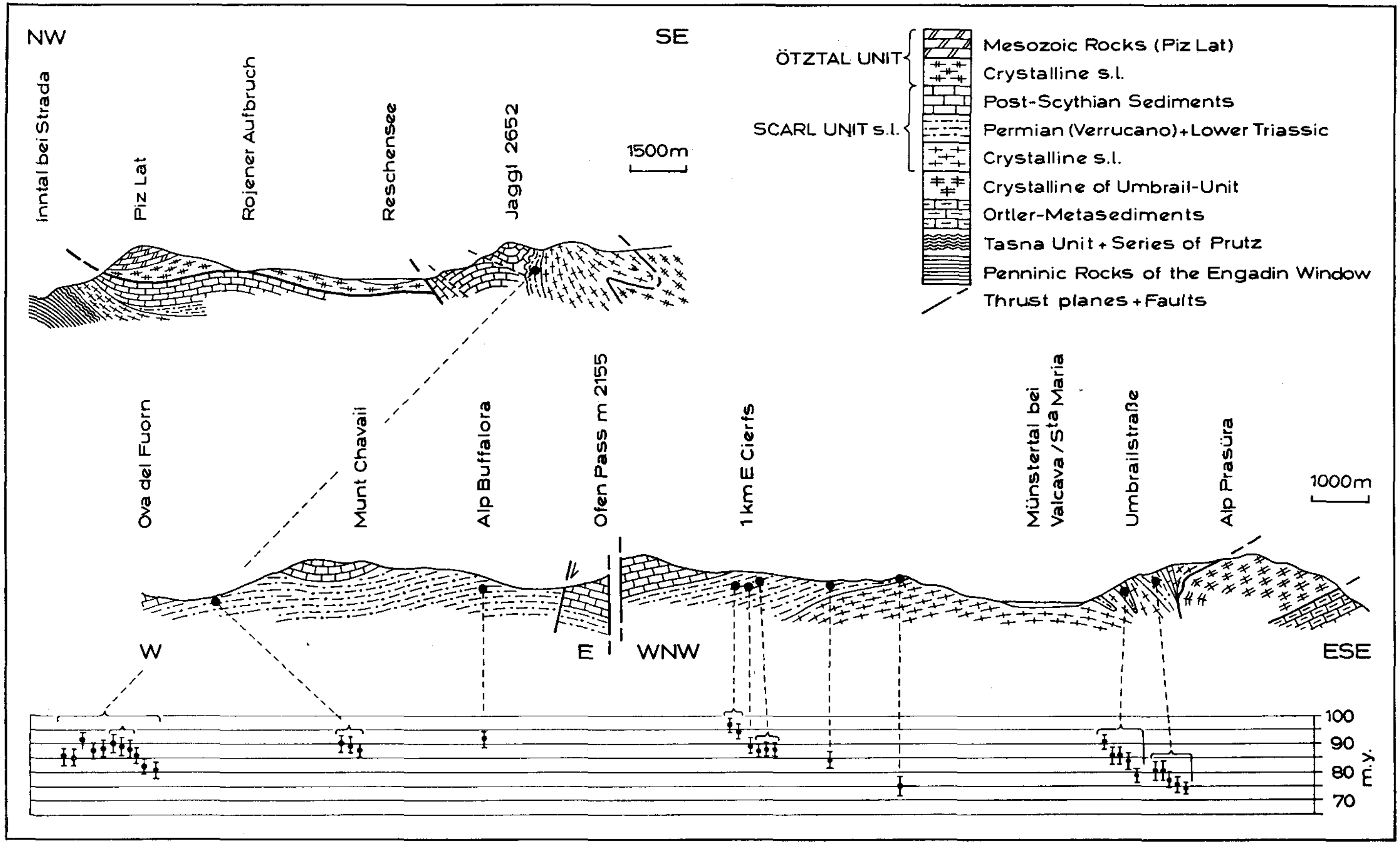
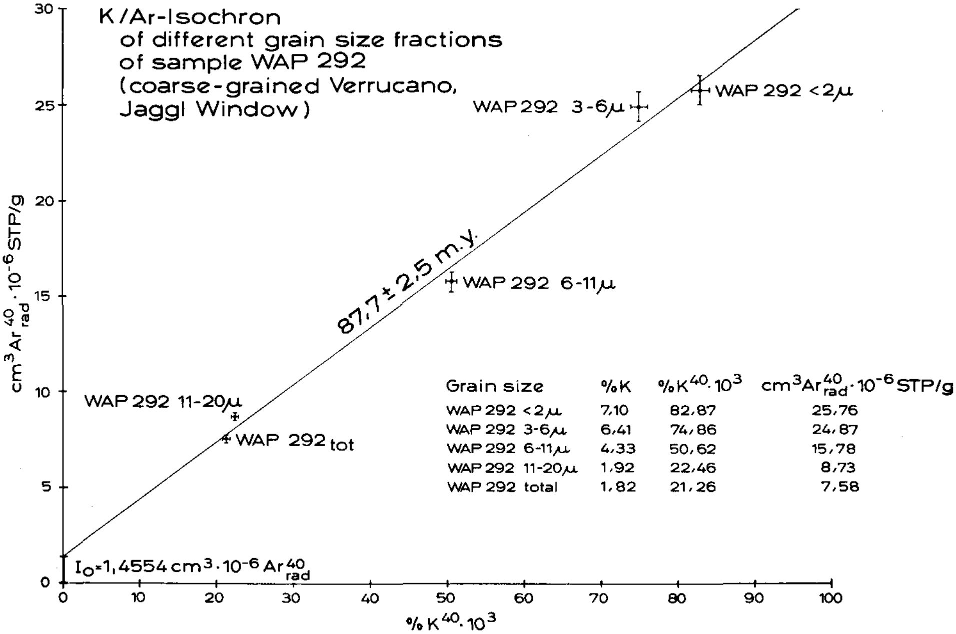


Fig. 4: Early Alpine K/Ar ages from white micas (grain size $<2\mu$) from the Permoscythian of the eastern Scarl Unit. Simplified sections of the Engadine Dolomites and the westernmost part of the Ötztal mass.



Grain size	%K	%K^{40}·10^3	cm^{3}Ar$^{40}_{rad}$·10^{-6}STP/g
WAP 292 <2μ	7,10	82,87	25,76
WAP 292 3-6μ	6,41	74,86	24,87
WAP 292 6-11μ	4,33	50,62	15,78
WAP 292 11-20μ	1,92	22,46	8,73
WAP 292 total	1,82	21,26	7,58

Fig. 5: The K/Ar isochron defined by four different grain size fractions plus the total rock of a coarse-clastic sample from the basal Permosythian of the Jaggl-area ranges with his model age of 87,7±2,5 m.y. within the same age group as most of the samples of the grain size <2μ (concentrated newly-formed white micas). The amount of inherited ^{40}Ar is relatively small and demonstrates that the ^{40}Ar-loss within these rocks was largely, but not entirely, completed during Early Alpine metamorphism. In the present case a coarse-clastic sample intentionally was analysed. Fine-grained rocks with only very low contents of coarse-clastic material should give still lower values of inherited ^{40}Ar.

demonstrates that the ^{40}Ar-loss within these rocks was largely, but not entirely, completed during metamorphism. Fine-grained rocks with only slight contamination of coarse-clastic material should give still lower values of inherited ^{40}Ar.

If we plot all the K/Ar values from the < 2μ-grain size samples of the Jaggl/Münstertal-area onto three different diagrams (as shown on Fig. 5 for different grain sizes of the same rock specimen), we can calculate the following initial values of inherited ^{40}Ar: a) southern Münstertal group (12 samples): $I_0 = 0,712$; b) northern Münstertal group (12 samples): $I_0 = 1,538$; c) Jaggl window (10 samples): $I_0 = 0,949$ cm^3 ^{40}Ar$_{rad}$ x 10^{-6} STP/g. Of course, it is not correct to calculate the respective "isochrons" because of the regionally varying conditions during metamorphism, but, in any case, we thus can show, with the relatively low I_0-values, that the falsification of the true metamorphic mica ages by inherited ^{40}Ar, if at all, is low.

The biotite ages from the western and northern part of the Ötztal crystlline mass obviously represent cooling ages of the Hercynian metamorphism. If we take the average value of 13 biotites analysed, the metamorphic rocks under discussion may have cooled to temperatures below

300° C in the time interval between approximately 285 and 295 m.y. Biotites No. 69 and No. 75 are from rocks which partly show an infiltration of weathering solutions along the s-planes; thus, these two age values can be explained satisfactorily as biotites slightly rejuvenated by weathering processes. For the relatively high values of the samples No. 67 and No. 73 we have no plausible explanation. Possibly it is a case of slight ^{40}Ar-excess.

The white micas from the Scarl-orthogneisses and from the metamorphic rocks of the western Ötztal mass yielded ages higher than 300 m.y. In the case of sample No. 58 we are dealing with a white mica from a strongly foliated augengneiss. From the petrographic-mineralogical results (p. 148), we would expect rejuvenated rather than Hercynian ages for the white micas of the Scarl-orthogneisses. Most probably, however, the newly-formed rims of the micas were entirely eliminated during the separation process (repeated grinding!), and thus only the Hercynian cores of these minerals have been concentrated in the sample used for the analysis. Younger ages may be expected for smaller grain sizes, not yet investigated.

The two mica-pairs analysed (Tab. 3, No. 61 and 71, No. 62 and 76) gave an age difference of 15 m.y. between white mica and biotite. If we use blocking temperatures similar to those noted in PURDY & JÄGER (1976), we can calculate a very slow uplifting during the final phase of the Hercynian metamorphism, in the range of only 0,1–0,2 mm/y.

What temperatures were reached during Alpine metamorphism in the area of Münstertal/Jaggl? Judging by textures, mineral content (biotite, pyrophyllite) as well as by the results of radiometric dating we conclude that temperatures in the range of 350° C (but not much higher) were effective during the Lower-Middle Senonian in this area. We should point out that biotites were not influenced by Alpine metamorphism in the western Ötztal mass; meanwhile, in the tectonically underlying metasediments of this greater unit, this process is readily traceable. In this context we should bear in mind, on the one hand, the fact that a rigid block of metamorphic rocks, poor in fluids, reacts quite differently to low-thermal events than water-rich sediments. But we should also consider, on the other hand, the westward trending tectonics of the Ötztal mass along the Schlinig thrust, a process which in our opinion partly took place in post-Cretaceous time (THÖNI 1980a). The resulting picture is therefore one of Hercynian crystalline rocks overlapping a basement which shows weak Alpine metamorphism.

Proceeding further in an eastsoutheasterly direction within the Ötztal crystalline mass, approximately east of the line Mals – Weißkugel – Wildspitze – Umhausen, we reach a zone where pre-Alpine biotites show an increasing loss of radiogenic Ar or ^{40}Ar-overpressure. This fact is due to the increasing temperatures which were reached during Alpine metamorphism, the closer we come to the "thermal high" of the Schneeberger Zug. The Ar-mobilisation decreases from south to north, i.e., with falling temperatures. This "zone of biotite-mixed-ages and/or ^{40}Ar-excess" (Plate 1) most probably can not be defined (at least in the northwest) by a clearly defined straight line because Ar-loss most probably depends on lithology and on the local tectonic situation. In any case, this line follows a northeastern direction, generally speaking, parallel to the northern boundary of Alpine chloritoid (PURTSCHELLER 1971, p. 39) and cuts the pre-Alpine tectonic structures obliquely. Locally, enormous amounts of such radiogenic excess-Ar have been absorbed by biotites (e.g., sample No. 88). The model ages of the minerals of this zone reflect only the fact of a process but not the geologic time of this event.

The area where biotite has been entirely rejuvenated (recrystallized or newly-formed biotite) can be seen in part on Plate 1. As analysis No. 63 (Tab. 3) shows, at least in the southern part of the "zone of biotite mixed-ages", the white micas have (also) been notably influenced by Alpine metamorphism (cf. also HARRE et al. 1968, SATIR 1975). An investigation of this object is in progress.

The Alpine biotite cooling ages from the wider area of the Schneeberger Zug fall in the age-group of 73–86 m.y. Age values in the same range have already been discussed for the southern part of the Engadine Dolomites, the Verrucano of Stilfs and the sericitic-phyllites near Eyrs/Vinschgau. The evolution of the Early Alpine metamorphism in this wider area is generally a well proven fact, especially in the light of radiometric investigations by HARRE et al. (1968), SCHMIDT et al. (1967), GRAUERT et al. (1974), SATIR (1975, 1976) and the petrological work of many other authors.

In the case of samples where biotite and chlorite occur side by side (especially as intergrowths), biotite-chlorite-mixtures have been analysed because it was not possible to separate pure concentrates from the two minerals. As can be seen from Tab. 3 (No. 91–98), the data of these biotite-chlorite-mixtures do not fit well into the general picture. A most probable explanation for the analyses of the samples No. 91, 92 and, especially 95, is the following: K was preferably removed from the lattice during chloritization of biotite; meanwhile, radiogenic Ar was partly retained (cf. M. SCHOELL, 1972, p. 106). Thus, the ^{40}Ar/K-ratio, i.e. the model age of the mineral increases. A similar explanation can probably be given (except for the case of the biotite-chlorite-mixtures of the "zone of biotite-mixed-ages" although here it is not possible to interpret the "ages" of these samples) in particular for sample No. 64 of the "Phyllitgneis-zone" because for this unit we would expect slightly rejuvenated or even Hercynian biotite ages. But one single analysis has no real significance at this moment.

The "zone of Alpine biotite cooling ages" extends farther to the south, affecting the crystalline rocks of Mauls – Meran (Mules – Merano; see Tab. 3, No. 97, 98; SATIR 1975). In the eastern part of this metamorphic rock sequence we find the Permomesozoic series of the Mauls – Penser Joch. The ages of the white micas (grain size $< 2\mu$) of the Mauls – Penser Joch-Permoscythian range from 15 to 22 m.y. and have been interpreted as Late Alpine cooling ages (FRANK et al. 1977). On the basis of the increasing age values from the floor of the valley (Eisacktal) to higher tectonic levels (Fig. 6), we deduce a very slow uplifting in the range of only 0,2 mm/y. for the area investigated. So far no biotites from the crystalline rocks in the immediate neighbourhood of the Penser Joch-Permoscythian, have been dated, but from thin section analysis we may conclude that the Late Alpine metamorphism in the Penser Joch-area was just slightly higher than the Eearly Alpine metamorphism in the Münstertal/Jaggl-area.

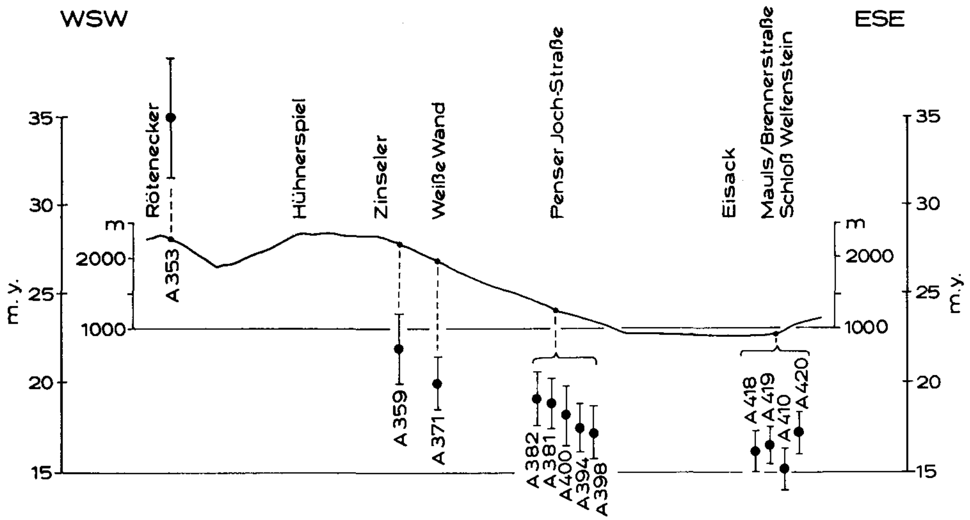


Fig. 6: The K/Ar mica ages from the Permoscythian metasediments of the Mauls — Penser Joch, plotted as a function of the altitude. Topographic section across the Eisack valley (Valle d'Isarco). For the data which are not listed on Tab. 3, see FRANK et al. 1977, p. 5.

We cannot say in the present state of our knowledge to what extent the Early Alpine metamorphism was effective just as we cannot determine the time at which the main structures (B-axes, east-west-lineations) were formed in the Penser Joch-area. The highest and westernmost age value of this region, of 36,4 ± 2,2 m.y. (No. 57), is from an isolated sample not controlled by other data but which can be explained, at the present stage, as an Early Alpine mica age, strongly rejuvenated by Late Alpine metamorphism. This would imply that the effects of this Miocene metamorphism of the Penser Joch decline fairly rapidly towards the west. Farther east, on the other hand, large parts of the Austroalpine crystalline rocks south of the Tauern Window have been affected by this young metamorphism, as BORSI et al. (1973, 1978) have shown.

This Late Alpine event is also traceable in the tectonic units below the Austroalpine crystalline plate, the Lower Austroalpine and the Penninic rocks (Tab. 3, No. 50–53). The temperatures in the now exposed area around Sterzing fell below approximately 300–350° C only in the Upper Miocene, if we interpret the age values of the white micas from Penninic schists at Sterzing in the same way as the others, as cooling ages.

This very young metamorphism is, on the one hand, obviously connected with the weakening metamorphism of the Tauern-area. But for the wider area of Sterzing it is necessary, on the basis of the data discussed, to modify the cooling-model proposed by SATIR (1975), according to which in the western Tauern Window, a central, later cooled part with lower age values is superimposed, concentratically by rock series of continuously higher age values, in the direction of the outer part of the structure.

Four white micas (grain size $< 2 \mu$) from Permoscythian quartzites of the Lower Austroalpine unit, tectonically intercalated as thin lenses between the Penninic schists and the Austroalpine crystalline rocks north of Brenner Pass, yielded K/Ar ages of 20,3–32,2 m.y. The samples were separated from homogeneous, fine-grained, greenish quartzites entirely free of coarse-detrital components. The specimens were all taken from the same outcrop. No suitable explanation for the wide distribution of the age values can be given. Possibly we are dealing with Ar-mobilisation (Ar-loss and/or Ar-excess) during late- to postmetamorphic tectonic movements.

However, the youngest ages within the Austroalpine unit are restricted to a relatively narrow zone along the Periadriatic Lineament and are concentrated, judging by what has been surveyed so far, in the area around and south of Sterzing. Most probably, this very young metamorphism can be interpreted plausibly in connexion with Late Alpine activity along the Judicarian Lineament which took place according to E. SEMENZA (1974) mainly in the Eocene/Oligocene and lasted well into Pliocene times. In a wider context and as a primary causal factor this northward trend of the South Alpine protrusion ("Südalpenkopf") was also responsible for the northward movement and, later, rotation and westward thrusting of the Ötztal crystalline mass which, in its westernmost part, probably underwent significant Tertiary thrusting in a westerly and – along the Engadine updoming – partly also in a southwesterly direction (TRÜMPY 1977).

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An other paper concerning the wider area of the Ötztal mass will be published by FRANK et al. in the next volume (vol. 73) of the Mitt. Geol. Ges. Österr.

4) Abstract

56 K/Ar analyses on fine-grained muscovites/phengites, mainly from the eastern Scarl Unit are given. These data cluster around 90 ± 5 m.y. in the northern part and around 80 ± 6 m.y. in the southern part of this unit. Geological-petrographic investigations favour the argument that in the south we are dealing with cooling ages; meanwhile the data of the northern group, at present, are interpreted as possible formation ages which belong to the Upper Cretaceous metamorphism. Analyses of different grain sizes show that the ^{40}Ar-loss within the metasediments (Permoscythian) was largely completed during this weak metamorphism.

40 K/Ar measurements on micas from crystalline rocks show a slight rejuvenation of biotites of the Scarl orthogneisses and in the metamorphics of the Silvretta mass in the neighbourhood of the Engadine Window. Within the southern Ötztal crystalline mass the K/Ar mica ages define three zones from W to E: a) zone of Hercynian mica cooling ages, b) zone of mixed mica ages and ^{40}Ar-excess in biotite, c) zone of Early Alpine biotite cooling ages. These zones cut the pre-Alpine structures obliquely. Thus the Alpine metamorphism increases clearly from W to E. The thermal aureole of the Schneebergerzug is well traceable in SW direction into the Campo crystalline mass (unpublished data), but is flanked in the SE (Penser Joch – Tonale zone) by a zone which shows very weak Alpine overprinting.

The young metamorphism in the Mauls – Penser Joch area is connected with a special tectonic situation at the "South Alpine protrusion" and may only partly be correlated with the cooling history of the Pennine Tauern Window.

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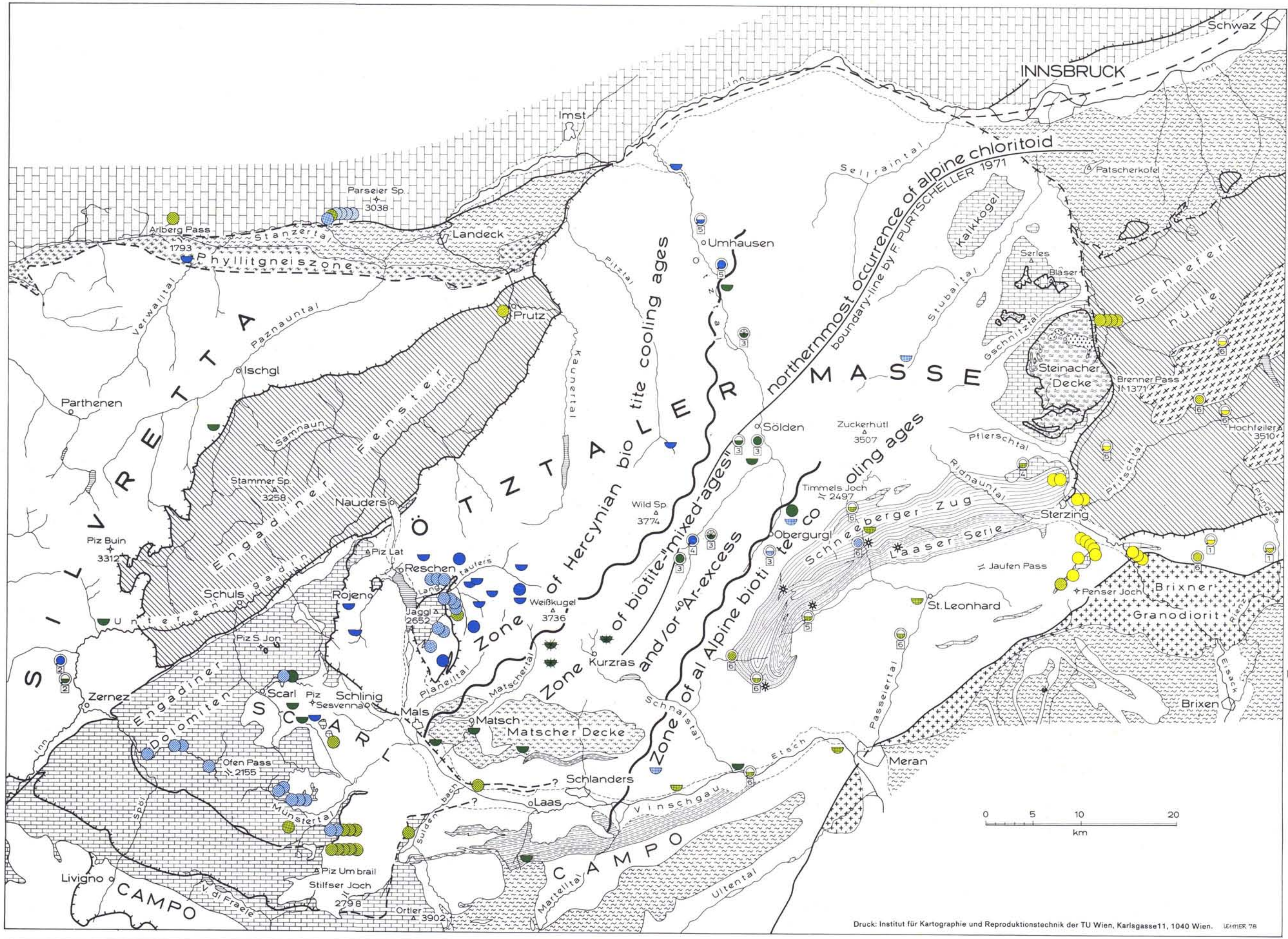
DISTRIBUTION OF PRE-ALPINE AND ALPINE METAMORPHISM W OF THE TAUERN WINDOW –

a preliminary picture based on radiometric age determinations

by M. THÖNI, partly in collaboration with H. ALBER & W. FRANK



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a) Geological Units

- ▥ Northern Calcareous Alps
- ▤ Mesozoic Series of the Central Alps
- ▨ Nappe of Steinach, incl. Carboniferous
- ▨ Zone of the "Phyllitgneise"
- ☐ Austroalpine Crystalline s.l. (Ötztal, Silvretta + Scarl, Campo)
- ▨ Unit of Matsch (Biotite - plagioclase - micaschists, garnetphyllites)
- ▤ Schneeberger Zug (Monteneve) + Laaser Serie (marbles + micaschists)
- ▨ Quartzphyllites s.l. (Landeck, Innsbruck, Martell, Brixen)
- ▧ Penninic + Lower Austroalpine Units (Engadin Window, Tauern Window)
- ✚ "Zentralgneise" of the Tauern Window
- ✚ Periadriatic Intrusive Rocks (Brixen, Iffinger)
- Major Alpidic Thrust Planes and Lineaments
- ✳ Occurrence of Early Alpine staurolite

b) K/Ar mineral ages

- ○ White mica
- ◡ Biotite
- ● > 270 m.y. (hercynian)
- ● 270-100 m.y.
- ● 100-85 m.y.
- ● 73-86 m.y.
- ● 70-35 m.y.
- ● 35-20 m.y.
- ● 20-12 m.y.
- ✳ Ar-overpressure
- ○ Age data from the literature
- ⊖ Rb/Sr ages (from the literature)

1. BORSI et al. 1978
2. GRAUERT 1969
3. HARRE et al. 1968
4. MILLER et al. 1967
5. SCHMIDT et al. 1967
6. SATIR 1975

PLATE 1

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