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P - T - conditions of the high - pressure Hercynian event in the Alps as deduced from petrological, Rb-Sr and O^{18}/O^{16} data on Phengites from the Schwazer Augengneise (EASTERN ALPS, AUSTRIA)

by *M. Satir* [1][2] and *G. Morteani* [3]

Abstract

According to TOLLMANN (1963, 1977) the Schwazer Augengneise (also called Kellerjoch-Gneise) belong to the middle Austroalpine cover. This cover ist interbedded between the lower Austroalpine Innsbrucker Quarzphyllit and the upper Austroalpine Grauwackenzone. The here studied augengneisses originate from the Trattenbachtal and are found at the basis of the Steinkogelschiefer. The Steinkogelschiefer are garnet-mica schists and belong also to the middle Austroalpine cover. From Rb-Sr-whole rock isochrones SATIR and MORTEANI (1979) deduced that the metamorphism of amphibolite facies of the Schwazer Augengneise and of the Steinkogelschiefer was of hercynian age. The white micas originating from the augengneiss bodies of the Trattenbachtal (State of Salzburg, Federal Republic of Austria) have been analysed by optical, chemical, and radiometrical methods. The O^{18}/O^{16}-ratio of the coexisting white micas and quartz has also been determined.

The augengneisses of the Trattenbachtal belong to the series of the "Schwazer Augengneise". The white micas are phengites. They show a hercynian Rb-Sr-cooling age of 273 m. y. and of 260 m. y., resp. From oxygen stable isotope data the phengites show a crystallisation temperature of about 400° C. From the Si-content of the phengites the crystallisation pressure was about 5 kb. The phengites were formed during a high-pressure phase at the beginning of the hercynian metamorphism. This metamorphism was later on increasingly of a high-temperature type. It is the first time that in the Alps the occurence of hercynian phengites could be demonstrated.

Zusammenfassung

Die Schwazer Augengneise (auch Kellerjochgneise genannt) gehören nach TOLLMANN (1963, 1977) zum Mittelostalpin. Die mittelostalpinen Schwazer Augengneise liegen zwischen dem unterostalpinen Innsbrucker Quarzphyllit und der oberostalpinen Grauwackenzone. Die hier untersuchten Augengneise stammen aus dem hinteren Trattenbachtal und liegen an der Basis der Steinkogelschiefer. Diese Steinkogelschiefer gehören ebenfalls zum Mittelostalpin. Rb-Sr-Gesamtgesteins-

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altersbestimmungen zeigen, dass die amphibolitfazielle Metamorphose der Schwazer Augengneise und der Steinkogelschiefer herzynisch war (SATIR und MORTEANI, 1979).

Die Hellglimmer aus den Augengneisen des hinteren Trattenbachtales (Land Salzburg, Österreich) wurden mikroskopisch, chemisch, radiometrisch und isotopenchemisch untersucht. Die Augengneise des hinteren Trattenbachtales gehören zu der Serie der Schwazer Augengneise. Die Hellglimmer sind Phengite und geben herzynische Rb-Sr-Abkühlungsalter von 273 bzw. 260 Mio. Jahren. Die Bildungstemperatur der Phengite wurde aus $0^{18}/0^{16}$-Messungen abgeleitet; sie beträgt ca. 400° C. Der Bildungsdruck wurde aufgrund der Si-Gehalte der Phengite mit etwa 5 kb abgeschätzt. Die Bildung der Phengite erfolgte in einer druckbetonten Phase am Anfang der später temperaturbetonten herzynischen Metamorphose. Es konnte hier zum ersten Mal das Auftreten von herzynischen Phengiten im alpinen Bereich nachgewiesen werden.

I. INTRODUCTION AND PROBLEM

As is shown in the lower part of fig. 1 thick bodies of augengneisses occur at the limit between the Upper Austroalpine Grauwackenzone and the Lower Austroalpine Innsbrucker Quarzphyllit. These augengneisses are called Schwazer Augengneise or Kellerjochgneise, resp. In the upper part of fig. 1 it is shown that little bodies of such augengneisses also occur at the limit between the Innsbrucker Quarzphyllit and the Steinkogelschiefer. The Steinkogelschiefer are metapelites in amphibolite facies (ACKERMAND and MORTEANI, 1977). The Innsbrucker Quarzphyllites underlie the Steinkogelschiefer. They show only a weak metamorphism. Until now there is no detailed study of the metamorphic grade of this Innsbrucker Quarzphyllit. To the east of the studied area SCHRAMM (1977) found in the rocks of the Grauwackenzone pyrophyllite, chloritoide and stilpnomelane. These are minerals typical of the low grade greenschist facies.

According to TOLLMANN (1963, 1977) the Schwazer Augengneise are part of the Middle Austroalpine cover. From their tectonic position the Steinkogelschiefer should belong also to this tectonic unit. The staurolite + garnet + chlorite-bearing micaschists of the Patscherkofel and of the Glungezer as well as of the Ötztalkristallin belong also to this unit. The low to high grade metamorphic rocks of the Middle Austroalpine form part of the so called Altkristallin of the Eastern Alps.

The augengneisses of the Trattenbachtal show medium-grained, light-green white micas. From the green colour and from a first microscopic investigation it could be supposed that these white micas should be phengites. Furthermore, from the fact that the phengitic micas showed until now in the Alps only alpine radiometric ages it could be supposed that these micas also should show such an alpine age.

The alpine metamorphism is a two-staged event. The older event is called the eoalpine phase; the younger the young alpine phase. The eoalpine phase is often called unproperly eoalpine metamorphism. The white micas from the Altkristallin of the Eastern Alps show Rb-Sr- and K-Ar-ages between 120 and 75 m. y. Radiometric ages between 120 and 75 m. y. are considered in particular to be eoalpine crystallisation ages whereas the ages between 90 and 75 m. y. should correspond to the eoalpine cooling (MILLER et al. 1967, SCHMIDT et al., 1967; BREWER, 1970; SATIR, 1975 and MORAUF, 1977). Therefore it could be expected that the phengites from the augengneisses of the Trattenbachtal should give an eoalpine crystallisation, or cooling age. This would then be the first eoalpine age north of the western Tauern Window.

For petrological study as well as for Rb-Sr-age-and oxygen isotope determination two samples have been taken from the augengneisses in the Trattenbachtal (fig. 1).

II. RESULTS

II. 1 Microscopy

Microscopy shows that in the Schwazer Augengneise of the Trattenbachtal the old magmatic minerals and structures can be recognized in spite of a strong metamorphic overprinting. The magmatic minerals have been: subhedral plagi-

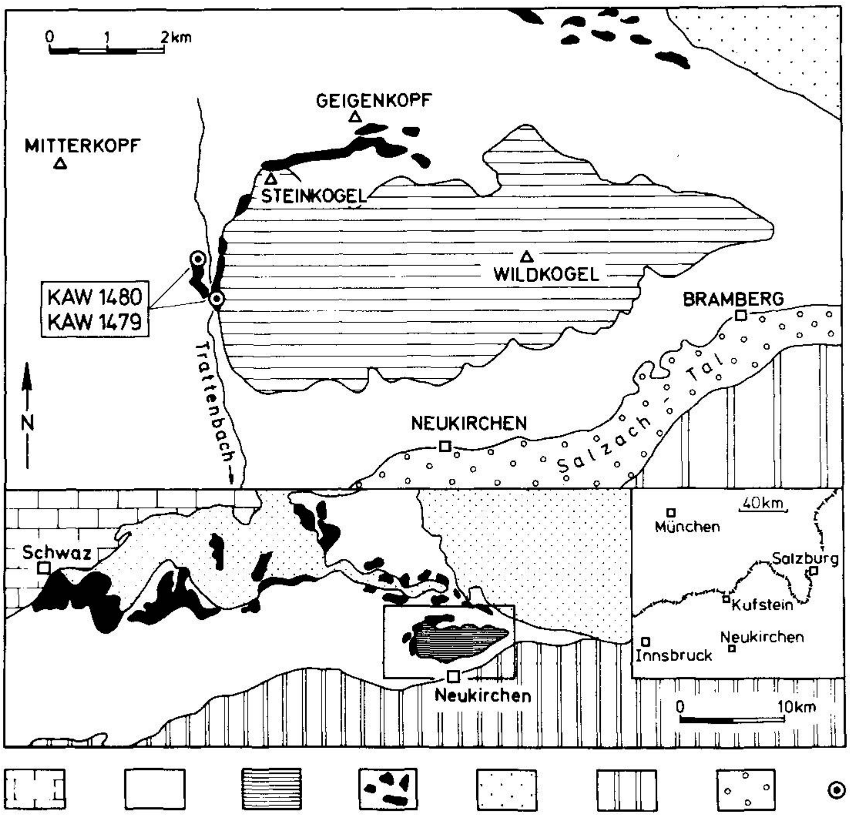

Fig. 1: Geological sketch-map according OHNESORGE (1933) showing the position of the sampling points.
The lower part of the figure shows the geology of the surroundings of the studied area and the position of the Schwazer Augengneise at the limit between the Grauwackenzone and the Innsbrucker Quarzphyllit. The symbole are:
a=Kalkalpen, undefined, b=Innsbrucker Quarzphyllit, c=Steinkogelschiefer, d=Schwazer Augengneise (Kellerjochgneise), e=Grauwackenzone, f=Penninic rocks, undefined, g=gravels, h=sampling points.

oclase, biotite, K-feldspar and anhedral quartz. During metamorphism the magmatic minerals first have been deformed and then recrystallised. The plagioclases show a metamorphic sericitisation and epidotisation, the K-feldspar is partly albitised and on the shear planes 1 to 2 mm long light green white micas have crystallised. These white micas show a 2V of 36° (KAW 1479) to 30° (KAW 1480) which suggests a phengitic composition of the white micas (TRÖGER 1967). The augengneisses occurring south of the town of Schwaz show chloritised magmatic biotites. During this chloritisation fine-grained opaque minerals were also formed. Around the chloritised biotites a rim of new formed, fine-grained biotite and muscovite was formed during a later increase of the metamorphic grade (SATIR and MORTEANI, 1979). In the augengneisses of the Trattenbachtal no chlorite could be observed and the biotite is present only in traces. In some cases a rim of fine-grained white mica is present around the bigger grains of white mica.

From X-ray data it can be assumed that the fine-grained white mica is a muscovite. The quartz formed during the magmatic crystallisation and deformed during the metamorphism shows a recrystallisation with polygonalisation. As a whole, it can be said that the structures of the Schwazer Augengneis is characterised by a strong postdeformative recrystallisation. Although in some samples a very late and only weak postcrystalline deformation can be observed. This late deformation occurred at very low temperatures.

II. 2. X-ray data

According CIPRIANI et al. (1968) muscovites can be distinguished from phengites by X-ray-data.

According SCHALLER (1950), FOSTER (1956) and VELDE (1965) the phengites are solid solutions between muscovite

$$K[(R_2^{+3})\,Si_3Al0_{10}\,(OH)_2]$$

and celadonite

$$K[(R^{+2}R^{+3})\,Si_n\,O_{10}\,(OH)_2]$$

In muscovites the R_2^{+3}-position is occupied only by Al, whereas in the celadonites $R^{+2}$is occupied by Fe^{+2}, Mg^{+2} and the R^{+3} is occupied by Al^{+3} and Fe^{+3}, resp. The celadonites show therefore four end-members. Natural celadonites approximate the composition of the Mg, Fe^{+3} end-member.

According to RADOSLOVICH (1962) the b_o-value is influenced mainly by the Fe^{+2}-, Fe^{+3}- and the Mg-content. According to CIPRIANI et al. (1968) b_o is related to the (Mg+Fe)- content by the following equation:

$$b_o = 8.990 + 0.327\ RM$$

with RM=mol. prop. 0.5 Fe_2O_3 + mol. prop. FeO+mol. prop. MgO.

According to FREY et al. (in prep.) $d_{(060)}$ is related to $(Mg + Fe_{tot})/\ O_{10}(OH)_2$ by the equation

$$d_{(060)} = 1.497 + 0.020 \times$$

with $\times = (Mg + Fe_{tot})/O_{10}\,(OH)_2$.

The limit between muscovite and phengite was set by CIPRIANI et al. (1968) at the b_o -value of 9.025 Å. This corresponds to a $d_{(060)}$-value of 1.504 Å.

The white micas of the sample KAW 1479 and of the sample KAW 1480 show $d_{(060)}$-values of 1.508 Å and of 1.507 Å., resp. This values suggest strongly a phengitic composition of the white micas.

	KAW 1479		KAW 1480	
SiO_2	50.88		50.23	
Al_2O_3	25.16		26.42	
TiO_2	0.39		0.33	
Fe_2O_3	1.84		2.02	
FeO	3.51		4.65	
MnO	0.06		0.10	
MgO	2.99		1.28	
CaO	0.04		0.08	
Na_2O	0.16		0.16	
K_2O	11.29		11.27	
H_2O	4.24		3.76	
Total	100.56		100.30	
Si	6.865	8.00 IV	6.717	8.00 IV
Al	1.135		1.283	
Al	2.865		2.968	
Ti	0.040		0.034	
Fe^{3+}	0.187	4.10 VI	0.208	4.02 VI
Fe^{2+}	0.396		0.531	
Mn	0.007		0.017	
Mg	0.601		0.260	
Ca	0.006		0.012	
Na	0.042	1.99 XII	0.042	2.02 XII
K	1.943		1.963	
OH	3.816		3.424	
P	24.34		19.69	
F	4.57		5.18	
S	6.05		5.24	
A	69.95		73.87	
2P (Mol%celad.)	48.68		39.38	
2V	36°		30°	

Tab. 1: Chemical composition and mineral formulas on the basis of 24 (O, OH) for the phengites of the augengneisses of the Trattenbachtal. The P-, S- A- and 2P-values are calculated according to GRAESER and NIGGLI (1967). For further explanation see text. Analyst was P.K. HÖRMANN (Kiel).

It should be mentioned that from the b_0-value alone it can not be descriminated between a celadonitic muscovite, a ferrimuscovite and a Fe^{+3}-celadonitic muscovite (GUIDOTTI and SASSI, 1976). Therefore the phengitic composition of a white mica cannot be definitely established from X-ray data alone. For this reason the white micas of the Trattenbachtal have been analysed by wet chemical methods.

II. 3. Chemical data

The white micas of the samples KAW 1479 and KAW 1480 have been separated from the other constituents of the rocks by magnetic separation and by a shaking table. The fine-grained inclusions have been eliminated from the concentrates by selective grinding in an agate mortar and sieving. The purity of the white mica concentrate was better than 99%. In tab. 1 the results of the chemical analyses of the white micas, the corresponding mineral formulas as calculated on the basis of 24 (0, OH) and the P-, F-, S- and A-values according GRAESER and NIGGLI (1967) are represented. The P-, F-, S- and A-values discriminate between phengitic and muscovitic white micas and are defined as follows:

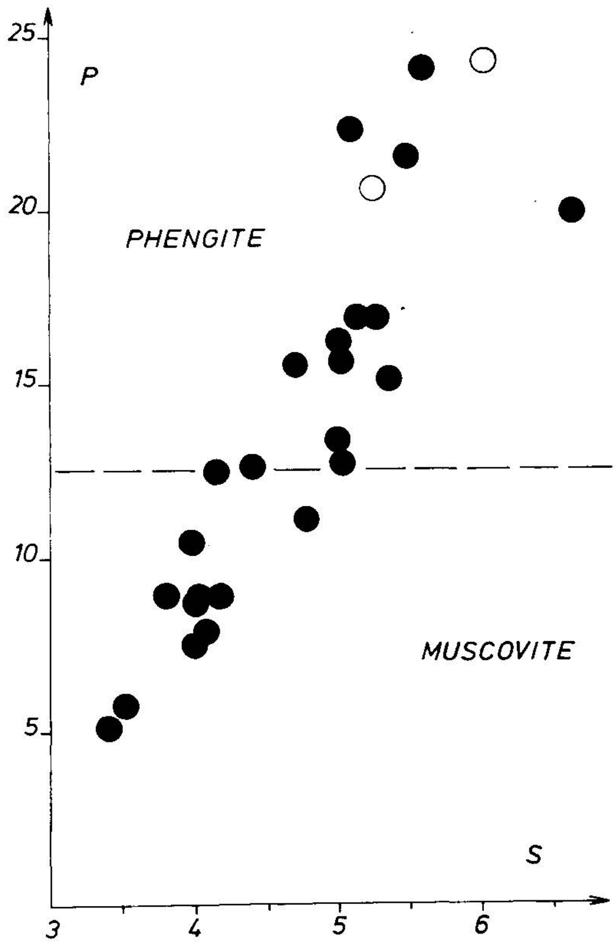

Fig. 2: The S-values of the white micas of the Trattenbachtal are plottet against the corresponding P-values (o) and compared to the P- and S-values of the white micas of the western, central, and eastern Alps (•) as taken from FREY, et al. (1976) and SATIR and MORTEANI (1979). The S- and P-values are calculated according to GRAESER and NIGGLI (1967). The limit between muscovites and phengites is, according to GRAESER and NIGGLI (1967) at P=12.5. The diagram shows the phengitic composition of the studied white micas.

$P=[Mg + Fe^{+2}]^{VI} \cdot 100/ [Al + Ti + Fe^{+3} + Fe^{+2} + Mn + Mg]^{VI}$
$F=[Fe^{+3}]^{VI} \cdot 100/ [Al + Ti + Fe^{+3} + Fe^{+2} + Mn + Mg]^{VI}$
$S=[Si]^{VI} / [Al]^{VI}$
$A=[Al]^{VI} \cdot 100/ [Al + Ti + Fe^{+3} + Fe^{+2} + Mn + Mg]^{VI}$

In fig. 2 the P-value of the white micas of the samples KAW 1479 and KAW 1480 is plottet against the corresponding S-value (o). As a comparison, the P- and S-values of the white micas of the swiss and italian Central Alps according to GRAESER and NIGGLI (1967), of the Monte Rosa granite (FREY et al., 1976) and of the augengneisses from the area of the Grossvenediger (JÄGER et al., 1969) are also plottet in fig. 2 (•).

In a P versus S diagram the limit between muscovites and phengites is at P=12,5 or 2P=25.0, resp. (GRAESER and NIGGLI, 1967). The white micas of the Trattenbachtal show P-values of 24.3 or 19.7, resp. (2P=48.6 or 39.4, resp.) and S-values of 6.05 and 5.24. As related to the other white micas considered here the white micas of the augengneisses from the Trattenbachtal show in the P versus S – diagram an extreme phengitic composition.

The phengitic composition of the white micas of the augengneisses of the Trattenbachtal is confirmed furthermore by the A-values. The ideal muscovite shows an A-value of 100, the white micas studied here show to contrary an A-value of about 70.

II. 4. Radiometric data

According to the X-ray data and the chemical composition the white micas of the augengneisses from the Trattenbachtal are true phengites. In order to fix the age of the phengites Rb-Sr-radiometric age determinations have been performed. The Rb-Sr-ages have been computed with the decay constant of:

$$\lambda=1.42\times10^{-11}\text{years}^{-1}$$

A within the error limits concordant hercynian Rb-Sr-age of 260 ± 10 m. y. and of 273 ± 11 m. y., resp. results if the age is calculated with common Sr. If the age is corrected with the Sr of the total rock, then ages of 254 ± 6 and 269 ± 6 m. y. result. For details of the measuring technique see SATIR and MORTEANI (1979).

It must now be discussed if this Rb-Sr-ages are hercynian cooling or crystallisation ages. In a discussion following facts have to be considered:

1. – According to PURDY and JÄGER (1976) the closing temperature for the Rb-Sr-system of the white micas is 500 ± 50° C.

2. – According Rb-Sr-whole rock age determination the climax of the hercynian metamorphism of the Schwazer Augengneise and of the Steinkogelschiefer was at 325 m. y. (SATIR and MORTEANI, (1979).

3. – According to SATIR and MORTEANI 1979), during the eoalpine event the Steinkogelschiefer reached temperatures of about 350° C at maximum only. The young alpine event lags totally.

4. – From O^{18}/O^{16}- determinations on quartz, biotite, white mica, garnet and ilmenite it can be deduced that in the Steinkogelschiefer the hercynian metamorphism reached maximum temperatures of 560 ± 10° C. From the fact that the augengneisses studied here lie at the basis of the Steinkogelschiefer and probably have a similar tectonic history as these rocks, it can be supposed that in the augengneisses the hercynian metamorphic temperatures have been also 560° C (SATIR et al. 1979). From the fact that the Rb-Sr-blocking temperatures of the white micas are 500° C and therefore lower than the temperature of the hercynian metamorphism it can be deduced that the Rb-Sr-ages of the phengites correspond in a first approximation to the age of the cooling of the rocks under a temperature of 500° C at the end of the hercynian metamorphism.

In the Altkristallin of the Eastern Alps the cooling ages of the white micas are about 300 m. y. (GRAUERT, 1969, BORSI, et al. 1973 and SATIR, 1975). The cooling ages of the phengites as determined in this work (273 and 260 m. y.) are 30 m. y. younger than the cooling ages in the remaining areas of the Altkristallin. The young cooling ages could be produced by the following processes:

1. From a very slight lowering of an older hercynian age of the phengites by a alpidian metamorphic overprint. The cooling ages are in this case mixed ages between a hercynian and an alpidian metamorphism. A lowering of the hercynian Rb-Sr-ages by an alpidian metamorphism requires alpidian temperatures of metamorphism as high as 500 ± 50° C. At this temperature the Rb-Sr-system is open in the white micas.

The temperatures of the alpine metamorphism of the augengneisses can be deduced from the K-Ar-ages of the white micas of these rocks as determined by SATIR and MORTEANI (1979). The white micas of the augengneisses show mixed K-Ar-ages of 192 ± and 182 ± 6 m. y. The blocking temperature for the K-Ar-system in the white micas is (according to PURDY and JÄGER, 1976) about 350° C. From this temperature estimate it follows that if the temperatures of the alpidian metamorphism would have reached temperatures higher than 350° C, then the white micas should show unequivocally alpine ages. From the fact that the alpine temperatures have not been higher than 350° C and the blocking temperature of the Rb-Sr-System in the white micas is about 500° C the Rb-Sr-ages of 273 and 260 m. y. as determined for the phengites of the augengneisses of the Trattenbachtal cannot be interpreted as mixed ages of an alpine and an hercynian event.

2. It can be supposed that this young hercynian age is produced by a mixture of alpine and hercynian micas in the analysed mica concentrate. This hypothesis cannot be excluded completely. The microscopical investigations show in fact that around the coarse-grained phengites a fine-grained white mica can be observed. It was impossible to separate these fine-grained white micas for radiometric analysis. The white mica taken for the radiometric analysis showed a size between 0.42 and 0.25 mm. From this grain size it is unlikely to suppose that the radiometric age is influenced by an admixture of fine-grained white mica of possible alpidian age. In any case, an alpidian age is rather improbable for this fine-grained white mica. SATIR and MORTEANI (1979) could in fact show that the fine-grained white mica in the Schwazer Augengneise is generally formed in the climax of the hercynian metamorphism from the breakdown of the coarse phengites.

3. Finally, it can be supposed that the young cooling ages are due to a very long lasting cooling process at the end of the hercynian metamorphism. A rough calculation shows that the climax of the hercynian metamorphism was at 325 m. y. The Rb-Sr-cooling age of the white mica is 270 m. y. From this data it follows that the cooling rate was 60° in 55 m.y.
The cooling rate is influenced mainly by the postmetamorphic uplift and erosion. From the above calculated very low cooling rate (60° C/55 m. y.) follows a very low uplift rate.
The uplift rates during the hercynian orogeny are (according to ZWART [1967]) between 0.1 and 0.04 mm/y. The alpine uplift rates in the Alps are to the contrary much higher. According to CLARK and JÄGER (1969), JÄGER (1973) and WAGNER et al. (1977) they have been around 0.8 mm/y.

In conclusion, it can be said that most likely the above given Rb-Sr-ages of the phengites are hercynian cooling ages. These ages demonstrate the very low postmetamorphic hercynian cooling and uplift.

III. P-T-CONDITIONS OF THE HERCYNIAN METAMORPHISM

With the exception of the two radiometrically dated here, no phengites of hercynian age have been described for the whole area of the Alps. This may be due to the fact that white micas have been only rarely chemically analysed. It should in fact be mentioned that until now about some hundred radiometric white mica ages have been published but unfortunately only some of these white micas have been chemically analysed. Generally there are also no $d_{(060)}$-data of these micas, although the $d_{(060)}$-data can be used as a rather good indication for the phengitic composition of the white mica. The greenish color cannot be considered a sure indication for the phengitic nature of the white micas.

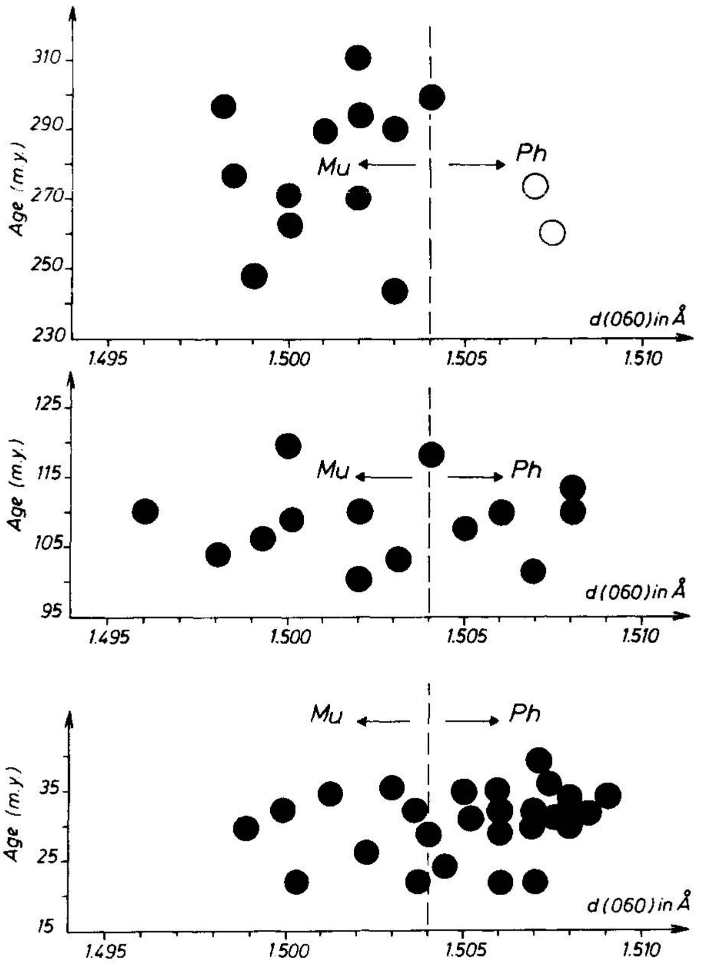

Fig. 3: Rb-Sr-ages versus $d_{(060)}$-values of the white micas from the western Tauern Window and of the rocks of the border of the window (SATIR, 1974, 1975; SATIR, unpubl.) and from the Monte Rosa - granite from FREY, et al. (1976). Phengites and muscovites are formed in the eoalpine (120 to 80 m. y.) as well as in the late alpine phase (40 to 15. m.y.). The only hercynian phengites are the two phengites from the augengneisses from the Trattenbachtal (o). All other hercynian white micas are muscovites.

In fact, solid solutions between muscovite and iron free Mg^{+2}, Al^{+3}- celadonite are practically colorless.

As the above described $d_{(060)}$value is a relatively sure indication for the phengite component of the white micas, the $d_{(060)}$-values can be used to see if some of the until now radiometrically dated white micas of hercynian age in the Alps are phengites. In fig. 3 the $d_{(060)}$-values of the white micas from SATIR (1974, 1975) and from FREY et al. (1976) are plotted again their Rb-Sr-ages.

In fig. 3 are also included the unpublished $d_{(060)}$-data of 25 radiometrically dated white micas from the western Tauern Window (Satir, unpubl.). It can be seen that phengites of hercynian age seem to be completely absent in the Alps, whereas in the eoalpine as well as in the young alpine phase phengites as well as muscovites are formed. This absence of phengitic micas can be due to the particular P-T-conditions of the hercynian metamorphism.

The pressure of the hercynian metamorphism can be estimated from the composition of the phengites and their crystallisation temperature as deduced from O^{18}/O^{16}-data on the parageneses quartz-phengite. According to VELDE (1967), the Si-content of the phengites at a given temperature depends strongly on the pressure. The Si-content increases with increasing pressure. From the composition of natural phengites, VELDE (1967) deduced that the composition of the rocks is without influence on the Si-contents of the phengites. The Si-content of the phengites should also be roughly independent from the composition of the fluid phase (VELDE, 1967).

In our case there is no indication that P_S should not have been equal to P_{H_2O}. Phengite occur in paragenesis with chlorite so that it can be assumed that Fe and Mg have been present in the required amounts during phengite-forming processes.

With increasing temperature and probably decreasing pressure phengite breaks down and muscovite is formed instead (SATIR and MORTEANI, (1979). The occurence of the phengite is therefore due to a particular geothermal gradient during the metamorphic event. In fig. 4 the possible geothermal gradient of the alpidian, hercynian and caledonian metamorphism according ZWART (1967) and the mean Si-content of the white micas from the Trattenbachtal are given in relation to P and T. From this figure it can be seen that the hercynian geothermal gradient is generally lower than that of the alpine metamorphism.

The occurence of Si-rich phengites in the alpidian metamorphism can be easily understood from the comparison of the P-T-diagram of the alpidian metamorphism and the form of the curves representing the Si-contents of the white mi-

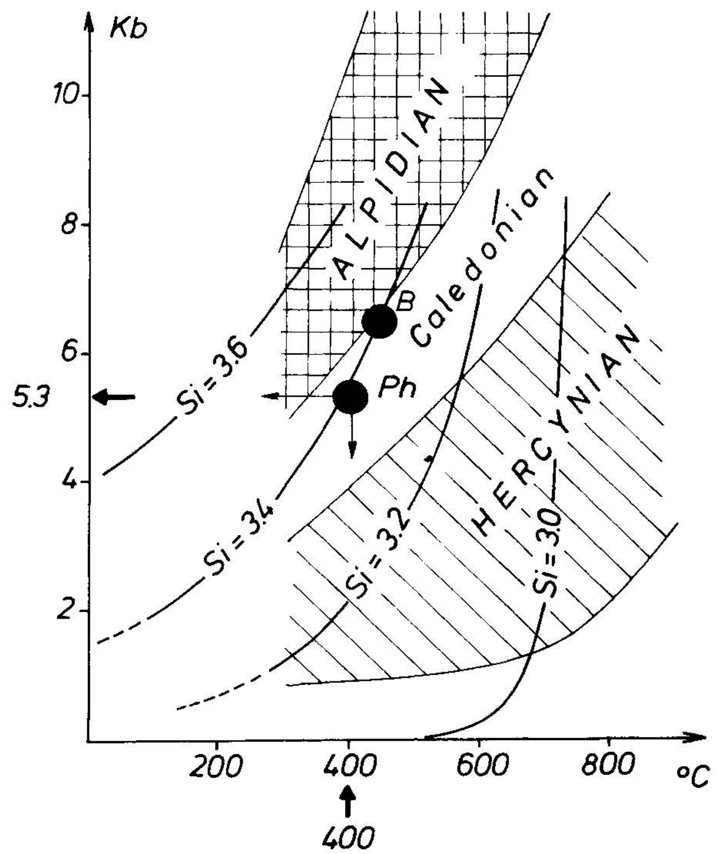

Fig. 4: P-T-diagram of the alpidian, caledonian and hercynian metamorphic series according ZWART (1967). In this diagram are plotted according VELDE (1967) also the "stability relation of the white micas" as related to the Si-contents. The mean Si-value of the studied phengites (Ph) is 3.4 and the corresponding crystallisation temperature is about 400° C(Ph). For a comparison the mean composition of the alpine phengites as analysed by FREY et al. (1967) is also plotted (B). Further information see text.

cas according to VELDE (1967). Unfortunately, only in the paper of FREY, et al. (1976) on the granite of the Monte Rosa the relation between the chemical composition of the white micas, the metamorphic grade and the radiometric age is discussed. The alpine phengites studied by FREY et al. (1976) show compositions and crystallisation temperatures at the limit between the P-T-conditions of the alpine and the caledonian P-T-conditions.

The Si-content of the phengites of the Schwazer Augengneise is between 3.3 and 3.4. From $0^{18}/0^{16}$-fractionation in the mineral pair phengite-quartz the crystallisation temperature of this phengite is (according to SATIR et al., 1980) about 400° C. From this data it can be deduced that the phengites crystallised at a pressure of about 5.3 kb (fig. 4).

From fig. 4 it can be seen that the crystallisation temperatures and pressures of the hercynian phengites are very far from the P-T-conditions of the hercynian metamorphism as assumed by ZWART (1967). Comparing the P-T-conditions of the hercynian phengite-forming event with the P-T-conditions of the alpidian metamorphism as deduced from the phengite of the Monte Rosa granite by FREY et al. (1976) it can be seen that these conditions are very similar.

Both phengite forming events lie in the P-T-range of the caledonian metamorphism. It should be noted in this context that phengites of caledonian age are well known from the Caledonides of Scandinavia (A. Reymer, pers. comm.).

From the high Si-content it must be assumed that the hercynian metamorphism was not as a whole (as assumed by ZWART, 1967) a low pressure metamorphism. The augengneisses from the Trattenbachtal belong to the series of the Schwazer Augengneise. From a microscopic study of these rocks, SATIR and MORTEANI (1979) could show that in these rocks the early formed phengites breakdown to a fine-grained muscovite according to the reaction:

$$\text{phengite+chlorite=muscovcite+biotite+quartz+}H_2O \quad 1.$$

This breakdown is due to a temperature increase.

It can therefore be supposed that the hercynian metamorphism was at first a high pressure and later on a high temperature metamorphism. Such a supposition would also help to explain the lack of hercynian phengites in the Alps. The phengites formed during the first high pressure stage of the hercynian metamorphism probably broke down later, e.g. according to reaction 1., and so became very rare.

In the future it should be possible, combining chemical and microscopical work with radiometric age determinations and stable isotope studies, to define the pressures and the temperatures of the whole hercynian metamorphism in the Alps from its beginning to the end.

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SMPM = Schweiz. Mineral. petrogr. Mitt.

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