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High-pressure Metamorphism in the Tauern window

By Ch. MILLER*, M. SATIR** and W. FRANK***

With 2 Figures and 2 Tables

Zusammenfassung

Eklogite und Glaukophangesteine treten vor allem in einer Zone tektonischer Mélange an der Basis der Glocknerdecke südlich der Venedigerdecke auf. Detaillierte Dünnschliffuntersuchungen lassen sechs Stadien im Ablauf der Metamorphose erkennen: Grünschieferfazies in Einschlüssen – Omphacit I und II – Glaukophanbildung – blaugrüne Hornblende/Albit – Prasinitparagenesen. Für die Eklogitbildung können Drucke von 10 kb bei 500–550° C angenommen werden. Die jüngere Hauptmetamorphose (vor allem Phase 5, 6) ist durch eine deutliche Erniedrigung des Druckes (ca. 5–6 kb bei 500° C) und Zutritt von Wasser gekennzeichnet. Minerale der Hochdruckparagenesen haben sich bisher wegen merklicher Ar^{40}-Überschußmengen für die K/Ar-Datierung als ungeeignet erwiesen. Bei der späteren Symplektitbildung wurden diese Überschußmengen wieder abgebaut.

Summary

Eclogites and glaucophane bearing rocks are concentrated at the base of the Glockner nappe, especially in a tectonic melange in the southern Venediger area. Detailed petrological studies exhibit six phases in metamorphic evolution: greenschistfacies in inclusions – eclogites with omphacite I and II – formation of glaucophane – bluegreen hornblende/albite – prasinitic assemblages. Pressures of 10 kb at 500–550° C are indicated during the formation of eclogites. The younger main metamorphic event (esp. stage 5, 6) is characterized by a considerable lower pressure (about 5–6 kb and 500° C) and access of water. Due to variable amounts of excess Ar^{40}-content in minerals of the high-pressure assemblages it was not possible up to now to date this earlier metamorphic event satisfactory. This excess Ar^{40}-content was later then removed from the system during the formation of symplectites at the expense of omphacite.

Introduction

Mafic and serpentinized ultramafic rocks of obvious ocean floor affinities (cf. chapter on chemistry) constitute an important part of the Mesozoic Penninic

Adresse der Verfasser: * Institut für Mineralogie und Petrographie der Universität Innsbruck, Universitätsstraße 4, A-6020 Innsbruck.
** MTA Enstitüsü, Jeoloji Dairesi, Ankara.
*** Institut für Geologie der Universität Wien, Universitätsstraße 7, A-1010 Wien.

"Glocknerdecke" now overthrusted onto the Hercynian basement unit "Venedigerdecke" (FRISCH, 1976). Their lithologies include coarse-grained gabbros, pillow-lavas (Fig. 1), associated volcanic breccias, lava-flows and tuffitic material. Some of these mafic rocks have been subjected to a complex recrystallization history which involved an earlier high-pressure production of eclogites and their subsequent gradual transformation into prasinitic assemblages (MILLER 1974, 1977, RAITH et al. 1977).

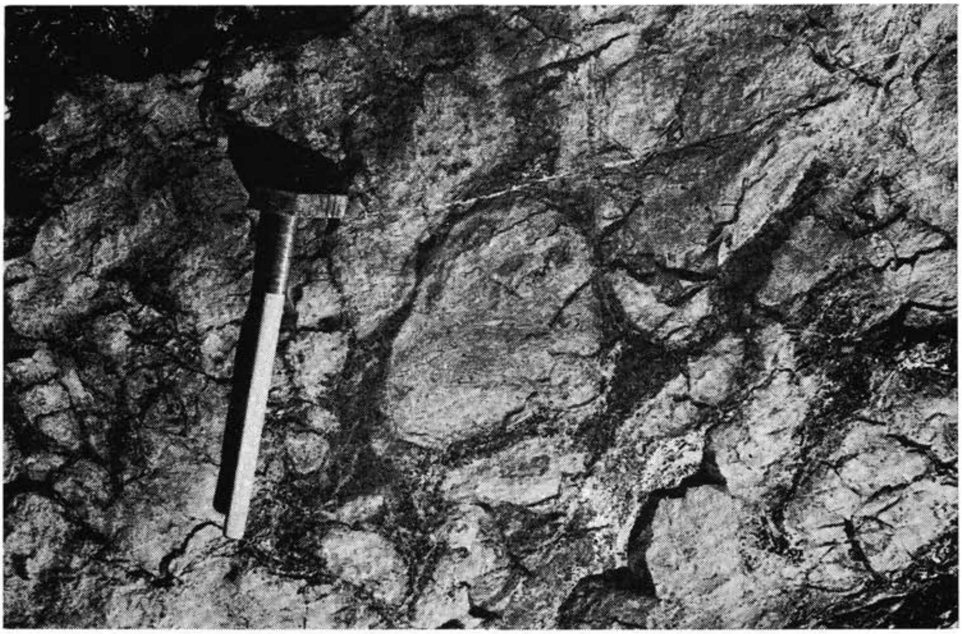

Fig. 1: Well preserved pillow structures in the ophiolites of Frosnitz valley (South Venediger). Moraine blocks at northern flank of Mailfrosnitz valley 2100 m.

In the southern Venediger area the eclogitic rocks are practically confined to a narrow zone south of the central sialic massifs where they are now associated with Permotriassic shelf and Jurassic-Cretaceous slope and trench sediments. Amphibolized eclogite, however, was also observed near the western end of the Tauern window by LAMMERER (1978, pers. comm.) and as far east as Modereck (CORNELIUS & CLAR, 1939, FRASL, 1954). This intensely tectonized zone near the base of the overthrust Glocknerdecke in the southern Venediger area may be interpreted as part of a tectonic melange where the lithologies bearing the imprint of an early high-pressure event are separated from those without by thrust-planes defined by slices of Permotriassic rocks (FRANK, MILLER & HOKE 1980) or marked by serpentinites.

Metamorphic Petrography

As the minerals are often zoned, partly replaced by other species or present in two generations, the Tauern eclogites exhibit textural evidence of the following metamorphic history.

A metamorphic stage 1 is recorded by the inclusions in the core of the zoned eclogite garnets. Epidote, paragonite, phengite, barroisite, chlorite, quartz, albite, ilmenite, magnetite, pyrite already indicate metamorphic temperatures above 400° C.

Eclogites: A marked increase in pressure produced the stage 2 eclogite assemblages best documented in coronitic metagabbros with omphacite I (Jd 34.3 Ac 12.0), garnet (pyrope-content of rim = 33 mole %), kyanite, quartz, talc, rutile and sulfide ores. Ensuing cataclasis obliterated many of these early textures and was followed by the formation of finegrained stage 3 eclogites with large relict omphacite I porphyroclasts. Newly produced omphacite II is significantly more jadeite-rich (Jd 47.0 Ac 3.6) implying increasing pressures of formation as constant high activity of SiO_2 is suggested by the presence of quartz. The average pyrope content in these garnet-rims is 37.6 mole %. Kyanite, talc, quartz, rutile and sulfides are also stable.

Glaucophanized eclogites: The growth of finegrained glaucophane I, corroding omphacite, probably indicates addition of water to the system. Large kyanite II porphyroblasts may overgrow omphacite, rutile, glaucophane, garnet and small, euhedral and inclusion-free kyanite I. Kyanite is then replaced by paragonite and thus found as inclusion in large and zoned glaucophane II/barroisite-blasts. Another interesting replacement reaction observed during this stage 4 is the formation of Mg-chloritoid (64 mole % sismondine, MILLER 1978) and paragonite at the expense of omphacite, kyanite and talc.

Blue-green hornblende assemblages (stage 5): Resulting from a change in operating P, T, P_{H_2O}-conditions subcalcic, barroisitic or actinolitic amphiboles and albite become major phases at the expense of omphacite. Garnet is replaced by amphiboles, chlorite, epidote ± magnetite, rutile by sphene and kyanite by paragonite ± epidote.

Prasinitic assemblages: The growth of actinolite, porphyroblastic albite, chlorite and epidote during stage 6 have obliterated almost all earlier mineral assemblages.

Equilibration conditions

Based on a large number of phase analyses (MILLER, 1977) an estimate of the physical conditions of eclogite formation can be made with the help of available experimental data.

High pressures of formation of about 10 kb are indicated by the jadeite content in omphacite (KUSHIRO, 1969) and by the occurrence of ky + tc + qtz (SCHREYER & SEIFERT, 1969) and of ky + zo + qtz (CHATTERJEE, 1976). This estimate has been independently confirmed by the investigations of LUCKSCHEITER and MORTEANI 1979 as the values obtained from liquid CO_2-inclusions in quartz of eclogite-veins yield 7 kb. This is, of course, only a minimum value.

The mean of the K_D-values obtained from the Fe-Mg-partitioning between coexisting omphacite and garnet (using rim compositions) in stage 3 eclogites is

14.58±1.22. Applying RAHEIM and GREEN's (1974) experimentally calibrated geothermometer, temperatures of 500–550° C are calculated. This is in excellent agreement with the values of 510, 520 and 560° C obtained from $^{18}O/^{16}O$-fractionation data between quartz and rutile in eclogites (HOERNES, pers. comm.).

The reaction omphacite → diopside + albite, preserved in many omphacite breakdown symplectites, implies that a significant pressure decrease occurred between stages 4 and 5. The pervasive formation of amphiboles also suggests an influx of water. Again applying experimental data to the observed phase equilibria during the later prasinitic stage of metamorphism, temperatures around 500° C can be estimated (MILLER, 1977) at a maximum pressure of 5.5 kb as deduced from the thickness of the overlying rock units at that time (FRANK, 1969; CLIFF et al., 1971).

Discussion of results

The deduced prograde PT-path of these eclogites follows the low geothermal gradient typical of subduction zone metamorphism (ERNST, 1973). The eclogite formation is therefore interpreted as having occurred in a tectonic setting different from today's, whereas the prasinitic overprint postdates the development of the present large-scale structures.

Discussed in the context of plate tectonics the evolution of the Penninic series in the Tauern window can be seen as follows. Oceanic crust was generated during the opening of the South Penninic ocean since early Jurassic time, sedimentation being predominantly calcareous Schists lustrés (i.e. Glocknerfazies, FRASL & FRANK, 1966).

Subduction of these rocks commenced in the Early Cretaceous (FRISCH, 1978). The induced high-pressure metamorphic event preserved in mafic and sedimentary material (MILLER, 1977) is still undated, but one published glaucophane date of 70±12 my (RAITH et al., 1978) suggests an Early Alpine age. During the subsequent resurrection of a part of this subducted complex its phase assemblages were more or less adapted to the changing conditions of environment. The tectonic contact of the eclogite-bearing unit with the adjacent prasinite-calcareous mica-schist complex may reflect important differential movement because the latter shows no evidence of having passed through an eclogite crystallisation stage, although widespread lawsonite-pseudomorphs (FRY, 1973, HÖCK, 1974, MILLER, 1977) also indicate an earlier high-pressure event in parts of this segment. Final emplacement took place at the base of the overriding Austroalpine unit after closure of the Penninic ocean which occurred around 80 my (CLIFF et al., 1971). It was followed by regional metamorphism ("Tauernkristallisation", SANDER, 1911) producing the greenschist assemblages with a thermal peak beetween 40–30 my (CLIFF et al., 1971, SATIR, 1975, RAITH et al., 1978).

As the observed "eclogite zone" developed mostly in a highly tectonized melange zone composed also of rocks which had a position somewhere on the southern slope of the Pennine continental wedge, the postulated subduction zone was situated at the base of the Glocknernappe. It might therefore be possible that this was not the only subduction zone acting during the closure of the Pennine ocean floor and that another one, situated at the former southern end of the Piemont sediments was also active during the first stages and was subsequently completely overridden by the Austroalpine units.

K-Ar data from high pressure metamorphics from Frosnitz Valley

The minerals from 4 samples were separated and analyzed by M. SATIR partly in the Geochronological Laboratory of the Institute for Mineralogy in Bern, partly in Vienna (Tab. 1).

All high-pressure phase minerals (garnet, omphacite, epidote) have a slight Ar^{40}-excess content in the range of $0.2–0.8 \times 10^{-6}$ cm^3 Ar^{40}_{rad} STP/g. Unfortunately, it was not possible to separate a pure glaucophane concentrate from these samples.

The amount of this excess Ar^{40}-content is comparatively low, equaling the amount of Ar^{40}_{rad} being formed in 1–3 m.y. in a K-mica, but a meaningful age calculation is impossible for minerals with a low K-content. The model ages are as high as 250 to 500–600 m.y., and even higher. The strong disequilibrium conditions in the mineral parageneses shown by the detailed petrologic investigations (MILLER 1977) render these rocks very unfavourable for dating (Fig. 2).

Although the analytical results are not conclusive, paragonite may also have similar (or even higher) amounts of excess Ar^{40} as the other high-pressure minerals and probably was also partly formed during the earlier metamorphism. The results scatter widely, partly due to the admixture of phengite; in general the paragonite gives higher ages than phengite. The calculated age of the pure paragonite from sample KAW 1140 would be about 300 m.y.; this points to a considerable amount of excess Ar^{40} in this mineral. The paragonite ages obtained are difficult to explain and have no clear significance, as one may also expect similar blocking temperatures of paragonite as for K-white mica.

The earlier Ar^{40}-excess content present in the high-pressure minerals was released during the later mineral reactions in the course of the "Tauernkristallisation". This is shown by the results of the symplectites (albite, hornblende, diopside a.o.) formed at the expense of the earlier omphacite, which gave ages in the usual Late Tertiary cooling range.

It is suggested that the presence of the Ar^{40}-excess content in the high-pressure metamorphic rocks is the result of a special dynamic situation. The high-pressure conditions in the subduction zone were probably rapidly attained and diffusion of the fluids did not overcome the production rate of Ar^{40} in the rock volume.

It should also be considered that the high-pressure metamorphic rocks occur in a tectonic melange zone where they are intimately associated with different sediments rich in K-white mica.

From the results it can only be stated that the Early Alpine formation of the high-pressure event is still a plausible suggestion, but so far no really conclusive arguments from geochronology are available if this took place during

Sample	Ar^{40}rad cm^3 . 10^{-6}/g STP		% rad	% K	model ages 10^6Y
KAW 1130 glaucophane schist	paragonite	1,099	33,4	0,60	46,5 ± 5,6
- " -	quartz	0,0389	12,26	0,0199	49,7 ± 16
- " -	garnet	0,2067	36,39	0,0743	70,2 ± 7,7
- " -	epidote ± klinozoisite	0,3516	39,50	0,0334	+253 ± 26
- " -	symplectite (omphacite)	0,2087	8,22	0,275	19,4 ± 9,5
KAW 1140 glaucophane schist	phengite/paragonite	10,33	87,01	4,37	+59,8 ± 3
- " -	phengite	9,751	75,50	8,12	31 ± 2
- " -	garnet	0,4555	11,51	0,0246	+422 ± 147
- " -	epidot ± clinozoisite	0,8382	61,01	0,066	+299 ± 20
- " -	symplectite	0,9626	51,47	0,556	44 ± 3,4
KAW 1180 eclogite	garnet	0,2308	34,93	0,00985	+520 ± 74
- " -	epidote (+omph.+ Ca glauc.)	0,6606	62,00	0,00692	+1550 ± 100
- " -	omphacite	1,044	60,22	0,0384	+590 ± 39
- " -	paragonite	0,399; 0,398	5,67; 5,56	0,157	64,1 ± 4,6
KAW 1181 eclogite	garnet	0,2350	41,5	0,0076	+659 ± 63
- " -	epidote	0,445	48,5	0,0159	+606 ± 50
- " -	paragonite/phengite	3,625	37,64	3,44	26,9 ± 2,8

the first high-pressure phase at 80–100 m.y. found by HUNZIKER 1974 or if it is somewhat younger.

RAITH et al. 1978 reported a K/Ar age of 70±12 m.y. of a glaucophane. The age was interpreted as a maximum value for the formation of the glaucophane as the coexisting garnet contains some excess argon.

The same samples which were analysed by M. SATTR for the high pressure metamorphic event, have been also investigated for their Rb/Sr isotope chemistry (the analytical procedure was the same as described in SATIR 1975).

The analytical results (Tab. 2) clearly show that glaucophane schist sample KAW 1133 is strongly enriched in radiogenic Sr, which is obviously the effect of an admixture of detrital pelitic sediments, which is also reflected in the special layering and mineral paragenesis of this sample.

Analyzed sample	Rb^{87} ppm	Sr^{87}rad ppm	% rad	Sr comm. ppm	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	age *
1. KAW 1133 glaucophane schist	3,223	0,1331	1,318	143,5	0,7194	0,2296	* meaningless
2. KAW 1140 glaucophane schist	8,471	0,0862	0,6051	206,5	0,7056	0,4195	
3. KAW 1180 eclogite	0,1211	0,0997	0,7260	199,3	0,7048	0,0062	
4. KAW 1181 eclogite	0,8032	0,1879	0,6879	396,1	0,7050	0,0207	

Tab. 2: Rb/Sr isotope analysis from high pressure metamorphic rocks of the South Venediger area (Frositz valley).

The three others yielded Sr^{87}/Sr^{86} values which point to initial values close to 0.7045, which is fairly low, but a bit higher than those of mid-ocean ridge basalts and similar to those of within-plate basalts (FAURE 1977). Here again a slight increase in radiogenic Sr caused by exchange with the intercalated sediments could

calculation values used:

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

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

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

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

$\text{error} = \pm \frac{\text{age} \times 4}{\%\ \text{rad}}$

+ presence of excess Ar^{40}. age meaningless

The K-contents of the K-poor minerals have also been measured by atomic absorption using a hornblende standard (K-value known by isotope dilution) for correction.

Tab. 1: Analytical results of K/Ar-dates from high pressure metamorphic rocks form the Frosnitz valley (South Venediger area).

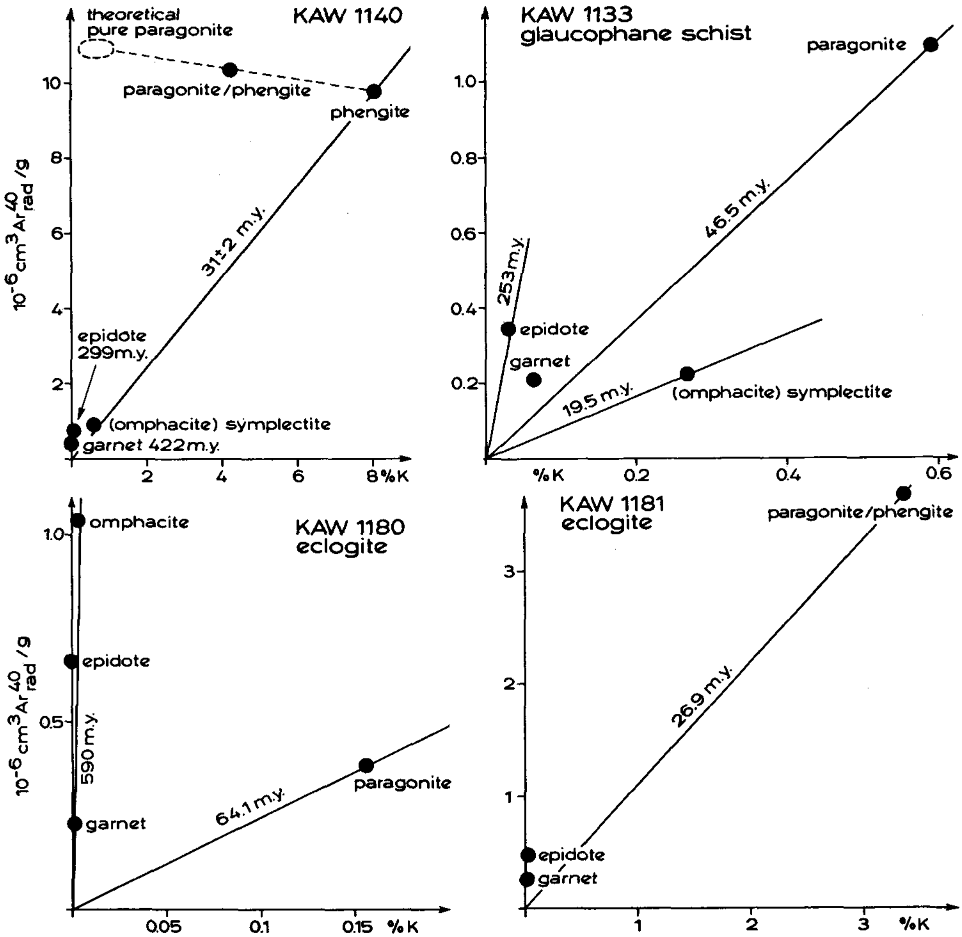

Fig. 2: Ar^{40}/K diagrams of four high pressure mineral assemblages from Frosnitz valley (South Venediger area).

The data show the distinct disequilibrium between the mineral phases analyzed. The absolute Ar^{40}-excess content is not very high (except for the pure paragonite in sample KAW 1140), but a conclusive time limit for the high pressure event cannot be given.

have affected the rocks, therefore no definite conclusions in respect to the environmental conditions of the basaltic material can be drawn from these results.

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