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Degree and Evolution of the Alpine Metamorphism in the Austroalpine Unit W of the Hohe Tauern in the light of K/Ar and Rb/Sr Age Determinations on Micas

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With 12 Figures, 16 Tables and 5 Plates (= Beilagen 1, 2)

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Schlüsselwörter
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zentralalpines Mesozoikum
variszische Abkühlung
kretazische Metamorphose
K/Ar- und Rb/Sr-Datierungen

CONTENT

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Abstract

Distribution, grade and evolution of the Alpine metamorphism in the Austroalpine Unit W of the Tauern Window are described.

According to petrographic observations four different Alpine temperature zones are distinguished within the pre-Alpine basement rocks (Fig. 2): a) Hercynian zone, b) Stilpnomelane zone, c) Chloritoid zone, d) Staurolite zone. The radiometric age results (K/Ar and Rb/Sr) on micas show a clear correlation with this metamorphic zoning, thus resulting in different mineral age zones: 1) Zones of Hercynian mica cooling ages (a), 2) Zones of mixed ages (b and c), 3) Zone of Alpine mica cooling ages (c p. p. and d).

The long lasting Hercynian cooling is documented with K/Ar and Rb/Sr ages from biotite and white mica of 330–270 m. y. From K/Ar and Rb/Sr data on neogenic white micas from the weakly metamorphic post-Hercynian metasediments (Permoscythian of the Scarl-Ortler area) it is concluded that the thermal peak of the Early Alpine metamorphism was reached not before 100 and most probably around 90 m. y. The relations of this Cretaceous metamorphism with tectonic-orogenetic movements are discussed.

Zusammenfassung

Es wird ein Überblick über a) die Verbreitung, b) die Intensität und c) den zeitlichen Ablauf der alpidischen Metamorphose im Ostalpin W der Hohen Tauern gegeben. Die Aussagen stützen sich einerseits auf Dünnschliffuntersuchungen, andererseits aber vor allem auf K/Ar und Rb/Sr-Analysen an Glimmern.

Das Silvrettakristallin blieb im W und S von der alpidischen Metamorphose unbeeinflußt, zeigt mit Annäherung an das Engadiner Fenster jedoch zunehmend deutliche Beeinflussung des voralpidischen Glimmerbestandes. Die das Silvrettakristallin im N begrenzende Phyllitgneiszone lieferte im zentralen und westlichen Abschnitt nur variszische Glimmerabkühlalter von 280–320 Mio. J.

Im Ötztalkristallin ist von W nach E bzw. von N nach S eine kontinuierliche Zunahme der alpidischen Überprägung zu beobachten: Hand in Hand mit der Zunahme der Diaphthoreseerscheinungen im voralpidischen Mineralbestand geht eine zunehmende Verjüngung (Verlust von radiogenem ^{40}Ar bzw. ^{87}Sr) der Glimmer. Die alpidische Metamorphose erreicht im zentralen Schneeberger Zug die Bedingungen der niedriggradigen Amphibolit-Fazies, aus diesem Bereich liegen fast nur kretazische Glimmeralter vor. Die Schneeberger „Wärmebeule" taucht gegen SW mit flacher Achse ab. Im zentralen Ortler-Campo-Kristallin ist die alpidische Überprägung mit Mischaltern bei Muskowit und Biotit und retrograden Erscheinungen im gesamten voralpidischen Mineralbestand gut mit der Mischalterszone im Ötztalkristallin zu vergleichen und erreichte die mittlere Grünschiefer-Fazies. Gegen NW (Scarl-Umbrail- und Languardkristallin) und SE (östlichste Tonalezone) nimmt die alpidische Beeinflussung deutlich ab. Biotite aus dem Languardkristallin bei Pontresina ergaben noch variszische Alter. Alle K/Ar- und Rb/Sr-Alter an Biotit und Hellglimmer aus den variszischen, alpidisch nur sehr schwach (anchizonal) beeinflußten Kristallinarealen (westliches Ötztalkristallin, westliches und südliches Silvrettakristallin, Languardkristallin p. p.) sowie die meisten Rb/Sr-Hellglimmeralter aus dem gesamten Untersuchungsgebiet fallen in den Zeitraum von 330–270 Mio. J. und weisen auf eine langsame Abkühlung (Hebungsrate 0,1–0,2 mm/Jahr) nach dem Höhepunkt der variscischen Metamorphose hin.

In den Engadiner Dolomiten erreichte die alpidische Metamorphose die tiefe Anchizone bis schwächste Grünschiefer-Fazies (vor allem im Verrucano) mit Neubildung von Phengit/Muskowit, Stilpnomelan und Chlorit; in der Ortler-Trias und im Jaggl-Permoskyth wurde Biotitneubildung beobachtet. Diese schwache Metamorphose war mit einem erhöhten Lösungsumsatz im unterlagernden Scarl-Orthokristallin verbunden und hat das Rb/Sr-System dieser Einheit im Gesamtgesteinsbereich vermutlich leicht gestört. Die Scarl-Muskowitgranitgneise ergaben ein Rb/Sr-Gesamtgesteins-Errorchronenalter von 336 ± 7 Mio. J.

Die K/Ar-Alter der neugebildeten Hellglimmer aus den Metasedimenten der zentralen Scarl-Einheit gruppieren sich um das Zeitintervall von 90 ± 5 Mio. J. Anhand von Rb/Sr-Daten wird wahrscheinlich gemacht, daß diese Altersgruppe den thermischen Höhepunkt der kretazischen Metamorphose widerspiegelt. Daraus wird für das gesamte Untersuchungsgebiet abgeleitet, daß der Höhepunkt dieses Metamorphoseereignisses nicht vor 100 und wahrscheinlich erst um 90 Mio. J. erreicht war. Die darauffolgende weitspannige Abkühlung ist für weite Areale des ostalpinen Kristallins der gesamten Ostalpen mit K/Ar- und Rb/Sr-Altern an Glimmern gut belegt. Die 300°C-Grenze dürfte um 75 (bis 70) Mio. J. unterschritten worden sein.

Eine Rb/Sr-Kleinbereichsisochrone aus einem stark mylonitisierten Gestein des Jaggl definiert ein Alter von 113 ± 2 Mio. J. und zeigt damit, daß anderseits mit noch wesentlich früheren tektonischen Vorgängen im Ostalpin zu rechnen ist. Insgesamt war die kretazische Metamorphose das maßgebende alpidische Ereignis in diesem Abschnitt des Ostalpins, wennschon lokal auch postkretazische Beeinflussung nachzuweisen ist (z. B. Umbrail-Gebiet, Penser Joch, Thialspitz-Gebiet/Basis Kalkalpen). Das für die alpidische Metamorphose entwickelte Modell steht mit sedimentologischen Daten und großtektonischen Vorstellungen im Sinne der Plattentektonik in Einklang.

Folgende allgemeine Gesichtspunkte können aus den regionalen Untersuchungen abgeleitet werden.

a) Die Temperaturentwicklung war im Untersuchungsgebiet der maßgebende Parameter, der das K/Ar- und Rb/Sb-System in den Glimmern kontrollierte. Das Konzept der Blocking-Temperaturen, wie es in den Schweizer Alpen seit vielen Jahren modellhaft angewendet wird (z. B. JÄGER et al. 1967, PURDY & JÄGER 1976) ist im Prinzip, wenn auch mit gewissen Einschränkungen, auch im vorliegenden Gebiet anwendbar. Für das Kristallin gilt außerdem, daß auf Grund des Erhaltungszustandes der voralpidischen Mineralparagenesen aus dem Dünnschliffbefund in vielen Fällen eine Voraussage möglich ist, ob und wie intensiv die Isotopensysteme beeinflußt wurden.

b) Mehrere Beispiele zeigen, daß tektonische Durchbewegung allein, auch wenn sie sehr intensiv ist, nicht ausreicht, um die Isotopensysteme deutlich zu beeinflussen.

c) Verstärkte Zufuhr oder Zirkulation von fluider Phase kann jedoch, insbesondere bei gleichzeitiger Durchbewegung, Mineralreaktionen beschleunigen und damit auch die Mobilität in den Isotopensystemen erhöhen. Dies kann lokal die Sr-Isotopenhomogenisation beschleunigen, in anderen Fällen aber zu abweichenden Mineralaltern führen, die mit dem Konzept der Schließungstemperaturen nicht gut übereinstimmen.

1. Introduction

Problem Presentation

This paper gives a synopsis of the geochronological data from the Austroalpine unit W of the Hohe Tauern (see Plates 2–5). All the work has been carried out in the Laboratory for Geochronology (under the guidance of Prof. W. FRANK) of the Vienna University as part of the Austrian geoscience project "Geologischer Tiefbau der Ostalpen" (Project No. 25 and S 15/2 respectively). All the Rb/Sr data presented in this paper are new, whereas the greater part of the K/Ar data included in the discussions has already been published. In order to give as complete a picture as possible the most important data from the literature has been displayed on Plates 2–5, part of this data comes from the unpublished theses of L. KRECZY, J. MAURACHER, R. PESCHEL, R. TESSADRI.

The classification of the age data in different "radiometric age groups" may seem questionable in some cases. It is also not possible to find a difinite conclusion for every single data point. Moreover, with the presented classification we presume that the Hercynian cooling history as well as the evolution of the Alpine metamorphism was similar and contemperaneous in all parts of the extensive area investigated, an assumption which might not correspond with the reality. The most serious problem in this context is, where to draw the boundary between "mixed ages" and "Early Alpine formation ages". An explanation for the used age classification is given partly in chapter 4, 1–3.

Summarizing, the following topics will be discussed:

a) Regional distribution and metamorphic grade of the Alpine metamorphism on the basis of mica ages and petrographic observations.

b) Evolution and timing of the Alpine metamorphism.
c) Comparison between the K/Ar and the Rb/Sr systematics in micas and discussion of the parameters controlling the age of micas.
d) Correlation between the reactions in the isotopic systems (model ages of the micas) and the alterations within the corresponding mineral parageneses in polymetamorphic crystalline rocks.
e) How do the results fit in with sedimentological-paleogeographic considerations and conventional tectonic evolution concepts?

Geological-tectonic Outline of the Area Investigated

Middle-Upper Austroalpine rock series cover by far the larger area of the central Alps between the Pennine Tauern Window in the E and the Lower Austroalpine/Pennine domains of the Bernina-Prätigau area in the W (Plate 1). Today only a small remnant of a once certainly greater Austroalpine unit, the so called Tonale Zone extends further to the W, accompanying the lower tectonic units of the Swiss Central Alps ("Ticino High") at their southern border and along the Periadriatic Lineament.

The Austroalpine consists mainly of pre-Alpine medium to high grade crystalline rocks of metapelitic to metapsammitic origin with intercalations of orthogneisses or subordinately amphibolites. This so called "Altkristallin" is overlain in the southwestern part (Ortler-Campo crystalline complex) by pre-Mesozoic rocks of much lower metamorphic grade (greenschist facies) and of phyllitic character. The autochthonous Permomesozoic sedimentary cover of the basement is preserved only very incompletely, but reaches in places a thickness of some thousand meters and has been affected by the Alpine metamorphism in different grade (anchizone to higher greenschist facies). Well-known occurrencies of these metasediments are: the Ducan-Landwasser area, the Ortler-Fráele Zone, the Engadine Dolomites, the mesozoic of the Stubai-Brenner area and the Permotriassic syncline of the Mauls-Penser Joch.

Tectonically, the Austroalpine crystalline rocks belong to different units (blocks, masses) which can only partly be clearly separated from one another and which before the Alpine orogenesis formed a coherent basement complex. In this paper we distinguish the following units:

1. Zone of the "Phyllitgneise" (Phyllitgneiszone)
2. Silvretta Crystalline Mass (Silvretta basement)
3. Ötztal Crystalline Mass (Ötztal basement)
4. Ortler-Campo Complex, including the "Languardkristallin" and the "Tonalezone"
5. Scarl-Umbrail Unit and Engadine Dolomites.

Sample Preparation and Analytical Technique

Grain sizes of less than 70 μ (only from post-Hercynian metasediments) were separated by sedimentation in distilled water. For this purpose only hand specimens were used. After being crushed the rocks were grinded for a short time (max. 30 sec) in an agate grinding mill. A longer grinding was avoided in order to prevent admixture of fragments of coarse-detrital components (especially white mica!) with the finer fractions. Carbonaceous samples were treated with strongly diluted acetic acid before sedimentation. Thin sections, X-ray diagrams and RF-analyses gave preliminary information about the suitability of the separated samples for isotopic analysis. For whole rock analyses with the K/Ar method, especially for the analysis of the pseudotachylites, largely homogeneous and fresh pieces of a few ccm were cut and pulverized for 50 sec in an agate grinding mill. From this still coarse-grained powder the grain sizes of 150–250 μ were separated by sieving and used directly for the analysis.

For the mineral separation from crystalline rocks mostly samples of some 5–15 kg were used, for Rb/Sr whole rock analysis however quantities of 15–30 kg. The purity of the mineral concentrates used for Rb/Sr analysis lay above 99%. For the K/Ar analysis biotite/chlorite mixtures were occasionally used as it was not always possible to separate the two minerals using conventional methods. The symbol GS1 used in the text means the original grain size of the mineral in the rock, whereas GS2 is used for the analysed grain sizes generated by mechanical crushing and grinding of GS1 during the separation/concentration process.

The Ar measurements were done with a BALZERS CMS 80 cycloid mass spectrometer (for a detailed description see FRANK et al. 1977). Using the GLO glauconite international standard (24,69 ccm × 10^{-6} $^{40}Ar_{rad}$) the reproducibility is better than 5‰. K was measured mostly in double by atomic absorption (PERKIN-ELMER 300). The error for the K analysis is ± 2%. For the muscovite standard KAW 4 M Brione (see PURDY & JÄGER 1976, p. 6) we found a value of 8,69 ± 0,12% K (mean of 15 analyses during 3 years).

For all Rb/Sr analyses the isotopic dilution method was used. All Rb and Sr measurements were done with a MICROMASS M 30 machine. The long time reproducibility for the $^{87}Sr/^{86}Sr$ ratio using the NBS987 Sr-standard is better than 0,15‰ (1 σ); the measured mean $^{87}Sr/^{86}Sr$ ratio for this standard is 0,71010. The blank for the whole chemical treatment is < 2 ng Sr.

All "uncorrected" Rb/Sr model ages were calculated using an initial $^{87}Sr/^{86}Sr$ ratio of 0,71014.

The follwing constants have been used for the age calculation (see STEIGER & JÄGER 1977):

K/Ar method: $\lambda\,(^{40}K_{\beta}-) = 4.962 \times 10^{-10}/y$
$\lambda\,(^{40}K_{e}) + \lambda'\,(^{40}K_{e}) = 0{,}581 \times 10^{-10}/y$
$^{40}K = 0{,}01167\%$ (atomic percent)
Rb/Sr method: $\lambda\,(^{87}Rb) = 1.42 \times 10^{-11}/y$
strontium atomic ratio: $^{86}Sr/^{88}Sr = 0{,}1194$

Abbreviations used on the tables: B = biotite; M = white mica s. l. (mostly muscovite, with different amounts of phengite and/or paragonite); WR = whole rock.

2. Petrographic and Geochronological Data from the Polymetamorphic Altkristallin and the post-Hercynian Metasediments

2.1 Phyllitgneiszone and Basal Parts of the Calcareous Alps in the Arlberg Area

The crystalline of the Phyllitgneiszone in the Arlberg area is composed mainly of garnet-, rarely staurolite-bearing paragneisses to micaschists with thick layers of muscovite granitegneisses. Apart from their "phyllitic" character the rocks can not be distinguished macroscopically from lithologically comparable rock types of the Silvretta or Ötztal basement.

Most of the samples investigated from this region were collected by J. KAISER (western part) and F. KUNZ (eastern part) during the construction of the Arlberg road tunnel. The thin sections generally show well-preserved pre-Alpine mineral parageneses, partly with postcrystalline deformation (kinking of biotite, chlorite; sample T 675). Diaphthoresis seems to be restricted to certain horizons and is more intense in the eastern part of the tunnel. The sericitization of feldspar is the most common phenomenon, chloritization of biotite and carbonate infiltration were observed only in a few cases (sample T 744). It is probable that this retrograde alteration is limited to areas where the transport of fluids is enhanced, such as along post-crystalline faults and bleaching zones.

Table 1: K/Ar Analytical Data from Micas of the Phyllitgneiszone and Related Units

Sample No. Lab. No.	Lithology Sample locality	Analysed mineral Analysed grain size	% K	$^{40}Ar_{rad}$ ccm . 10^{-6} NTP/g	% rad	Model age (m. y.)	Notes
T 656 WAP 483	Garnetiferous paraschist St. Anton/Arlberg	M 150 – 430 μ	6,14	78,16	98,70	301 ± 12	
T 676 WAP 499	Quartzose micaschist Arlbergtunnel W	M 150 – 420 μ	6,85	87,10	89,62	301 ± 13	sample collection by J. KAISER
T 679 WAP 502	Paragneiss Arlbergtunnel W	B 150 – 420 μ	6,48	84,60	97,70	308 ± 13	" Rb/Sr 311 ± 12
T 679 WAP 502	"	M 150 – 420 μ	6,69	85,86	96,57	303 ± 12	"
T 745 WAP 552	Garnetiferous mica-schist	B >150 μ	5,79	74,44	86,32	304 ± 14	Sample collection by F. KUNZ
T 745 WAP 552	Arlbergtunnel E "	M >150 μ	6,21	80,47	96,56	306 ± 13	"
T 746 WAP 554	Paragneiss Arlbergtunnel E	B 150 – 420 μ	6,45	84,18	97,97	308 ± 13	"
T 746 WAP 554	"	M 150 – 420 μ	7,05	89,94	90,02	302 ± 13	"
T 890 WAP 726	Paragneiss Rellstal/Montafon	B 170 – 420 μ	7,02	93,69	96,63	314 ± 13	Rb/Sr 283 ± 11
T 889 WAP 725	Permoscythian Rellstal	M <2 μ	4,86	20,19	79,84	114 ± 6	
T 887 WAP 723	Chl-two-mica-gneiss Gampadelstal	M 170 – 430 μ	8,69	113,69	98,95	308 ± 12	

The K/Ar ages of five white micas and three biotites from the Arlberg tunnel between St. Anton (E) and Langen (W) fall in the interval of 301–308 m. y. They are interpreted as Hercynian cooling ages (Tab. 1, 3). The biotites may have incorporated small quantities of excess radiogenic argon because their model ages are in some cases slightly higher than those of the white micas of the same rock specimen.

The westernmost part of the Phyllitgneiszone in the Montafon area shows still better preserved pre-Alpine mineral parageneses with Hercynian biotite ages.

H. MOSTLER (1972, p. 172) described diaphthoritic phyllite-gneiss pebbles in Permocarboniferous conglomerates of the Montafon area thus inferring a Late Hercynian diaphthoresis for the rocks of the Phyllitgneiszone. Our results are not in contradiction to this interpretation. Nevertheless the apparent mica ages of the area discussed compare very well with those of neighbouring Hercynian crystalline areas (western Ötztal mass, southern Silvretta and Languard crystalline) which show no or only very weak Alpine overprinting.

The investigations by L. KRECZY (1981, unpubl.) however, show, that the K/Ar system has been partly reopened in pre-Alpine micas of the eastern Phyllitgneiszone near Landeck by the Alpine metamorphism. Seen in this context it is plausible to interpret the above described diaphthoresis in the phyllitic gneisses of the eastern Arlberg tunnel, at least partly, as an Alpine process.

The basal parts of the Calcareous Alps in the area of Arlberg Pass–Flirsch show a weak metamorphism in the lowest greenschist facies. Earlier published K/Ar data from neogenic white micas of Permoscythian rocks of this region point to an Upper Cretaceous metamorphism with probable later overprinting. This interpretation has been confirmed by the results of KRECZY (l. c.) in the metasediments of the Thialspitz, SW of Landeck. Lithologically comparable rocks from the Montafon on the other hand, show that greenschist facies conditions were most probably not reached during Alpine metamorphism in this western part of the Calcareous Alps. This can be stated from textural as well as from mineralogical criteria. Sample T 889, a fine-grained silty schist from the Rellstal still shows detrital biotite in the thin section. The K/Ar age of the $< 2\ \mu$ grain size from this sample however, lies with a value of 114 ± 4 m. y. (Tab. 1) already near to the "Early Alpine formation age group" (see p. 141). Thus it is shown that already a high percentage of this mineral concentrate must be Alpine newly-formed mica and only a small amount belongs to detrital phases with inherited $^{40}Ar_{rad}$. Similar K/Ar ages have been found in the northern Scarl Unit.

Summarizing, the following can be stated for the Arlberg area:

a) A clear separation of the Upper Austroalpine Phyllitgneiszone (which forms the stratigraphic basis of the Nortnern Calcareous Alps) from the Middle Austroalpine Silvretta crystalline (TOLLMANN 1963, 1977 a) is not possible by petrographic and geochronological means. The Phyllitgneiszone however, shows in many places a clear tectonic contact to the neighbouring Silvretta crystalline mass in the S (cf. REITHOFER 1931, 1935).

b) The Alpine metamorphism increases slightly from the western to the eastern part of the Phyllitgneiszone. The absolute age of the weak diaphthoresis in the central and western Phyllitgneiszone is still unknown and could not be classified by the above reported analytical results.

c) The weak Alpine metamorhism of the basal Calcareous Alps should be interpreted as a transported metamorphism with locally later (Late Cretaceous – Tertiary) overprinting. Similar observations have been reported from the Calcareous Alps further to the E, in the area of Salzburg (c. f. J.-M. SCHRAMM 1980, p. 382).

2.2 Silvretta Crystalline Mass and Engadine Window

In the southern Silvretta crystalline the dying Hercynian metamorphism has been proved by GRAUERT (1966, 1969) with Rb/Sr mineral cooling ages around 300 m. y. (278–316 m. y.). Approaching the Engadine Window however, this author found more and more younger model ages for biotites reaching 124 m. y. for a sample SE of Zernez. This reopening of the Rb/Sr system in biotite has been interpreted by GRAUERT (1969, p. 4) as the result of reheating the pre-Alpine basement during an Early Alpine metamorphism, the existence of which had been proved two years before in the southern Ötztal crystalline mass (MILLER et al. 1967, SCHMIDT et al. 1967, HARRE et al. 1968).

We find a similar picture for the central Silvretta crystalline with K/Ar data (Tab. 2). Coming from the W (Montafon) along the Silvretta-Hochalpenstraße we still find Hercynian K/Ar ages in muscovite (sample T 1157). E of the Bieler Höhe we observe a notable loss of radiogenic argon in muscovite together with chloritization of biotite and Alpine stilpnomelane (thin section; sample T 1159). In the basal parts of the Silvretta S and E of Galtür, finally, we find typical mixed ages in white mica as well as in biotite (e. g. sample T 1165).

In the northeastern Silvretta (S of Landeck) a regional Alpine reopening of the K/Ar system in both biotite and muscovite has been established by KRECZY (1981) with model ages of 140–240 m. y. (7 analyses). Very similar and typical mixed ages in micas could be found in the easternmost corner of the Silvretta crystalline near Puschlin E of the Inn Valley (Tab. 2, sample T 916).

Thus, observing the regional distribution of all available age data, a zone of mixed ages extends along the northwestern border of the Engadine Window from Zernez/Süsch in the SW to the northeastern end of the Silvretta crystalline mass. As all the above discussed

Table 2: K/Ar Analytical Data from Micas of the Silvretta Crystalline Mass

Sample No. Lab. No.	Lithology Sample locality	Analysed mineral Analysed grain size	% K	$^{40}Ar_{rad}$ ccm . 10^{-6} NTP/g	% rad	Model age (m. y.)	Notes
T 1010 WAP 879	Granitegneiss Val Tours	M >150 μ	8,55	114,88	98,89	316 ± 13	
T 1010 WAP 879	"	B >150 μ	6,93	93,08 93,11	85,11 97,76	316 ± 15 316 ± 13	Rb/Sr 279 ± 11
T 1003 WAP 876	Muscovitegranitegneiss Flüela Pass	M >150 μ	8,71	117,18	96,73	317 ± 13	Rb/Sr 310 ± 12
T 1003 WAP 876	"	Bc >150 μ	5,36	61,12	69,38	272 ± 15	
T 1157 WAP 904	Granitegneiss near storage reservoir Vermunt	M >420 μ	8,69	114,50	98,33	311 ± 13	
T 1157 WAP 904	"	B >420 μ	8,11	71,21	94,41	213 ± 9	
68/2 WAP 621	Ga-stau-micaschist Jamtal	M 74 – 430 μ	6,95	52,80	94,27	186 ± 8	sample collection by G. FUCHS
77/19 WAP 622	Sil-paraschist Jamtal	Bci 74 – 430 μ	5,02	34,03	96,44	166 ± 7	"
T 1159 WAP 905	Granitegneiss Bieler Höhe – Galtür	M >420 μ	9,11	90,58	97,71	239 ± 10	
T 1165 WAP 906	Muscovitepegmatite Bergler Loch/SSE Mathon	M >150 μ	9,–	63,80	94,78	174 ± 7	Rb/Sr 223 ± 9
T 916 WAP 821	Paragneiss Puschlin/Prutz	M 150 – 430 μ	7,37	57,82	96,80	191 ± 8	
T 916 WAP 821	"	B 150 – 430 μ	6,55	68,59	97,42	251 ± 10	excess argon

Table 3: Rb/Sr Analytical Data from Micas of the Silvretta Crystalline Mass and the Phyllitgneiszone

Sample No. Lab. No.	Lithology Sample locality	Analysed sample	^{87}Rb ppm	$^{87}Sr_{rad}$ ppm	Sr_{total} ppm	%rad	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model age m. y.	Model age corr. m. y.	Notes
T 1010 WAP 879	Granitegneiss Val Tours	B >150 μ	298,0	1,184	2,79	91,39	1897,9	8,251	279 ± 11		K/Ar = 316 ± 13
T 1003 WAP 876	Granitegneiss Fluela Pass	M >150 μ	181,4	0,799	7,54	63,05	275,2	1,922	310 ± 12		K/Ar = 317 ± 13
T 1165 WAP 906	Pegmatite SSE Mathon	M >150 μ	187,6	0,606	0,957	96,14	5577,6	18,408	223 ± 8		K/Ar = 174 ± 7
T 679 WAP 502	Paragneiss Arlbergtunnel	B 150 – 420 μ	166,2	0,737	3,93	76,86	532,0	3,069	311 ± 12		K/Ar = 308 ± 13
T 890 WAP 726	Paragneiss Rellstal/ Montafon	B 170 – 420 μ	118,2	0,476	6,45	53,42	202,4	1,524	283 ± 11		K/Ar = 314 ± 13

model ages are related to only a partial reopening of the K/Ar isotopic system and are therfore interpreted as geologically meaningless mixed ages, the time of the metamorphic overprinting is not fixed. From the regional zoning of this Alpine metamorphism one could imply first of all a in situ reheating of the basal parts of the Silvretta basement during the Tertiary metamorphism of the series of the Engadine Window.

According to the petrological results of LEIMSER & PURTSCHELLER (1980) the metamorphism of the Pennine rocks of the Engadine Window reached only the lowest greenschist facies with maximum pT-conditions of 350 °C at 4–5 kbar in the central part of this structure. Based on these results and if we compare our results from neighbouring crystalline units (e. g. Scarl Unit) it is very improbable that this weak metamorphism in the Pennine rocks was able to disturb the K/Ar system especially of very coarse-grained white micas (from the overlying Silvretta crystalline), as intensely as shown above. Thus in the mixed age zone of the basal Silvretta crystalline we are most likely dealing with a transported metamorphism of pre-Tertiary i. e. Early Alpine age (possibly with very weak later influence; see below).

The allochthonous tectonic position of the high metamorphic (pre-Alpine) Silvretta crystalline block resting on Mesozoic to Tertiary meta-sediments of much lower metamorphic grade is very impressive. New findings of Paleogene microfossils (planktonic foraminifers) from the western Engadine Window by R. RUDOLPH (1979, unpubl.) show that the front of the Silvretta crystalline was still south of the discussed Pennine zone up to Upper Paleocene/Lower Eocene times.

As the evolution of metamorphism in the Pennine rock sequence of the Engadine Window must be connected with piling and overthrusting by Austroalpine units these processes should start (in the light of the results discussed above) sometime during the Eocene.

The K/Ar ages of 26–39 m. y. from white micas of the Engadine window are well in accordance with such an evolution. On the basis of the results by LEIMSER & PURTSCHELLER (l. c.) these age data (Tab. 4 b), at least those of the outer parts of the window, may be interpreted as formation ages related to the thermal peak of the metamorphism. A definite conclusion however, is not possible at the moment because of the wide spread of the ages and the insufficient amount of data available. The results compare very well with K/Ar and Rb/Sr ages from white micas of the much higher metamorphic western Tauern window, where the thermal peak of the Tertiary "Tauernkristallisation" is placed in the time interval of 30–40 m. y. (SATIR 1975, and lecture in Vienna, March 1981; cf. HUNZIKER 1974).

Pseudotachylites are widespread in the basal Silvretta crystalline along the north-western border of the Engadine Window. The genesis of these rocks has been interpreted in different ways (HAMMER 1930, MASCH 1974, TOLLMANN 1977 a). According to MASCH (1974) the pseudotachylites are younger than the thrusting (= final emplacement) of the Silvretta mass and their formation is connected with the updoming of the Pennine rocks of the today's antiform of the Engadine Window (l. c., p. 507).

Some of these pseudotachylites from the area S of Ischgl have been analyzed according to the K/Ar method. For the preparation of samples see p. 115. Analytical data and apparent ages are listed in Tab. 4 a. Provided that the outgassing and thus the loss of radiogenic argon was fairly perfect during the melting process (= formation of the pseudotachylites), at least in the central parts of the "dikes", the following interpretations are possible for the listed model ages of 53–77 m. y.:

Table 4: K/Ar Analytical Data from Pseudotachylites of the Basal Silvretta Crystalline Mass and from Metasediments of the Engadine Window

Sample No. Lab. No.	Lithology Sample locality	Analysed mineral Analysed grain size	% K	$^{40}Ar_{rad}$ ccm . 10^{-6} NTP/g	% rad	Model age (m. y.)	Notes
a) Pseudotachylites							
T 614 WAP 986	Pseudotachylites Pardatscher Grat/ Idalpe	WR 150 – 250 µ	2,04	4,51	78,08	56,– ± 3	
T 642 WAP 615	Pseudotachylite Fimbertal	WR { fine powder	3,59	10,59	27,49	75,– ±3,–	
		WR { 150 – 250 µ	3,80	11,70	78,50	77,5 ± 3,–	
T 644 WAP 617	"	WR 150 – 250 µ	4,07	9,53	77,56	55,3 ± 2,3	
T 645 WAP 618	"	WR 150 – 250 µ	3,66	8,39	79,22	58,– ± 3,–	
T 648 WAP 619	" Berglerhorn	WR 150 – 250 µ	4,24	12,22	90,58	72,6 ± 3,2	
T 840 WAP 698	Pseudotachylite Road to Idalpe	WR 150 – 250 µ	2,47	11,27	89,28	114,– ± 5	biotite relics in thin section
T 841 WAP 699	Pseudotachylite Idalpe/Höllenkar	WR 150 – 250 µ	3,41	7,14	88,33	53,– ± 2,4	
b) Engadine Window							
T 619 WAP 606	"Tasna flysch" Idalpe	M <2 µ	4,75	13,46	45,52	71,5 ± 6,3	(+ chlorite, X-ray diagram) ? excess argon
T 629 WAP 611	Violet carbon. schist Puschlin/Prutz	M <2 µ	5,39	6,34	54,28	30,– ± 2,2	+ chlorite
T 845 WAP 702	calcschist Pfunds/Inntal	M <2 µ	5,13	5,22	35,64	26,– ± 3	
T 846 WAP 703	calcschist Nauders	M <2 µ	5,19	7,88	67,84	38,6 ± 2,3	
III WAP 392	sericite-schist Prutz/Ladis	M <2 µ	7,49	10,12	86,98	34,4 ± 1,6	sample preparation KRECZY

a) The model ages are true formation ages. The formation of the pseudotachylites is a polyphasic event of Upper Cretaceous to Early Paleogene age.

b) The pseudotachylites are of Early Alpine (Cretaceous) age and their apparent ages were lowered partly by later thermal/tectonic processes (loss of $^{40}Ar_{rad}$).

c) The pseudotachylites were formed in Tertiary times; the higher K/Ar model ages being due to an excess of $^{40}Ar_{rad}$.

According to the regional situation and the pattern of the mica ages in the basal Silvretta crystalline, interpretation (c) may most probably be excluded. The high age value of sample T 840 can plausibly be explained by incomplete degassing of the rocks melt as there are still observable biotite relics within the fine-grained matrix in the thin section. The variation of the model ages of the other six samples may at best be explained by with interpretation b). The results by KRECZY (l. c.) in the Thialspitz area demonstrate that we can probably reckon with a partial reopening of the K/Ar system in the most fine-grained parts of the rocks during post-Cretaceous thermal processes.

As the geological background for the formation of these pseudotachylites one could discuss the following picture:

During the Cretaceous décollement of the today's Silvretta crystalline mass from its deeper parts a considerable shear stress developed in higher tectonic levels. This situation resulted in local melting, thus forming the pseudotachylites. The pseudotachylites which we observe today in the basal Silvretta crystalline must not necessarily have been formed during the earliest phases of the formation of the main basal thrust plane. They may also correlate with later shearing off processes of crystalline slabs, at a time when part of the basement was already overriding the Pennine series.

Until now, no pseudotachylites are known which also cut rocks of the Engadine Window. Pseudotachylites are widespread also in the westernmost (Kaunertal) and the southern (Schneeberger Zug) Ötztal mass as well as in the western part of the Penser Joch crystalline. A pseudotachylite from the northern border of the Schneeberger Zug (N of St. Martin/Schneeberg) gave a K/Ar age of 74 ± 2,6 m. y. (PESCHEL 1980, unpubl.). It is interesting to note that the so-called "Plattengneistektonik" of the easternmost Austroalpine "Altkristallin" is placed somewhere in the interval of 75–80 m. y. (FRANK, pers. inform.).

2.3 Ötztal Crystalline Mass

The Ötztal block (Ötztaler-Stubaier Altkristallin) forms an overthrusted mass which shows clear tectonic contacts to Pennine rocks in the E (Tauern Window) and in the NW (Engadine Window) and to the Northern Calcareous Alps in the N; whereas in the south there is to date no direct proof from field observations for a clear separation of this unit from the southernmost Austroalpine basement (Complesso Mules-Merano and /or Ortler/ Campo crystalline complex p. p.).

It is known from petrological and from radiometric investigations on rocks and minerals that in the Ötztal crystalline, as in the Silvretta, we are dealing with pre-Hercynian (to ?pre-Cambrian) rock series which have gone intensive Hercynian deformation (with schlingen structures in km scale) combined with a medium to high grade regional metamorphism (SCHMIDT 1965 a).

Increasing diaphthoresis of the pre-Alpine parageneses from N to S has been known of for many years as has been proved by petrographic observations (cf. also RAMMLMAIR 1980, unpubl.). But only radiometric data on minerals was able to fix the time of this overprinting process. This was first done by SCHMIDT et al. (1967) and by HARRE et al. (1968). The results by these authors showed that this diaphthoresis may most probably be connected with an Early Alpine metamorphism of greenschist grade, the final phase fo which had been dated by MILLER et al. (1967) with Rb/Sr cooling ages on biotites of 77 m. y. from the Brenner mesozoic metasediments.

Our results from the southwestern Ötztal mass compare very well with those just mentioned and have partly been already discussed elsewhere (THÖNI 1980 a, b). Summarizing, the following can be stated.

a) From petrographic investigations we distinguish three different areas in the southwestern Ötztal crystalline from W to E. b) These areas show a clear relationship between the distribution pattern of the K/Ar and Rb/Sr model ages of biotite and white mica. c) The results fit in with an increasing thermal overprinting of the pre-Alpine parageneses from W to E, reaching almost perfect recrystallization as well as homogenization of the isotopic systems in a small area in the E, in the central Schneeberger Zug and partly S of this unit (see Plate 1). d) The radiometric results are with a few exceptions well in accordance with the blocking temperature concept in micas (e. g. JÄGER et al. 1967). Thus this region is a reference area for the interpretation of all the other results discussed in this paper.

Fig. 1. Mineral reactions in Austroalpine basement rocks as a result of Alpine reheating and deformation.

a) Kinking in biotite. Pervasive post-Hercynian deformation without recrystallization. Hercynian mineral ages are preserved. Biotite: K/Ar = 285 m. y., Rb/Sr = 283 m. y. Sample T 598, from the Hercynian Zone (see Fig. 2).

c) Pre-Alpine white mica (I) with Alpine phengite rim (II). Enhanced chemical reactivation may lead to "anomalous" Rb/Sr ages in pre-Alpine micas. Sample T 855 from the Alpine stilpnomelane zone.

e–g) Recrystallization behaviour of quartz. e) Deformation lamellae (dl) and strong undulation in quartz; Alpine recrystallization is entirely missing. Sample T 598 – see a)!

g) Polygonal recrystallization of quartz in pre-Alpine crystalline rocks is observed in the chloritoid zone. Sample T 799.

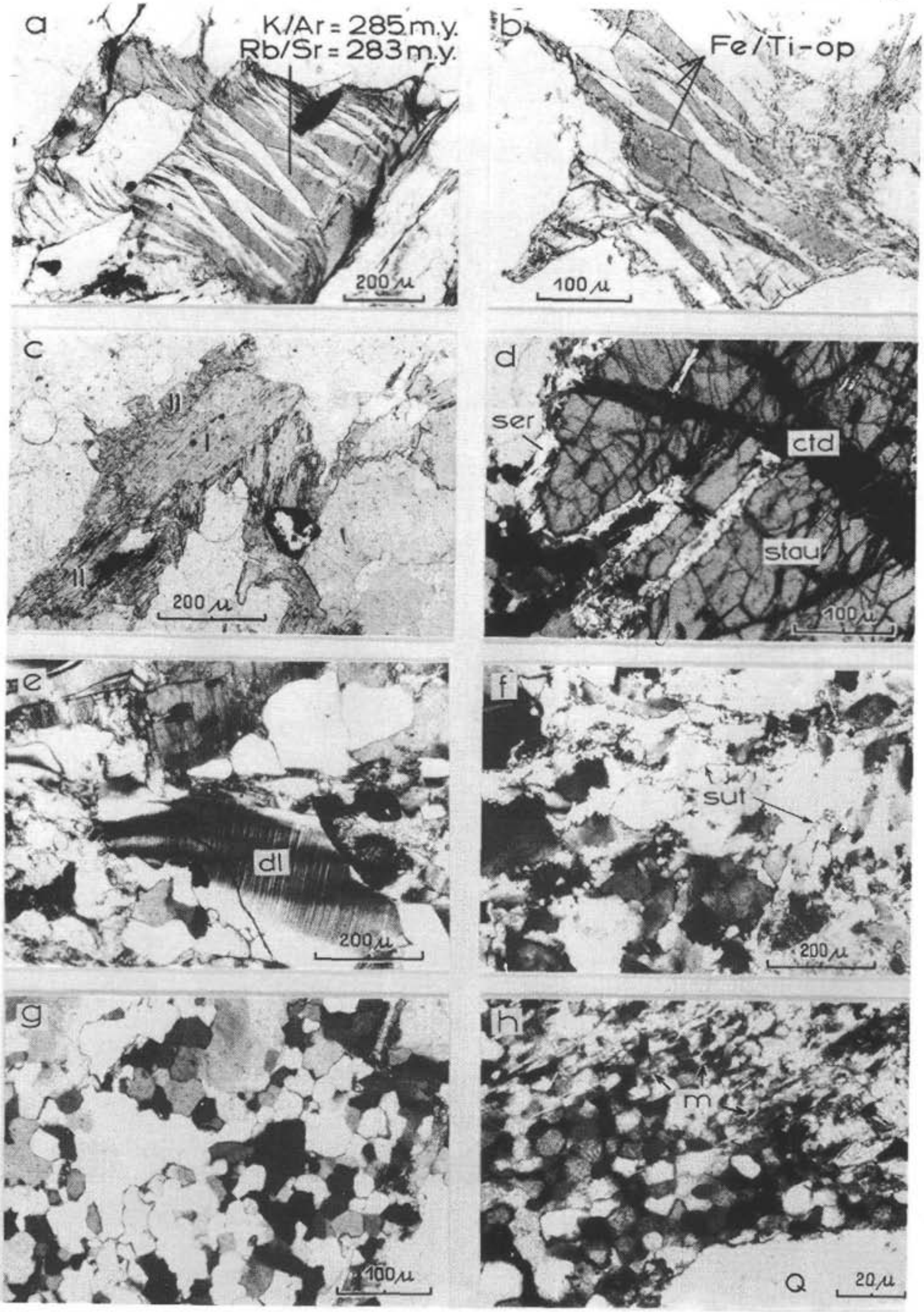
b) Kinked biotite with secondary segregation of Fe and Ti; segregation trails are arranged mainly along the kink bands (Fe/Ti-op); Mixed ages in micas. Sample T 937, from the Alpine chloritoid zone.

d) Diaphthoresis of staurolite: neoformation of sericite = ser (randomly) and chloritoid = ctd (along cracks within the staurolite = stau). Sample T 683 (Ortler crystalline), from the Alpine chloritoid zone.

f) Intense suturation (sut) and beginning recrystallization in the most fine-grained parts and along new grain boundaries. Sample T 1112, from the Alpine stilpnomelane zone.

h) Post-Hercynian metasediments show recrystallization of quartz in the most fine-grained parts, m = neoformation of Alpine mica, Q = coarse detrital quartz. Sample T 544, Jaggl.

Fig. 1


a
K/Ar = 285 m.y.
Rb/Sr = 283 m.y.
200 µ
b
Fe/Ti-op
100 µ
c
200 µ
d
ser
ctd
stau
100 µ
e
dl
200 µ
f
sut
200 µ
g
100 µ
h
m
Q
20 µ

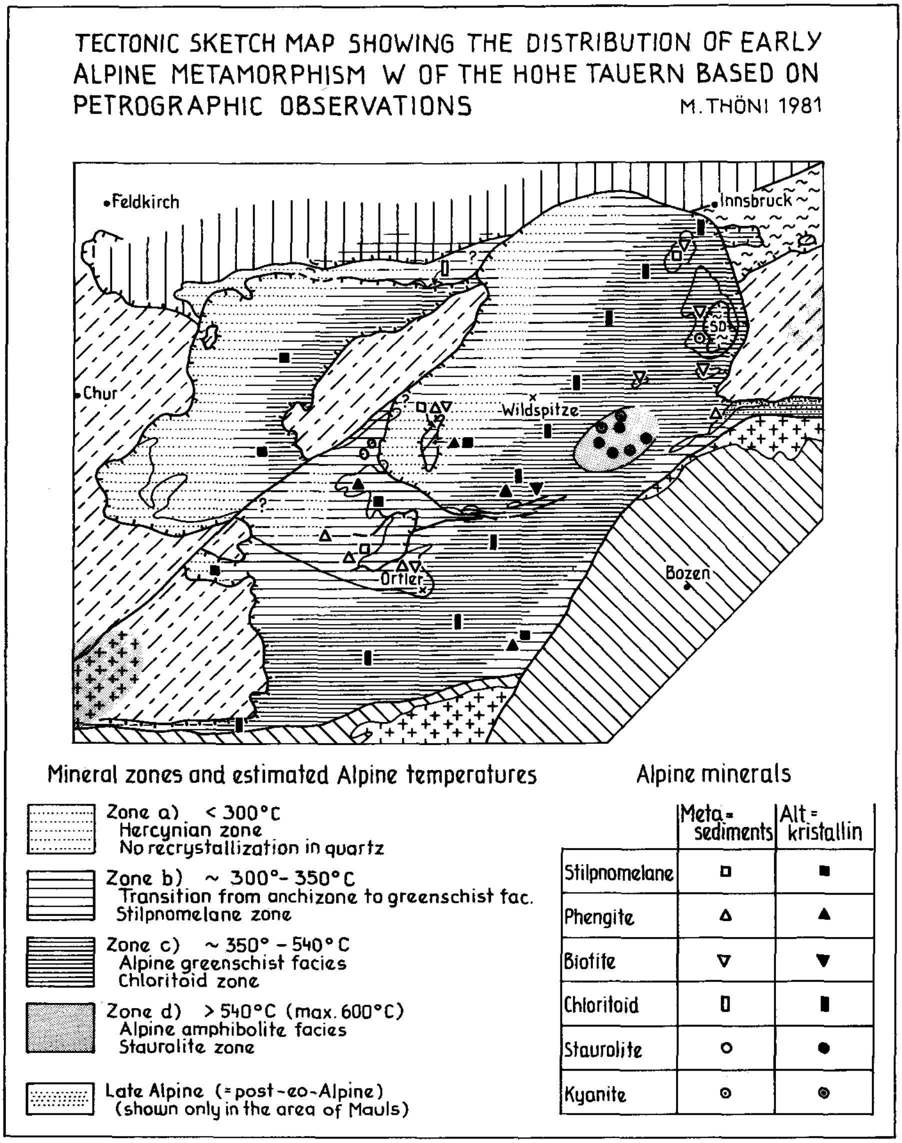


Fig. 2. Alpine temperatures are estimated mainly from the recrystallization behaviour of quartz, feldspars and micas as well as from the intensity of retrograde alterations and/or neoformation of Alpine minerals in Altkristallin rocks and metasediments.

The three zones can be characterized as follows:

α) Zone of Hercynian mica cooling ages. Biotite K/Ar and Rb/Sr ages around 290 m. y. (mean of 16 analyses). White mica: K/Ar and Rb/Sr: 300–330 m. y. Conspicuous retrograde reactions are lacking; only weak sericitization of feldspars, staurolite and kyanite may be observed in some places. This holds also for rocks with very penetrative postcrystalline deformation (sample T 598; see Fig. 1). Quartz shows no recrystallization in the Hercynian zone. Deformation lamellae and kinkbands occur frequently, but a very first fine suturing is observable in some rocks. According to VOLL (1976, and pers. communication) this would reflect Alpine temperatures of $\leq$ 280 °C (cf. Fig. 1).

β) The transition from Zone α) to the β) Zone of mixed ages takes place gradually and can not really be defined with a sharp line as done schematically on Plate 1. More and more retrograde reactions are observable within the primary mineral parageneses of this zone from W to E.

Frequent retrograde reactions are: Alteration of staurolite to sericite, chloritoid and chlorite. The reaction starts with sericite formation randomly and along cracks of the staurolite in the western part of zone β); in the central part however pseudomorphs of chloritoid + sericite after staurolite are observed. The brwon colour of pre-Alpine biotites is more and more lost by "bleaching", and together with this process we very often observe the segregation of Fe-Ti-rich minerals. Such decoration trails occur frequently along kink bands cutting the single grains. Intense chloritization of biotite (or less frequently garnet) comes in in this zone too. Plagioclases are partly altered. The recrystallization behaviour of quartz starts with subgrain formation in very strongly undulatory aggregates and reaches partly well recrystallized mosaic textures in the area of Schlanders (Fig. 1g). In this area we also find very fine-grained biotite which is interpreted as an Alpine neogenic product. It is important to note that the retrograde alterations cannot be observed everywhere in this zone and that partly there exist also better preserved pre-Alpine parageneses. In our opinion these gradual differences in diaphthoresis must be correlated mainly with the varying supply of fluids during Alpine metamorphism; whereas enhanced deformation and textural criteria as differences in schistosity, grain size etc. may be the more negligible parameters.

The K/Ar and Rb/Sr model ages of micas from this zone show the following behaviour from W to E as well as among one another (i. e. from the same sample):

B-Rb/Sr $\leq$ B-K/Ar $<$ M-K/Ar $<$ M-Rb/Sr

In detail: the Rb/Sr system in white micas has not been affected, the white micas yield Hercynian Rb/Sr model ages; whereas the K/Ar ages on biotite and muscovite as well as the Rb/Sr ages of biotite are typical mixed ages falling in the interval between the Early Alpine and the Hercynian metamorphism (100–300 m. y.) and thus representing geochronologically meaningless figures. In some cases considerable amounts of excess radiogenic argon have been incorporated in biotite. This is only clear in those cases where the K/Ar model ages for biotite are much higher than the Hercynian cooling ages from zone α) or if the model ages are higher than the K/Ar ages for white micas from the same rock (cf. sample T 799 in Tab. 5).

As white micas never show (at least high amounts of) excess argon, we think that this excess radiogenic argon in biotite was released from muscovite during the thermal peak of the metamorphism and then incorporated in biotite before cooling below 300 °C. Argon

Table 5: New K/Ar Analytical Data on Micas from the Ötztal Mass

Sample No. Lab. No.	Lithology Sample locality	Analysed mineral Analysed grain size	% K	$^{40}Ar_{rad}$ ccm . 10^{-6} NTP/g	% rad	Model age (m. y.)	Notes
T 1019 WAP 883	Gneissose micaschist Sellraintal	M >150 μ	7,29	90,38	97,53	294 ± 12	
,,	,,	B >150 μ	7,24	94,35	98,37	307 ± 12	? excess argon
T 920 WAP 823	Diaphthoritic gneiss Kaunertal	M >150 μ	7,41	80,18	97,02	259 ± 10	contact zone to Engadine Window
T 917 WAP 822	Paragneiss Kaunertal	Bc 150 – 430 μ	5,84	66,81	98,29	273 ± 11	
T 1023 WAP 886	Granitegneiss Radurscheltal	M 150 – 430 μ	8,71	109,94	90,83	299 ± 13	
T 595 WAP 463	Micaschist Rojental	M 150 – 450 μ	7,75	98,85	96,54	301 ± 12	B–K/Ar 310 ± 9
T 552 WAP 306	Ms-plag-orthogneiss E Jaggl	M >180 μ	9,06	116,34	96,90	303 ± 13	Rb/Sr 327 ± 13
T 598 WAP 464	Paragneiss Langtaufers	M 150 – 430 μ	7,65	98,78	97,39	305 ± 13	
,,	,,	B >150 μ	6,91	82,97	96,43	285 ± 12	Rb/Sr 283 ± 11
T 602 WAP 467	Paragneiss Langtaufers	Quartz >150 μ	0,0467	0,838	15,99	(411 ± 103)	B–K/Ar 297 ± 9 M–K/Ar 312 ± 10
T 864 WAP 712	Pegmatite Schlandraun	M 150 – 250 μ	8,75	52,95	85,01	149 ± 8	Rb/Sr 345 ± 20
T 799 WAP 679	Gneissose micaschist N Schlanders	M 150 – 430 μ	8,05	55,33	97,36	169 ± 7	Rb/Sr 321 ± 84
,,	,,	B 150 – 430 μ	6,99	74,16	95,0	254 ± 11	excess argon, Rb/Sr 155 ± 11
T 715 WAP 522	Quartzose paraschist Stubaital	M 150 – 430 μ	7,30	55,82	97,11	187 ± 8	B–K/Ar 95 ± 4
T 716 WAP 523	Gneissose paraschist St. Leonhard/ Passeier	M 150 – 430 μ	7,45	23,42	95,21	79 ± 3,3	B–K/Ar 78 ± 3
T 717 WAP 524	Paraschist Töll/Meran	M 150 – 430 μ	7,33	22,15	93,11	76 ± 3	B–K/Ar 75 ± 3
T 543 WAP 603	"Hyänenmarmor" Obernberger Tribulaun	M <2 μ	5,16	17,12	66,24	83,4 ± 5	
T 873 WAP 715	Stau-ky-micaschist Penser Joch	M 170 – 430 μ	6,40	80,30	97,14	297 ± 12	
,,	,,	B 170 – 430 μ	6,42	68,80	98,43	257 ± 10	Rb/Sr 271 ± 11

mobilization would thus work within a small rock volume without migration over large distances, micas being the only argon rich minerals in the rocks investigated (no K-feldspar is present in these rocks). It should be noted that all Rb/Sr ages on biotite from zone β) are younger than their corresponding K/Ar ages and are partly already Early Alpine cooling ages (cf. Sample T 704, T 794, Tab. 6).

γ) For the zone of Alpine biotite cooling ages we refer mainly to the results of other authors. The transition zone between β) and γ) is less well known in the southern Ötztal mass.

Table 6: Rb/Sr Analytical Data from Biotites of the Southwestern Ötztal Mass

Sample No. Lab. No.	Lithology Sample locality	Analysed sample	^{87}Rb ppm	$^{87}Sr_{rad}$ ppm	Sr_{total} ppm	%rad	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model age m. y.	Model age corr. m. y.	Notes
T 602 WAP 467	Paragneiss Langtaufers	B 150 – 450 μ	138,1	0,565	4,59	66,87	350,6	2,143	287 ± 12	286	K/Ar = 297 ± 9
T 598 WAP 464	Paragneiss Langtaufers	B 70 – 250 μ	140,8	0,566	7,62	53,63	204,1	1,531	283 ± 11		K/Ar = 285 ± 12
T 635 WAP 478	Paragneiss H. Matscher Alm	B 150 – 430 μ	116,3	0,307	5,99	43,80	209,2	1,263	186 ± 7,5		K/Ar = 749 ± 23 (excess argon)
T 768 WAP 648	Bi-sil-schist Schluderns	B 170 – 430 μ	126,8	0,236	4,95	41,84	274,74	1,221	131 ± 5,2		
T 799 WAP 679	Gneissose micaschist N Schlanders	B 150 – 430 μ	132,8	0,293	12,97	24,97	107,12	0,946	155 ± 11		K/Ar = 254 ± 11 (excess argon)
T 794 WAP 664	Paragneiss Schlanders	B 170 – 430 μ	126,2	0,1468	13,91	13,31	93,74	0,8191	82 ± 11,5		K/Ar = 438 ± 18 (excess argon)
T 704 WAP 513	Ga-micaschist Schnals	B 150 – 450 μ	172,1	0,1883	6,06	31,59	299,89	1,0381	77 ± 4,1		K/Ar = 462 ± 14 (excess argon)
T 873 WAP 715	Micaschist Penser Joch	B 170 – 430 μ	196,0	0,756	2,50	86,15	1146,0	5,129	271 ± 11		K/Ar = 257 ± 10

Table 7: Rb/Sr Analytical Data on White Micas from the Southwestern Ötztal Crystalline Basement

Sample No. Lab. No.	Lithology Sample locality	Analysed sample	^{87}Rb ppm	$^{87}Sr_{rad}$ ppm	Sr_{total} ppm	%rad	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model age m. y.	Model age corr. m. y.	Notes
T 520 WAP 293	Ms-plag-granitoid E Jaggl	M >250 μ	676,7	3,004	5,29	94,98	3025,2	14,142	312 ± 12		K/Ar = 313 ± 10
T 552 WAP 306	"	M >180 μ	697,6	3,244	8,14	90,51	1457,4	7,253	327 ± 13		K/Ar = 303 ± 13
T 864 WAP 712	Pegmatite Schlandraun	M >150 μ	112,6	0,563	20,01	29,41	59,20	1,006	351 ± 20	345	K/Ar = 149 ± 8
"	"	WR	55,2	0,334	127,38	3,65	4,44	0,737	425 ± 229		
T 602 WAP 467	Paragneiss Langtaufers	WR	26,93	0,168	146,47	1,63	1,88	0,7219	438 ± 534		
"	"	M 150 – 430 μ	45,23	0,248	212,89	1,65	2,17	0,7221	385 ± 463	Isochron age 316 ± 10 (Fig. 9) [T 602 M to T 799]	K/Ar = 312 ± 10
T 761 WAP 645	Paragneiss Tannas	M 70 - 170 μ	72,1	0,344	197,36	2,45	3,74	0,7280	335 ± 270		K/Ar = 263 ± 11 + phengite + paragonite
T 768 WAP 648	Gneissose mica-schist Schluderns	M 170 – 430 μ	50,4	0,246	64,48	5,23	8,02	0,7493	343 ± 127		
T 794 WAP 664	Paragneiss N Schlanders	M 150 – 430 μ	48,6	0,232	165,89	1,98	3,00	0,7244	335 ± 336		K/Ar = 228 ± 9
T 799 WAP 679	Gneissose micaschist N Schlanders	M 150 – 430 μ	48,3	0,2205	39,93	7,40	12,43	0,7669	321 ± 84		K/Ar = 169 ± 7

In the eastern part of the Ötztal-Stubaier Altkristallin the Alpine metamorphic zone extends far to the N: neoformation of Alpine biotite has been reported (and temperatures exceeding 400 °C) by H. DIETRICH (1980, unpubl.) from the northernmost Brenner metasediments (Kalkkögel area) just S of Innsbruck.

From the Schneeberger Zug area very fresh coarse-grained mineral parageneses without striking diaphthoritic alterations are known. Geological and petrological investigations over the last years have shown that most probably amphibolite facies conditions were effective in the central-southwestern Schneeberger Zug and partly south of this unit (PURTSCHELLER et al. 1980, MAURACHER 1980, PESCHEL 1980, HOINKES 1981) during the Early Alpine metamorphism. In different localities new findings of tiny fresh staurolites have been mentioned by the above authors and are interpreted as Alpine minerals. According to petrological investigations by HOINKES (1981 and pers. comm.) temperatures exceeding 550 °C were effective in the area of Pfelders–St. Leonhard/P. during the Cretaceous metamorphism (see also GREGNANIN & PICCIRILLO 1969 a).

The final phase of this metamorphism has been well documented by SCHMIDT et al. (1967) and by SATIR (1975) with Rb/Sr and K/Ar cooling ages of 75–82 m. y. on biotite and with K/Ar ages on white micas of 77–90 m. y. (cf. Tab. 5). However, the question as to when this Cretaceous metamorphism reached the thermal peak is still not entirely solved. K/Ar ages of 90–110 m. y. on hornblende reported by MAURACHER (l. c.) from the Texelgruppe as well as Rb/Sr ages on white micas of 110–130 m. y. from the Altkristallin adjoining the central Schneeberger Zug area by SATIR (1975) do not fit well into the tectonic-metamorphic evolution scheme of the Austroalpine unit, if interpreted as formation ages (cf. 4.2).

The southernmost part of the southern Altkristallin, the "Merano-Mules complex" shows fairly well preserved pre-Alpine parageneses, a fact which is well in agreement with the weak (here Late Alpine) metamorphism of the Permotriassic rocks of the Mauls-Penser Joch syncline (FRANK et al. 1977). A micaschist from the Penser Joch (Tab. 5, sample T 873) shows randomly very slight sericitization of staurolite and kyanite and still yields a Hercynian K/Ar muscovite age of 297 m. y. Similar conditions are found further to the SW, S of St. Leonhard/P. Thus, with the above described Alpine temperature conditions in the area of St. Leonhard we note a very rapid decrease in the (Alpine) metamorphic grade from N to S. It is still to be proved whether we are here dealing with a continuous or with a tectonically disturbed metamorphic profile.

2.4 Ortler-Campo Complex, Languard Crystalline and Tonale Zone

In the eastern part of this greater unit we refer mainly to the detailled studies carried out by ANDREATTA (e. g. 1951, 1954; cf. geological map, sheet "Monte Cevedale" 1 : 100.000, etc.). Lithologically and in respect to the metamorphic grade this author gives the following classification:

a) Phyllite group (type quartzphyllite)
b) Meso-epizonal paraschists
c) Mesozonal paraschists
d) Katazonal paraschists.

a) The tectonically highest unit, the phyllites form a large synclinorium striking ENE to WSW from Meran in the E to the Valtellina in the W. The most widespread parageneses can be described as follows:

Qz + Ms + Chl ± Bi ± Ga ± Ab/Plag + Acc (tourm, clzo/ep, ap, zr, haem, lim, tit)

According to ANDREATTA (1951, 1954 a) there can be observed continuous gradations of the phyllites into the higher metamorphic subjacent rocks (of type c and b) and/or interbedding with them. These "epizonal" (greenschist facies) phyllites show a clear diaphthoritic character, e. g. chloritization of biotite and garnet, neoformation of sericite/phengite etc., as described already in detail by ANDREATTA. However, contrary to this author, we would not use the term "phyllonites" as derivates from a former much higher metamorphic "mesozonal" crystalline for these rocks (l. c., 1954 b, p. 70). Anticipating, the main metamorphism (reaching middle to max. higher greenschist facies conditions) must be of Hercynian age, whereas the diaphthoresis should represent, in our opinion the effects of Alpine events. This diaphthoresis is readily traceable in the underlying crystalline.

b) Meso-epizonal and c) mesozonal paraschists. According to ANDREATTA (l. c.) the meso-epizonal group accompanies the phyllites in the S; meanwhile, the mesozonal paraschists underly the phyllites in the N. This northern paragneiss/micaschist series forms the southern slopes of the Vinschgau and contains as special intercalations the famous "Laaser Marmore". Lithologically very similar to this rock sequence is the "Laaser Serie", a rock series rich in marbles and micaschists which accompanies the Schneeberger Zug in the S. A direct primary connection between these rock series is possible and was probably disturbed by late Cretaceous/Tertiary tectonic rotation and westward movements of the Ötztal mass along the Schlinig thrust (cf. p. 157).

There are no striking differences between b) and c). Staurolite has not been mentioned by ANDREATTA from the unit b), but has been found during our field work in different localities (upper Val di Rabbi: sample T 854; upper Val della Mare: T 877; S of Passo di Gavia: T 869, here also sillimanite).

d) The medium grade metamorphic Ortler-Campo basement is bordered and partly overthrust from the S along the "linea di Peio" (ANDREATTA 1948) by the Katazonal paraschists. These rocks form the socalled Tonale Zone, a narrow (near Malé only about 10 km) wedge which extends from S of the lower Ultental (SW Meran), far to the W, still being affected by the Lepontine metamorphism in the area E and W of Lago di Como. In the area in discussion this high grade metamorphic zone is delimited tectonically by the Tonale/Judicarien Line in the S and SE and by the already mentioned Peio Line in the N. In the eastern part this crystalline consists of high metamorphic paragneisses rich in garnet, kyanite, biotite and sillimanite (kinzigites p. p., see ANDREATTA 1935 and/or "granulites" p. p., see HAMMER 1902). Vortex structures ("Schlingenbau") are also typical for the central part of the eastern Tonale Zone. In this area granitegneisses, migmatites (orthoclase bearing parageneses) and many small lenses (10 m scale) of basic to ultrabasic rocks are intercalated between the "normal" paragneisses. The latter rocks are known from the older literature as "Olivinfelse" (HAMMER 1902) and as "oliviniti" (ANDREATTA 1935) and have been interpreted recently partly as mantle-peridotites (spinel-garnet-lherzolites, HERZBERG et al. 1977; ROST & BRENNEIS 1978).

The direct continuation of this southernmost Austroalpine crystalline W of the Lago Maggiore would be the Canavese Zone which is a part of the "Tessiner Wurzelzone". Lithologically, however, there are only weak affinities between the Canavese Zone and the eastern Tonale Zone; but there are very striking similarities of the latter unit with the rock suite (high grade metamorphic paragneisses with intercalations of acid and basic magmatites) of the so called "Kinzigitzone". This "Kinzigitzone" there (WALTER 1950) is situated S of the main Periadriatic Lineament and makes part of the crystalline basement of the Southern Alps ("Seenplatte"). According to CARRARO et al. (1970) however, this high metamorphic zone is a part of the root zone of the Austroalpine Unit s. l. (there represented e. g. by the Dent Blanche Nappe), together with the Ivrea Zone S and the Canavese and the Sesia-Lanzo Zone N of the Insubric Line. In this context the eastern Tonale Zone could be a unit of great tectonic-paleogeographic importance.

Dealing with this topic we should mention also the striking similarities of the Tonale schists with the Unit (Nappe) of Matsch (HAMMER 1931, GREGNANIN & PICCIRILLO 1974). The main rock type of the Tonale Zone between the Valtellina and the Val di Rabbi are coarse-grained paragneisses to micaschists rich in biotite, plagioclase and sillimanite with frequent intercalations of orthogneisses, marbles and amphibolites. The same holds for the Unit of Matsch from the southern Ötztal mass.

Table 8: K/Ar Analytical Data from Micas of the Campo-Ortler Crystalline Complex and Ortler Metasediments (OM); Sample arrangement from E to W

Sample No. Lab. No.	Lithology Sample locality	Analysed mineral Analysed grain size	% K	$^{40}Ar_{rad}$ ccm . 10^{-6} NTP/g	% rad	Model age (m. y.)	Notes
T 747 WAP 555	Chl-ab-phengite-schist NW Innersulden (OM)	M <2 μ	2,22	7,58	53,87	85,8 ± 6,4	sample rich in chlorite and albite
T 749 WAP 557	Bio-phengite-schist NW Innersulden (OM)	M (+ B) <2 μ	5,88	20,11	89,20	85,9 ± 3,9	neoformation of Alpine biotite
T 833 WAP 693	Ms-chl-schist Martelltal	M 74 – 170 μ	7,46	33,48	98,09	112 ± 4,5	
T 834 WAP 694	Muscovitegranite-gneiss Martelltal	M >150 μ	9,01	41,63	95,11	115 ± 4,8	Rb/Sr 254 ± 10
T 584 WAP 942	Metadiorite W Prad/Vinschgau	Bci 170 – 430 μ	5,96	60,34	95,87	234 ± 10	
T 862 WAP 710	Ga-micaschist Ultental	M 170 – 430 μ	7,43	39,93	96,49	133 ± 5,5	
T 854 WAP 707	Stau-ga-micaschist Val di Rabbi	B 170 – 430 μ	6,70	181,08	97,21	588 ± 24	excess argon Rb/Sr 99 ± 8
"	"	M 170 – 430 μ	7,22	35,67	94,73	123 ± 5	
T 849 WAP 705	Biotitite Val di Rabbi	B 150 – 430 μ	7,85	68,33	96,48	211 ± 9	
T 969 WAP 848	Paragneiss S Passo di Gavia	B >250 μ	7,37	53,61	98,33	178 ± 7	excess argon Rb/Sr 145 ± 6
"	"	M >250 μ	8,23	44,90	94,04	135 ± 5,7	
T 966 WAP 845	Pegmatite S Passo di Gavia	M 150 – 430 μ	8,24	42,73	90,16	129 ± 5,7	Rb/Sr 314 ± 13
T 945 WAP 832	Gneissose micaschist Val Grosina	B >150 μ	7,49	49,90	96,77	164 ± 6,7	
"	"	M >150 μ	8,42	62,67	96,08	182 ± 7,6	
T 946 WAP 833	Pegmatite Val Grosina	B >150 μ	6,99	34,14	84,20	122 ± 5,8	Rb/Sr 97 ± 4
"	"	M >150 μ	8,46	64,65 64,98	90,26 89,53	187 ± 8 187,5 ± 8	Rb/Sr 329 ± 15
T 977 WAP 852	And-schist (contact rock) Val della Mare/Peio	B >150 μ	7,53	8,99	81,30	30,5 ± 1,5	
"	"	M >150 μ	7,75	9,42	68,0	31,0 ± 1,8	

Summarizing, the crystallization of the apparent medium to high grade parageneses N and S of the Peio Line must be of Hercynian age (with ?pre-Hercynian relics in the highest metamorphic parts, of the eastern Tonale Zone), as shown by Rb/Sr cooling ages on white micas of 310–330 m. y. (Tab. 11). These data compare very well with corresponding results from the Austroalpine crystalline units further N.

The diaphthoresis of these pre-Alpine parageneses by a metamorphism of much lower grade (as mentioned already above for the phyllite group) is clearly traceable all over the Ortler-Campo crystalline complex as well as the Tonale Zone and is more intense in the central parts of this greater unit. Retrograde alterations may be observed in micas, garnet, staurolite, plagioclase, kyanite, sillimanite, K-feldspar. Secondary products are sericite, phengite, chlorite, epidote/clinozoisite, and chloritoid. A very widespread and remarkable similarity with the southern Ötztal mass is the bleaching and segregation of "ilmenite" (Fe-Ti rich aggregates) trails along kinks within biotites of the Tonale Zone between Sondrio and the upper Val di Sole.

Table 9: K/Ar Analytical Data from Micas of the Tonalezone. Sample arrangement from E to W

Sample No. Lab. No.	Lithology Sample locality	Analysed mineral Analysed grain size	% K	$^{40}Ar_{rad}$ ccm . 10^{-6} NTP/g	% rad	Model age (m. y.)	Notes
T 984 WAP 857	Kinzigitegneiss W Rumo	B >150 μ	7,10	49,52	97,39	171 ± 7	
”	”	M >150 μ	8,49	65,71	98,02	189 ± 8	
T 985 WAP 858	Granitegneiss Val di Lavazzé	B >150 μ	7,47	99,36	80,24	313 ± 15	excess argon Rb/Sr 215 ± 9
”	”	M >150 μ	8,62	85,49	95,80	239 ± 10	
T 855 WAP 708	Ms-plag-orthogneiss S. Bernardo/Rabbi	M >300 μ	9,06	112,28	99,17	294 ± 12	M with phengite rims (thin section) Rb/Sr 234 ± 9 (!)
T 980 WAP 855	Ms-granitegneiss S. Bernardo/Rabbi	M >150 μ	9,04	110,02	98,12	289 ± 12	Rb/Sr 317 ± 13
T 971 WAP 850	Micaschist E Tonale Pass	B >150 μ	6,77	27,29	86,67	101 ± 4,6	
”	”	M >150 μ	7,92	49,34	96,33	154 ± 6,4	
T 970 WAP 849	Paragneiss Ponte di Legno	B >150 μ	7,37	81,06	97,70	263 ± 11	excess argon
”	”	M >150 μ	8,30	47,57	93,27	142 ± 6	
T 943 WAP 830	Quartzose micaschist Tirano/Valtellina	B 150 – 430 μ	7,65	119,19	95,82	362 ± 15	excess argon
T 935 WAP 826	Hybrid gneiss Val Fontana	M >150 μ	8,05	48,25	96,57	148 ± 6	
T 937 WAP 828	Bi-sil-micaschist Val Fontana	B >150 μ	7,14	87,62	94,22	291 ± 12	excess argon
”	”	M >150 μ	6,32	51,81	97,02	200 ± 8	

This low grade metamorphic event is reflected in partial reopening of both the K/Ar and Rb/Sr systems in biotite and of the K/Ar system in white mica, producing mixed ages of mostly 100–200 m. y. (Tab. 9). The Rb/Sr system in white micas, however, has not been affected (except in one special case; cf. p. 151). There are no striking differences in the

K/Ar age results, whether very coarse-grained and more resistent (e. g. the very coarse-grained muscovites from weakly foliated pegmatites) or whether fine-grained rock types were investigated. Excess argon is present in biotites also in this region. The loss of radiogenic ^{87}Sr in biotites was partly almost accomplished reaching model ages of ≦ 100 m. y. (samples T 854, T 946 in Tab. 9). Early Alpine Rb/Sr cooling ages on biotites (77, 78 m. y.) have already been reported by GRAUERT et al. 1974 from the upper Martelltal, E of the Ortler.

If we consider the regional picture (Fig. 2), the diaphthoritic zone of the Ortler-Campo crystalline which extends to the W as far as to the Lower Austroalpine of the Bernina area, is a direct southwestern continuation of the mixed age zone of the Ötztal mass, probably produced by a SW plunging of the "Schneeberg thermal high". As in the Ötztal crystalline, within the Ortler-Campo Complex we observe a notable decrease of the described retrograde metamorphic imprints towards the NW. The westernmost Languard crystalline near Pontresina yielded Hercynian K/Ar and Rb/Sr biotite cooling ages (Tab. 10, 11). The pre-Alpine parageneses are well preserved; however, tiny Alpine neogenic stilpnomelane was observed in one sample. A slight decrease in the Alpine metamorphic grade may also be observed in the SE. In the easternmost part of the Tonale Zone we still find Hercynian K/Ar ages in white micas from parageneses showing neoformation of Alpine stilpnomelane and phengite (sample T 980, Tab. 9). This weakly overprinted zone has its correspondence in the fairly well preserved crystalline of the southern part of the Merano-Mules complex further NE (cf. p. 128).

Summarizing, and considered in a regional context the diaphthoresis of pre-Alpine parageneses as well as the lowering of the Hercynian mica ages may be mainly due to the Early Alpine metamorphism, but later effects can not be excluded (p. 158).

Table 10: New K/Ar Analytical Data from the Languardkristallin and from the Scarl-Umbrail Unit

Sample No. Lab. No.	Lithology Sample locality	Analysed mineral Analysed grain size	% K	$^{40}Ar_{rad}$ ccm . 10^{-6} NTP/g	% rad	Model age (m. y.)	Notes
T 957 WAP 841	Granitegneiss Livigno	Bci >150 μ	6,59	66,88	97,03	244 ± 10	
T 953 WAP 838	Flaser gneiss Val di Livigno	M >150 μ	8,00	106,37	97,50	313 ± 13	
T 1013 WAP 880	Paragneiss Pontresina	B >150 μ	7,85	91,20	96,44	277 ± 11	Rb/Sr 280 ± 11
T 1014 WAP 881	Paragneiss Pontresina	B >150 μ	7,58	91,24	95,00	286 ± 13	
"	"	M >150 μ	8,66	112,90	98,91	308 ± 12	
T 1112 WAP 899	Granitegneiss N Umbrail Pass	M >150 μ	8,88	114,87	98,68	305 ± 12	Rb/Sr 274 ± 11 (!)
T 1125 WAP 901	Muscovitegranitegneiss Val Muraunza	M >150 μ	8,73	113,01	96,39	306 ± 13	
T 732 WAP 539	Augengneiss Val Sesvenna/Scarl	M 150 – 430 μ	8,60	112,17	98,29	308 ± 13	Rb/Sr 328 ± 13
T 503 WAP 287	Verrucano Cierfs/Münstertal	WR 140 – 250 μ	2,65	10,23	69,64	96,7 ± 5,5	K/Ar <2 μ 87 ± 3
T 1000 WAP 873	Verrucano Cierfs/Münstertal	WR 140 – 250 μ	2,05	8,49	85,39	103 ± 5	see Fig. 6
T 757 WAP 642	*Sericitephyllite* Tannas/Vinschgau	WR 140 – 250 μ	2,41	7,69	52,31	80,3 ± 6	K/Ar <2 μ 78,5 ± 4,7

Table 11: Rb/Sr Analytical Data from Micas of the Ortler-Campo Crystalline Complex (OC), the Tonalezone (TZ) and the Languardkristallin (L)

Sample No. Lab. No.	Lithology Sample locality	Analysed sample	^{87}Rb ppm	$^{87}Sr_{rad}$ ppm	Sr_{total} ppm	%rad	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model age m. y.	Model age corr. m. y.	Notes
T 834 WAP 694	Granitegneiss (OC) Martelltal	M >150 μ	199,0	0,720	4,50	73,28	538,3	2,658	254 ± 10		K/Ar = 115 ± 5
T 854 WAP 707	Micaschist (OC) Val di Rabbi	B 170 – 430 μ	218,1	0,307	17,36	20,57	130,7	0,894	99 ± 8,6		K/Ar = 123 ± 5
T 966 WAP 845	Pegmatite (OC) S Passo di Gavia	M 150 – 430 μ	253,7	1,133	2,43	92,59	1988,2	9,591	314 ± 13		K/Ar = 129 ± 6
T 969 WAP 848	Paragneiss (OC) S Passo di Gavia	B >250 μ	117,4	0,245	5,30	41,13	237,4	1,206	147 ± 6		K/Ar = 178 ± 7
T 946 WAP 833	Pegmatite (OC) Val Grosina	B >150 μ	281,4	0,389	2,55	72,18	1332,1	2,553	97 ± 4	96	K/Ar = 122 ± 6
"	"	M >150 μ	135,2	0,633	17,53	35,03	81,76	1,093	329 ± 15	327	K/Ar = 187 ± 8
"	"	WR	48,7	0,242	82,08	4,09	6,08	0,7404	350 ± 167		
T 985 WAP 858	Granitegneiss (TZ) Val di Lavazzé	B >150 μ	207,2	0,632	4,88	68,15	498,0	2,229	215 ± 9		K/Ar = 313 ± 15 (excess argon)
T 855 WAP 708	Orthogneiss (TZ) Val di Rabbi	M >300 μ	401,8 403,8	1,312 1,344	2,33 2,57	94,89 94,02	4036,0 3354,3	13,889 11,879	230 ± 9 234 ± 9		K/Ar = 294 ± 12 Phengite rims!
T 980 WAP 855	"	M >150 μ	327,0	1,476	3,18	92,55	1955,2	9,537	317 ± 13		K/Ar = 289 ± 12
T 1013 WAP 880	Paragneiss (L) Pontresina	B >150 μ	126,9	0,506	4,57	64,22	319,5	1,984	280 ± 11		K/Ar = 277 ± 11

Direct proof for the age of this metamorphism should be given from mineral ages of the Ortler mesozoic metasediments. Similarily to the metasediments of the Scarl Unit, these rocks show metamorphic imprints of weakest greenschist facies conditions. The few investigated samples collected NW of Innersulden show partly well recrystallized quartz textures and neogenic white mica (10–50 μ) and chlorite. Additionally, sample T 749, a fine-grained greybrown schist (?Upper Triassic) shows an already intense biotite growth. In our opinion the chemical suitability for this mineral reaction was much better in those rocks than in all Permoscythian rocks investigated from the Scarl Unit (see next chapter), where Alpine biotite formation was observed only in one special case. The Early Alpine metamorphic conditions reached in the Ortler sediments during the Cretaceous however, should not differ very much from those of the southern Scarl Unit, as deduced from mineralogical, textural and K/Ar isotopic criteria. Thus, the two K/Ar ages of 86 m. y. from fine fractions of the Ortler metasediments (Tab. 8) could reflect just the first phase of cooling after the thermal peak which was reached in the Scarl Unit around 90 m. y.

2.5 Scarl-Umbrail Basement and Engadine Dolomites

Seven white micas from different localities of the Scarl-Umbrail orthocrystalline yielded Hercynian K/Ar ages of 300–310 m. y.; meanwhile, the biotites of the Sesvenna area show partly little loss of radiogenic argon (Tab. 11 and THÖNI 1980 a, b). The few Rb/Sr analyses on micas show, in priciple, Hercynian ages, but a partly anomalous behaviour within the Rb/Sr system should be noted (p. 144).

In Fig. 3 eight whole rock samples from the Scarl orthocrystalline are plotted in a Rb/Sr evolution diagram. Sample T 612, a biotitegranitegneiss, shows kyanite in the thin section and is possibly a hybrid rock, mixed with paramaterial. This sample has not been included for the age calculation. Sample T 563, a strongly foliated muscovitegranitegneiss with a much higher Rb/Sr ratio than all the other samples, was collected at a distance of several km from the localities of all the other samples. If we include this sample in the age calculation, we get an errorchron age of 325 ± 4 m. y. ($I_0 = 0{,}7191$). The remaining six samples define a total rock errorchron age of 336 ± 7 m. y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0,7172.

We should discuss now, whether this result of 336 (325) m. y. should be related with the intrusion of the metagranitoids or with a metamorphic event. The regional distribution of the mica ages of the wider area investigated shows that a widespread cooling process after the intensive Hercynian metamorphism started sometime between 330 and 300 m. y. within the Austroalpine crystalline. The K/Ar and Rb/Sr system in biotite was closed definitely and on a regional scale around 270 m. y.

Table 12: Rb/Sr Analytical Data from Whole Rocks and Micas of the Scarl Unit (= Münstertal orthogneisses)

Sample No. Lab. No.	Lithology Sample locality	Analysed sample	^{87}Rb ppm	$^{87}Sr_{rad}$ ppm	Sr_{total} ppm	%rad	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model age m. y.	Model age corr. m. y.	Notes
T 563 WAP 563	Muscovitegranite-gneiss Fuldera/Lü	WR	141,1	0,665	20,2	32,9	73,9	1,0588	331 ± 17		
T 566 WAP 562	Muscovitegranite-gneiss Val d'Avigna	WR	48,6	0,269	35,7	9,9	14,02	0,7882	390 ± 75		
T 569 WAP 561	"	WR	40,6	0,267	136,4	2,75	3,05	0,7304	462 ± 331	Errorchron age 336 ± 7 (325 ± 4) m. y. $I_o = 0{,}7172 \pm 0{,}0017$	
T 571 WAP 559	"	WR	64,8	0,336	30,2	13,9	22,15	0,8251	364 ± 49		
T 612 WAP 473	Hybrid gneiss N Taufers	WR	30,9	0,21	223,1	1,34	1,416	0,7200	478 ± 709		
T 731 WAP 538	Granite gneiss Val Sesvenna	WR	52,4	115,–	0,31	3,81	4,67	0,7384	422 ± 218		
T 732 WAP 539	Muscovitegranite-gneiss Val Sesvenna	WR	72,2	0,35	22,6	18,7	33,16	0,8735	346 ± 33		
T 804 WAP 681	Muscovitegranite-gneiss Schlinig	WR	46,36	0,272	82,36	4,55	5,77	0,7440	412 ± 177		
T 562 WAP 564	Muscovitegranite-gneiss Fuldera/Lü	M 150 – 430 μ	446,2	1,904	3,18	95,53	3555,7	15,881	300 ± 12	295	K/Ar = 300 ± 9
T 612 WAP 473	Bi-plag-gneiss Val d'Avigna	B 140 – 450 μ	83,2	0,354	6,42	45,61	140,1	1,306	298 ± 12	296	K/Ar = 272 ± 8
T 732 WAP 539	Muscovitegranite-gneiss Val Sesvenna	M 150 – 430 μ	214,2	1,001	2,34	86,0	934,3	5,074	328 ± 13	327	K/Ar = 308 ± 13
T 803 WAP 680	Metatonalite Schlinig	B 150 – 250 μ	117,4	0,433	7,56	46,68	168,5	1,332	259 ± 10		K/Ar = 298 ± 13
T 804 WAP 681	Muscovitegranite-gneiss Schlinig	M 250 – 430 μ	147,0	0,681	10,05	51,17	160,45	1,454	326 ± 13	323	K/Ar = 302 ± 14
T 804 WAP 681	"	M < 3,5 μ	83,50	0,229	56,69	5,53	15,11	0,7517	(193 ± 68)	(58)	K/Ar = 90 ± 5,6
T 1112 WAP 899	Granitegneiss P. da Rims/Umbrail	M > 150 μ	347,9 348,7	1,355 1,315	2,76 2,40	93,30 94,57	2536,9 3280,9	10,596 13,080	274 ± 11 265 ± 11		K/Ar = 305 ± 12 new separation

Thus the thermal peak of this Hercynian metamorphism should have been reached up to or before 325 m. y. (= Visé/Namur). According to the partly intense foliation and the metamorphic textures the Scarl orthogneisses underwent strong deformation after their intrusion. The relatively high initial $^{87}Sr/^{86}Sr$ ratio of 0,7172 points to a metamorphic rather

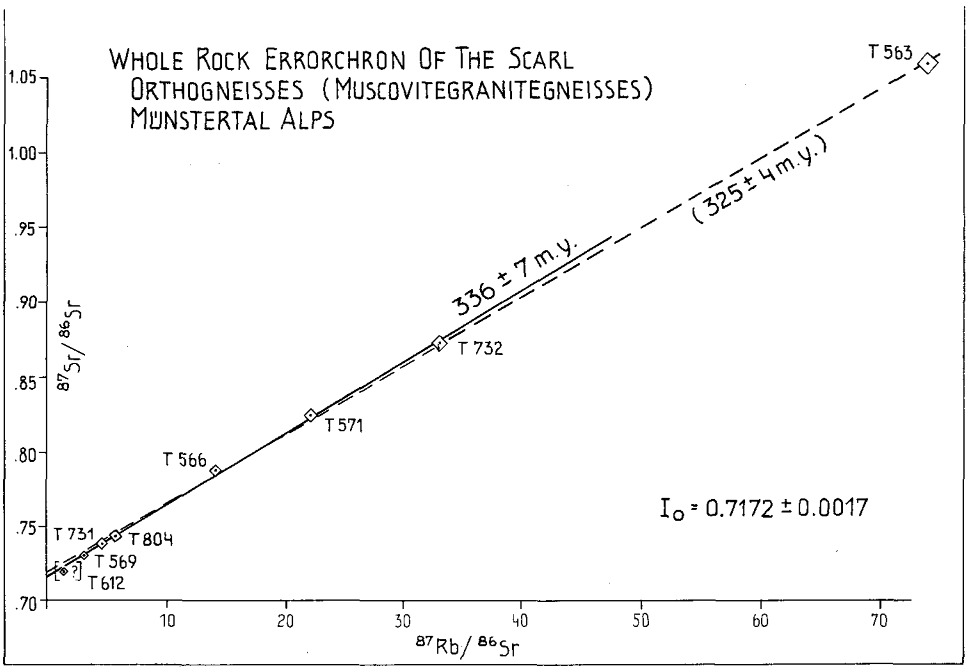


Fig. 3. The Rb/Sr errorchron age of 336 ± 7 m. y. falls in the time interval where the thermal peak of the Hercynian metamorphism could be expected. Almost all Hercynian mineral ages of the area investigated are younger than 330 m. y.

than to a primary-magmatic event. The errorchron age of 336 m. y. falls, in our opinion, in the time interval where the thermal peak of the Hercynian metamorphism could be expected. Thus, we can not decide, whether in the case of the Scarl orthogneisses we are dealing with Hercynian or with pre-Hercynian intrusives. But beyond all doubt, these rocks have been affected to great extent by the Hercynian metamorphism.

Lithologically very similar to the Münstertal orthogneisses are the "aplitic-pegmatitic muscovitegranitegneisses" of the southern Silvretta crystalline (GRAUERT 1969, p. 113). These intrusives gave a Rb/Sr whole rock age of 350/351 m. y. According to GRAUERT the rocks are acid differentiation products still belonging to the Caledonian petrogenetic cycle, and were intruded as late descendants only during the Hercynian crustal movements.

As described elsewhere the orthogneisses of the Scarl (and Umbrail) Unit show imprints of a (retrograde) low temperature metamorphism with partial recrystallization of quartz, local chloritization of biotite and by partly intense crystallization of fine-grained phengite/-muscovite. Stilpnomelane is present in some thin sections of these rocks. In our opinion these secondary alterations of the metamorphic mineral parageneses can be related to the Early Alpine metamorphism. In one case it could be demonstrated that this interpretation may be suitable. From a strongly deformed muscovitegranitegneiss of the eastern Scarl Unit, near to the Schlinig thrust, the grain size $< 3.5\ \mu$, was separated by sedimentation.

Because of the admixture of small amounts ($\leq$ 10%) of feldspar (plagioclase and K-feldspar) and quartz ($\sim$ 20%) in the mica concentrate the age result is not very reliable but the K/Ar model age of 90 $\pm$ 6 m. y. of this sample falls in the same time interval as the K/Ar ages of the neogenic white micas from the overlying Verrucano and points thus to an Upper Cretaceous formation of the fine-grained micas within the Scarl crystalline *). In many of the crystalline rocks small quantities of carbonate were observed in the thin section. We think that the weak Cretaceous metamorphism in the Scarl Unit was probably connected with an intense mobilization of fluids in the post-Hercynian sediments. These fluids could have even slightly affected the Rb/Sr system of the underlying crystalline, as supposed by thin section analysis. The scattering of the data points in the Rb/Sr evolution diagram of Fig. 3 may be partly related to such processes (cf. GEBAUER & GRÜNENFELDER 1974, 1976).

The Alpine metamorphism of the Scarl metasediments (Engadine Dolomites) reaches lowest greenschist facies conditions in the basal parts (Verrucano). Apart from textural criteria such as partial recrystallization in quartz the presence of neogenic phengite/-muscovite, chlorite and stilpnomelane support this statement. In the Jaggl area biotite was observed in one special case. Within the separated white micas (fine fractions < 2 µ) only the 2 M modification is present (cf. MAXWELL & HOWER 1967; FRANK & STETTLER 1979). This weak metamorphism decreases slightly from S to N as well as from bottom to top within the Scarl Unit. The occurrence of pyrophyllite in two samples from S Sta. Maria points to anchizonal conditions (cf. SCHMID 1973, FREY 1978). However, in this special case the pyrophyllite formation may be related with a post-Cretaceous tectonic reactiviation, as suggested by Rb/Sr data (see below).

The K/Ar data of the neogenic white micas (grain size < 2 µ) from the Scarl Permoscythian show a fairly clear separation in two age groups. For these analytical results we refer to THÖNI 1980 a, b. When plotted on a ^{40}Ar/K diagram (cf. Fig. 4) 24 samples from the (northern) Münstertal-Jaggl area scatter along a trend line of 90 m. y.; whereas 20 analyses of the southern Scarl Unit, including Ortler metasediments and the sericite-phyllites of the Vinschgau, point to an age of 80 m. y. Additionally, Fig. 4 shows that no or only very small amounts of inherited radiogenic argon can be present in the analysed samples and that the apparent ages may well be related with a geological event as discussed in detail in chapter 3. The former interpretation was that the 80 m. y. age group represents cooling ages, whereas the age group around 90 m. y. could be related with the thermal peak of the Early Alpine metamorphism. To verify this interpretation, several samples have been investigated using the Rb/Sr small scale isochron method. Most of these results, plotted in Fig. 5, 6, are not conclusive enough to make a definitive statement, but shall however be discussed shortly. The following facts make Rb/Sr analytical work more difficult:

a) A possibly incomplete Sr isotopic homogenization during the weak Alpine metamorphism even in restricted areas (m-scale, see Fig. 5).

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*) The corrected Rb/Sr model age (58 m. y.; Tab. 12) of this sample is geologically meaningless and demonstrates (as in the case of the Verrucano samples) that the neogenic white micas did not equilibrate their Sr isotopes with all the whole rock system. Thus (apart from the problem of the mineral separation), it may be rather impossible to calculate a geologically correct Rb/Sr model age in such a case, because the true initial ^{87}Sr/^{86}Sr ratio of the mineral is unknown.

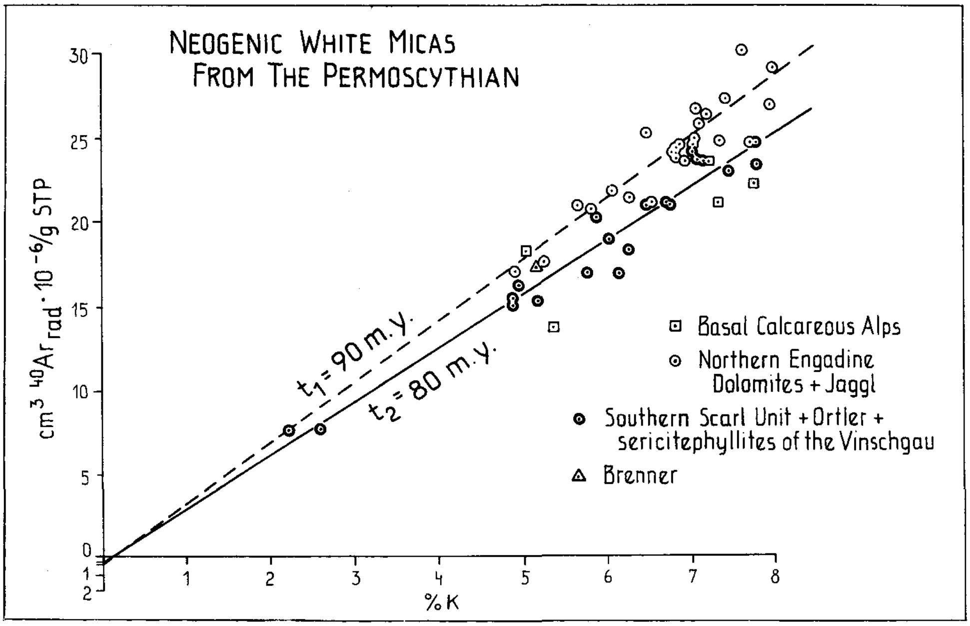


Fig. 4. The calculated trend line of 90 m. y. is related with the thermal peak of the Early Alpine metamorphism, whereas at 80 m. y. regional cooling had begun within the Austroalpine unit.

b) Admixture of small amounts of detrital material in the analyzed fine fractions (e. g. detrital white mica, which is present in most cases in the rock) with different and in any case high concentrations of radiogenic ^{87}Sr. Such "impurities" in the analyzed sample, not detectable with sufficient accuracy by any method would not influence very much the K/Ar ages as demonstrated above, but could well have a notable influence on the Rb/Sr analytical results.

c) Using the small-scale (m-scale) sampling method (because, we can only expect a sufficient isotopic homogenization within small areas if at all), the chances of getting reasonable spread in the Rb/Sr ratios of the lithologically very similar samples are poor. Insufficient spread in the Rb/Sr ratios, however, makes isochron calculation impossible (Fig. 6).

d) As a complete isotopic homogenization is questionable, the age calculation from whole rock/mineral pairs (two point isochrons) is problematic and may give erroneous results (cf. Fig. 8).

Fig. 5 shows the grain sizes $< 2\ \mu$ and 2–6 μ of six Permoscythian rocks from S Sta. Maria/M. in a Sr evolution diagram. Whereas five samples of the fraction $< 2\ \mu$ are alined along a trend line corresponding to an errorchron age of 50 $\pm$ 7,5 m. y., the coarser grain size shows a much more pronounced scattering of the data points. The corresponding errorchron age is 90 $\pm$ 20 m. y. The K/Ar ages of the $< 2\ \mu$ grain size (using the same concentrates for the analysis) are Upper Cretaceous, but show an unusual wide scattering of 77–92 m. y. (THÖNI 1980 b, p. 152) if compared with other results. A postmetamorphic deformation which is much more intense than in other areas of the Münstertal, can be

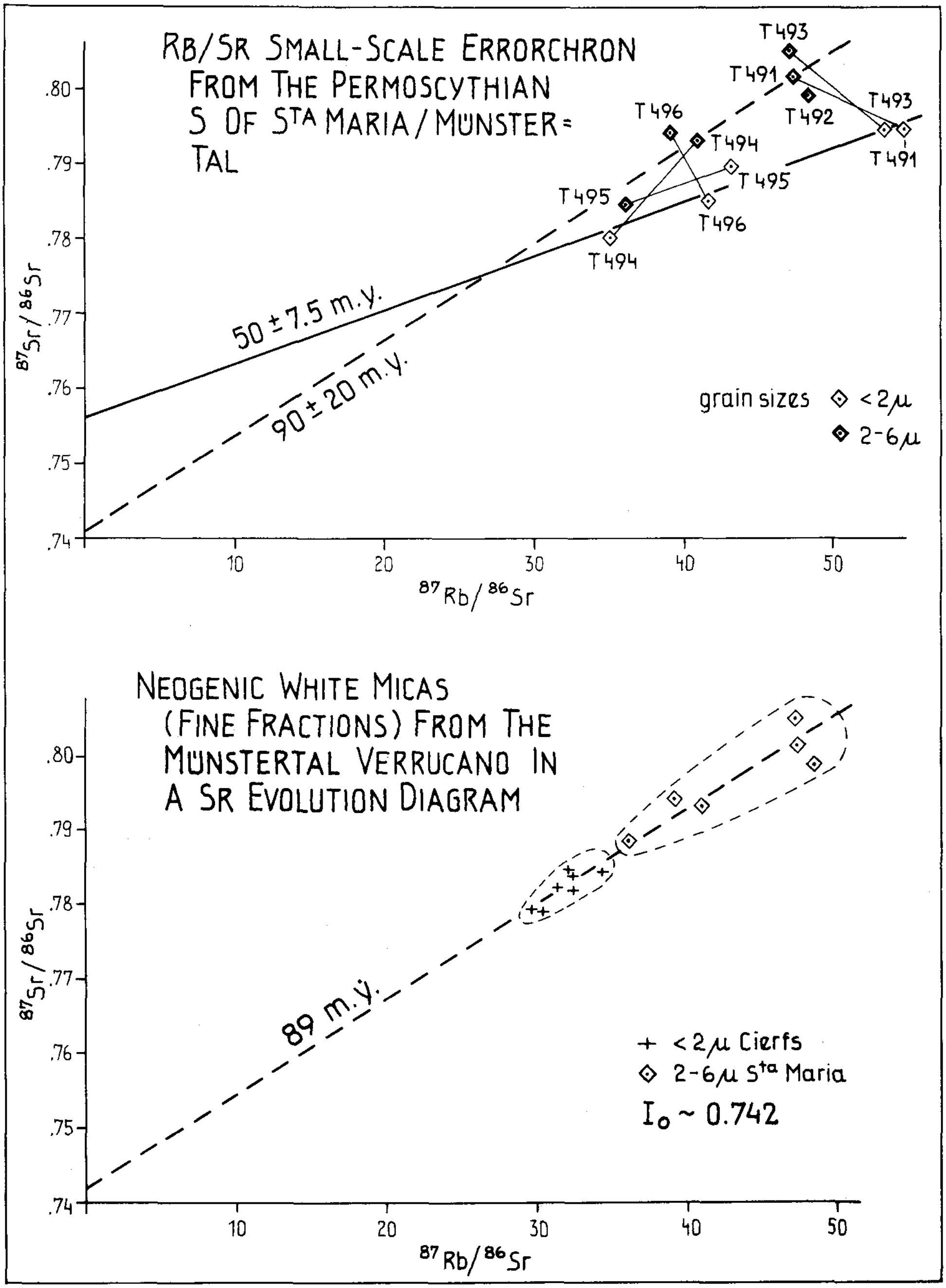


Fig. 5, 6. Rb/Sr small-scale "errorchrons" from the Engadine Dolomites demonstrate that good isotopic homogenization was not reached during the Early Alpine metamorphism within the metasediments. Thus the computed age values are of poor reliability, but they agree well with a thermal peak around 90 m. y. Furthermore, Fig. 5 shows that locally post-Cretaceous reactivation of isotopic systems can be expected.

Table 13: Rb/Sr Analytical Data from fine fractions of Permoscythian Rocks from the Southern Engadine Dolomites (S Sta. Maria/Road to Umbrail Pass)

Sample No. Lab. No.	Lithology Sample locality	Analysed sample	^{87}Rb ppm	$^{87}Sr_{rad}$ ppm	Sr_{total} ppm	%rad	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model age m. y. $I_o = 0{,}71014$	Model age corr. m. y.	Notes
T 491 WAP 279	Quartz–sericite/phengite–schists road to Umbrail Pass, at Hotel „Alpenrose" S of Sta Maria/Münstertal	M <2 μ	123,1	0,189	23,08	10,62	54,99	0,7945	(108 ± 19)	Errorchron age 50 ± 8 m. y.	K/Ar = 86,5 ± 3
T 492 WAP 924		"	132,5	0,29	33,52	11,2	40,76	0,7999	(155 ± 26)		
T 493 WAP 280		"	121,6	0,19	23,43	10,6	53,51	0,7946	(111 ± 20)		K/Ar = 84 ± 3
T 494 WAP 281		"	110,3	0,22	32,34	9,0	35,08	0,7804	(141 ± 30)		K/Ar = 77,5 ± 3
T 495 WAP 282		"	118,1	0,22	28,12	10,1	43,24	0,7898	(129 ± 24)		K/Ar = 92 ± 3
T 496 WAP 283		"	111,2	0,20	27,48	9,53	41,69	0,7851	(126 ± 27)		K/Ar = 79,6 ± 3
T 491 WAP 279		M 2 – 6 μ	114,1	0,22	24,78	11,41	47,45	0,8018	(136 ± 22)	„Errorchron" age 90 ± 20 m. y.	
T 492 WAP 924		"	118,2	0,22	25,20	11,12	48,37	0,7992	(129 ± 22)		
T 493 WAP 280		"	108,3	0,22	23,68	11,77	47,20	0,8051	(141 ± 23)		
T 494 WAP 281		"	107,5	0,22	27,10	10,46	40,88	0,7933	(143 ± 26)		
T 495 WAP 282		"	109,8	0,23	31,37	9,47	36,07	0,7846	(145 ± 29)		
T 496 WAP 283		"	108,8	0,23	28,74	10,57	39,01	0,7943	(151 ± 28)		

Table 14: Rb/Sr Analytical Data from Fine Fractions and Whole Rocks of the Münstertal Verrucano/Cierfs

Sample No. Lab. No.	Lithology Sample locality	Analysed sample	^{87}Rb ppm	$^{87}Sr_{rad}$ ppm	Sr_{total} ppm	%rad	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model age m. y. $I_o = 0{,}71014$	Model age corr. m. y.	Notes
T 994 WAP 867	Quartz–sericite–schist ca. 800 m ESE Cierfs/Münstertal 2 m profile	M <2 μ	110,8	0,252	35,26	9,38	32,37	0,7837	(160 ± 32)		"Errorchron" age 90 ± 26 m. y. (89 ± 7 m. y.) see Fig. 6
T 995 WAP 868		"	110,5	0,245	35,10	9,18	32,43	0,7819	(156 ± 32)		
T 996 WAP 869		"	106,6	0,245	35,04	9,20	31,32	0,7821	(162 ± 33)		
T 997 WAP 870		"	112,4	0,255	37,92	8,85	30,31	0,7791	(160 ± 35)		
T 998 WAP 871		"	113,0	0,245	33,93	9,46	34,31	0,7844	(152 ± 31)	(45)	
T 999 WAP 872		"	110,2	0,256	35,45	9,50	32,01	0,7847	(164 ± 33)		
T 1000 WAP 873		"	111,7	0,262	38,87	8,89	29,59	0,7794	(165 ± 35)	(63)	
T 998 WAP 871		WR	47,2	0,126	18,92	8,83	25,68	0,7789	188 ± 41		
T 1000 WAP 873		WR	38,1	0,127	22,28	7,62	17,59	0,7687	234 ± 59		K/Ar = 103 ± 5

derived from field observations (cf. SCHMID 1973). Our present interpretation for the data in discussion is, that the Rb/Sr system has been more intensely affected during post-Cretaceous tectonic processes (eventually combined with a slight rise in temperature or with hydrothermal events) than the K/Ar system in the most fine-grained parts of these rocks. But this raises the question then, whether or not the K/Ar ages have a geological significance or if they should be related to excess argon which did not leave the rocks during this late tectonic-metamorphic event. In any case, the Rb/Sr system points to a post-Cretaceous disturbance. The Rb/Sr errorchron age of 50 m. y. may be interpreted as a true age (thus being related with a geological event), or as a mixed age. In the latter case the overprinting process should have taken place after 50 m. y.

From the Verrucano of Cierfs 7 fine fractions $< 2\ \mu$ from a postmetamorphic undisturbed profile of ca. 2 m have been analyzed (Tab. 14). Earlier K/Ar analyses of $< 2\ \mu$ fractions from the same outcrop gave model ages of 87–89 m. y. If plotted on a Rb/Sr evolution diagram the seven samples show a very small spread in their Rb/Sr ratios between 30–34. Thus no reliable isochron calculation is possible and the computed value of 90 ± 26 m. y. may be no more than a chance hit. From a combination of Fig. 6 with the 2–6 μ data points form S of Sta. Maria (Fig. 5) (an operation which is justified to a certain extent by a similar lithology and by a very similar initial ratio of the two rock series) there results an errorchron age of 89 ± 7 m. y.

Possibly more reliable information about the timing of the Early Alpine metamorphism could be drawn from K/Ar analyses on total rocks from the Permoscythian.

A complete argon loss in the weak metamorphic Scarl metasediments is not very likely as deduced by the presence of partly still well recognizeable detrital components (thin section). On the other hand we should bear in mind that total argon loss could take place most probably before "breaking up all lattice bonds" (FRANK & STETTLER 1979) and that thus the coarse detrital mineral components (white micas) which can be observed microscopically in these rocks must not necessarily have retained all their inherited (pre-Alpine) radiogenic argon (cf. chapter 3). In any case we would expect that the maximum argon loss was reached in these rocks when the temperature reached its (last) climax. Thus such K/Ar whole rock ages could be interpreted as "maximum formation ages" which "predate" possibly the thermal peak of the Cretaceous metamorphism by a few millions of years due to different small amounts of inherited $^{40}Ar_{rad}$ from the most coarse-grained detrital components. Three K/Ar whole rock ages from the Permoskythian of the Jaggl area range between 102–104 m. y. (THÖNI 1980 a, b), whereas two ages from the Münstertal Verrucano near Cierfs lie at 97 and 103 m. y., respectively (Tab. 10). The $< 2\ \mu$ fine fractions from four of these five samples gave K/Ar model ages of 87–93 m. y. On the other hand, two sericitephyllite samples from the Vinschgau area (part of these sericitephyllites are interpreted as the eastern continuation of Scarl metasediments) gave younger K/Ar whole rock ages and are well in agreement with an increase of the Alpine temperature pattern from W to E. We think that the K/Ar whole rock age of 92 ± 4 m. y. from a sericitephyllite near Eyrs/Vinschgau (just at the western end of the „Zone of mixed ages" see p.) is very near to the thermal peak of the Cretaceous metamorphism; whereas the K/Ar age of 80 ± 6 m. y. from a sericitequartzite further east (Tab. 10, sample T 757) may be related to the Upper Cretaceous cooling. Both samples show well recrystallized textures of quartz and white mica.

Table 15: Rb/Sr Analytical Data from Whole Rocks and Fine Fractions of a Mylonite of the Jaggl Area

Sample No. Lab. No.	Lithology Sample locality	Analysed sample	^{87}Rb ppm	$^{87}Sr_{rad}$ ppm	Sr_{total} ppm	%rad	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model age m. y. $I_o = 0{,}71014$	Model age corr. m. y.	Notes
T 718 WAP 525	Mylonite (?Permoscythian, ?Metaporphyroid) Tectonic contact Jaggl Metasediments /Ötztal Altkristallin Val Truyen/Langtaufers	M <2 μ	88,1	0,148	39,43	5,16	22,93	0,7488	(119 ± 45)	Isochron age 113,4 ± 1,8 m.y. $I_o = 0{,}71245 \pm 0{,}0005$ (Fig. 7)	
T 720 WAP 527		"	64,7	0,125	96,65	1,83	6,85	0,7233	(136 ± 147)		
T 721 WAP 528		"	75,2	0,140	77,95	2,53	9,88	0,7286	(131 ± 102)		
T 722 WAP 529		"	68,9	0,128	83,25	2,18	8,48	0,7259	(131 ± 119)		
T 723 WAP 530		"	87,45	0,153	39,23	5,34	22,88	0,7502	(123 ± 45)		
T 724 WAP 531		"	94,45	0,158	28,94	7,33	33,55	0,7663	(118 ± 33)		K/Ar = 93 ± 4
T 718 WAP 525		WR	42,04	0,114	99,45	1,63	4,327	0,7219	(192 ± 233)	Errorchron age (= mixed age) 181 ± 18 m. y. $I_o = 0{,}7113 \pm 0{,}0014$	
T 720 WAP 527		WR	33,76	0,095	123,82	1,09	2,79	0,7180	(198 ± 360)		
T 722 WAP 529		WR	33,74	0,099	111,41	1,27	3,10	0,7192	(207 ± 324)		
T 723 WAP 530		WR	35,92	0,112	61,17	2,58	6,01	0,7289	(220 ± 168)		
T 724 WAP 531		WR	50,06	0,13	55,29	3,30	9,28	0,7343	(184 ± 109)		K/Ar = 104 ± 12
T 723 WAP 530		M 3 – 11 μ	60,0	0,131	45,98	3,94	13,381	0,7393	(153 ± 76)	(99)	
T 723 WAP 530		M 11 – 20 μ	47,0	0,117	50,28	3,26	9,58	0,7341	(176 ± 106)	(102,5)	

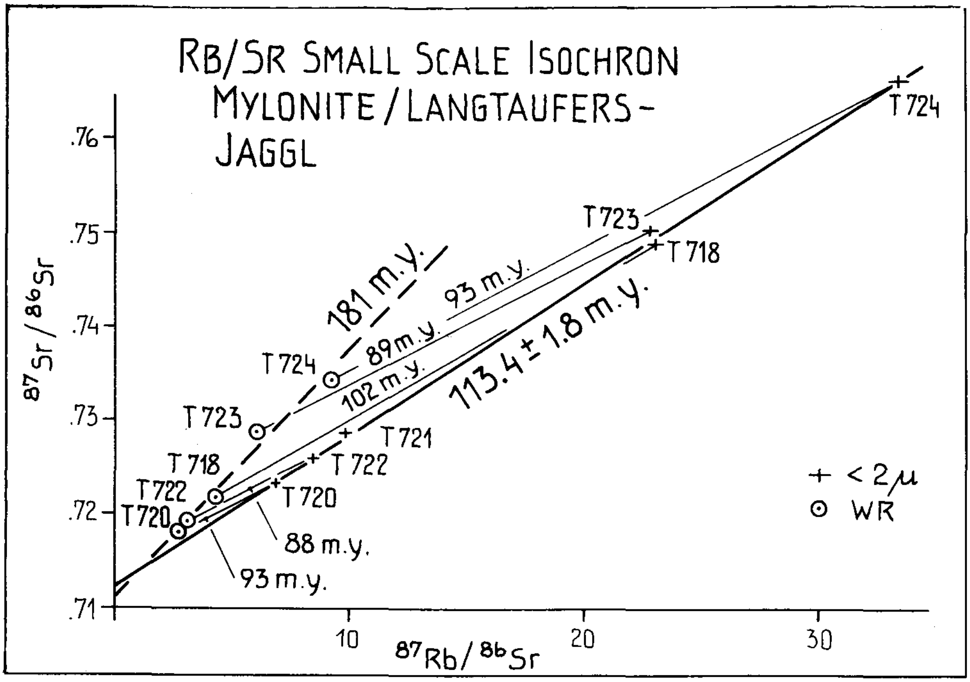
To summarize, all the data now being discussed is irrespective of its good or poor reliability, well in agreement with the assumption of a thermal peak roughly around 90 m.y. (and probably not older than 100 m.y.).

Rb/Sr data from a mylonite of the northeastern Jaggl window however, still point to earlier tectonic processes in the Austroalpine Unit. The samples T 718–T 724 plotted in Fig. 7 belong to a profile of only ca. 4 m in thickness forming a mylonite horizon which is in tectonic contact to the overlying Ötztal crystalline. Most probably we are dealing with Permoscythian rocks (?metaporphyroid), but the participation of Altkristallin can not be excluded (?sample T 723). The thin sections show neoformation of phengite, chlorite, stilpnomelane, clinozoisite, and, in two cases, also biotite (microprobe analyses). On the other hand, coarse detrital components are still recognizable (strongly deformed quartz pebbles, partly with resorption tubes, plagioclase and white mica). Five whole rock samples from this mylonite scatter along a trend line of 181 ± 20 m. y.; whereas the < 2 μ fine fractions define a fairly reliable isochron of 113,4 ± 1,8 m. y. If we calculate the different twopoint isochrons of the fine fractions (< 2 μ) and their corresponding whole rock data point, we get model ages of 88, 89, 93 and 93 m. y.; sample T 718 which does not belong directly to the 4 m profile, yields a value of 102 m.y.

The following interpretation is given at present, for these age results.

a) The WR errorchron age of 181 m. y. is a mixed age and has no geological significance.

b) Though well in agreement with the regional metamorphic evolution, the two-point isochrons of 88–93 m. y. do not reflect a geological event. This must be derived from microscopical observations, which demonstrate clearly that a perfect homogenization of the Rb and Sr isotopes in the whole rock system cannot be expected for the last metamor-



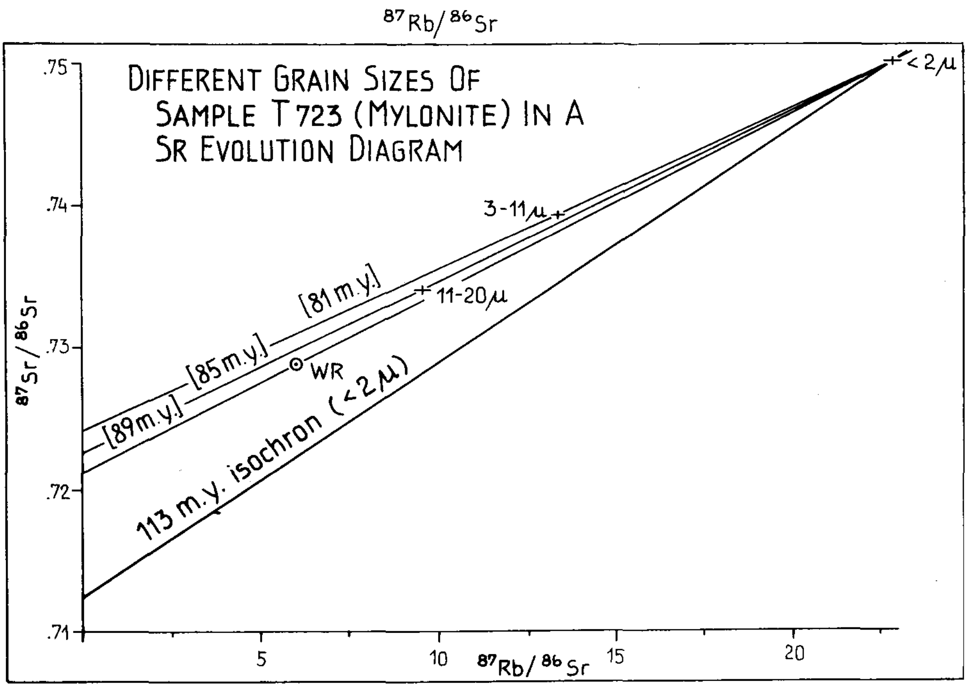


Fig. 7, 8. The 113 m. y. isochron is related with early tectonic movements, which started in the Austroalpine unit before the thermal climax of the Early Alpine metamorphism was reached. All the other (except the 113 m. y.) "ages" figured in the two diagrams are interpreted as geologically meaningless mixed ages, due to an incomplete isotopic homogenization in the coarse-grained parts of the rocks analyzed.

phic event effective in these samples, as coarse-grained detrital components still are well recognizeable. This is demonstrated also by Fig. 8: the coarser the analyzed grain size, the higher are the amounts of inherited $^{87}Sr_{rad}$.

c) From the fairly good linear arrangement of the < 2 μ data points we deduce that a good isotopic homogenization took place between the fine-grained parts of the 4 m profile. Thus the 113 m. y. isochron reflects a geological event.

Theoretically, the 113 m. y. trend line could represent a mixed age, the geological event connected with the isotopic homogenization being younger than 113 m. y. and older than 90 m.y. This, however, would be possible only if the admixture of not homogenized material within the < 2 μ fraction is very similar for all six samples alined along the 113 m. y. isochron and must be excluded on the basis of petrographic observations.

Thus, if the 113 m. y. isochron reflects a geological event, it is the analytically most reliable one among all the Rb/Sr data of the Scarl metasediments; but the 90 m. y. metamorphic event is not corroborated by this result.

As deduced from structural criteria, the isotopic homogenization could have taken place during a pervasive deformation of the rock analysed; even more, we think that the mylonitization was the main reason for the good isotopic homogenization, never reached in other cases where this deformation is missing (cf. Fig. 5, 6). Furthermore, we could expect a considerable and early increase of the local temperature regime in this mylonite horizon by frictional processes (cf. BRUN & COBBOLD 1980). Thus, the 113 m. y. isochron would reflect a tectonic process. On the other hand, the microfabrics show, that the crystallization onlasted the deformation process; this means, that the thermal peak of the regional metamorphism was reached after 113 m. y., as deduced also from K/Ar data of sample T 724: < 2 μ = 93 m. y., WR = 103 m. y. (see Tab. 15).

Thus, the data now being discussed does not contradict with the postulation of a 90 m. y. regional metamorphic event. But it can be deduced thereof that tectonic processes had started much earlier within the Austroalpine rock series (cf. p. 156).

3. General Remarks and Interpretation Problems

Some general problems concerning the behaviour of isotopic systems should be discussed in order to realize the geological significance of model ages and/or isochron ages listed in chapter 2.

3.1 K/Ar versus Rb/Sr (see Plates 2–5)

Considering the areas which show only very weak or no post-Hercynian metamorphic imprints, good concordance is reached in some cases with the K/Ar and Rb/Sr method for the same biotite concentrate. In other cases the two age values do not overlap within the limits of error (sample T 612). Obviously the K/Ar and/or Rb/Sr system could have been slightly influenced in these areas, though Alpine metamorphism reached only anchizonal to weakest greenschist metamorphic conditions. The Scarl crystalline is a good example for beginning reactions in the isotopic systems of pre-Alpine micas.

However, it has been mentioned (p. 136) that the Rb/Sr system of total rocks could have been slightly opened during the very weak/weak Alpine metamorphism in the Scarl Unit. According to this interpretation the beginning of a mobilization of the Sr and/or Rb isotopes is postulated. T and p conditions of the Alpine metamorphism in the Scarl orthogneisses should have been definitely too weak to destroy the linear arrangement of a Rb/Sr whole rock isotopic system (Fig. 3). But enhanced mobilization of fluids (e. g. from the overlying sediments of the Engandine Dolomites) could make this possible. Sr mobilization could thus work by reopening of only a small part of the mineral systems of the rock, and the scatter of the data points in the Rb/Sr evolution diagram depends on the quantity of $^{87}Sr_{rad}$ lost or gained in the analyzed sample.

In the areas where Alpine greenschist facies metamorphism definitely prevailed, both the K/Ar and the Rb/Sr system in biotite as well as the K/Ar system in white micas were clearly reopened producing geologically meaningless model ages (= Hercynian/Alpine mixed ages).

In almost all cases biotites from the overprinted basement rocks show higher K/Ar than Rb/Sr ages. In some cases the K/Ar biotite age is even higher than the calculated K/Ar model age of the white mica from the same rock specimen, often exceeding the 300 m. y. (Hercynian cooling age) limit. The following explanation may be given for this fact. The Rb/Sr system was disturbed mainly in biotite during the low grade Alpine metamorphism by a partial loss of radiogenic Sr from the crystal lattice; whereas the second, and in paraschists the only still Rb and Sr rich mineral, the white mica, was not affected. Considering the K/Ar system however, both biotite and white mica were reopened and part of the radiogenic ^{40}Ar, accumulated in these minerals since the Hercynian cooling was lost from these minerals. But the metamorphic conditions during Early Alpine times were not only to low to produce a total argon loss from the minerals (micas), they were especially too weak to expell the radiogenic argon, released from the mineral lattices, from the whole rock system. Thus, the white micas closed again their K/Ar isotopic system at a time when the peak of the overprinting metamorphism was reached or shortly after this time. The biotites however, closed later, i. e. at the final phase of the cooling processes and could thus incorporate different and in some cases high amounts of the $^{40}Ar_{rad}$ remaining in the rock and present today as excess argon in biotite. As already mentioned, the number of such K/Ar model ages are geochronologically meaningless; but they are not without any significance.

Firstly, these ages reflect polyphase metamorphism and secondly, presuming Hercynian ages for the micas analyzed, the figure of the age is proportional to the quantity of $^{40}Ar_{rad}$ lost (or gained) during the Early Alpine metamorphism.

Generally the K/Ar model ages of white micas show a direct and ± continuous relationship to the increase of Alpine metamorphism. This may best be studied in the mixed age zone of the southern Ötztal mass: the further we go to the E, the younger are the calculated K/Ar model ages of white mica. In the weakest metamorphic parts of these mixed age zones, where the Hercynian K/Ar ages of pre-Alpine white micas have been preserved, we never find excess argon in biotite, but only argon loss. Further, to rearrange the K/Ar system in both white mica as well as biotite, i. e. to reach an almost perfect argon loss in the whole rock system of metamorphic rocks, we should reach middle to higher greenschist facies conditions, considering the regional distribution of pre-Alpine mineral parageneses and fabrics. Finally, we should point out, that we could not detect any relation between argon loss and primary grain size in Altkristallin rocks. Coarse grained pegmatites show similar K/Ar white mica model ages to finer grained paraschists or even phyllites from the same area (cf. e. g. T 833, T 834, T 862 in Tab. 8). Thus the retentivity for ^{40}Ar in white micas can not be explained mainly by volume diffusion (cf. p. 132).

It is possible that argon diffusion from coarse-grained micas is attained mainly by mechanical deformation along optically not detectable subgrain boundaries, provided that the critical "opening temperature" is reached within the rock.

We find a much different situation in the weakly and monometamorphic metasediments (Scarl/Ortler). The Verrucano samples with varying amounts of detrital components of the Scarl Unit yield model ages which in our opinion are already near to real metamorphic ages. Thus a considerable loss of radiogenic argon must also be expected for detrital pre-Alpine micas. Argon loss from the whole rock system of these metasediments would have taken place partly during diagenesis and could have continued during Alpine metamorphism when part of the detrital components recrystallized. In any case, considering the very low/low metamorphic grade of these metasediments, the ^{40}Ar retention level would be considerably lower than in the polymetamorphic crystalline rocks. This may partly be related to the much higher amount of fluids present in the sediments contrary to the pre-Alpine crystalline rocks during metamorphism, thus, accelerating mineral reactions and, of course, isotopic mobilization.

The Rb/Sr system in white micas has in most cases not been affected in the area investigated except for the region of the Schneeberger Zug, where higher greenschist to amphibolite facies conditions were reached during Alpine metamorphism (see p. 127); and even for this area it is still questionable, whether a perfect Rb and Sr homogenization between the white micas and the whole rock system has taken place in Alpine times.

We would not doubt that white micas from the area where Alpine amphibolite facies conditions were reached really recrystallized. But these minerals could incorporate different small amounts of $^{87}Sr_{rad}$ (e. g. deriving from pre-Alpine muscovite itself) when the thermal peak was reached, or shortly after this time, thus preventing a perfect homogenization of the Sr isotopes. According to this interpretation the Rb/Sr ages on white micas mentioned by SATIR (1975, and unpubl. data) from the Schneeberger Zug area of 110–145 m. y. could predate the Early Alpine metamorphism, due to small amounts of "excess $^{87}Sr_{rad}$".

3.2 Reopening of Isotopic Systems and Related Mineral Reactions

We have already shown in chapter 2 that the influencing of the K/Ar and Rb/Sr system in micas of the crystalline rocks may be partly related to metamorphic mineral reactions observable in the thin sections. We shall summarize here the most important facts.

In Fig. 2 we distinguish four different "zones" with (continuously) increasing Alpine metamorphic grade. We should emphasize that Fig. 2 was sketched on the basis of microscopical observations as well as radiometric dating. This is important to note, because secondary mineral reactions are not observable in every rock where the isotopic systems have already been notably influenced.

Zone a) Hercynian Zone. Unaltered pre-Alpine parageneses. Locally sericitization of feldspar or kyanite. Beginning of Alpine stilpnomelane (Languard crystalline) and chlorite. Partly penetrative deformation of pre-Alpine minerals (deformation lamellae in quartz, kinkbands in micas, see sample T 598) which may be probably of Alpine age. No recrystallization in quartz. Hercynian mica ages.

Zone b) Alpine stilpnomelane Zone or transition zone from anchi- to epimetamorphic conditions. Neogenic stilpnomelane, phengite/muscovite and chlorite in metasediments and crystalline rocks. In special cases also neoformation of biotite (Ortler; Jaggl/Val Truyen mylonite). Beginning chloritization of biotite. Intense reactions in quartz: suturation and subgrain formation, recrystallization in the most fine-grained parts; deformation lamellae disappear. Slightly lowered K/Ar or Rb/Sr ages in biotites, but generally still Hercynian K/Ar ages in pre-Alpine white mica.

Zone c) Alpine chloritoid zone. Alpine stilpnomelane disappears. Typical zone of retrograde mineral reactions such as: bleaching, segregation of Fe and Ti in biotite (inclusion trails, arranged especially along kink bands), chloritization of biotite; diaphthoresis of staurolite (chloritoid, chlorite and sericite), sericitization of feldspars, chloritization of garnet, more rarely sericitization of kyanite and sillimanite. Recrystallization and collective crystallization is observed in quartz. Typical mixed age zone. Rb/Sr ages in biotite partly Alpine, locally high amounts of excess radiogenic argon in biotite. Neoformation of phengite, biotite, kyanite and garnet in post-Hercynian metasediments (Brenner area). White micas retain normally their pre-Alpine Rb/Sr ages.

Zone d) Alpine staurolite zone. Generally coarse-grained, fresh, slightly deformed parageneses prevail. Retrograde alterations are almost missing. Fresh tiny staurolite is interpreted as an Alpine mineral. Early Alpine mineral ages, possibly with small amounts of inherited or excess radiogenic ^{87}Sr in white micas. For the area S of the central Schneeberger Zug Alpine metamorphic conditions of 570 °C at 5 kbar are postulated by HOINKES (1981).

3.3 Parameters controlling K/Ar and Rb/Sr Systematics

a) K/Ar and the blocking temperature concept

Fig. 11 shows 25 K/Ar analyses of white micas from crystalline rocks in an ^{40}Ar versus K diagram. All the plotted samples belong to regions where Alpine metamorphism was missing (Phyllitgneiszone, Silvretta mass p. p., western Ötztal mass and Languard crystalline) or reached only weakest greenschist facies conditions (Scarl Unit). For the Scarl basement maximum Alpine temperatures of $\leqq$ 350 °C were postulated (THÖNI 1980 b).

The K/Ar model ages of all these pre-Alpine white micas, deriving from different areas and rock types vary only within a narrow time span of 300–317 m. y. From this we deduce, that these model ages may be related to a certain evolution stage of the Hercynian metamorphism and we presume that the argon clock has not been disturbed any more (whether by loss or incorporation of radiogenic argon in the crystal lattice) after the time of approximately 290 m. y. (lowest values form Fig. 11: 300 $\pm$ 10 m. y.).

If we calculate a K/Ar isochron using all the data points from Fig. 11 there results an age of 321 m. y. with a negative intercept, pointing to an ^{40}Ar deficiency of −5,2 cm^3 $^{40}Ar_{rad}$. 10^{-6} for these metamorphic minerals. According to HARPER (1970) such K/Ar isochrons can be identified with "metamorphic crystallization". Our computed intercept value of −5 cm^3 $^{40}Ar_{rad}$. 10^{-6} corresponds to the amount of radiogenic argon which is produced by a K-white mica with a "normal" K-content of about 7–9 weight-% K within a time span of about 15 m. y. If each of our micas would have lost $\sim$ 5 cm^3 . 10^{-6} of radiogenic argon from its crystal lattice after crystallization (i. e. ordering of the main elements), as deduced

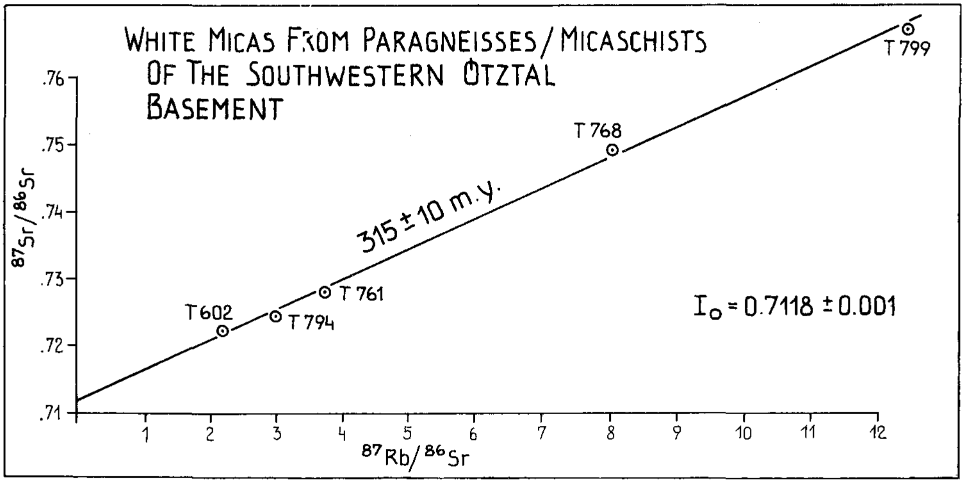


Fig. 9, 10. The Hercynian muscovite "isochron" of 315 ± 10 m. y. was calculated under the presumption that all these micas (separated from lithologically comparable rocks) started with similar $^{87}Sr/^{86}Sr$ initial ratios. The age value agrees with the more reliable results from micas with high Rb/Sr ratios and thus small analytical errors (Fig. 10).

from the calculated isochron of Fig. 11, the white micas should have been closed for argon at about 306 m. y. This number is identical to the mean value of all the K/Ar model ages of each single sample plotted in Fig. 11, which is 306 ± 11 m. y.

We can make the same consideration using K/Ar biotite analyses from the Hercynian regime (Fig. 12). In this diagram we note a much wider spread of the data points resulting in a higher variation of the single model ages (272–314 m. y.). This may be due, in cases, to a very slight disturbance of the argon reservoir in biotites by the Alpine metamorphism, as the minerals derive partly from the Alpine stilpnomelane zone. The calculated K/Ar isochron gives an age of 312 m. y., but the intercept value corresponding to the amount of ^{40}Ar lost from the biotite lattice after crystallization of these minerals, is in the same order as the value for white micas ($-6\ cm^3 . 10^{-6} Ar^{40}$).

Following HARPER (l. c.) the model age (so called ^{40}Ar retention ages) of the single minerals would have no geological significance, as the amount of ^{40}Ar lost from the crystal lattice thus influencing the model age to be calculated from the $^{40}Ar/K$ ratio, would be controlled firstly from the partial pressure of ^{40}Ar accumulated along grain boundaries and lattice defects and not from regional parameters, such as the metamorphic temperature regime. We think that this must not necessarily be so and can be demonstrated only if we have a perfect K/Ar isochron with negative intercept and with a wide spread in $K/^{40}Ar$ ratio and secondly a very similar distribution of all the other parameters controlling metamorphic mineral reactions. These conditions however are hardly to be fulfilled. And moreover, from a perfect K/Ar isochron identical ^{40}Ar retention ages (= K/Ar model ages) would result and it is hardly believable that the "argon saturation level" (HARPER, l. c.) varies very much in similar metamorphic mineral parageneses. As the K/Ar isochron with negative intercept implies equal argon loss for K-poor and K-rich minerals the ^{40}Ar overpressure in

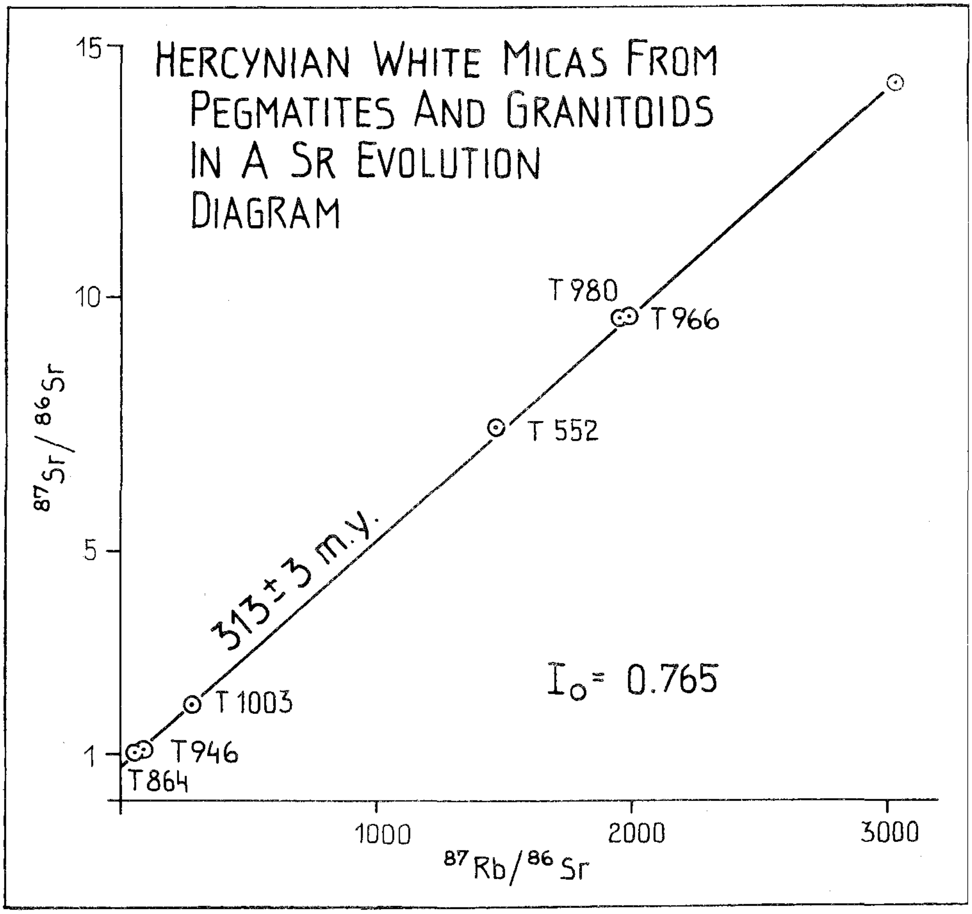
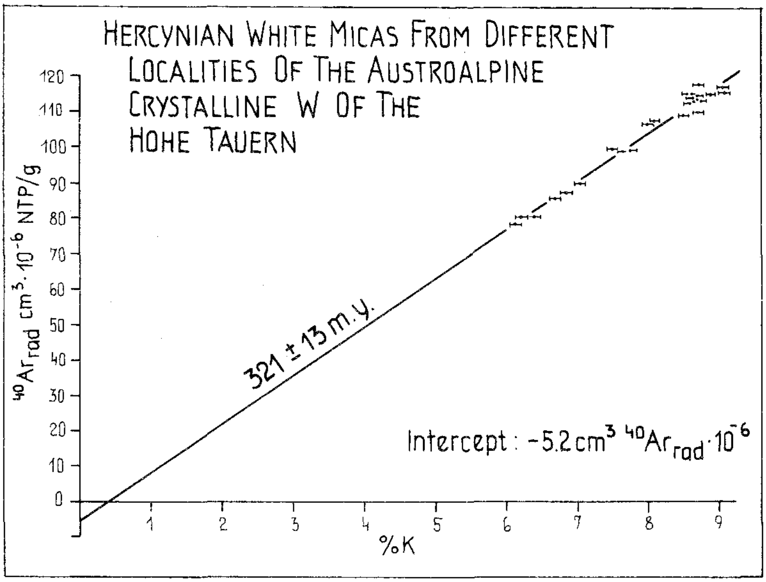


Fig. 10

the coexisting K-poor of K-free minerals of the rocks system should vary considerably, because the radiogenic argon lost from the crystal lattice of K-rich minerals, such as micas, is not expelled from the rock. Further, if the loss of radiogenic argon from metamorphic minerals would be stopped only after a critical "saturation level", i. e. argon overpressure along the grain boundaries is reached, it would be impossible to date fast cooling or even contact metamorphic processes by the conventional K/Ar method. Finally, the good concordance of the K/Ar and Rb/Sr model ages calculated for biotite from the Hercynian as well as from the Alpine metamorphic area (Schneeberger Zug) should be a reliable indicator that ^{40}Ar retention ages have a geological significance (cf. e. g. ARMSTRONG et al. 1966) and that these ages must be controlled mainly by external and regionally efficient parameters.

In summary, if the blocking temperature concept is applied to the K/Ar data points of Fig. 11 (and presuming a contemporaneous Hercynian cooling history within the Austroalpine basement), then the isochron model of HARPER would be meaningless and vice-versa. However, if the negative intercept in Fig. 11, 12 is due to a slight Alpine reopening



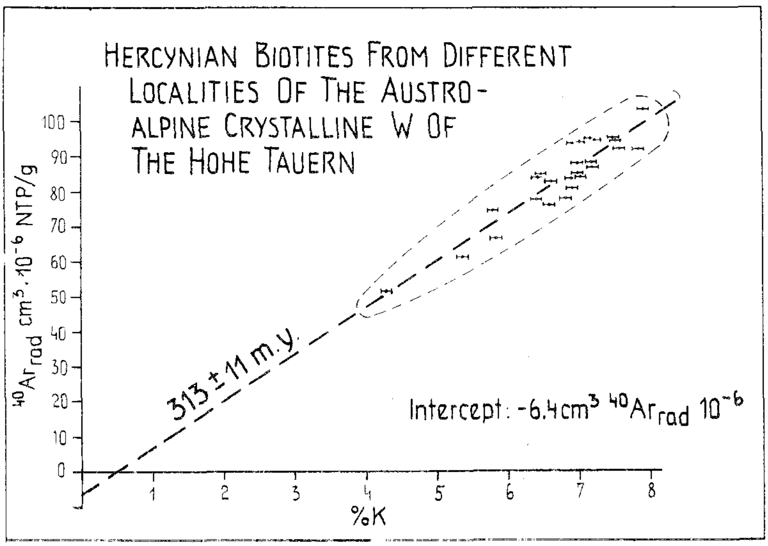


Fig. 11, 12. Biotites as well as white micas from the Hercynian zone point to a similar deficiency of $^{40}Ar_{rad}$, when the relative K/Ar "isochrons" are calculated. Applying the interpretation of HARPER (1970) these isochron ages could be related with metamorphic crystallization of the analyzed minerals. The data agree well with the Hercynian metamorphic evolution, but we would not accept this interpretation as the only reliable one (see text).

of the K/Ar system (argon loss and/or incorporation – an explanation which in our opinion may most probably be excluded – see p. 146) then there should exist a mechanism which makes argon loss easier in micas with low K-contents than in K-rich ones.

The blocking temperature concept for the K/Ar and Rb/Sr system in micas developed in the Swiss Central Alps by the geochronology team at Bern (e. g. JÄGER et al. 1967, JÄGER 1973, PURDY & JÄGER 1976; DODSON 1973, 1979), has not remained without contradiction. In the most strict sense the blocking temperature concept would imply that a special mineral would not only close for a given isotopic sytem when a critical temperature, the related blocking temperature, is reached by regional cooling, but it should also behave as closed during later metamorphic phases, supposed that this critical temperature is not surpassed. Thus sealing and opening temperature would be more or less identical. CHOPIN & MALUSKI (1980) demonstrated that "the opening of a system is not dictated by the temperature" and, moreover, that "a temperature-determined closure of isotopic systems cannot be systematically assumed ..." (l. c., p. 117).

From the regional distribution of the mineral ages in the Austro-alpine domain in discussion and the petrographic observation of the related differently polymetamorphosed mineral parageneses (Chapter 2) we deduce that temperature was the most important parameter in controlling K/Ar and Rb/Sr systematics in micas. This holds for the Hercynian as well as for the Alpine metamorphism in this area. However, we should emphasize that temperature is not the only parameter that influences isotopic systems. Intense deformation, especially when effective in combination with enrichment in fluid phases can highly accelerate reactions in the mineral parageneses (neoformation and/or recrystallization processes) and so of course the related isotopic systems are also influenced. As typical examples already discussed we remember the Verrucano of S Sta. Maria (Fig. 5), the mylonite of Val Truyen (Fig. 7, 8).

On the other hand, we have shown that tectonic deformation alone, also when very intense, is not able to reopen the K/Ar and Rb/Sr system in micas. Sample T 598, a biotite-kyanite-paragneiss from the western Ötztal mass (Zone of Hercynian mica cooling ages) shows a very pervasive deformation of the pre-Alpine mineral paragenesis which is definitely of post-crystalline (and probably of Early Alpine) age. Nevertheless the K/Ar and Rb/Sr mica ages compare very well with those of other mica ages from weakly deformed paragneisses from the same locality (Tab. 5, 6). Similarly the strongly deformed Scarl-orthogneisses of the (Alpine) Schlinig thrust near Schlinig show very intense neoformation of Alpine white mica (cf. p. 135), but the K/Ar system of the pre-Alpine micas has not been affected.

b) Rb and Sr isotopic homogenization and the Rb/Sr system in white micas

Metasediments. Rb and Sr isotopic homogenization in pelitic sediments during diagenesis was postulated more than once in the literature on the basis of Rb/Sr isochrons which are well in accordance with the supposed time of sedimentation. GEBAUER & GRÜNENFELDER (1974) however, stressed that such ages could be "reinterpreted in favour of metamorphic and not sedimentary ages". From these observations follows that Rb and Sr isotopic equilibration is expected before or at least at the beginning of very weak/weak metamorphism (= with beginning greenschist facies).

Our samples analyzed from the Münstertal metasediments show that the Alpine metamorphic conditions were not sufficient to reach good isotopic homogenization (Fig. 5, 6, 8).

The Münstertal Verrucano is normally a very coarse-grained rock type. Also if the metamorphic character is well recognizable, Sr isotope equilibration can not be expected within the whole rock system, as still coarse-grained detrital white mica can be observed macro- and microscopically. But even the most fine-grained matrix (the size of the neogenic Alpine micas is normally $> 2\ \mu$) did not reach Rb and Sr isotopic homogenization. Using the described separation method (p. 114), the fine fractions $< 2\ \mu$ should be composed more or less of fragments of neogenic white micas. This is also supposed from the K/Ar age results. Two possibilities may be discussed in order to explain the scatter of the data points of the fine fractions in the Rb/Sr evolution diagram. Firstly small amounts of detrital material (mica) with highly different Rb and/or Sr contents (or ratios) could disturb the linear arrangement of data points. Secondly, the neogenic white micas which received their radiogenic Sr mainly from degraded or recrystallizing detrital mica, could have incorporated varying amounts of $^{87}Sr_{rad}$ during crystallization, thus starting with different initial ratios. It has been shown by microprobe analysis, that the variation in the chemistry of major elements of detrital white micas from the Münstertal Verrucano is notable (FRANK et al. 1979).

On the other hand, using the same separation method as for the Münstertal samples, a reliable isochron resulted from the $< 2\ \mu$ fractions for the mylonite of Val Truyen/Jaggl area (see Fig. 7). Also in this case no Rb and Sr equilibration was reached, within the whole rock system. This is clearly shown in Fig. 8: coarser grain sizes show higher amounts of detrital white mica and thus also higher contents of $^{87}Sr_{rad}$. The model ages and isochron ages resulting from such samples analyzed are typical mixed ages: model ages of single samples are higher, two-point isochron ages lower than the related (Cretaceous) metamorphic event. For the $< 2\ \mu$ fraction of these mylonite samples however, we must suppose that the admixture of detrital material, which the Rb and Sr isotopes did not equilibrate during the 113 m. y. event, is negligible (or, at least does not strongly vary within the different samples). Otherwise a linear arrangement of the data points would not be possible. We think that the very intense deformation, probably connected with a local increase in temperature by production of frictional heat (biotite growth!) and with a much better circulation of the rock's fluids was the main reason for such a good isotopic homogenization being reached in this special case.

Pre-Alpine white micas. According to the blocking temperature concept in its most strict sense, pre-Alpine white micas from the Alpine greenschist facies area should have retained all radiogenic Sr produced within their crystal lattice since the Hercynian cooling below 500 ± 50 °C (JÄGER 1973, PURDY & JÄGER 1976). Thus, considering our area of investigation, we could expect mixed ages or Alpine Rb/Sr ages for these minerals only in the area of the Schneeberger Zug, as shown on Fig. 2.

However, apart from Hercynian we found several "Late Hercynian" Rb/Sr ages on white micas deriving from the Alpine chloritoid (T 834, T 1165) or even from the Alpine stilpnomelane zone (T 855, T 1112). It is important to note, that the white micas from the Alpine stilpnomelane zone (T 855, T 1112) show still Hercynian K/Ar ages.

According to this interpretation one could conclude, that the Rb/Sr system in pre-Alpine white micas has in some cases been reopened during the Alpine metamorphism, whereas the K/Ar system was not affected (T 1112!). One might suspect, that anomalous fluid conditions could favour locally an enhanced Sr diffusion ($^{87}Sr_{rad}$) from the crystal lattices. But why then did such processes not also affect the argon reservoir? Anyhow, it is

Table 16: Comparison of mineral chemistry, Alpine temperature zones and radiometric age data on pre-Alpine white micas from granitoid gneisses **and pegmatites.** Selected microprobe analyses on polished micas taken from the same concentrate used for the isotopic analysis. *) Sample T 855 shows phengite rims in the thin section. T 520: thin section analysis.

SAMPLE	T 520	T 552	T 562	T 732 centre	T 732 rim	T 804 centre	T 804 rim	T 834	T 855	T 864	T 946	T 966	T 980	T 1003	T 1112	T 1165
SiO_2	46,70	47,37	47,54	46,35	48,97	45,80	50,20	45,28	46,97	46,07	45,91	45,68	46,48	46,66	48,41	45,88
TiO_2	0,27	0,18	0,20	0,28	0,31	0,70	0,39	0,05	0,18	0,12	0,45	0,00	0,33	0,46	0,42	0,00
Al_2O_3	32,00	30,91	28,99	32,99	28,80	34,51	29,51	34,93	32,08	35,75	34,60	35,12	30,49	34,20	28,28	35,55
FeO	4,50	4,32	5,62	2,76	3,78	1,52	2,18	2,31	4,31	1,46	1,79	2,45	4,28	1,77	6,41	1,31
MnO	0,16	0,18	0,18	0,06	0,09	0,00	0,00	0,00	0,13	0,00	0,00	0,04	0,07	0,00	0,14	0,00
MgO	0,18	0,42	0,16	0,64	1,15	0,72	2,11	0,37	0,19	0,42	0,59	0,41	0,56	0,76	0,34	0,39
CaO	0,01	0,02	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00
Na_2O	0,60	0,41	0,36	0,56	0,40	0,60	0,37	0,39	0,33	0,57	0,51	0,55	0,40	0,50	0,17	0,44
K_2O	10,30	10,48	10,50	10,40	10,17	10,58	10,42	10,78	10,77	10,54	10,37	10,68	10,65	10,66	10,32	10,48
TOTAL	94,72	94,29	93,57	94,05	93,66	94,43	95,19	94,11	94,96	94,94	93,82	94,93	93,27	95,00	94,50	94,04
Zoning yes/no	---	---	---	partly		partly		rarely	--*)	---	---	---	---	rarely	---	---
Alpine T zone (Fig. 2)	a	a	b	b		b		c	b	c	c	c	b	b	b	c
K/Ar age	313±10	303±13	300±9	308±13		302±14		115±5	294±12	149±8	187±8	129±6	289±12	317±13	305±12	174±7
Rb/Sr age	312±12	327±13	300±12	328±13		326±13		254±10	234±9	345±14	329±15	314±13	317±13	310±12	274±11	223±9

very clear that we can not apply the blocking temperature concept for the cases being discussed, if this interpretation is suitable.

CHOPIN & MALUSKI (1980) have demonstrated that the K/Ar isotopic system behaves differently if muscovites or phengites are analyzed (cf. also FRANK & STETTLER 1979). Our analytical results show no clear correlation between the mineral chemistry and the behaviour of isotopic systems – see Tab. 16 (possibly except sample T 1112).

As an improbable, but after all possible explanation we could suggest that the "late Hercynian" Rb/Sr ages are produced by admixture of Alpine mica in the analyzed concentrate (not eliminated during the separation process). This explanation could hold true for sample T 855 which shows broad rims of Alpine phengite (cf. Fig. 1). If the differences in the Rb/Sr ratios between pre-Alpine and Alpine mica would be very pronounced, the admixture of very small amounts of Alpine mica could notably lower the Rb/Sr age, whereas at the same time the K/Ar age would be hardly influenced.

At the moment no definitive explanation can be given for the data in discussion, but most probably we have to choose between these two possibilities (cf. p. 155): or such late Hercynian muscovite/phengite ages represent mixed ages, produced by a partial reopening of the Rb/Sr isotopic system under locally anomalous metamorphic conditions (p_f!) during the Early Alpine metamorphism, or they are due to the mixture of Hercynian and Alpine mica (intergrowth!) in the analyzed concentrate.

c) Alpine temperatures and isotopic systems

From a combination of petrographic observations (Fig. 2) and isotopic analyses we dare a general statement for the behaviour of the K/Ar and Rb/Sr system in micas during reheating in polymetamorphic rocks. However, we should emphasize that the following values can be applied only in similar rock series which undergo metamorphic conditions similar to the Austroalpine Altkristallin in discussion.

α) Beginning loss of $^{87}Sr_{rad}$ and/or $^{40}Ar_{rad}$ from biotite when ca. 300 ± 20 °C are reached.

β) Beginning loss of $^{40}Ar_{rad}$ from white micas at ca. 350 ± 30 °C.

γ) Total loss of $^{87}Sr_{rad}$ (i. e. Alpine ages) may be reached in biotite at ca. 380–420 °C. Total loss of $^{40}Ar_{rad}$ in biotite would be possible at ca. 400 °C, but from a secondary incorporation of radiogenic argon (not expelled from the rock) during the cooling in most cases higher K/Ar than Rb/Sr ages result from the same biotite sample (excess argon).

δ) Total loss of $^{40}Ar_{rad}$ from white mica at ca. 450 °C (or above). Perfect argon loss from the whole rock system is most probably not accomplished in this temperature range in a "dry" crystalline. This is supposed by the fact, that the K/Ar model ages from biotites are partly higher than those of coexisting white micas (excess argon in biotite? – SATIR 1975, unpubl. data p. p.).

ε) Total loss of $^{87}Sr_{rad}$ from pre-Alpine white mica most probably is reached only with beginning amphibolite facies (540 °C). The first reopening of the Rb/Sr system in white micas however, is a crucial point, but may probably be possible already when middle greenschist facies conditions are reached (especially when enhanced chemical reactivity is observed within the paragenesis; quartz-phengite-microcline-gneisses!). Most probably the retentivity of $^{87}Sr_{rad}$ is higher in pure muscovites or muscovites/paragonites than in white micas with high celadonite contents (cf. PURDY & JÄGER 1976, FRANK & STETTLER 1979, CHOPIN & MALUSKI 1980).

4. Relationship between Metamorphism and Tectonic Movements

4.1 Hercynian Event

Mica ages from those parts of the Austroalpine crystalline where well preserved, non diaphthoritic mineral parageneses prevail are interpreted as Hercynian cooling ages. If we use the same blocking temperatures for micas as accepted by PURDY & JÄGER (1976), the Austroalpine crystalline plate would have cooled from 500 to 300 °C approximately between 330 and 270 m. y. Hence, we can calculate a very low rate of uplift (erosion) during the final phase of the Hercynian metamorphism which is in the range of 0.1–0.2 mm/y only. SATIR & MORTEANI (1978, p. 297) give still lower Hercynian uplift rates for the area N of the western Tauern Window.

There exist good arguments for the area in discussion that suggest that this cooling process was not a steady one, but that the cooling rate was higher at the beginning. Meanwhile most of the K/Ar and Rb/Sr ages on white micas fall in the interval of 300–330 m. y., biotite ages belong mainly to the 300–270 m. y. time interval:

M-Rb/Sr ages: 318 ± 10 m. y. (mean of 10 uncorrected model ages; see also Fig. 9, 10)

M-K/Ar ages: 306 ± 11 m. y. (mean of 25 analyses)

B-K/Ar + B-Rb/Sr ages; 290 ± 20 m. y. (mean of 32 analyses).

With this simplified model we presume that the late to postmetamorphic evolution was similar all over the area in discussion.

The Hercynian pT conditions of the Austroalpine crystalline basement were studied, for instance, by HOERNES (1972), GREGNANIN & PICCIRILLO (1974), PURTSCHELLER & SASSI (1975), SATIR & MORTEANI (1979) and can partly be calculated by p or T index minerals such as andalusite, kyanite, phengite (?), etc. According to some of these authors we note a change from a high-pressure to a more temperature controlled type of metamorphism during the Hercynian event (SATIR & MORTEANI 1979). A clear differentiation of the Hercynian orogenetic cycle from an older ("Caledonian"; see PURTSCHELLER & SASSI 1975) event has not been succeeded to date in the Eastern Alps (cf. also BOCCHIO et al. 1981).

Late Hercynian Event – yes or no?

Several Rb/Sr ages on white micas are known from the Austroalpine/Southalpine Altkristallin which do not fit well into the above mentioned simple Hercynian cooling model (cf. p. 151). The Rb/Sr phengite ages of 260/273 m. y. published by SATIR & MORTEANI (1978) from the Schwazer Augengneise have been interpreted as cooling ages related to a very slow, long-lasting uplift process after the Hercynian metamorphism. Similar ages (260/275 m. y.) were published by GRAUERT et al. (1974; and found again during our investigations, see Tab. 11, sample T 834) from pegmatites/muscovitegranites of the Martelltal, E of the Ortler; meanwhile, one muscovite from a pegmatite of the Val Grosina (Campo crystalline) yielded a Rb/Sr age of 252 m. y. (HANSON et al. 1966, p. 410). Micas from the Southalpine crystalline gave still lower Rb/Sr age values of roughly 200–250 m. y. (HANSON et al., l. c.; HUNZIKER 1974, FERRARA et al. 1962). The preferred interpretation for most of these cases is that we are dealing with geologically meaningful ages, related or with cooling processes (SATIR & MORTEANI, HUNZIKER, l. c.) or with Late Hercynian magmatic events (GRAUERT et al., HANSON et al., l. c.).

GRAUERT (1969, p. 117) did not exclude a slight affecting of the Rb/Sr muscovite ages in the southeastern Silvretta by the Alpine metamorphism. If we use this interpretation for this special area, the Rb/Sr system in white micas would have been affected within an Alpine temperature range which is much below (Alpine stilpnomelane!) the related critical sealing/opening temperature. We have already shown with several examples (chapter 3, p. 151), that this presumption may probably hold true for special (local) metamorphic conditions and that a very strict use of the blocking temperature concept may lead, in cases, to erroneous interpretations of apparent ages. To summarize the problem, we see the possibility that geologically meaningful Late Hercynian ages may exist when there is a relationship with a contemporaneous (Permian/Triassic) magmatic activity, as shown e. g. by HUNZIKER (1974). But, as derived from the regional K/Ar and Rb/Sr biotite cooling age pattern (Plate 2, 3), the existence of real Late Hercynian (post 270 m. y.) muscovite ages produced by long-lasting regional cooling or even by a late Hercynian regional temperature increase is not a realistic interpretation for the area in discussion.

4.2 Cretaceous Orogenesis

Most of the geochronological data demonstrate that the most important and in many areas the only Alpine tectonic-metamorphic processes within the Austroalpine Unit are of Cretaceous age. This results also from many published and unpublished data from the Austroalpine crystalline E of the Tauern Window (OXBURGH et al. 1966, FRANK pers. inform., MORAUF 1980, S. SCHARBERT 1981).

Further, the regional distribution of K/Ar and Rb/Sr biotite ages shows, that the final cooling of this Early Alpine metamorphism was a remarkably contemperaneous process all over the Austroalpine domain, occurring at ~ 80–75 m. y. We can regard the definitive décollement of the today's Austroalpine crystalline from its deeper crustal parts as the geological reason for this regional cooling. According to stratigraphic-sedimentological informations shortly after this time, namely during the Campanian a markable change in the composition of debris deposited within the Calcareous Alps took place (Gosau/Flyschgosau). More and more debris originating from crystalline rocks lying further to the S was poured from S to N. This change in sedimentation must most probably be related with tectonic movements of Austroalpine basement rocks which were to be thrusting further to the N during the "intragosauic event" (FAUPL 1978).

It is much more difficult to fix the time of the thermal peak or even the first stages of this Cretaceous (Early Alpine, eo-Alpine) metamorphism. It is interesting to note that the term "80 m. y. phase" used very often in the literature for the eo-Alpine phase, is not very correct, when related with the metamorphic evolution, as the time interval around 80 m. y. corresponds to the last stages of cooling and not to the metamorphism itself.

According to plate tectonics models the subduction of the Southern Pennine Zone below the Austroalpine Domain (= Austroalpine-Southalpine-Adriatic plate after DIETRICH 1976) is the main reason for the internal deformation (compression) and first thrusting of Austroalpine units upon the northern (Pennine) domain. According to different authors these processes started in late lower to mid Cretaceous (120–100 m. y.) times (e. g. DIETRICH & FRANZ 1976, FRISCH 1979, HAWKESWORTH et al. 1975).

Within this time interval we would than expect an updoming of the isotherms, especially in the southern Austroalpine domain. As crustal thickening and thus burial is only reached with the aid of tectonics, we can reckon with starting tectonic movements within the Austroalpine unit at this early time. The 113 m. y. isochron from a mylonite as shown in Fig. 7 most probably reflects such processes.

From the southwestern Engadine Dolomites (Val Trupchun area) we have paleontological evidence that sedimentation lasted at least up to Albien, but most probably up to Cenomanian/Lower Turonian times = ~ 95 m. y. b. p. (TRÜMPY 1981, pers. inform.).

As shown by the regional distribution of the Alpine metamorphism (Fig. 2, Plates 2–5) the southern Ötztal mass (Schneeberger Zug) as well as the Ortler-Campo crystalline complex underwent reasonable burial in pre-Upper Cretaceous times. In the Brenner area some 10–15 km of overburden are needed for reaching higher greenschist facies conditions in the Mesozoic sediments. This burial metamorphism might have been produced by the overburden pressure of today already eroded Austroalpine elements or/and of rock units lying today farther N (Northern Calcareous Alps). In any case this tectonic overburden varied strongly within the Austroalpine crystaline as demonstrated by mineralogical observations as well as by the radiometric age pattern. Other criteria might be also found, such as differences in the internal tectonic situation (flat or steep lying s-planes, macrofolds, etc.) which would as a result of varying thermal conductivity, raise the thermal gradients partly into higher tectonic-lithostratigraphic levels.

In principle we have three possibilities in order to raise the thermal gradients and thus to produce the metamorphism within the Austroalpine unit:

a) Production of a thermal heat flow in connection with extensive magmatic processes in deeper levels of the crust.

b) Convective transfer of the heat by circulating fluids.

c) Heat transfer by conduction alone, i. e. more or less without circulating fluids.

In all these cases probably we have to take into account the local production of frictional heat by internal tectonic movements.

We have no evidence for an extensive magmatic activity in the Austroalpine, at least not in Middle Cretaceous times. The main magmatic activity which may be connected with the subduction process of the Southern Pennine zone is restricted to the Southalpine Domain and is of Upper Cretaceous/Tertiary age (DIETRICH & FRANZ 1976). Moreover, enhanced circulation of fluids (in order to accelerate heat transport as well as mineral reactions) is not very likely, at least in deeper levels of the basement, as the Austroalpine crystalline must be derived from a "basement" very similar in lithology and thus of amphibolite metamorphic grade without high contents of fluids. Thus the heat flow for the generation of the Cretaceous metamorphism in the Austroalpine, reaching higher greenschist and partly even (Schneeberger Zug area) amphibolite facies conditions must have worked greatly by conduction alone *). Considering such a model, a time span of several tens of millions of years

*) We should emphasize however, that in the Schneeberger Zug area we are dealing most probably with a special situation. As far as known to date, the rock sequences there did not suffer amphibolite facies metamorphism in pre-Alpine times – – contrary to the neighbouring Altkristallin. The content of fluids in the Schneeberg rocks could have been notably higher than in the Altkristallin during Alpine times, thus accelerating mineral reactions and producing very coarse-grained Alpine parageneses, partly of amphibolite metamorphic grade, in this special area.

is needed for amphibolite facies temperature conditions to be reached in a "dry" crystalline according to calculations by OXBURGH & TURCOTTE (1974) in the area of the southeastern Tauern Window. If we fix the thermal peak of this Cretaceous metamorphism around 90 m. y. (cf. HAWKESWORTH 1976, BONHOMME et al. 1980), this process could have begun to evolve some 20–30 m. y. earlier, i. e. in late lower to mid Cretaceous times. This is well in agreement with stratigraphic-sedimentological and paleogeographic considerations.

4.3 Post-Cretaceous Events in the Austroalpine Unit

During the final décollement and/or the following thrusting phase to the N, the Austroalpine crystalline "plate", broke to several smaller units which were to form the different masses, such as Ötztal mass, Silvretta mass, etc. The thrusting movements occurred along new or already existing shear zones such as the "Paleo Schlinig thrust". Considering these tectonic movements we are confronted with the difficult problem of distinguish between late metamorphic (= Upper Cretaceous) and really postmetamorphic, i. e. Tertiary tectonics and metamorphism.

The Silvretta crystalline mass overthrusted the today's area of the Pennine Engadine Window only in post-Paleocene times. As discussed on p. 119, the imprints of the Alpine metamorphism in this crystalline must most probably be related with the Cretaceous thermal evolution, but there is also evidence for local post-Cretaceous regeneration in the Thialspitz area as well as at the base of the Calcareous Alps E of Arlberg Pass. The partial reopening of the K/Ar system in the most fine grained fractions of the metasediments (p. 121) may be correlated with locally intense tectonic deformation or with a slight increase in temperature (in connection with the Tertiary metamorphism of the underlying Pennine rocks) or both.

Tertiary northward movements are documented for the Ötztal crystalline mass along the Inn valley between Prutz and Innsbruck (HAMMER 1931, MÜLLER 1953, TOLLMANN 1977 a). At the front of this crystalline, in the immediate neighbourhood to the Pennine rocks of the Engadine Window we find partly intense deformation connected with diaphthoresis as well as partial loss of radiogenic argon in micas (Table 5, sample T 920). A connection between these alterations with Tertiary processes would thus seem more probable than with Cretaceous ones. The westward trending tectonics of the western Ötztal mass along the so called Schlinig thrust is in part definitely of Cretaceous age (p. 141), but noticeable Tertiary movements along this thrust plane have been postulated as well (SCHMID 1973, TRÜMPY 1977, THÖNI 1980 a). A clear two-phased tectonic evolution is well observable in the field all over the Scarl Unit, including Jaggl. The prevailing structural element however, the very striking EW lineation which is observable in the Scarl metasediments (Verrucano, Jurassic radiolarites) and in the Scarl Altkristallin as well as in the sericitephyllites (p. p. a phyllonitic facies of the easternmost Scarl Unit) of the middle Vinschgau area, must be obviously of Cretaceous age. On the other hand, we should point out that there is no direct proof until now, whether by radiometric or by other experimental investigations, that the m a i n movements along this Schlinig thrust took place in post-Cretaceous times. As an alternative to the earlier proposed conception (of Tertiary tectonic movements), the Ötztal mass could have overridden the Scarl Unit already during the final phase of the Early Cretaceous cooling (80–70 m. y.). If the Ötztal block suffered considerable rotation and westward thrusting after the Early Alpine metamorphism took place, we would expect a penetrative postcrystalline deformation in the middle-eastern Vinschgau area, where the Schlinig thrust as a discrete thrust plane disappears. Further investigations concerning this topic are in progress.

Post-Cretaceous tectonics and probably also a slight increase in temperature are postulated for the southern Scarl Unit in the area of Sta. Maria/Umbrail Pass according to field observations as well as analytical results (Fig. 5).

A unique example for Tertiary metamorphism within the area in discussion is the area of Mauls-Penser Joch (FRANK et al. 1977, RATHORE & HEINZ 1979). While the young metamorphism of the Austroalpine crystalline E of Mauls (BORSI et al. 1978) may be correlated with the Tertiary metamorphism of the Pennine Tauern Window, we must find an other explanation for the late metamorphism (K/Ar muscovite/phengite cooling ages of 15–22 m. y.) in the Penser Joch area. Possibly an extraordinary strong tectonic compression and subsequently a slight rise in temperature took place in this area during the later northward push and indentation of the South Alpine spur along the Judicarien-Pusterer (Periadriatic) Line (SEMENZA 1974).

ANDREATTA (e. g. 1935, p. 126) mentioned Alpine polyphase metamorphic/tectonic evolution in the Ortler-Campo and Tonale crystalline rocks. From a regional point of view the main Alpine metamorphic imprints must be correlated with the Cretaceous event (p. 132), but post-Cretaceous effects on the mineral assemblages and isotopic systems can not be excluded, especially along the late active Tonale Line. However, if at all we would expect that such post-Cretaceous influence is only of local importance and must not be correlated with a new regional increase in temperature. GRAUERT et al. (1974) published a Rb/Sr biotite age of 45 ± 3 m. y. from the Martelltal and a Rb/Sr age of 57 ± 2,5 m. y. on white mica was mentioned by SATIR (1981, personal comm.) from the Texelgruppe NNW of Meran.

Among the numerous and different dikes of the Ortler-Campo crystalline we also find rocks which, according to ANDREATTA (1954 a, b), must be correlated with obviously "posttectonic" magmatic activity. An andalusite bearing contact-metamorphosed paraschist sampled in the neighbourhood of a small diorite stock from the upper Val della Mare (Val di Peio; see ANDREATTA 1954 b, p. 185) yielded a K/Ar age of 31 ± 1.5 m. y. for both biotite and white mica (Table 8). This value falls in the same age group as the great intrusions of Bergell, Adamello and, farther east, the Rieserferner and shows that late Alpine magmatic activity was probably more widespread within the Austroalpine unit than presumed until now (see DIETRICH & FRANZ 1976). The existence of post-Cretaceous dikes has already been proved by GATTO et al. (1976, p. 35) for the Altkristallin W of Meran.

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5. Appendix: Sample Description

Abbreviations:

SL = sample locality. C = cobble (specimen not taken directly from solid bedrocks). Mi = paragenesis observed in the thin section: qz = quartz, bi = biotite, ms = colourless white mica s. l., ab/plag = albite/plagioclase, ga = garnet, stau = staurolite, ky = kyanite, sil = sillimanite, and = andalusite, pheng = phengite, stilp = stilpnomelane, ctd = chloritoid, car = carbonate (mostly calcite), ep = epidote, clzo = clinozoisite, kf = K-feldspar, acc = accessories, ap = apatite, zr = zircon, il = ilmenite, ser = sericite, rut = rutile, gr = graphitic material, tourm = tourmaline, pyro = pyrophyllite. I = pre-Alpine paragenesis, II = neogenic (Alpine) minerals (distinguished only in a few clear cases).

B = biotite concentrate. Bc = biotite + chlorite (chlorite > 5 vol-%). Bci = biotite-chlorite-intergrowth. M = White mica concentrate. P = purity of the mineral concentrate, estimated (in vol-%). GS1 = original grain size of the analysed mineral. GS2 = grain size as produced by crushing during the separation process. S = mineral separation/concentration by sedimentation in distilled water (only for post-Hercynian metasediments; grain sizes < 50 µ). M-K/Ar = K/Ar model age of white mica. M-Rb/Sr = Rb/Sr model age of white mica. B-K/Ar = K/Ar model age of biotite. B-Rb/Sr = Rb/Sr model age of biotite.

In this list have been incorporated partly also K/Ar data published earlier, to get a better correlation between the K/Ar and the Rb/Sr age data: (a) = THÖNI 1980 a, (b) = THÖNI 1980 b.

Numbers in parenthesis refer to the corresponding tab. number used in the text of this work.

PZ = Phyllitgneiszone, Si = Silvretta crystalline, Sc = Scarl Unit, U = Umbrail Unit, Ö = Ötztal crystalline, O = Ortler metasediments, OC = Ortler-Campo crystalline, TZ = Tonale Zone, L = Languard crystalline.

T 491–T 496 (WAP 279–WAP 283 + WAP 924)
Permoscythian quartz-sericite-schist. SL: S of Sta. Maria/Münstertal, road to Umbrail Pass, at Hotel "Alpenrose" (all six samples), Sc. Mi: qz + ms/pheng ± carb ± stilp ± acc (pyro, graph, zr, tourm, haem, ep, tit).
Fine-grained parts are partly well recrystallized (clear, polygonal quartz fabrics and neogenic white micas, mostly 5–25 µ); but coarse-grained parts are readily recognizable as detrital components. Intense deformation. M: S of fine fractions, P = ≦ 90% (X-ray diagrams of < 2 µ grain size: + qz ± chl ± pyr. M-K/Ar (< 2 µ) = 75–92 m. y. (b), M-Rb/Sr: see Fig. 5, 6.

T 503 (WAP 287)
Verrucano, light quartz-sericite-schist. SL: 800 m ESE Cierfs/Münstertal (road outcrop), Sc. Mi: qz + ms/pheng + chl + carb + stilp + acc (zr); good recrystallization of fine-grained matrix (quartz and white mica); detrital muscovite and quartz pebbles with resorption tubes (porphyry qz). WR-K/Ar (10): 97.5 ± 6, M (< 2 µ)-K/Ar: 87 ± 3 (b).

T 520 (WAP 293)
Muscovite-plagioclase-metagranitoid. SL: ca. 1.5 km E of Jaggl. Mi: plag + ms + qz + kf. Unaltered gently foliated pre-Alpine paragenesis. White mica slightly phengitic. Locally neoformation of sericite. M: GS 1, 2 > 250 µ, P = ± 100%. M-Rb/Sr = 312 ± 12 (7), M-K/Ar = 313 ± 10 (b).

T 543 (WAP 603)
"Hyänenmarmor", sial-feldspathic calcite marble (Jurassic). SL: Path to Oberndorfer Tribulaun, m 2270, Brenner mesozoic metasediments. Mi: carb (cc) + plag + qz + clzo/ep + ms. M: S < 2 µ, M-K/Ar = 84 ± 5 (5).

T 552 (WAP 306)
Muscovite-plagioclase-metagranitoid. SL: ca. 1.5 km E of Jaggl (Ö). Mi: plag + qz + ms. Very similar to sample T 520, quartz shows first reactions: suturation and subgrain formation. M: GS1 > 450 µ, GS2 > 180 µ. P = ± 100% (few inclusions). M-K/Ar = 303 ± 13, M-Rb/Sr = 327 ± 13 (5.7).

T 562 (WAP 564)
Strongly foliated muscovitegranitegneiss. SL: Road from Fuldera to Lü (m 1750), Münstertal, Sc. Mi: I = plag + kf + qz + ms + acc (op); II = ms/pheng + stilp ± qz. Clear reactions in qz, neogenic white mica of ca. 5–50 µ size, pre-Alpine ms: mm size and deformed. M: GS1 = GS2 150–430 µ, P = ± 100%, M-K/Ar = 300 ± 9 (b), M-Rb/Sr = 300 ± 12 (12).

T 563 (WAP 563)
Muscovitegranitegneiss. SL: equal to T 562. Mi: I = ms + qz + kf + plag + acc (op), II = pheng + stilp ± qz. Strong foliation. Intense reactions in qz: subgrain formation, recrystallization p. p.; Coarse-grained mm sized pre-Alpine mica shows green

colour (phengite). Intense growth of Alpine phengite (10–50 μ): ms/pheng I: pheng II = ~ 1 : 1. WR-Rb/Sr = 331 ± 17 (Fig. 3).

T 566 (WAP 562) Muscovite-plagioclase-orthogneiss. SL: Val d'Avigna, m 1730 NNW Taufers/M. C. Sc. Mi: I = plag + ms + qz + acc (ep), II = pheng ± qz ± stilp + carb; ms I: pheng II ~ 3 : 2; reactions in qz; plag partly unmixed. WR-Rb/Sr: Tab. 12.

T 569 (WAP 561) Muscovitegranitegneiss. SL: equal to T 566. Mi: I = plag + ms + qz + kf + acc (zr, op, ap, ep/clzo); II = ms/pheng ± qz + stilp + carb; intense alteration. WR-Rb/Sr: Tab. 12.

T 571 (WAP 559) Strongly foliated muscovite-plagioclase-orthogneiss. SL: Val d'Avigna, m 1460, NNW Taufers/M. Sc. Mi: I = plag + ms + qz ± kf + acc (ap, op/haem), II = pheng + stilp; slightly sericitized. WR-Rb/Sr = 364 ± 49 (Tab. 12).

T 584 (WAP 925) Metadiorite. SL: ca. 2.5 km WSW of Prad/V, at outlet of Suldental. C. OC. Mi: qz + bi + clzo/plag-ab + ms + acc (op, tit). plag: totally unmixed to clzo ± ser, bi: mm-sized slightly greenish-brown flakes together with much finer grained (20–100 μ) ones, locally chloritized. B: GS1 = GS2 170–420 μ, P: + ca. 7% chl. Bci-K/Ar = 243 ± 10 (8).

T 595 (WAP 463) Staurolite-plagioclase-biotite-micaschist. SL: Rojental, Fallung, m 2400, Ö. Mi: bi + plag + qz + stau + ms + ga + ky + sill + chl + acc (zr, tourm, tit). Locally very slight chloritization of bi and sericitization of plag. B: GS1 = GS2 150–420 μ, P ± 100%, B-K/Ar = 310 ± 10 (b). M: GS1 = GS2 150–430 μ, P 99% (± B), M-K/Ar = 301 ± 12 (5).

T 598 (WAP 464) Biotite-plagioclase-gneiss (paragneiss). SL: Ridge from Mitterlochspitze to Thiergarten, m 2950, Langtaufers, Ö. Mi: bi + plag + qz + ky + ms ± chl ± ga + acc (tit, zr, op, ap, ser, lim). Pervasive deformation in bi (kinking), qz (deformation lamellae) and ky. Locally very slight diaphthoresis along grain boundaries: chloritization in bi and sericitization in plag and ky. B: GS1 = > 150 μ, GS2 = 70–250 μ, P ± 100% (few inclusions). B-K/Ar (GS1) = 285 ± 12, B-Rb/Sr (GS2) = 283 ± 11. M: GS1 = GS2 150–430 μ, P ~ 99% (+ ca. 1% bi + qz), M-K/Ar = 305 ± 12 (5, 6). Minerals separated from a small, wheathered hand specimen.

T 602 (WAP 467) Paragneiss. SL: 1.5 km SE Melager Alm/Freibrunn, Langtaufers, Ö. Mi: qz + plag + bi + ms + stau + ga ± chl ± sil + acc (ilm, zr, tit). Very fresh, unaltered paragenesis. B: GS1 = GS2 150–450 μ, P 100%, B-K/Ar = 297 ± 9 (b), B-Rb/Sr = 287 ± 12 (6). M: GS1 = GS2 150–430 μ, P 100%, M-K/Ar = 312 ± 10 (b), M-Rb/Sr: see Tab. 7, Fig. 9. Qz shows no greater amounts of excess argon (5).

T 612 (WAP 473) Biotiteplagioclasegneiss. SL: Val d'Avigna, m 1600, NNW Taufers/M., C, Sc. Mi: plag + bi + qz + ms ± chl ± ga ± ky ± sil + acc (zr, op, carb). ?Hybrid rock (ky, sil). Sericitization of plag and ky, bi locally slightly chloritized with segregation of Fe-Ti opaques. WR-Rb/Sr see Tab. 12. B: GS1 = GS2 140–450 μ, P ± 100% (opaque inclusions), B-K/Ar = 272 ± 8 (b), B-Rb/Sr = 298 ± 12 (12).

T 614 (WAP 926) Pseudotachylite, appr. 8 cm thick, contact to paragneiss. SL: SW flank of Pardatscher Joch/Idalpe, Si. Mi: fine-grained matrix, mostly 5 μ grain size (determination not possible with the microscope) including coarse-grained qz grains (relics); rock deformed by late cracks with neogenic chl. WR (150–250 μ) – K/Ar = 56 ± 3 (4).

T 619 (WAP 606) Carbonaceous ms-chl-schist, "Tasna flysch". SL: W flank Bürkelkopf/Idalpe, Si. Mi: ms + qz + carb (cc) + chl + acc (op). Microfabric intensely folded, slaty cleavage. M: S < 2 μ, M-K/Ar = 71.5 ± 6 (4).

T 629 (WAP 611) Red-violet, slightly cabonaceous schist, dislogded slices of the Arosa zone at the base of the Silvretta crystalline. SL: near Puschlin/NE Prutz. Mi: ms + qz ± ab + chl + "graphitic" material. M (< 2 μ)-K/Ar = 30 ± 2.2 (4).

T 635 (WAP 478) Paragneiss, SL: Hintere Matscher Alm via Salurnspitze, C, Ö. Mi: plag + qz + stau + ga + ms + chl + acc (tit, zr). Sericitization of stau and plag, locally bleaching of bi. B: GS1 = GS2 150–430 μ, P ± 100%, B-K/Ar = 749 ± 23 (b, excess argon), B-Rb/Sr = 186 ± 7 (6).

T 642 (WAP 615)	Pseudotachylite. SL: Ascent to Zirmli, m 2390, Fimbertal, Si. Sample taken from the central part of an s-parallel "dike", about 1 m thick. M: fine-grained matrix (?white mica) = recrystallized glass with relics of rounded or strongly deformed qz and of ab/plag. Parent rock: paragneiss. WR (150–250 μ) – K/Ar = 77.5 ± 3 (4).
T 644, T 645 (WAP 617, WAP 618)	Pseudotachylite. SL: near T 642, m 2575. Samples taken from an s-parallel "dike" of ca. 8 cm thickness; parent rock: paragneiss. Mi: Very homogeneous, fine-grained (≦ 5 μ) recrystallized glass matrix with rounded qz relics. WR (150–250 μ) – K/Ar = 55 ± 2, 58 ± 3 (4).
T 648 (WAP 619)	Pseudotachylite. SL: m 2600 E Berglerhorn/Fimbertal, Si. Parent rock: pegmatite. Mi: fine-grained matrix with flow structures and relics of qz and feldspar. Parent rock shows strong cataclastic deformation. WR (150–250 μ) – K/Ar = 72.6 ± 3.2 (4).
T 656 (WAP 483)	Quartzitic ga-two mica-paraschist. SL: near St. Anton/Arlberg, PZ. Mi: qz + ms + ga + ab/plag + bi ± chl + acc (op, tourm, op, clzo); bi and ga are partly chloritized, plag shows weak sericitization. Bci: GS1 = GS2 150–430 μ, bi: chl ~ 3 : 1, Bci-K/Ar = 286 ± 9 (b). M: GS1 = GS2 150–430 μ, P > 99% (± bi), M-K/Ar = 301 ± 12 (1).
T 676 (WAP 499)	Quartz-rich ga-micaschist. SL: Arlberg road tunnel, western sector (03/360, 4 m); sample collection by J. KAISER. Mi: qz + ms + bi + ga ± ab ± chl + acc (carb, op). M: GS1 = GS2 150–420 μ, P > 99.5% (± bi), M-K/Ar = 301 ± 13 (1).
T 679 (WAP 502)	Paragneiss. SL: equal to T 676 (03/3248 m); sample collection by J. KAISER. Mi: qz + ab + plag + ms + bi + ga + chl + acc (op, gr, ap, carb). Inverse zoning in plag; no alterations. B, M: GS1 = GS2 150–420 μ, B: P = 99% (+ 1% chl), M: P = ~ 98% (+ bi, inclusions), B-K/Ar = 308 ± 13, B-Rb/Sr = 311 ± 12, M-K/Ar = 303 ± 12 (1.3).
T 704 (WAP 513)	Ga-feldspathic-micaschist. SL: m 2842, NW Krahwand, Schnalstal, Ö. Mi: I = qz + ab/plag + ms + bi + ga + acc (tourm, op, zr, op); II = chl + ser + Fe-Ti-opaques. Clear diaphthoresis: Chloritization of ga, partly of bi, neoformation of sericite. B: GS1 = GS2 150–450 μ, P > 99% (± chl), B-K/Ar = 462 ± 14 (b), B-Rb/Sr = 77 ± 4 (6).
T 715 (WAP 522)	Quartzose paraschist. SL: near Ranalt/Stubaital (Unterbergtal), Ö. Mi: qz + bi + ms + ga + ab/plag + chl + acc (clzo, ser, op, ap). B: GS1 = GS2 150–430 μ, P ~ 95% (+ 4–5% chl), B-K/Ar = 95 ± 4 (b), M: GS1 = GS2 150–430 μ, P > 99% (± bi, + inclusions), M-K/Ar = 187 ± 8 (5).
T 716 (WAP 523)	Gneissose paraschist. SL: St. Leonhard/Passeiertal, Marienbrücke. Mi: qz + plag + ms + bi + ga ± chl + acc (tourm, op, zr). M: GS1 = GS2 150–430 μ, P > 99% (± bi), M-K/Ar = 79 ± 3.3 (5).
T 717 (WAP 524)	Quartzose feldspathic micaschist. SL: Töll/Meran. OC. Mi: qz + bi + ms + ab/plag + acc (gr, op, clzo, carb, tourm, ep, tit). Locally neoformation of sericite. Postcrystalline deformation in qz. B: GS1 = GS2 150–430 μ, P > 98% (+ 1–2% chl), B-K/Ar = 75 ± 3 (b); M: GS1 = GS2 150–430 μ, P 97% (~ 3% chl), M-K/Ar = 76 ± 3 (5).
T 718 (WAP 525)	Mylonite. SL: NNW Kapron/Lehmgrube, Langtaufers, C, Sc. Mi: qz + ab/plag + pheng + chl + carb (cc) + acc (op, tit). Fabric well comparable with T 720–T 724, see below. WR, M-Rb/Sr see Fig. 7, Tab. 15.
T 720–T 724 (WAP 527–WAP 531)	Mylonite, SL: NW Kapron, m 1850/Langtaufers, Sc – Ö. Samples taken from a profile of ca. 4 m thickness. Tectonic contact Ötztal Altkristallin – Jaggl metasediments. Mi: T 720: qz + pheng + stilp + chl + ab/plag + clzo + carb (cc) + acc (op, tit, gr); T 721: qz + ab/pheng + stilp + clzo + bi + tit; T 722: qz + ab/plag + stilp + pheng/ms + chl + carb + clzo + acc (tit, op); T 723: qz + ab/plag + pheng/ms + stilp + bi + carb (cc) + acc (op, tit, clzo); T 724: qz + ab/plag + pheng/ms + stilp + bi + cc + acc (zr, clzo, tit). Coarse-grained (?detrital) components of plag and qz (mainly as strongly deformed qz-fishes showing resorption tubes and beginning subgrain formation); partly also coarse-flaky, kinked layers of colourless (?pre-

Alpine) white mica are observable (T 722) within the fine-grained, recrystallized or neogenic matrix. Grain size of neogenic pheng, stilp and clzo mostly 5–30 μ. Obviously crystallization onlasted the deformation process, as deduced from partly poor orientation of stilp, pheng and, especially, clzo. White micas are strongly phengitic and show intense green colour (FeO + MgO ≧ 10%, e. g. T 721, microprobe analysis). See Fig. 7, 8, Tab. 15.

T 731 (WAP 538) — Biotitegranitegneiss. SL: Val Sesvenna/E Scarl, C. Sc. Mi: I = plag + qz + kf + bi + acc (op, zr, carb). II = ser + clzo + chl. Qz: undulatory extinction, suturation, subgrain formation, plag unmixed, kf perthitic, bi partly chloritized. Carb infiltration along cracks. Bci: GS1 = GS2 150–430 μ, bi: chl 3 : 1, Bci-K/Ar = 226 ± 7 (b), WR-Rb/Sr see Fig. 3, Tab. 12.

T 732 (WAP 539) — Muscovitegranitegneiss. SL: Val Sesvenna/E Scarl, C, Sc. Mi: qz + plag + kf + ms + pheng II + acc (op, zr, clzo). Fine-grained qz recrystallized. Ms I: pheng II ~ 1 : 1. Locally green white mica occurs with numerous inclusions of tit and op (= ilm?): ?alteration product of pre-Alpine bi. M: GS1 = GS2 150–430 μ, P > 99%, M-K/Ar = 308 ± 13, M-Rb/Sr = 328 ± 13, WR-Rb/Sr see Fig. 3, Tab. 10, 12.

T 745 (WAP 552) — Garnetiferous paraschist. SL: Arlberg road Tunnel, E (02/2895 m), PZ. Sample collection by F. KUNZ. Mi: qz + ms + bi + ga ± ab + acc (tourm, tit, clzo, op). No alterations. B: GS1 = GS2 > 150 μ, P > 90% (< 10% chl, ± ms), B-K/Ar = 304 ± 14. M: GS1 = GS2 > 150 μ, P > 99.5% (+ inclusions), M-K/Ar = 306 ± 13 (1).

T 746 (WAP 554) — Paragneiss. SL: Arlberg road tunnel, E (02/3303 m), PZ. Sample collection by F. KUNZ. Mi: qz + plag/ab + ms + bi + ga + acc (op, tit, ap, chl). No alterations. B: GS1 = GS2 150–420 μ, P 99% (+ 1% chl), B-K/Ar = 308 ± 13. M: GS1 = GS2 150–420 μ, P > 99% (< 1% bi-intergrowth), M-K/Ar = 302 ± 13 (1).

T 747 (WAP 555) — Ab-chl-pheng-schist. SL: NW Innersulden, m 1720 (bridge), C, O. Mi: chl + ab + pheng + carb + qz + op. Fairly well recrystallized fabric. M: GS < 2 μ (S; apart from ms/pheng the X-ray diagram shows chl, ab, qz), M-K/Ar = 86 ± 6 (8).

T 749 (WAP 557) — Carbonaceous pheng-bi-schist (?Upper Triassic). SL: equal to T 747, C. Mi: pheng + bi + qz + ab + acc. Qz well recrystallized (polygonal structures), grain size of neogenic pheng and bi mostly 10–50 μ. < 2 μ-K/Ar (M + B!) = 86 ± 4 (8).

T 757 (WAP 642) — Sericitephyllite. SL: Tannas/Vinschgau, Sc. Mi: qz + ms/pheng + acc. Polygonal qz structure, grain size of ms 20–100 μ. WR-K/Ar (150–250 μ) = 80 ± 6 (10). M (< 2 μ)-K/Ar = 78.5 ± 5 (a).

T 761 (WAP 645) — Medium-grained paragneiss. SL: 800 m NNW Tannas/Vinschgau, Ö. Mi: I = qz + plag + bi + ms + op + acc (ap); II = ser + chl + tit (leucoxene) + carb. Conspicuous difference in grain size of primary and secondary micas. Intense growth of Alpine sericite (partly from unmixed plag) and chl. Locally chloritization of bi. Sample rich in ilm with leucoxene rims. B: GS1=GS2 74–170 μ, P > 98% (+ 1–2% chl), B-K/Ar = 231 ± 10 (a). M: GS1 = GS2 74–170 μ, P > 99%, M-K/Ar = 263 ± 11 (a), M-Rb/Sr = 335 ± 270 (7; Fig. 9).

T 768 (WAP 648) — Gneissose bi-sil-schist. SL: Saldurschlucht, Schluderns/Vinschgau, Ö (Matsch). Mi: bi + sil + qz + plag + ms ± chl + acc (zr, op, tourm). Bi partly intensely kinked. B: GS1 = GS2 170–430 μ, P 100%, B-Rb/Sr 131 ± 5 (6). M: GS1 = GS2 170–430 μ, P > 99% (inclusions), M-Rb/Sr 343 ± 127 (7; Fig. 9).

T 794 (WAP 664) — Medium-grained paragneiss. SL: Schlanderser Sonnenberg, road-outcrop Schlanders-Talatsch, m 1390/Vinschgau, Ö. Mi: I = ab/plag + qz + ms + bi + ga + acc (op, zr, ap); II = ser + clzo + chl + carb. Fabric very similar to T 761, but diaphthoresis is still more intense (bi, plag). B: GS1 = GS2 170–430 μ, P 99% (+ 1% chl), B-K/Ar = 438 ± 18 (a), B-Rb/Sr = 82 ± 11 (6); M: GS1 = GS2 150–430 μ, P 99% (+ 1% inclusions + bi-intergrowth), M-K/Ar = 228 ± 9 (a), M-Rb/Sr = 335 ± 336 (7; Fig. 9).

T 799 (WAP 679) — Gneissose micaschist. SL: Obergruben, m 2550, N Schlanders/Vinschgau, Ö (Matsch). Mi: I = bi + plag + ms + qz + ga + amph + sil + acc (tourm, zr, rut); II = ser

+ ctd + chl + bi (fine) ± qz + Fe-Ti + op. Typical paragenesis from the mixed age zone with intense alteration of the pre-Alpine minerals. Ser occurs mainly together with ctd as fine-grained heap; probably as pseudomorph after stau. B: GS1 = GS2 150–430 μ, P 100% (op inclusions!), B-K/Ar = 254 ± 11, B-Rb/Sr = 153 ± 11. M: GS1 = GS2 150–430 μ, P ≫ 99%, M-K/Ar = 169 ± 7, M-Rb/Sr = 321 ± 83 (5, 6, 7; Fig. 9).

T 803 (WAP 680)
Metatonalite. SL: 500 m SE Schlinig (road-outcrop), Schlinigtal, Sc. Mi: plag + qz + bi + amph + ser II ± chl + acc (clzo, op, carb). Very strong undulation in qz with beginning suturation. Sericitization of plag, intergranular growth of neogenic pheng; bi strongly kinked, but no chloritization. GS1 = 150–430 μ, GS2 = 150–250 μ, P ≫ 99% (± chl), B-K/Ar = 298 ± 13 (a), B-Rb/Sr = 259 ± 10 (12).

T 804 (WAP 681)
Muscovitegranitegneiss. SL: equal to T 803, Sc. Mi: qz + plag + kf + ms ± bi ± chl + ser/pheng II + acc (carb, op, il/tit). Very penetrative deformation: kinking in micas, undulation and beginning subgrain formation in qz; bi partly chloritized. Intense neoformation of Alpine pheng: ms I: pheng II ~ 1 : 2. M: GS1 = GS2, P 99% (± bi), M-K/Ar = 302 ± 14 (a), M-Rb/Sr = 326 ± 13 (12). Pheng II: S < 3.5 μ (+ qz + feldspar), Pheng II – K/Ar = 90 ± 5.6 (a).

T 833 (WAP 693)
Ms-chl-schist (Phyllite group). SL: Upper Martelltal, road-outcrop m 2050 (near "Enzian Haus"), OC. Mi: ms + qz + chl + ab ± ga + acc (op). Crenulation cleavage; slight undulation within well recrystallized qz fabric; neoformation of fine-scaly ms and chl (transverse chl); ga partly chloritized. M: GS1 = 150–430 μ, GS 2 = 74–150 μ, P > 99% (± chl, ± qz), M-K/Ar = 112 ± 4.5 (8).

T 834 (WAP 694)
Muscovitegranitegneiss. SL: Martelltal, at reservoir (m 1820), OC. Mi: plag + kf + qz + ms I + ms/pheng II + acc (clzo/ep, ga, bi). Plag unmixed and with bent twinning lamellae; undulation in qz; ms I mm-size, ms/pheng II ca. 50–150 μ. M (I): GS1 = 150–1000 μ, GS 2 = > 150 μ, P ± 100%. M-K/Ar = 116 ± 5 (8), M-Rb/Sr = 254 ± 10 (11).

T 840 (WAP 698)
Pseudotachylite. SL: Road Fimbertal-Idalpe, m 2000, C, Si. Mi: Fine-grained (up to 10 μ) recrystallized glass with numerous relics of qz + plag + bi. Parent rock: paragneiss. WR (150–250 μ)-K/Ar = 114 ± 5 (4).

T 841 (WAP 699)
Pseudotachylite. SL: road to Idalpe (m 2160), deviation to Höllenkar. Si. Mi: very similar to T 840. Sample taken from 5–10 cm thick discordant dike. Contacts to parent rock (= paragneiss) very sharp. WR (150–250 μ) – K/Ar = 53 ± 2.4 (4).

T 845 (WAP 702)
Calcschist. SL: Pfunds/Inntal, road outcrop at E end of the village. Engadine Window. Mi: qz + cc + ms ± plag ± chl. Size of ms up to ca. 200 μ. M: S < 2 μ (+ chl + few percent cc, X-ray), M-K/Ar = 26 ± 3 (4).

T 846 (WAP 703)
Fine-grained calcschist. SL: road outcrop at last curve from Finstermünz to Nauders, Engadine Window. Mi: cc + qz + ab/plag + ms (up to ca. 50 μ size only!) + chl. Alternation of mm-cm thick carbonaceous/pelitic layers. M: S < 2 μ (+ chl), M-K/Ar = 39 ± 2.3 (4).

T 849 (WAP 705)
Biotitite. SL: Val di Rabbi, ca. 3 km NW Sonrabbi, C, OC. Mi: bi + plag + qz ± ms + acc (zr, ilm, clzo). Very coarse-grained rock (bi: cm-size) with gentle kinking in bi; qz: strong undulation and subgrain formation; zoning in plag, partly sericitized. B: GS1 = > 150 μ, GS2 = 150–430 μ, P ± 100%, B-K/Ar = 211 ± 9 (8).

T 854 (WAP 707)
Stau-ga-micaschist. SL: upper Val di Rabbi, at Malga Stablazol, m 1500. C, OC. Mi: I = ms + bi + qz + stau + ga + plag + acc (op, tourm, ep, gr); II = ser + bi II + chl. Synkinematic crystallization of I (si of op, gr in stau, plag). Clear diaphthoresis: sericitization of stau, bleaching and Fe-Ti segregation in bi I. Late (= postdiaphthoritic) deformation documented by strong undulation in qz. B: GS1 = GS2 170–430 μ, P > 99% (± chl), B-K/Ar = 589 ± 18 (excess argon, 8), B-Rb/Sr = 99 ± 9 (11). M: GS1 = GS2 170–430 μ, P ca. 98.5% (+ 1.5% bi-intergrowth), M-K/Ar = 123 ± 5 (8).

T 855
(WAP 708)

Ms-plag-orthogneiss. SL: 1 km SE S. Bernardo/Rabbi, TZ. Mi: I = plag + qz + ms ± kf + acc (op, haem); II = pheng ± qz. Strong undulation, suturation and beginning recrystallization in qz. Neoformation of Alpine pheng mainly as rims around coarse ms I. M: GS1 = > 430 μ, GS2 = > 300 μ, P ≫ 99%. M-K/Ar = 294 ± 12 (9), M-Rb/Sr = 231 ± 9 (!) (11; Fig. 1).

T 862
(WAP 710)

Phyllitic ga-micaschist (Phyllite group). SL: upper Ultental, near O. Weißbrunn Alm. OC. Mi: ms + ser + qz + chl + ga + acc (op, tourm). Strongly varying grain size in ms: from 10 μ up to mm-size. Postcrystalline deformation in qz. M: GS1 = GS2 170–430 μ, P 100%. M-K/Ar = 133 ± 5.5 (8).

T 864
(WAP 712)

Ms-pegmatite. SL: Schlandrauntal N Schlanders, m 1550, Ö (Matsch). Mi: plag + kf + qz + ms I + ser II + acc (ga, clzo, tit, haem). Very intense cataclastic deformation in feldspars, fissures filled with mortar qz and partly with greenish ms II. Ms = cm-size. M: GS1 > 150 μ, GS2 = 150–250 μ, P 100%, M-Rb/Sr = 351 ± 20 (7), M-K/Ar = 149 ± 8 (5).

T 873
(WAP 715)

Stau-ky-gneiss-micaschist. SL: 100 m E Penser Joch (road outcrop), Merano-Mules complex. Mi: qz + bi + stau + ky + plag + ms + ga + ser II + acc (op, gr, ep). Beginning sericitization in plag, ky, stau. Pre-Alpine bi (greenish brown) locally slightly chloritized. Suturation and subgrain formation in qz. B: GS1 = GS2 170–430 μ, P ± 100% (inclusions), B-K/Ar = 257 ± 10 (5), B-Rb/Sr = 271 ± 11 (6). M: GS1 = GS2 170–430 μ, P > 99%, M-K/Ar = 297 ± 12 (5).

T 887
(WAP 723)

"Grüngneis" (Porphyric metagranite). SL: Gampadelstal/Montafon, m 1550, Lower Austroalpine Unit; C. Mi: qz + plag + ms + chl II ± bi + carb + acc (op, ep, zr). Intense chloritization in bi, especially along bleaching zones. M: GS1 = GS2 170–430 μ, P ≫ 99%, M-K/Ar = 308 ± 12 (1).

T 889
(WAP 725)

Meta-Siltstone (Permoscythian). SL: Rellstal/Montafon, ca. 2 km WSW Vandans, Basis Northern Calcareous Alps, C. Mi: qz + ser/pheng + chl + bi ± ab ± ?pyro (X-ray diagram) + acc (ep, op). Slightly altered sedimentary structure with poor orientation of detrital ms and bi (grain size 50–> 200 μ). Neogenic mica 10 μ, orientation along s. M: S < 2 μ, M-K/Ar = 114 ± 6 (1).

T 890

Paragneiss. SL: equal to T 889, C. PZ. Mi: qz + plag/ab + bi + ms + ga + acc (zr, op). Slight sericitization in plag. Subgrain formation starts within qz. B: GS1 = GS2 170–420 μ, P ± 100%, B-K/Ar = 314 ± 13 (1), B-Rb/Sr = 283 ± 11 (3).

T 916
(WAP 821)

Paragneiss. SL: ca. 500 m S Puschlin/Prutz, Si. Mi: I = qz + plag + bi + ms ± ga + acc (ep). II = ser ± chl. Bi: greenishbrown, kinked, partly chloritized. Sericitization of plag. B: GS1 = GS2 150–430 μ, P 100%, B-K/Ar = 251 ± 10 (excess argon, 2). M: GS1 = GS2 150–430 μ, P > 99%, M-K/Ar = 191 ± 8 (2).

T 917
(WAP 822)

Paragneiss. SL: Kaunertal, road outcrop near Vergötschen, Ö. Mi: plag + qz + bi + ms ± ga ± kf + acc (ser, chl, clzo). Slight sericitization of plag, beginning suturation in qz. B: GS1 = GS2 150–430 μ, P 96% (+ ca. 4% chl), Bc-K/Ar = 273 ± 11 (5).

T 920
(WAP 823)

Diaphthoritic gneiss. SL: Kaunertal, Bridge W Kaltenbrunn, basal parts of the Ötztal Altkristallin. Mi: I = plag + qz + ms ± bi + ga + acc; II = chl + ser + clzo + tit + carb. Sericitization of plag, bi chloritized, strong deformation (deformation lamellae, undulation) and subgrain formation in qz. M: GS1 430 μ, GS2 > 150 μ, P ~ 97% (± qz ± plag), M-K/Ar = 259 ± 10 (5).

T 935
(WAP 826)

Hybrid gneiss (paragneiss alternating with pegmatitic layers). SL: Val Fontana, m 850, N Ponte/Valtellina, TZ. Mi: pegmatitic layers (cm): qz + plag + ms I, II + clzo + acc. Mi: dark layers: bi + amph + clzo/ep + qz + ga ± ms I ± chl + acc (orthite, op). Recrystallized microlites in plag, qz partly recrystallized with later deformation (undulation); bi partly fine-grained = ?Alpine product; slight chloritization in ga. M: GS1 > 430 μ, GS2 > 150 μ, P > 99% (± bi), M-K/Ar = 148 ± 6 (9).

T 937
(WAP 828)

Bi-sil-micaschist. SL: Val Fontana, m 930 (road outcrop), N Ponte/Valtellina, TZ. Mi: I = bi + sil + qz + ms + plag + acc (ep, zr); II = ser + cltd + ilm/tit. Bi: strongly kinked, bleaching and Fe-Ti-segregation mainly along kinkbands (Fig. 1); plag:

slight sericitization; pervasive deformation with subgrain formation in qz. B: GS1 > 430 μ, GS2 > 150 μ, P > 99% (± chl), B-K/Ar = 291 ± 12 (excess argon; 9). M: GS1 > 430 μ, GS2 > 150 μ, P > 99% (± bi), M-K/Ar = 200 ± 8 (9).

T 943 (WAP 830) Quartzose bi-schist. SL: road outcrop ca. 500 m NW Tirano, TZ. Mi: bi + qz + ab/ /plag + ser II + chl + clzo + acc (zr). Intense growth of fine-grained ms + chl; bleaching of bi; subgrain formation and recrystallization p. p. in qz. B: GS1 = GS2 150–430 μ, P ≫ 99% (± chl), B-K/Ar = 362 ± 15 (excess argon, 9).

T 945 (WAP 832) Gneiss-micaschist. SL: Val Grosina, road outcrop at 1450 m, OC. Mi: qz + bi + ms + plag ± chl + acc (zr, ap). Kinking in micas, suturation in strongly undulated qz-domains. Locally neoformation of very fine-grained ser, chl and bi. B: GS1 > 430 μ, GS2 > 150 μ, P ≫ 99% (± chl), B-K/Ar = 164 ± 6.7 (8). M: GS1 > 450 μ, GS2 > 150 μ, P 99% (+ ca. 1% bi-intergrowth), M-K/Ar = 182 ± 7.6 (8).

T 946 (WAP 833) Pegmatite. SL: equal to T 945, OC. Mi: kf + plag + ms I + ser II + bi + qz ± chl + acc (ep, ga). Mortar qz in feldspar, strong suturation of coarse-grained qz. B: GS1 > 430 μ, GS2 > 150 μ, P ≫ 99%, B-K/Ar = 122 ± 6 (8), B-Rb/Sr = 96 ± 4. M: GS1 > 430 μ, GS2 > 150 μ, P ≫ 99%, M-K/Ar = 187 ± 8 (8), M-Rb/Sr = 329 ± 15 (11).

T 953 (WAP 838) Flasergneiss ("Grüngneis"). SL: Val di Livigno, ca. 2 km N Forcola di Livigno, C, L. Mi: I = qz + plag + ms ± ga + acc (op, clzo); II = ser + chl. Sericitization of plag, chloritization of ga, intense suturation in qz. M: GS1 > 430 μ, GS2 > 150 μ, P > 98% (+ 1–2% chl), M-K/Ar = 313 ± 13 (10).

T 957 (WAP 841) Granitoid gneiss. SL: Val di Livigno, ca. 3 km SW of the village, L. Mi: I = qz + plag ± kf + bi + ms + acc (clzo, tourm); II = chl + ser. Slight chloritization of bi along the rims, saussuritization of plag, intense suturation in qz fabric. Bc: GS1 = GS2 > 150 μ, P: + ca. 25% chl, Bc-K/Ar = 244 ± 10 (10).

T 966 (WAP 845) Pegmatite. SL: S of Passo di Gavia, road outcrop at m 2300, OC. Mi: qz + ms + kf + plag ± ser II + ga. Very coarse-grained s-parallel intercalations within the paraschists. M: GS1 > 430 μ, GS2 150–430 μ, P ± 100%, M-K/Ar = 129 ± 6 (8), M-Rb/Sr = 314 ± 13 (11).

T 969 (WAP 848) Paragneiss. SL: near T 966, road outcrop at m 2150, OC. Mi: qz + plag + bi + ms + acc (zr, ep/clzo). Well foliated, coarse-grained pre-Alpine texture. No reactions in plag and micas, qz sutured. B: GS1 > 430 μ, GS2 > 250 μ, P ± 100% (inclusions!), B-K/Ar = 178 ± 7 (excess argon; 8), B-Rb/Sr = 145 ± 6 (8). M: GS1 > 430 μ, GS2 > 250 μ, P ~ 98% (+ bi-intergrowth!), M-K/Ar = 135 ± 6 (8).

T 970 (WAP 849) Coarse-grained paragneiss. SL: road outcrop Ponte di Legno to Passo del Tonale. TZ. Mi: plag + bi + qz + ms + sil + acc (ep, ilm, tit, rut). Slight sericitization in plag. Very intense deformation in micas (kinking) and qz (undulation, subgrain formation, partly mortar qz). Segregation of Fe-Ti opaques in bi, mainly along the kink bands (microprobe analyses). Locally fine-grained aggregates of chl and ?bi II. Sericitization of sil p. p. B: GS1 > 430 μ, GS2 > 150 μ, P ± 100% (inclusions!), B-K/Ar = 263 ± 11 (excess argon; 9). M: GS1 > 430 μ, GS2 > 150 μ, P 99% (+ bi), M-K/Ar = 142 ± 6 (9).

T 971 (WAP 850) Diaphthoritic micaschist. SL: E Passo del Tonale, road outcrop at m 1600, TZ. Mi: I = qz + ms + bi ± ga + acc (ep, op); II = ser + chl + carb + tit. Intense diaphthoresis: chloritization of bi and ga; ms I (mm size): ms/pheng II (up to 100 μ) ~ 1 : 1.5; qz recrystallized with weak postcrystalline undulation. B: GS1 > 430 μ, GS2 > 150 μ, P > 99% (± chl ± ms), B-K/Ar = 101 ± 5 (9). M: GS1 > 430 μ, GS2 > 150 μ, P ± 100%, M-K/Ar = 154 ± 6 (9).

T 977 (WAP 852) Contact metamorphosed paraschist. SL: Upper Val della Mare (Val di Peio), Prabon, road to power-station, outcrop at m 1930, OC. Mi: bi + qz + ms + and + stau + acc (op, ga, zr, orthite). Primary fabric (foliation) overprinted by static thermal process. Qz well recrystallized with weak (later) undulation; s-oriented mica layers discordantly overgrown by fine-grained bi and ms and by partly idiomorphic and; stau forms xenomorphic relics within unoriented mica. Distance of SL from a small diorite stock (cf. ANDREATTA 1954 b) ca. 150 m. B: GS1 > 430 μ, GS2 > 150 μ, P > 99% (± chl), B-K/Ar = 30.5 ± 1.5 (8). M: GS1 > 430 μ, GS2 > 150 μ, P ~ 97% (+ bi), M-K/Ar = 31 ± 1.8 (8).

T 980 (WAP 855) — Granitegneiss. SL: equal to T 855, TZ. Mi: I = plag + qz + ms ± bi + kf + acc (ap, op, ilm); II = pheng/ser + stilp. Bending and cataclasis in feldspars, kinking in ms, suturation in qz. Neoformation of Alpine stilp and pheng. M: GS1 > 430 μ, GS2 > 150 μ, P ± 100%, M-K/Ar = 289 ± 12 (9), M-Rb/Sr = 317 ± 13 (11).

T 984 (WAP 857) — Kinzigitegneiss. SL: Val di Lavazzé W Rumo, m 1150, C. TZ. Mi: I = qz + plag + bi + ms + ky + ga + acc (ap, zr, tit, rut, ilm); II = ± ser ± chl. No foliation in the microfabric. Cataclastic deformation and slight diaphthoresis: sericitization of ky, beginning chloritization in bi and ga; plag slightly sericitized. B: GS1 > 430 μ, GS2 > 150 μ, P 98% (± chl ± ms), B-K/Ar = 171 ± 7. M: GS1 > 430 μ, GS2 > 150 μ, P ~ 97% (+ bi-intergrowth), M-K/Ar = 189 ± 8 (9).

T 985 (WAP 858) — Granitegneiss. SL: equal to T 984, TZ. Mi: I = kf + qz + plag + bi + ms ± ga + acc (ep/clzo, zr); II = ser ± chl. Very slight alteration. B: GS1 > 430 μ, GS2 > 150 μ, P 99% (± chl), B-K/Ar = 313 ± 15 (excess argon; 9), B-Rb/Sr 211 ± 8 (11). M: GS1 > 450 μ, GS2 > 150 μ, P 97–98% (bi-intergrowth!), M-K/Ar = 239 ± 10 (9).

T 994–T 1000 (WAP 867–WAP 873) — Verrucano. SL: 800 m ESE Cierfs/Münstertal (road outcrop), Sc. Samples taken from a profile of ca. 2 m only. Mi: qz + ms/pheng ± chl ± stilp ± carb (cc) ± plag/ab + acc (haem, op). All samples show detrital components in fine-grained, recrystallized/neogenic matrix. Detrital: mm-sized qz-pebbles, partly with deformation lamellae or BÖHM lamellae, partly idiomorphic porphyry qz with resorption tubes, generally no suturation; clastic, coarse-flaky white mica shows randomly intense intergrowth with neogenic pheng; locally totally degraded bi-relics and unmixed plag with neogenic ab-rims occur. Neogenic: qz up to ca. 50 μ grain size is mostly well recrystallized (polygonal, slightly undulated fabric), newly-formed ms/pheng mostly of 5–30 μ size. Metamorphic temperature estimated from recrystallization behaviour of qz: 300 ± 20 °C (p. p. VOLL, pers. comm.). M (< 2 μ)-Rb/Sr see Fig. 6, Tab. 14; same outcrop M-(< 2 μ)K/Ar = 87–89 m. y. (b). T 1000: WR-K/Ar 103 ± 5 (10).

T 1003 (WAP 876) — Granitegneiss. SL: Flüela Pass, ca. 150 m right E of Hospiz (road outcrop), Si. Mi: kf + plag + qz + ms + bi ± chl II + acc (zr, ap, rut, carb). Chloritization of bi, sericitization of plag; qz shows strong undulation, but subgrain formation is at the very beginning. Bc (+ sagenite): GS1 = GS2 > 150 μ, bi: chl ~ 2 : 1, Bc-K/Ar = 272 ± 15 (2). M: GS1 = GS2 > 150 μ, P ≫ 99% (± bi), M-K/Ar = 317 ± 13 (2), M-Rb/Sr = 310 ± 12 (3).

T 1010 (WAP 879) — Granitegneiss. SL: Val Tours, m 1760 near Punts A., WNW Piz Kesch, C, Si. Mi: qz + plag + kf + ms + bi ± chl + acc (zr). Very slight alterations in bi (chloritization), plag (sericitization) and qz (suturation starts). B: GS1 = GS2 > 150 μ, P ≫ 99% (± chl), B-K/Ar = 316 ± 13, B-Rb/Sr = 279 ± 11. M: GS1 = GS2 > 150 μ, P > 99% (± bi), M-K/Ar = 316 ± 13 (2, 3).

T 1013 (WAP 880) — Paragneiss. SL: ca. 200 m N Pontresina (village centre), L. Mi: qz + plag + ms + bi + acc (clzo, zr, ap, chl, tit). Very slight alteration: sericitization of plag, chloritization in bi beginning, qz shows strong undulation and deformation lamellae, first subgrain boundaries appear. B: GS1 = GS2 > 150 μ, P 100%, B-K/Ar = 280 ± 11 (10), B-Rb/Sr = 277 ± 11 (11).

T 1014 (WAP 881) — Medium-grained paragneiss. SL: equal to T 1013, L. Mi: qz + plag + ms + bi ± chl + acc (monazite, ap, ga). Similar to T 1013. Intercalated ms-plag-gneisses (T 1015) show neogenic Alpine stilp. B: GS1 > 430 μ, GS2 > 150 μ, P 100%, B-K/Ar = 286 ± 13 (10). M: GS1 >450 μ, GS2 > 150 μ, P ~ 97% (bi-intergrowth!), M-K/Ar = 308 ± 12 (10).

T 1019 (WAP 883)	Gneissose micaschist. SL: ca. 1 km S Kematen, lower Sellraintal (road outcrop), Ö. Mi: qz + bi + ms + plag/ab + ga + stau + acc (ap, op); ± unaltered paragenesis; stau shows locally very fine rims of neogenic ser. B: GS1 > 430 μ, GS2 > 150 μ, P > 99% (± chl, inclusions), B-K/Ar = 307 ± 12 (?excess argon, 5). M: GS1 > 430 μ, GS2 > 150 μ, P 97% (+ bio-intergrowth), M-K/Ar = 294 ± 12 (5).
T 1023 (WAP 886)	Granitegneiss. SL: Radurscheltal, ca. 200 m N Hohenzollernhaus, C. Ö. Mi: plag + kf + qz + ms + pheng II + bi + acc (zr, op). Deformation in micas; qz shows suturation and beginning recrystallization; neogenic ser/pheng, sericitization of plag p. p. M: GS1 = GS2 150–430 μ, P > 99% (± bi, ± qz), M-K/Ar = 299 ± 13 (5).
T 1112 (WAP 899)	Granitegneiss. SL: E side Piz da Rims, ca. 2900, N Umbrail Pass; crystalline klippe, U. Mi: qz + kf + plag + pheng I + II + acc (op, ap). Very strong undulation and suturation in qz; green pre-Alpine pheng I, mm-size (16), with rims of fine-scaly Alpine pheng II. Cataclasis of feldspars. M: GS1 > 430 μ, GS2 > 150 μ, P 100%, M-K/Ar = 305 ± 12 (10), M-Rb/Sr = 274 ± 11 (12).
T 1125 (WAP 901)	Granitegneiss. SL: Val Muraunza, m 2200, vis-à-vis Muraunza-Hütte, U. Mi: qz + plag + pheng I + II + kf + acc (zr, op). Very similar to T 1112, but still more intense deformation; qz recrystallizes in most fine-grained domains. M: GS1 > 430 μ, GS2 > 150 μ, P 100%, M-K/Ar = 306 ± 13 (12).
T 1157 (WAP 904)	Granitegneiss. SL: near storage reservoir Vermunt, S Parthenen, Si. Mi: qz + plag + kf + bi + ms ± chl + acc (clzo, zr, tit). Bi shows tiny chl-rims, slight sericitization in plag, subgrain formation in qz. B: GS1 = GS2 > 420 μ, P ± 100%, B-K/Ar = 213 ± 9. M: GS1 = GS2 > 420 μ, P 98% (bi-intergrowth!), M-K/Ar = 311 ± 13 (2).
T 1159 (WAP 905)	Granitegneiss: SL: Silvretta-Hochalpenstraße from Bieler Höhe to Galtür, m 1850, Si. Mi: I = plag + kf + ms + bi + qz + acc (ap, zr, ga); II = ser/pheng + stilp + chl. Cataclastic deformation in feldspars; subgrain formation in qz, bi (brown-olivegreen) partly bleached or chloritized; neogenic pheng occurs randomly along ms I. M: GS1 = GS2 > 430 μ, P ~ 99% (+ bi-intergrowth), M-K/Ar = 239 ± 10 (2).
T 1165 (WAP 906)	Ms-tourm-pegmatite. SL: Berglerloch, eastern side, m 2260, SSE Mathon, basal Si. Mi: plag + qz + ms ± kf ± ga ± tourm + ser II. Pervasive deformation in feldspars (bending, cracks filled with ser II); well recrystallized qz-fabric (weak undulation). M: GS1 > 430 μ, GS 2 > 150 μ, P 100%, M-K/Ar = 174 ± 7 (2), M-Rb/Sr = 223 ± 8 (3).
68/2 (WAP 621)	Ga-stau-micaschist. SL: ridge between Lareintal and Jamtal, Schnapfenloch, m 2736, Si. Sample collection by G. FUCHS. Mi: qz + ab/plag + ms + ga + bi + stau + acc (op, clzo, zr, tit). II = chl + ser + ?bi II. Intense chloritization of bi (green-brown), slight sericitization of stau. Bi: mostly fine-grained (?Alpine recrystallization). M: GS1 = GS2 > 150–430 μ, P ≫ 99%, M-K/Ar = 186 ± 8 (2).
77/19 (WAP 622)	Ga-stau-bi-sil-paraschist. SL: Jamtal, near Jamtalhütte/NW Pfannknecht, Si. Sample collection by G. FUCHS. Mi: I = qz + bi + ga + stau + sil + op + acc (clzo, ap); II = chl + ser. Chloritization of bi, sericitization of plag. Bci: GS1 = GS2 74–430 μ, P: + ca. 10% chl, Bci-K/Ar = 166 ± 7 (2).
III (WAP 392)	Sericiteschist. SL: near Unterfaggen/Prutz, Engadine Window. Sample collection and preparation by L. KRECZY. Very homogenous, fine-grained qz-ser-schist. M (< 2 μ)-K/Ar = 34.4 ± 1.6 (4).

Corrections of the Plates

Plate 4: The "K/Ar isochron on different grain sizes" ESE of Reschen Paß, Jaggl (88 m. y., see THÖNI 1980 b, Fig. 5) belongs to the 100–85 m. y. age group (green full) and not to the 230–100 m. y. age group.

Plate 5: The Rb/Sr small-scale-isochron ESE of Ofen Paß, Münstertal (50 m. y., see Fig. 5, this paper) belongs to the 70–40 m. y. age group (light red) and not to the < 40 m. y. age group.

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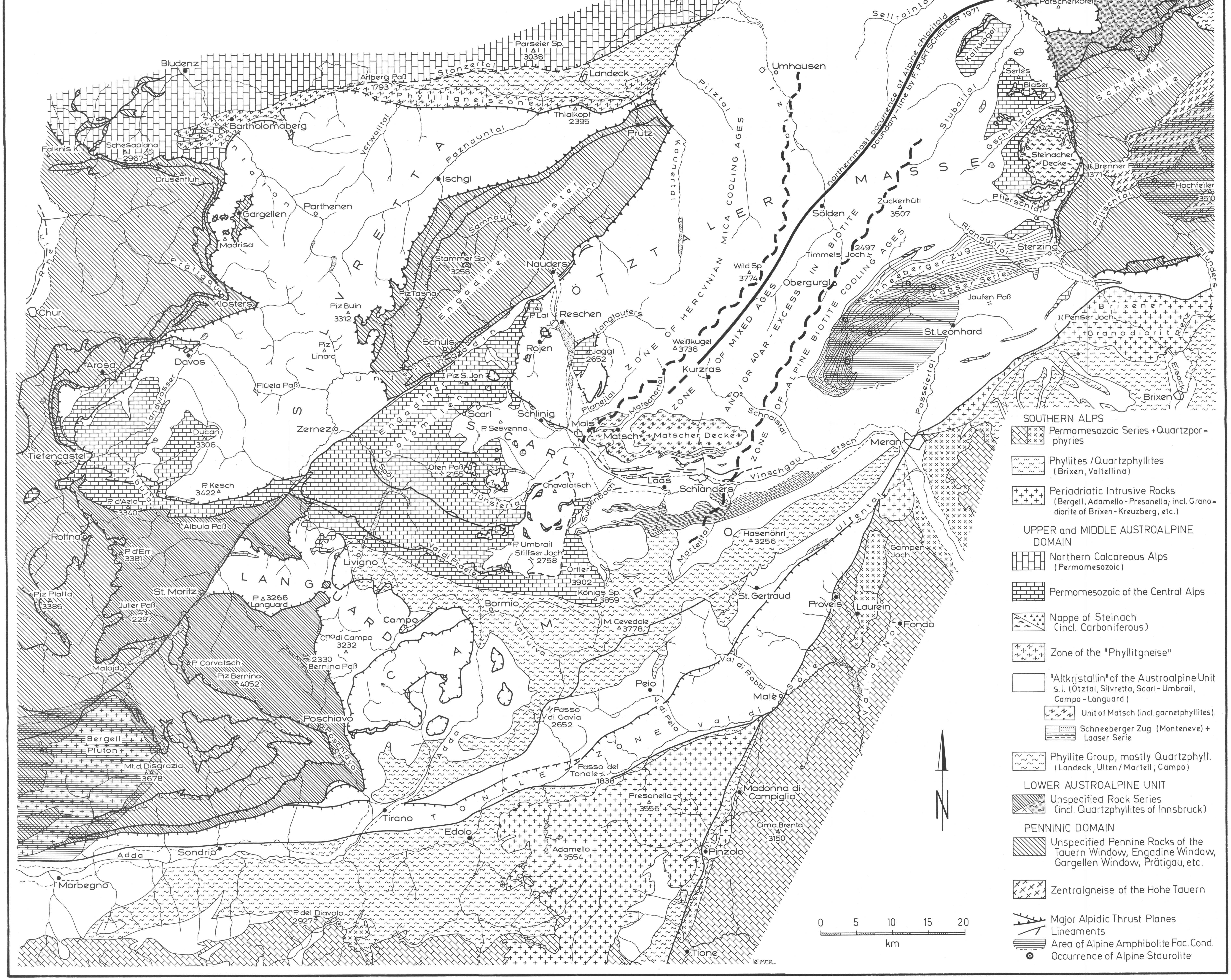
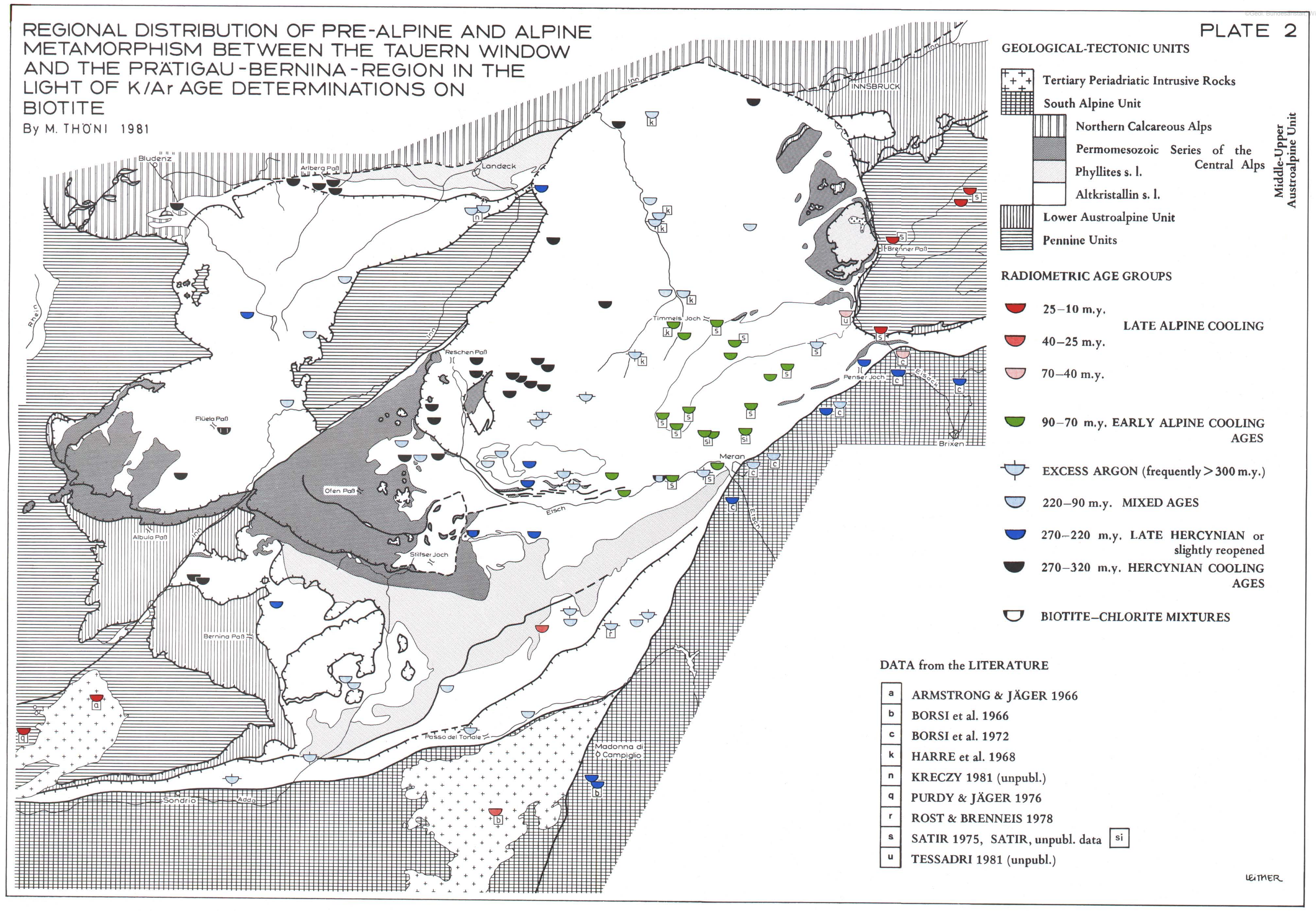
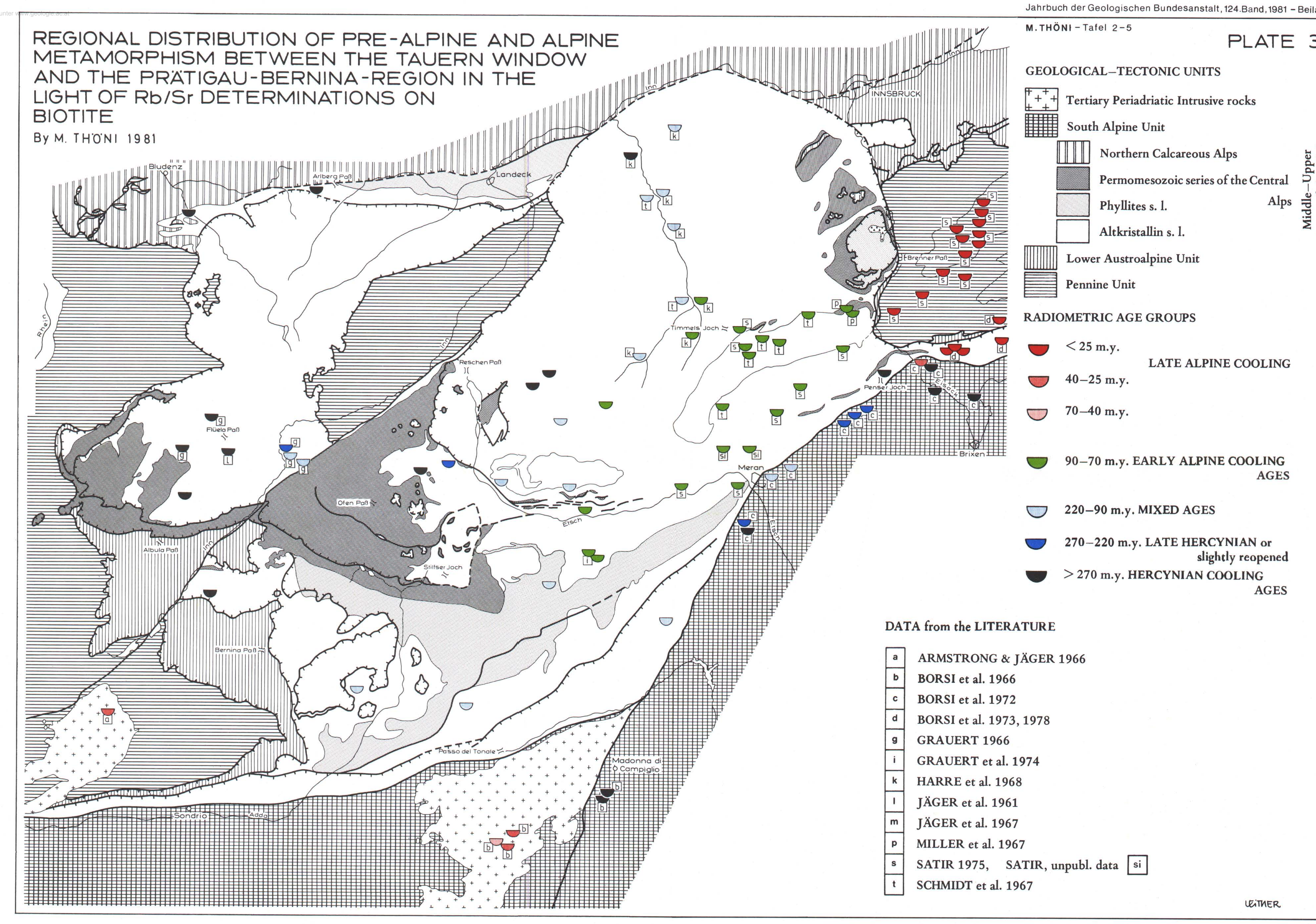
PLATE 1

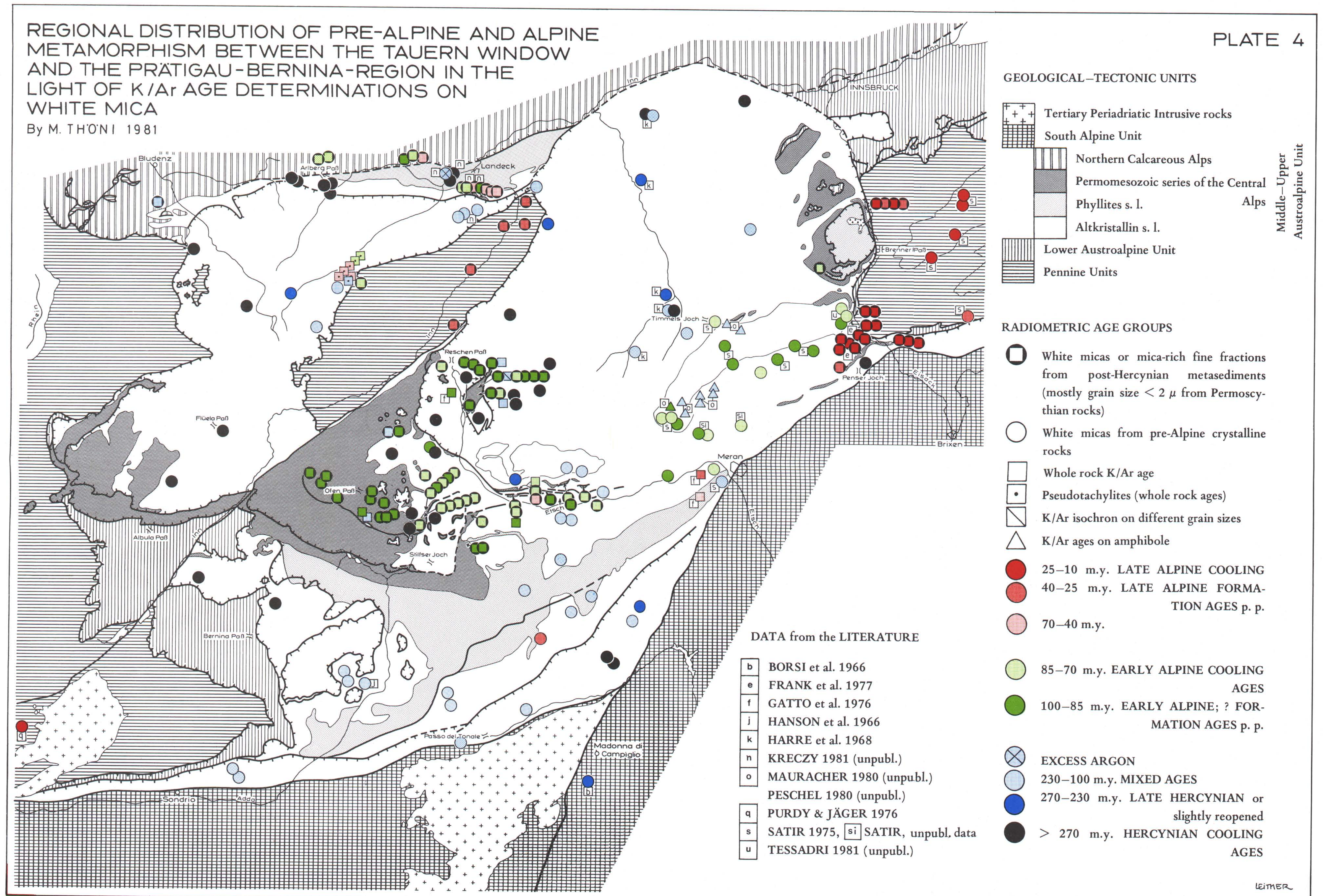
SIMPLIFIED GEOLOGICAL-TECTONIC MAP OF THE CENTRAL ALPS BETWEEN THE TAUERN WINDOW AND THE PRÄTIGAU-BERNINA-REGION

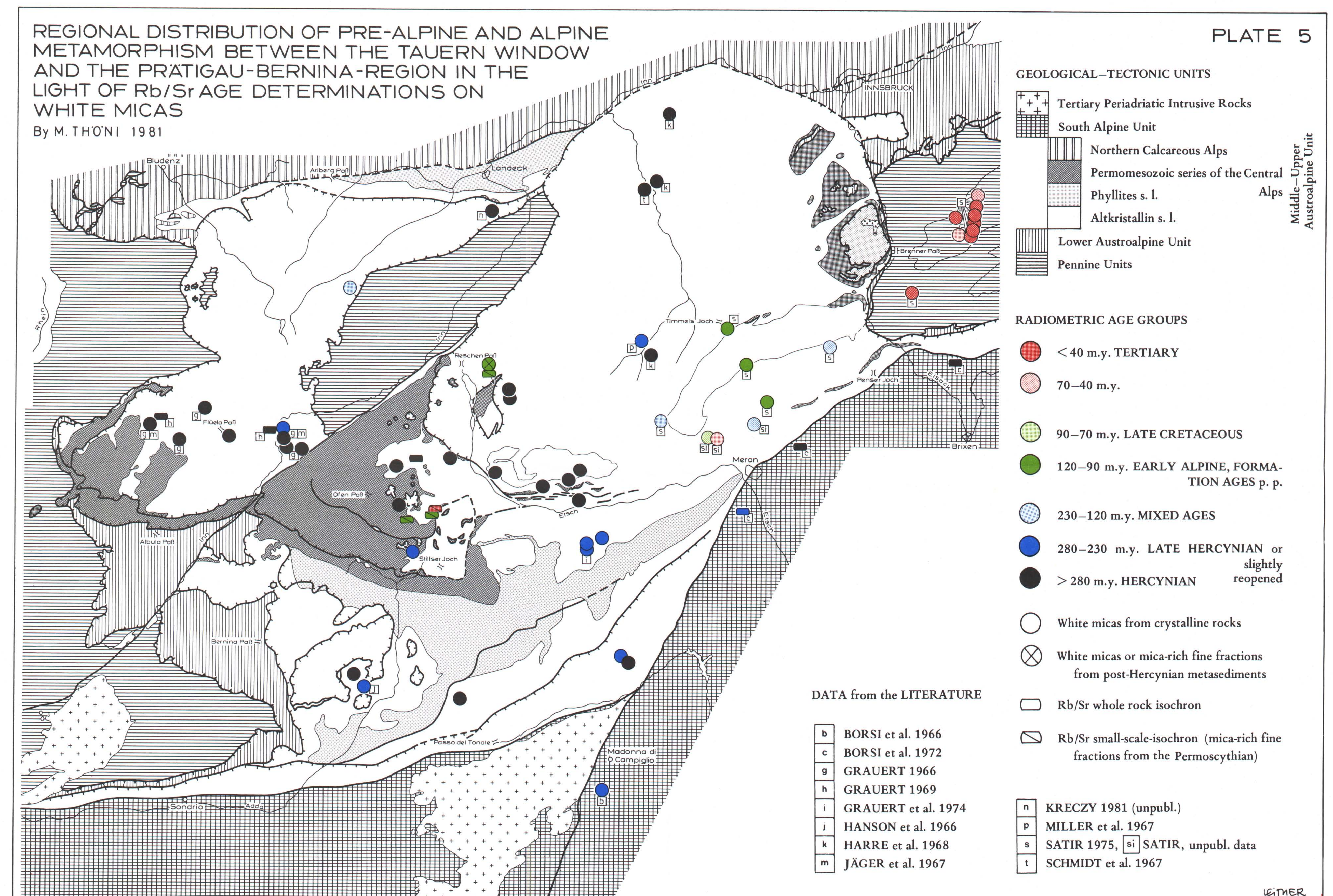
M. THÖNI 1981




REGIONAL DISTRIBUTION OF PRE-ALPINE AND ALPINE METAMORPHISM BETWEEN THE TAUERN WINDOW AND THE PRÄTIGAU-BERNINA-REGION IN THE LIGHT OF K/Ar AGE DETERMINATIONS ON BIOTITE
By M. THÖNI 1981
PLATE 2
GEOLOGICAL–TECTONIC UNITS
Tertiary Periadriatic Intrusive Rocks
South Alpine Unit
Northern Calcareous Alps
Permomesozoic Series of the Central Alps
Phyllites s. l.
Altkristallin s. l.
Middle–Upper Austroalpine Unit
Lower Austroalpine Unit
Pennine Units
RADIOMETRIC AGE GROUPS
25–10 m.y.
40–25 m.y.
LATE ALPINE COOLING
70–40 m.y.
90–70 m.y. EARLY ALPINE COOLING AGES
EXCESS ARGON (frequently > 300 m.y.)
220–90 m.y. MIXED AGES
270–220 m.y. LATE HERCYNIAN or slightly reopened
270–320 m.y. HERCYNIAN COOLING AGES
BIOTITE–CHLORITE MIXTURES
DATA from the LITERATURE
a ARMSTRONG & JÄGER 1966
b BORSI et al. 1966
c BORSI et al. 1972
k HARRE et al. 1968
n KRECZY 1981 (unpubl.)
q PURDY & JÄGER 1976
r ROST & BRENNEIS 1978
s SATIR 1975, SATIR, unpubl. data si
u TESSADRI 1981 (unpubl.)
INNSBRUCK
Landeck
Bludenz
Arlberg Paß
Reschen Paß
Timmels Joch
Brenner Paß
Penser Joch
Meran
Brixen
Ofen Paß
Flüela Paß
Albula Paß
Stilfser Joch
Etsch
Bernina Paß
Passo del Tonale
Madonna di Campiglio
Sondrio
LEITNER


REGIONAL DISTRIBUTION OF PRE-ALPINE AND ALPINE METAMORPHISM BETWEEN THE TAUERN WINDOW AND THE PRÄTIGAU-BERNINA-REGION IN THE LIGHT OF Rb/Sr DETERMINATIONS ON BIOTITE
By M. THÖNI 1981
PLATE 3
GEOLOGICAL–TECTONIC UNITS
Tertiary Periadriatic Intrusive rocks
South Alpine Unit
Northern Calcareous Alps
Permomesozoic series of the Central Alps
Phyllites s. l.
Altkristallin s. l.
Middle–Upper Austroalpine Unit
Lower Austroalpine Unit
Pennine Unit
RADIOMETRIC AGE GROUPS
< 25 m.y.
40–25 m.y.
LATE ALPINE COOLING
70–40 m.y.
90–70 m.y. EARLY ALPINE COOLING AGES
220–90 m.y. MIXED AGES
270–220 m.y. LATE HERCYNIAN or slightly reopened
> 270 m.y. HERCYNIAN COOLING AGES
DATA from the LITERATURE
a ARMSTRONG & JÄGER 1966
b BORSI et al. 1966
c BORSI et al. 1972
d BORSI et al. 1973, 1978
g GRAUERT 1966
i GRAUERT et al. 1974
k HARRE et al. 1968
l JÄGER et al. 1961
m JÄGER et al. 1967
p MILLER et al. 1967
s SATIR 1975, SATIR, unpubl. data si
t SCHMIDT et al. 1967
INNSBRUCK
Landeck
Bludenz
Reschen Paß
Timmels Joch
Brenner Paß
Meran
Brixen
Ofen Paß
Flüela Paß
Albula Paß
Stilfser Joch
Etsch
Bernina Paß
Passo del Tonale
Madonna di Campiglio
Sondrio
LEITNER


REGIONAL DISTRIBUTION OF PRE-ALPINE AND ALPINE METAMORPHISM BETWEEN THE TAUERN WINDOW AND THE PRÄTIGAU-BERNINA-REGION IN THE LIGHT OF K/Ar AGE DETERMINATIONS ON WHITE MICA
By M. THÖNI 1981
PLATE 4
GEOLOGICAL–TECTONIC UNITS
Tertiary Periadriatic Intrusive rocks
South Alpine Unit
Northern Calcareous Alps
Permomesozoic series of the Central Alps
Phyllites s. l.
Altkristallin s. l.
Middle–Upper Austroalpine Unit
Lower Austroalpine Unit
Pennine Units
RADIOMETRIC AGE GROUPS
White micas or mica-rich fine fractions from post-Hercynian metasediments (mostly grain size < 2 μ from Permoscythian rocks)
White micas from pre-Alpine crystalline rocks
Whole rock K/Ar age
Pseudotachylites (whole rock ages)
K/Ar isochron on different grain sizes
K/Ar ages on amphibole
25–10 m.y. LATE ALPINE COOLING
40–25 m.y. LATE ALPINE FORMATION AGES p. p.
70–40 m.y.
85–70 m.y. EARLY ALPINE COOLING AGES
100–85 m.y. EARLY ALPINE; ? FORMATION AGES p. p.
EXCESS ARGON
230–100 m.y. MIXED AGES
270–230 m.y. LATE HERCYNIAN or slightly reopened
> 270 m.y. HERCYNIAN COOLING AGES
DATA from the LITERATURE
b BORSI et al. 1966
e FRANK et al. 1977
f GATTO et al. 1976
j HANSON et al. 1966
k HARRE et al. 1968
n KRECZY 1981 (unpubl.)
o MAURACHER 1980 (unpubl.) PESCHEL 1980 (unpubl.)
q PURDY & JÄGER 1976
s SATIR 1975, si SATIR, unpubl. data
u TESSADRI 1981 (unpubl.)
INNSBRUCK
Landeck
Bludenz
Arlberg Paß
Reschen Paß
Timmels Joch
Brenner Paß
Penser Joch
Meran
Brixen
Ofen Paß
Flüela Paß
Albula Paß
Stilfser Joch
Etsch
Bernina Paß
Passo del Tonale
Madonna di Campiglio
Sondrio
LEITNER


REGIONAL DISTRIBUTION OF PRE-ALPINE AND ALPINE METAMORPHISM BETWEEN THE TAUERN WINDOW AND THE PRÄTIGAU-BERNINA-REGION IN THE LIGHT OF Rb/Sr AGE DETERMINATIONS ON WHITE MICAS
By M. THÖNI 1981
PLATE 5
GEOLOGICAL–TECTONIC UNITS
Tertiary Periadriatic Intrusive Rocks
South Alpine Unit
Northern Calcareous Alps
Permomesozoic series of the Central Alps
Phyllites s. l.
Altkristallin s. l.
Middle–Upper Austroalpine Unit
Lower Austroalpine Unit
Pennine Units
RADIOMETRIC AGE GROUPS
< 40 m.y. TERTIARY
70–40 m.y.
90–70 m.y. LATE CRETACEOUS
120–90 m.y. EARLY ALPINE, FORMATION AGES p. p.
230–120 m.y. MIXED AGES
280–230 m.y. LATE HERCYNIAN or slightly reopened
> 280 m.y. HERCYNIAN
White micas from crystalline rocks
White micas or mica-rich fine fractions from post-Hercynian metasediments
Rb/Sr whole rock isochron
Rb/Sr small-scale-isochron (mica-rich fine fractions from the Permoscythian)
DATA from the LITERATURE
b BORSI et al. 1966
c BORSI et al. 1972
g GRAUERT 1966
h GRAUERT 1969
i GRAUERT et al. 1974
j HANSON et al. 1966
k HARRE et al. 1968
m JÄGER et al. 1967
n KRECZY 1981 (unpubl.)
p MILLER et al. 1967
s SATIR 1975, si SATIR, unpubl. data
t SCHMIDT et al. 1967
INNSBRUCK
Landeck
Bludenz
Arlberg Paß
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Timmels Joch
Brenner Paß
Meran
Brixen
Ofen Paß
Flüela Paß
Albula Paß
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