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Metamorphic Evolution of the Habach Formation A Review

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With 3 figures

Abstract

This paper reviews the complex polymetamorphic history of the Habach Formation emphasizing the newest contributions from radiometric, petrologic and textural data.

The Habach Formation forms part of a Paleozoic sequence of metavolcanic and metapelitic rocks in the Penninic domain of the northern-central Tauern Window. It forms, in association with Hercynian granitic gneisses (Granatspitz massiv), one of the deepest tectonic units in the Eastern Alps.

Evidence of a Sardinian orogenic event is given by U-Pb zircon data from orthoamphibolites in the Habach Formation, which yield an intrusion age of 500 Ma.

A 40 Ma period of strong Hercynian thermal activity and/or magmatism is indicated by Rb-Sr whole rock ages of 320–280 Ma from granitic gneisses and by K-Ar ages from amphiboles. The development of a Hercynian regional metamorphism is documented mainly in the metapelites of the Habach Formation by relicts of chiastolite and almandine-rich garnet. Garnet-clinopyroxene equilibria in metarodingites intercalated with the metapelites further indicate Hercynian low pressure/medium temperature regional metamorphic conditions.

In Alpidic time only the Middle Alpine "Tauernkristallisation" (a Barrovian metamorphism) affected the rocks of the Habach Formation regionally, under low grade conditions. No evidence has yet been found for an Early Alpine high-pressure event, nor for a third so-called "Neo-Alpine" metamorphism.

During both the Hercynian and Alpine metamorphic events the Habach Formation experienced significantly lower metamorphic conditions than contemporary units in the western and eastern Tauern Window.

Zusammenfassung

In der vorliegenden Arbeit wird unter Berücksichtigung der neuesten radiometrischen, petrologischen und gefügekundlichen Untersuchungsergebnisse die komplexe polymetamorphe Entwicklungsgeschichte der Habach-Formation zusammenfassend dargelegt.

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Die Habach-Formation ist eine paläozoische Wechselfolge von Metavulkaniten und Metapeliten innerhalb des Penninikums im nördlichen Abschnitt des mittleren Tauernfensters. Herzynische Granitgneise bilden zusammen mit der Habach-Formation eine Untereinheit der Venediger Decke als eines der tiefsten tektonischen Stockwerke der Ostalpen.

Hinweise auf eine Sardische Orogenese ergeben sich aus U-Pb-Zirkon Altern von Orthoamphiboliten der Habach-Formation mit Intrusionsaltern um 500 Ma.

Eine rund 40 Ma dauernde Periode starker herzynischer thermischer Aktivität wird mit diversen Gesamtgesteinsaltern zwischen 320 und 280 Ma von granitischen Gneisen und mit K-Ar-Altern von Amphiboliten datiert. Die Entwicklung einer herzynischen Regionalmetamorphose ist insbesondere aus Chiastolith-Formrelikten und Almandin-reichem Granat in Metapeliten der Habach-Formation abzuleiten. Granat-Klinopyroxen Gleichgewichtsparagenesen in Metarodingiten, die in die Metapelit-Serie eingebettet sind, belegen weiterhin Niedrigdruck Mitteltemperatur Metamorphosebedingungen einer herzynischen Regionalmetamorphose.

Während der Alpidischen Orogenese wurden die Gesteine der Habach-Formation nur von der Mittelalpinen „Tauernkristallisation", einer Regionalmetamorphose des Barrow-Typs, überprägt. Derzeit gibt es weder für ein Altalpidisches Hochdruck-Ereignis noch für eine sogenannte „Neo-Alpine" Metamorphose Belege.

Die Habach-Formation wurde demnach sowohl während herzynischer als auch während alpidischer Zeit unter deutlich geringeren Metamorphosbedingungen überprägt als ihre äquivalenten Einheiten im westlichen und östlichen Tauernfenster.

Introduction

By virtue of its areal extent and thickness the Habach Formation is the most important pre-Mesozoic Penninic unit in the central Tauern Window. Between the Kapruner Achental and the Krimmler Achental it covers an area of approx. 40 km in the E–W direction and over 20 km N–S (Fig. 1). The geological significance of the Habach Formation is based on its position as a part of the pre-Alpine basement with a polymetamorphic evolution as well as on the occurrence of the scheelite ore deposits in Felbertal and such other well-known mineral occurrences as, for example, the "Knappenwand" in Untersulzbachtal (epidote) and the "Leckbachrinne" in Habachtal (emerald) (HÖLL, 1975; SEEMANN, 1978; GRUNDMANN, 1983 a).

The first detailed geological study of the Habach Formation was carried out by FRASL (1958), who defined the "Habachserie". He suggested that the "Habachserie" is a "black shale – ophiolite series with local acid volcanics" in a pre-Mesozoic geosynclinorium (FRASL, 1953; 1958). HÖCK et al. (1982) suggested that the term "Habachserie" was inconsistent with correct stratigraphic nomenclature, and renamed the unit the Habach Formation.

The unit forms, part of the "Lower Schieferhülle", which, together with the "Central Gneisses", underlies the "Upper Schieferhülle" and the Austroalpine nappes. The most recent geological and geochemical studies have interpreted the Habach Formation as "a relict of a Paleozoic island arc" (HÖCK et al., 1982; STEYRER, 1983). The structural framework of the Venediger nappe is principally the result of Alpine compressive tectonics (FRASL & FRANK, 1964, 1966; FRISCH, 1976; 1977).

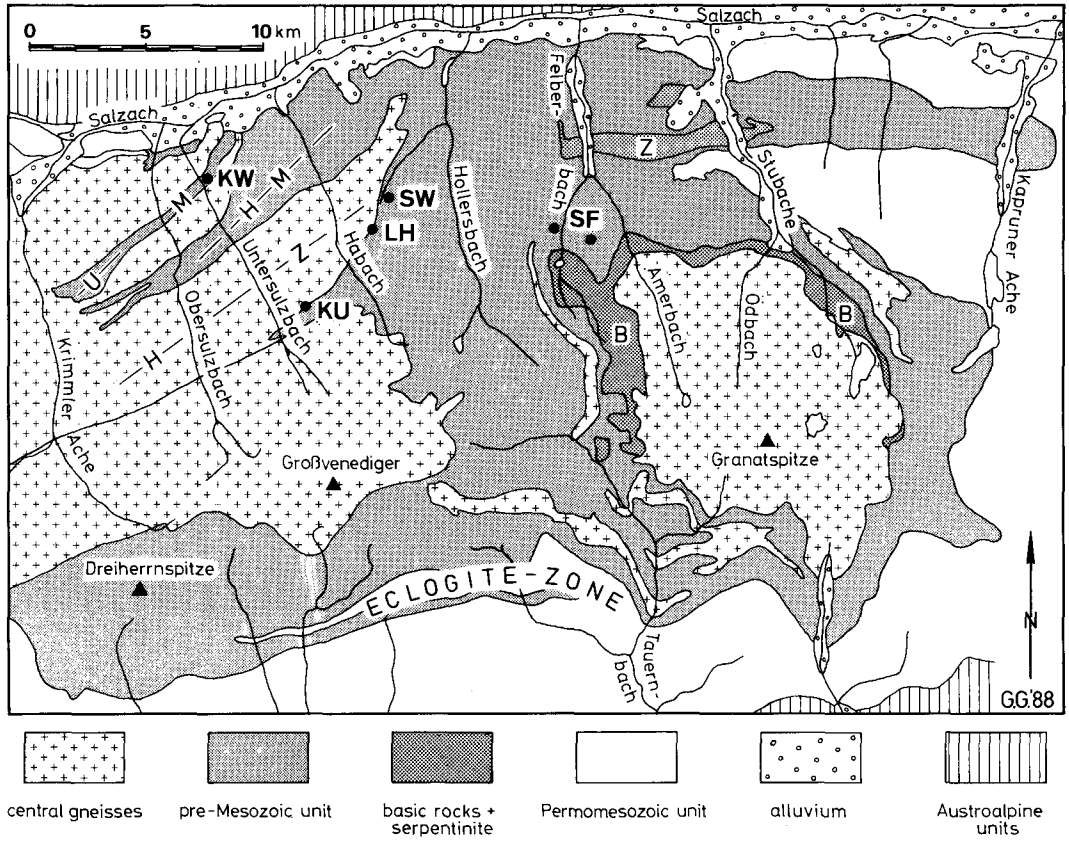

Fig. 1: Geological sketch map of the central Tauern Window, Austria (modified after HÖLL, 1975) (B = "Basisamphibolit", H–M = "Habachmulde", H–Z = "Habachzunge", KU = Kesselscharte/Untersulzbachtal, KW = Knappenwand/Untersulzbachtal, LH = Leckbachscharte/Habachtal, SF = Scheelite deposit/Felbertal, SW = Schwarze Wand/Hollersbachtal, U–M = "Untersulzbachmulde", Z = "Zwölferzug".

However, the Alpine movements may have been constrained by the pre-Alpine structural grain. The Alpine compression affected the relatively resistant core of the central gneisses as well as the infolded rocks of the Habach Formation. The metabasites and metasediments of the latter were especially strongly shortened. As a result of these movements and subsequent thermal events any possible primary magmatic contacts between the central gneisses and the Habach Formation have been tectonically overprinted and metamorphosed (FRASL, 1953; 1958; KARL & SCHMIDEGG, 1964; JÄGER et al., 1969; FRISCH, 1976; GRUNDMANN & MORTEANI, 1982).

The first concrete evidence of a polymetamorphic development of the Habach Formation was presented by CORNELIUS (1944) and FRASL (1953, 1958). Both authors recognized, in addition to the Middle Alpine regional metamorphism (= "Tauernkristallisation" of SANDER, 1911; 1921), an older weak regional or contact metamorphism associated with the supposed pre-Mesozoic granitic intrusions now exposed as the central gneisses. A Hercynian intrusive age of the "Augen- und Flasergneis" unit of the central gneisses from the Großvenediger and Granatspitze area was confirmed by the first whole-rock and mineral radiometric studies (JÄGER et al., 1969; BESANG et al.; 1968; CLIFF, 1977; 1981).

Extensive reviews of relevant aspects of the plate-tectonics, metamorphic evolution and thermal structure in the Eastern Alps overthrust complex are given by FREY et al. (1974), OXBURGH & TURCOTTE (1974), BICKLE et al. (1975), HAWKESWORTH et al. (1975), FRISCH (1976, 1979), ROEDER & BÖGEL (1978), and OXBURGH & ENGLAND (1980).

The following summary of the complex polymetamorphic development of the Habach Formation is based on the analysis of data from structural geology, metamorphic petrology and geochronology. The relative sequence of events in the petrogenesis of the Habach Formation has been deduced from a combination of radiometric age determinations, diagnostic mineral assemblages and the relationship between crystallization and deformation.

Uncertainties and contradictions exist in the literature and no effort is made to discuss the controversies in detail. Rather, this review attempts to present an integrated and necessarily simplified view of metamorphism of the Habach Formation in terms of Caledonian (Sardinian), Hercynian and Alpine events.

In the following section the term "Sardinian" is used instead of "Caledonian" for the pre-Hercynian Paleozoic event. The paleogeographic setting and radiometric data of the Habach Formation are more directly applicable to the Sardinian orogeny (German: "Sardische Orogenese") which is widely recognized in southern Europe (among others: TOLLMANN, 1986, 1987).

Sardinian Event

The main pre-Permian lithostratigraphic units in the northern central Tauern Window are the "Altkristallin Formation", the "Basisamphibolit" the "Zwölferzug" and the Habach Formation (Fig. 1) (FRASL, 1958; HÖCK et al., 1982; PESTAL, 1983). The banded amphibolites, a bimodal metavolcanic sequence of the "Zwölferzug", and the adjacent plutonic "Basisamphibolit" in the lower Habach Formation are

attributed to the first phase of development of a Sardinian island-arc. The "Basisamphibolit" contains zircons which yield an U/Pb intrusion age of 535±10 Ma but also have a detrital component giving evidence for a 2000 Ma crust. The lower intersection with the discordia at 313±4 Ma points to a Hercynian metamorphism (QUADT, 1985) (see below). The "Basisamphibolit", the basic rocks of the "Zwölferzug", and the intermediate to basic rock sequences of the lower Habach Formation are considered to be lithologies of an old oceanic crust (Cambrian, Ordovician) in the Penninic area (QUADT, 1984 a; 1985). The U/Pb-zircon intrusion age of the "Zwölferzug" at around 500 Ma was determined by QUADT (1987). According to a Sm/Nd-mineral isochron the "Zwölferzug" must have experienced a metamorphic overprint shortly after its emplacement (QUADT, 1987).

The extrusive basaltic and andesitic metavolcanics in the Habach Formation are seen as a second phase of island-arc development. The last dated event of island-arc volcanism is marked by rocks with a Pb-isotope model age of 400 Ma (now two-mica plagioclase gneisses and porphyroblastic biotite schists), and undated metaconglomerates (PESTAL, 1983; QUADT, 1984 b, 1985). Recent U-Pb zircon studies on mafic and ultramafic rocks from the scheelite deposit at Felbertal also indicate an intrusive age of 500 Ma (QUADT, 1987). The lower intersection with the discordia at around 60 Ma indicates an early stage of the Middle Alpine metamorphism (see below). The contacts between the rocks of the Habach Formation, the "Basisamphibolit" and the central gneiss complex must have been present in Hercynian times. Tungsten ore deposition at 400 Ma is implied by Pb-isotope model ages; the Pb-isotope data from scheelite, feldspar and whole rock give evidence that the lead represents a mixture of mantle and crustal components which is typical of island arc environments (QUADT, 1984 a, b; 1985). Besides the island arc complex, fragments of an ocean crust certainly exist. These rocks consist of metabasalts with typical MORB geochemistry. Probably the large ultramafic bodies and even the rodingites might be partly of primary gabbroic origin (STEYRER and HÖCK, 1985). According to KOLLER & RICHTER (1984) the serpentinites as well as the rodingites can be related to remnants of the oceanic crust.

Unambiguous Sardinian relict minerals have not survived the intensive Hercynian and Alpine metamorphic cycles. However, distinct primary magmatic textures shown by the irregular distribution of idiomorphic feldspar relicts in metabasites are widespread in the volcanic sequences of the Habach Formation (FRASL, 1958). In these the former anorthite component of the plagioclase is altered to a pseudomorphous filling of mainly epidote minerals. Furthermore, the Pb-isotope model age of 400 Ma from the fine-grained primary scheelite generation in quartzitic host rocks in the Felbertal deposit suggests that some scheelite has been locally preserved without any mobilization. The recent discovery of microfossil relicts (acritarchia?) in the metapelites of the "Habachphyllit"-series in the "Habachmulde" north of the "Habachzunge" in Habachtal gives a range in depositional age from 720–620 Ma (REITZ & HÖLL, 1988).

Taken together, the volcanic protolith of the metabasites in the lower Habach Formation represents an important pre-Hercynian, probably Sardinian orogenic event (Fig. 2). A Sardinian ("Caledonian") metamorphism of about 500 Ma is

generally accepted in the central and western Alps which agrees very well with the age determinations cited above. (BÖGEL et al., 1979; FRISCH et al., 1984; FRANK et al., 1976).

The data summarized above obviously do not allow a definite sequence of tectonic processes to be reconstructed. Nevertheless there is increasing evidence that a Sardinian event has affected the basic metavolcanics of the lower Habach Formation and the lowermost units of the Venediger nappe, such as the "Basisamphibolit", the "Zwölferzug", and the adjacent "Altkristallin" series (compare SCHÖNLAUB & SCHARBERT, 1978; QUADT, 1985).

Hercynian events

As mentioned above, evidence of a Hercynian regional and/or contact metamorphism in the Habach Formation was recognized in connection with the Late Carboniferous to Permian granitic intrusions now exposed as elongated "Augen- und Flasergneis" bodies in the central gneiss massif. The whole rock isochrons of "Augen- und Flasergneis", metatonalites, and migmatites within the Tauern Window show ages predominantly about 320 Ma and 280 Ma (LAMBERT, 1964; 1970; JÄGER et al., 1969; CLIFF, 1968; 1971; 1977; 1981; SATIR, 1975; HAWKESWORTH, 1976; PESTAL, 1983; SATIR & MORTEANI, 1982). These data provide indications of at least two Hercynian major thermal activities in the Penninic domain. PESTAL (1983) determined hornblende K-Ar dates of 320 Ma and 210 to 160 Ma from the rocks of the "Zwölferzug". The older age was interpreted as a true cooling age after the Hercynian metamorphism whereas the younger dates were attributed to partial resetting of Hercynian ages by the Alpine metamorphism. QUADT (1985) reported evidence of a 313±4 Ma metamorphic overprint on hornblendites, metagabbros, gneisses and amphibolites ("Basisamphibolit") of the lower Penninic unit of the Habach Formation, which agrees well with other geochronological studies from the Tauern Window (among others: BESANG et al., 1968; CLIFF, 1977; 1981; PESTAL, 1983; SATIR 1975; SATIR & MORTEANI, 1982).

The best documentation of pre-Alpine metamorphic textures is provided by discontinuously zoned, almandine-rich garnet porphyroblasts and relict chiastolite (muscovite pseudomorphs after andalusite) in the garnet-mica schists (metapelites) of the Habach Formation SE of the "Habachzunge" (GRUNDMANN, 1979; 1980; GRUNDMANN & MORTEANI, 1982). This rock unit is equivalent to the "Schwarzphyllit" or "Habachphyllit" of FRASL (1958). Certain evidence of Hercynian metamorphic textures has not yet been found – neither at the type locality of the Habach Formation N of the "Habachzunge", nor in the so-called "Habachmulde" and the "Untersulzbachmulde" between the outer Habachtal and the Untersulzbachtal, or in the adjacent area to the east (STEYRER, 1983).

The first determinations of P–T conditions of the Hercynian metamorphic event were made by KOLLER & RICHTER (1984). They calculated a temperature of 420° C and pressure of 2 kb with X_{CO_2} less than 0.05 from garnet-clinopyroxene assemblages in metarodingite occurrences adjacent to the garnet-mica schist unit from the SE edge of the "Habachzunge". The andalusite relicts reported by CORNELIUS (1944) from the "Schwarze Wand" area in Hollersbachtal and also found by GRUNDMANN

(1983 b) in the inner Habachtal (near Moaralm and Kesselscharte, Untersulzbach valley) occur in the same lithostratigraphic unit as the metarodingites. Thus the formation of andalusite may be assigned to the metamorphic event described by KOLLER & RICHTER (1984).

The question remains open whether the Hercynian metamorphism which affected the rocks of the Habach Formation was of a regional or contact nature. The nearby granitic protolith of the "Augen- und Flasergneis" of the "Habachzunge" could have caused contact metamorphism. This hypothesis would require a Hercynian intrusive contract between the tectonolithologic units of the "Lower Schieferhülle" (Habach Formation) and the central gneiss massif ("Habachzunge"). No compelling evidence for a primary intrusive contact has yet been found. If the contact is assumed to be tectonic and due to the Alpidic nappes, than one must assume that the andalusite and garnet-clinopyroxene relics – if due to a contact metamorphism – formed elsewhere and were tectonically separated from the magmatic heat source. On the other hand, the common occurrence of zoned almadine-rich garnets showing syndeformational growth features within the relict andalusite poikiloblasts argues for regional metamorphism (GRUNDMANN & MORTEANI, 1982). Furthermore, it seems improbable that chiastolite aggregates with average diameter of 2 cm and length of 20 cm, which occur both 20 m as well as 500 m from the central gneiss contact, could have formed by contact metamorphism. Chiastolite crystals of these dimensions have been mainly reported from regional metamorphic terranes, e.g. the "Koralpe", Austria (KIESLINGER, 1927), or the "Worcester Formation" in New England, USA (SPEAR, Troy, USA, pers. communication), or the "Saxothuringikum" in NE Bavaria, Germany (MIELKE & SCHREYER, 1969; STETTNER, 1980).

The distribution of the presumed Hercynian metamorphism in the pre-Permian rocks of the "Lower Schieferhülle" suggests that a deeper erosional level is exposed in the eastern and western Tauern Window than in the northern centre (site of the Habach Formation). Hercynian garnet-staurolite-kyanite assemblages from the Hochalm/Ankogel area (EXNER, 1967; DROOP, 1981), migmatite formation (MORTEANI, 1971; SATIR & MORTEANI, 1982) and Hercynian quartz-biotite, quartz-garnet and quartz-magnetite-ilmenite assemblages from the Zillertaler Alps (SATIR & FRIEDRICHSEN, 1983, 1986) are reported in the former areas, whereas in the northern central Tauern Window only relatively low-pressure/medium-temperature andalusite-grade rocks are present.

Alpidic events

The dominant and also youngest thermal event within the Tauern Window was the Middle Alpine regional metamorphism, the „Tauernkristallisation" of SANDER (1911; 1921). KREUZER et al. (1978) reviewed the following possible division of Alpine metamorphic events within the Eastern Alps: "Eo-Alpine event" (120–80 Ma), "Meso-Alpine event" (50–30 Ma), "Neo-Alpine event" (20 Ma). No Early Cretaceous ages have yet been detected by radiometric dating methods within the Habach Formation, whereas in the Central and Western Alps whole-rock Rb–Sr dating give ages between 130 and 110 Ma (among others see the review in: DAL PIAZ et al., 1975; HUNZIKER, 1974; FREY et al., 1974). According to RAITH et al. (1978;

1980) the so-called "early Alpidic phase" of high pressure/low-temperature conditions in the southern central Tauern Window ranges in age from 90 to 50 Ma (K–Ar dates determined on glaucophane and crossitic amphiboles from the southern Großvenediger area). However the age of the (probably Early Alpine) so-called "eclogite event" within the southern central Tauern Window is still uncertain because of considerable excess ^{40}Ar in the minerals of the high-pressure rocks (MILLER, 1974; 1977; MILLER et al., 1980). The P–T evolution of metasediments from the eclogite zone within the southern central Tauern Window is discussed by SPEAR and FRANZ (1986); peak metamorphic conditions of 19±2 kbar and 590±20° C are indicated, which correspond to a depth of 60–70 km.

The Middle Alpine "Tauernkristallisation", a Barrovian metamorphism, is called the "main alpidic event" by RAITH et al. (1978), and probably took place between 55–30 Ma (compare among others: OXBURGH et al., 1966; OXBURGH and TURCOTTE, 1974; CLIFF et al., 1971; KREUZER et al., 1973; SATIR, 1974; 1975). Several authors suggest the existence of a low grade metamorphism younger than the Middle Alpine "Tauernkristallisation" in the Penninic rocks of the central and western Tauern Window; this "Third Alpine metamorphic event", also termed "latest postkinematic crystallization representing the last climax of the Alpidic metamorphism", was caused by thermal doming at around 20 Ma (BORSI et al., 1973; SASSI et al., 1974; 1980; RAITH et al., 1978). The latest geochronological studies, which combine apatite fission-track dating with Rb–Sr and K–Ar mica cooling age data, conclusively contradict the suggestion that such a "Neo-Alpine" metamorphism at 20 Ma affected the central and western Tauern Window (GRUNDMANN & MORTEANI, 1985; STAUFENBERG, 1985; GRUNDMANN, 1987).

The large number of geological, petrological and geochronological studies from the Tauern Window cited above lead consistently to the conclusion that in Alpine time only the Middle Alpine "Tauernkristallisation" regionally affected the rocks of the Habach Formation, reaching its temperature peak between 65 and 35 Ma (Paleocene to Early Oligocene). Rb–Sr and K–Ar mica cooling ages from the northern Großvenediger area vary from 30 to 18 Ma depending on the elevation of the sample localities, the geothermal gradient and the uplift rate (JÄGER et al., 1969; RAITH et al., 1978); apatite fission track ages, depending on the same parameters, vary between 10 and 5 Ma (GRUNDMANN & MORTEANI, 1985). Based on these data an uplift/cooling history has been reconstructed for the area between the Krimmler Achental and the Felbertal/Amertal area (the main exposure of the Habach Formation) (Fig. 2). Unfortunately no mica cooling age data is available for the Granatspitze massiv, which could complete the picture. However, using an average geothermal gradient of 30° C/km for the Middle Alpine metamorphism, as suggestet by SASSI et al. (1974), HOERNES & FRIEDRICHSEN (1974), MORTEANI (1974) and MILLER (1974), and using an average uplift rate of 0,4 km/Ma as calculated for the Großvenediger and Granatspitze area by GRUNDMANN & MORTEANI (1985), the average cooling rate is 12° C/Ma.

The temperature distribution, metamorphic isograds and the occurrence of the pressure index-mineral kyanite are known for the Middle Alpine metamorphism in the Penninic rocks of the central Tauern Window from the work of, among others, KARL (1954), HOERNES (1973), HOERNES & FRIEDRICHSEN (1974), MORTEANI & RAASE

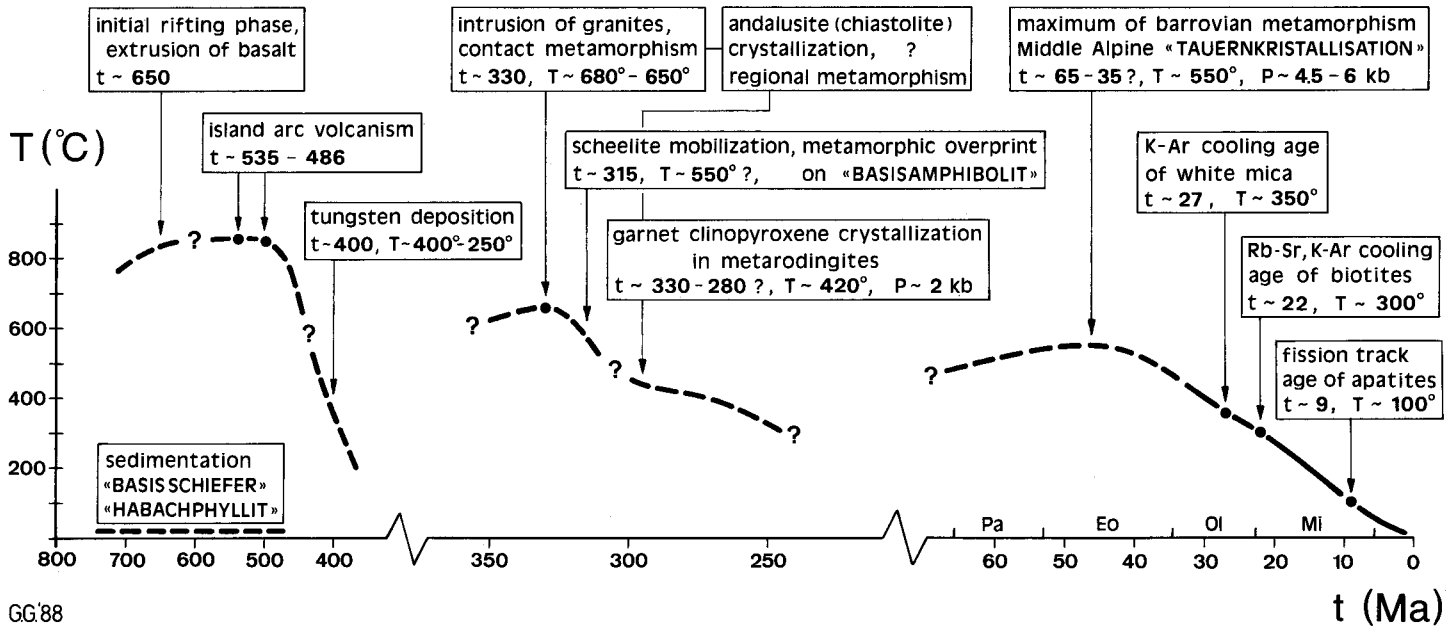

Fig. 2: Temperature – time diagram for the sedimentary, magmatic and metamorphic events in the Penninic rocks of the Habachformation (Habachtal, Hollersbachtal and Felbertal). Further informations see text.

(1974), RAASE & MORTEANI (1976), HÖCK (1974, 1980); HÖCK & HOSCHEK (1980), GRUNDMANN (1980), RAITH et al. (1978), BERNOTAT & MORTEANI (1982), STEYRER (1983), and SATIR & FRIEDRICHSEN (1983, 1986). The isograds and isotherms run subparallel to the margin of the Tauern Window. The metamorphic temperature increases significantly from the northern margin towards the central axis of the Tauern Window. However, revision of the ^{18}O studies of HOERNES & FRIEDRICHSEN (1974) shows that the isotherms constructed locally reflect a mixture of Hercynian and Alpine metamorphic grades (SATIR & FRIEDRICHSEN, 1983, 1986). Therefore the isotherms which are valid for the "Tauernkristallisation" must be slightly corrected, as the Alpine temperatures (at least in the western Tauern Window) are lower than given (SATIR & FRIEDRICHSEN, 1983, 1986).

The P-T-conditions of the Middle Alpine "Tauernkristallisation" in the area of the Habach Formation are estimated at 550° C and 6 kb (HÖLL, 1975; GRUNDMANN, 1980; PESTAL, 1983; KOLLER & RICHTER, 1984). The lowest Alpine P-T-conditions are reported at the northern edge of the central Tauern Window as 440° C and >4 kb by STEYRER (1983). Recent studies, in particular of stable isotopes of oxygen and hydrogen, have shown that the formation of the Alpine fissures and their filling by fissure minerals (e.g. quartz, feldspars, epidote, carbonates) occurred mainly at or shortly after the peak of the "Tauernkristallisation" (HÖRMANN & MORTEANI, 1972; FRIEDRICHSEN & MORTEANI, 1979; LUCKSCHEITER & MORTEANI, 1980).

Conclusions and Final Comments

The contribution from structural geology, metamorphic petrology and geochronology presented in summary form above allow a first attempt to form an integrated picture of the complex polymetamorphic evolution of the Habach Formation (Fig. 2).

Fig. 3 presents a metamorphic crystallization/deformation diagram compiled from published structural, petrographic and mineral analysis of the garnet-mica schist unit and the adjacent rocks (SE of the "Habachzunge"). It is representative for the upper Habach Formation at least in the area between Habachtal and Hollersbachtal S and E of the "Habachzunge". The diagramm summarizes the polymetamorphic development of the Habach Formation, which was involved in at least five main deformations (Fm_{1-5}), and at least two prograde metamorphic events (Kr_{1-2}), and a demonstrable retrograde metamorphism (diaphtoresis). The first, probably Hercynian metamorphic event (Kr_1) can be separated from the Alpine event (Kr_2). Both metamorphic events were clearly two-stage; that is, an earlier low-temperature syndeformational phase was followed by at least one higher-temperature largely post-deformational phase. The final retrograde metamorphism (diaphtoresis following the "Tauernkristallisation") is documented in the rocks by a late stage formation of albite, biotite and chlorite.

Evidence of a Sardinian event is based entirely on geochronology, and therefore no information on the Sardinian metamorphic grade is available. According to the wide range of whole rock isochrons, from 320 Ma to 280 Ma, a period of more than 40 Ma of strong thermal activity and/or magmatism characterised the Hercynian cycle.

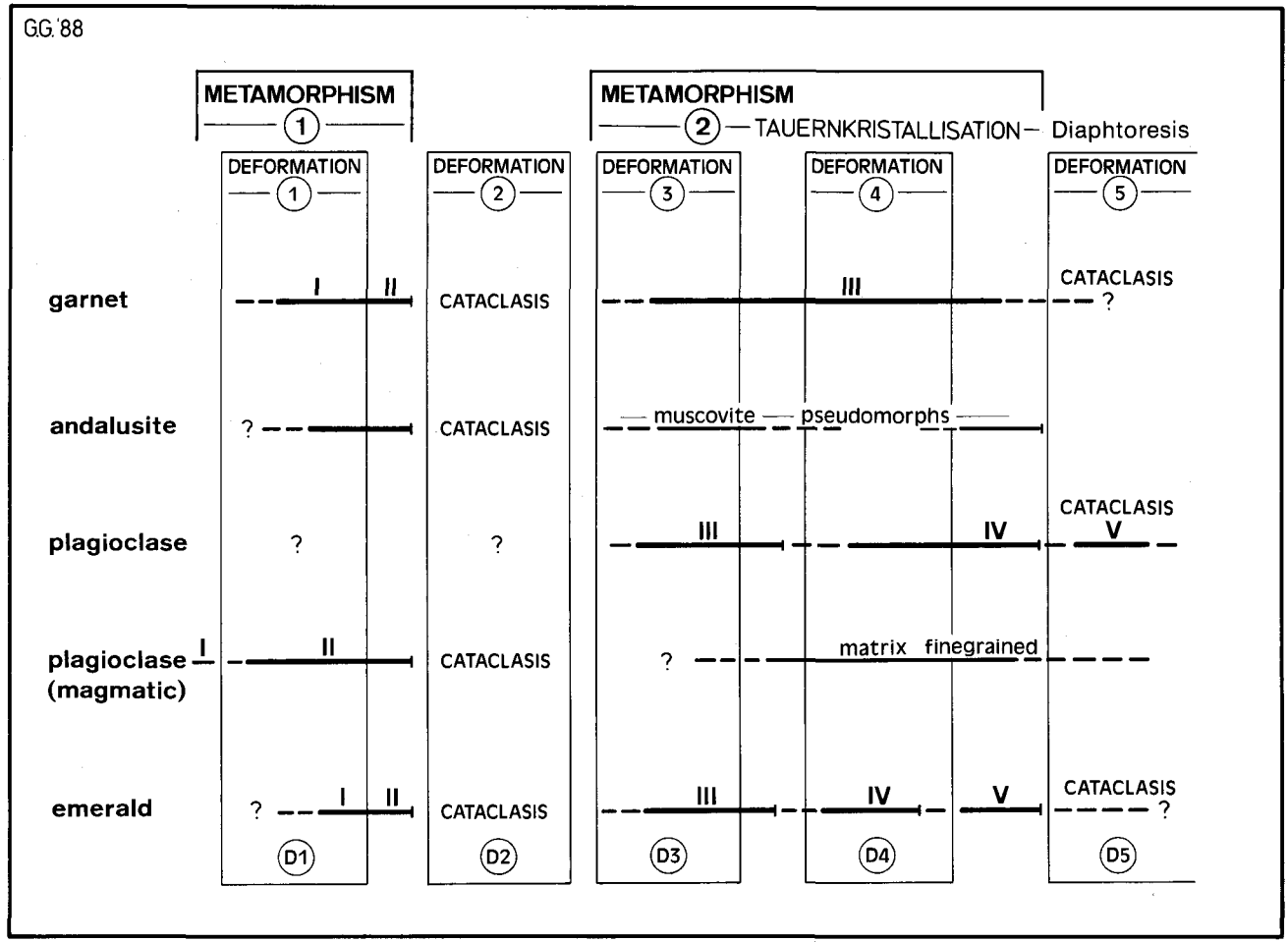

Fig. 3: Crystallization – deformation diagram for garnet, andalusite, plagioclase and emerald in the metapelites and adjacent metavolcanic rocks of the Habachformation southeast of the "Habachzunge" (Untersulzbachtal, Habachtal, Hollersbachtal) (modified after GRUNDMANN & MORTEANI, 1982).

Both the Hercynian and Alpine metamorphic events reached higher grades in the eastern and western parts of the Tauern Window than in the centre, where the Habach Formation is exposed (compare: GRUNDMANN, 1980; DROOP, 1981; GRUNDMANN & MORTEANI, 1982; SATIR & MORTEANI, 1982; SELVERSTONE et al., 1984; KOLLER & RICHTER, 1984; STEYRER, 1983; PESTAL, 1983).

It is concluded that in Alpine time only the Middle Alpine "Tauernkristallisation" regionally affected the rocks of the Habach Formation. No evidence of high-pressure assemblages has been found in the Habach Formation, and in this respect the protolith of the Habach Formation (at least in the northern-central part of the Tauern Window) cannot have been involved in significant subduction processes (compare OXBURGH & TURCOTTE, 1974; HAWKESWORTH et al., 1975; FRISCH, 1976; 1979; ZIMMERMANN et al., 1987).

Uncertainties still exist with regard to the exact structural separation of the Habach Formation from lower and/or higher lithostratigraphic units, especially the "Basisamphibolit", the "Zwölferzug" and the "Altkristallin". The paleogeographic relationship between the Habach Formation and the presumably contemporaneous formations in the western and eastern Tauern Window (e.g. the "Greinerschiefer" series in the Zillertaler Alps and the "Lower Schieferhülle" metapelites in the Hochalm/Ankogel area) are not known either.

The Habach Formation ist one of the key elements in piecing together the polymetamorphic evolution of the Penninic domain in the Eastern Alps. To complete our understanding of this evolution it will be neccessary to determine more completely the connection between tectonic and metamorphic events, to constructs accurate pressure-temperature-time-deformation paths of the tectonometamorphic development, and finally to develop consistent and realistic geodynamic models (compare for example: ANGENHEISTER et al., 1975; FRISCH, 1976; KREUZER et al., 1978; SELVERSTONE, 1985). However, it must be stressed that the structural complexity within the Tauern Window is such that each tectonic unit has its individual tectonometamorphic history and therefore the application of petrological and geochronological results from one unit to another or from one unit to the whole Penninic domain should be generally avoided.

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