Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 71 (1991)

Heft: 2

Artikel: Mafic-ultramafic rock associations in the Aar, Gotthard and Tavetsch massifs of the Helvetic domain in the Central Swiss Alps : markers of ophiolitic pre-Variscan sutures, reworked by polymetamorphic events?

Autor: Abrecht, Jürgen / Büno, Giuseppe G. / Mercolli, Ivan

DOI: https://doi.org/10.5169/seals-54365

SCHWEIZ. MINERAL. PETROGR. MITT. 71, 295–300, 1991

Mafic-ultramafic rock associations in the Aar, Gotthard and Tavetsch massifs of the Helvetic domain in the Central Swiss Alps: markers of ophiolitic pre-Variscan sutures, reworked by polymetamorphic events?*

by *Jürgen Abrecht*[1,2], *Giuseppe G. Biino*[1], *Ivan Mercolli*[1] and *Peter Stille*[3]

Abstract

The presence of eclogite and granulite facies rocks has been known for a long time in the European pre-Variscan and Variscan fold belts. Their age and origin is still controversial. Preservation of such rocks in the Alpine fold belts allows promising new insights into the early history of the European Continent. In the Gotthard massif the regional distribution of mineral assemblages with eclogite facies relics indicates in-situ high-Pressure transformation. Therefore, a common crustal evolution of the complete pre-Variscan basement of the Gotthard is likely. This polymetamorphic evolution was related to subduction-type tectonics and later uplift, suggesting the presence of plate tectonic regimes during pre-Variscan times.

Keywords: Helvetic domain, eclogite facies, metamorphic evolution, pre-Variscan, plate tectonics.

Introduction

In geologic terrains that suffered polycycle tectonic and metamorphic reworking, remnants of older high-grade metamorphic events are often only found in mafic-ultramafic rocks. Due to their suitable chemical and mineralogical compositions they often are useful in recording complex mantle and crustal activities and processes in various tectonic environments. Rocks with mineralogical and/or textural relics of their polycycle ancient evolution display rather complex and, necessarly, non-equilibrium mineral assemblages and textures.

The usefulness of such rock assemblages was considered in the highly structured pre-Permian basement of the Helvetic domain in the central Swiss Alps, the Aar, Tavetsch and Gotthard massifs.

Geological setting and petrography

In the pre-Permian basement of the Helvetic domain (Aar, Tavetsch and Gotthard massifs) small mafic-ultramafic bodies (1–1000 m long) are rather widespread and are associated with ortho- and paragneisses.

In the Gotthard massif these rocks are generally refolded together with poly-metamorphic paragneisses and occasionally with orthogneisses. These orthogneisses (commonly referred to as "Streifengneisses") are interpreted as intrusive meta-granites of Ordovician age (U/Pb on zircons: 460–560 Ma and Rb/Sr on total rock: 436 ± 17 Ma [Arnold, 1970a]; U/Pb on zircons: 440 Ma [minimum age] [Bossart et al., 1986]). This meta-granite and associated acid dikes crosscut the surrounding paragneisses and their mafic lenses. Sedimentary precursors of the paragneisses are of detrital to semi-pelitic composition.

---

* Extended abstract of a contribution presented at the annual meeting of the SSMP, Geneva, October 4 and 5, 1990.

[1] Mineralogisch-petrographisches Institut, Baltzerstrasse 1, CH-3012 Bern, Switzerland.
[2] Present address: GEOTEST AG, Birkenstrasse 15, CH-3052 Zollikofen, Switzerland.
[3] Université Louis Pasteur, CNRS Centre de Sédimentologie, 1, rue Blessig, Strasbourg, France.

Although the rocks of the Tavetsch massif are generally highly deformed and good outcrops are scarce, similarities to the Gotthard massif are evident.

In the Aar massif mafic-ultramafic rocks generally lie within high-grade quartzo-feldspathic gneisses of unknown age. A pre-Variscan age of the mafic-ultramafic lenses (e.g. Haslital) within migmatitic gneiss terrains was argued by SCHENKER and ABRECHT (1986). In the Sustenpass area small ultramafic lenses occur in association with retrograde garnet-amphibolites (SCHALTEGGER, 1986) in a flyschoid sequence indicating a possible olistostrome origin for mafic-ultramafic lenses.

On a regional scale in all three massifs the mafic-ultramafic associations are arranged parallel to the main Variscan (and Alpine) SW–NE structures. In the eastern Gotthard massif, a slight discordance with the "Streifengneiss"-basement contacts and the internal "Streifengneiss" textures is observed. Despite the poly-metamorphic character of the rocks, occasionally primary (magmatic?) internal structures (distinctly deviating from Variscan structures by up to 90°) have been preserved in larger meta-peridotite bodies (Fuorcla Paradis, Val Nalps, GM).

The mafic rocks display a wide mineralogical and textural variation which is related to their deformation and retrograde history. Relatively undeformed meta-gabbro bodies occur in the Gotthard massif and are generally associated with ultramafic rocks. Within the largest body (Kastelhorn) small irregular vein-like, coarse-grained plagioclase-quartz-rich rocks occur occasionally (possible plagiogranite melts?). The gabbros often show a magmatic texture, although variations in grain-size give the rock a heterogeneous appearance. The presence of marble xenoliths infers a high level of intrusion for at least some of the gabbros (Kastelhorn-Unteralptal).

Along with the gabbros, rocks consisting of garnet and hornblende rocks, garnet-amphibolites, banded and spotted amphibolites, and schollen amphibolites occur. Garnet-rich mafic rocks associated with ultramafic bodies are typical for the Gotthard massif, while schollen amphibolites seem to be characteristic of the Aar massif (e.g. Ofenhorn-Stampfhorn: ABRECHT, 1980; Belalp, Massa: LABHART, 1965). In the strongly retrograded and deformed amphibolites of the Gotthard massif (spotted and banded amphibolites) their origin from garnet-rich mafic precursors can still be inferred.

The mafic rocks investigated in the GM show a tholeiitic affinity. Whole-rock and trace element data support Fe-rich gabbros and/or Fe-rich basalts as being the protoliths for these garnet-bearing mafic rocks.

The ultramafic rocks are usually serpentinized, but the ultramafics show layers enriched in chlorite and magnetite. These are interpreted as being formed from magmatic chromite-rich layers. In the same locality ultramafics are crosscut by gabbroic dikes and sills (Fuorcla Paradis, GM). In other places (Gigestafel, Gotthard Railway tunnel) the metamorphic *olivine-clinopyroxene* assemblages are preserved. *Chromite* is usually preserved in serpentinites of the Aar massif. The ultramafic rocks are to be classified as mainly harzburgites or less commonly as lherzolites according to their normative mineral compositions.

Metamorphic evolution

Alpine deformation and recrystallization is mainly confined to shear zones. The metamorphic assemblages and textures in mafic and ultramafic rocks in areas that are not affected by Alpine deformation reflect metamorphic conditions different from P-T estimates for the Alpine event (Fig. 1). The metabasic rocks generally display amphibolite-facies mineral assemblages. However, older mineral relics occur when the rocks are only slightly affected by Variscan and Alpine deformation (especially in the area between Somvix Valley and Furka).

THE ECLOGITES OF THE GOTTHARD MASSIF

The oldest recognizable metamorphic mineral assemblages of the Gotthard massif indicate an eclogite-facies event. Relics of pre-eclogitic (magmatic?) minerals include *ilmenite, pyrite,* aggregates of *apatite* and fine grained oriented rutile inclusions within garnet. The eclogitic paragenesis (*Grt + Omp + Qtz + green/brown Hbl + Rt + Ilm ± Zo*) is preserved in samples from the Furka pass area, Unteralptal, Val Maighels, Val Nalps, and Somvix Valley. Pseudomorphs and symplectites of eclogitic garnet relics are preserved more or less throughout the Gotthard massif.

The quartz eclogite mineral assemblages indicate equilibrium temperatures of approximately 700 °C (Cpx-Grt FeMg-exchange, ELLIS and GREEN calibration, 1979; BERMAN, 1988). During this eclogitic event the pressure was in excess of 18 kbar according to Omp+Pl+Qtz equilibrium (BERMAN, 1988).

The eclogitic assemblages were later recrystallized by post-eclogite events to variable degrees, thus enabling the reconstruction of the evo-

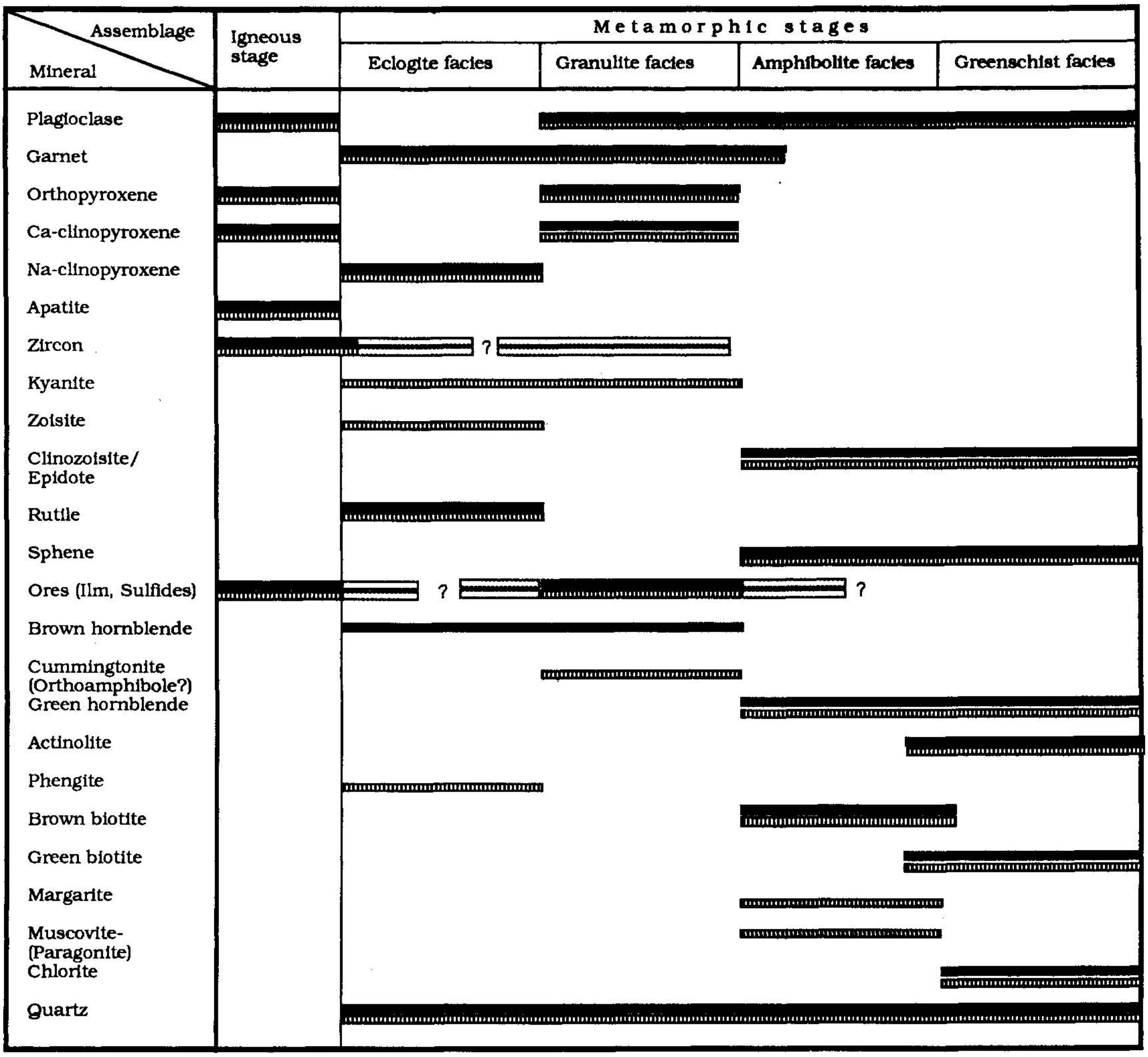

Fig. 1 Diagrammatic mineral parageneses in mafic rocks of the Gotthard massif. Black bars represent rocks of the Val Nalps area and bars with vertical patterns represent rocks from the Kastelhorn area. Empty bars represent uncertain values for both areas.

lution from eclogite to granulite and amphibolite facies conditions.

The granulite facies overprint is characterized by the breakdown of omphacite to *Na-Di + Pl (oligoclase) + Opx*. Orthopyroxene forms symplectitic intergrowths or lamellae with Na diopside, and is mainly found as corona around the quartz. Eclogitic garnet and hornblende were still stable during the granulite stage. A secondary *Hbl + Pl (oligoclase)* vermicular symplectite replaced the omphacite. The stable assemblage was *Grt + Na-Di + Opx + Pl (oligoclase) + Hbl + Rt ± Zo*.

From petrologic phase considerations and exchange equilibria temperatures are estimated to be between 625 and 700 °C and pressures around 8 kbar.

Later coarser grained green *Hbl + Pl (oligoclase)* symplectite replaced the eclogitic hornblende and pyroxenes/hornblende + oligoclase symplectites. Amphibole grew in idioblastic needle-like crystals which form a planar geometry in contrast to the irregular vermicular texture of earlier symplectites. Thus, in most samples the distinct eclogite and granulite textures are completely destroyed by green *Am + Pl (oligoclase)* intergrowths coexisting with garnet. Recrystallization at amphibolite-facies conditions stabilized the *Hbl + Pl (An 40–60) + Qtz ± Grt ± brown Bt* assemblages. A pale green actinolitic amphibole, green biotite, and epidote developed during the following evolution and mainly replaced garnet and hornblende. The latest stage of retrogression is characterized by chlorite and albite.

THE HIGH-P GABBROS FROM KASTELHORN AND GURSCHEN (GEMSSTOCK)

The Kastelhorn metagabbro (Gotthard massif) displays abundant plutonic relic textures. Predominant non-equilibrium textures are typically coronitic and symplectitic. These textures can be interpreted when the metamorphic history (based upon P-T information) obtained from the mineral relics in polymetamorphic garnet-bearing mafic rocks of the central Gotthard massif (Somvix, Val Nalps, Unteralptal) is known. The older event is represented by *Grt + Qtz + Ky + Zo + Rt ± Hbl.* A precursor phase coexisting with the previous paragenesis is completely replaced by the *Pl + Na-Di* symplectite. We interprete this symplectite precursor phase as the product of the omphacite breakdown, in comparison with the textures observed in the less retrograded eclogite of the Val Nalps. These relics indicate an early eclogite event that also occurred in the gabbros. This assumption is further supported by the presence of relictic *grossular-rich Grt + Ky + Qtz* assemblages indicating elevated pressures.

A granulite-facies event might be inferred from relic cummingtonite cores in hornblende with *Oam + Pl + Na-bearing Cpx ± Hbl* representing the stable assemblage. The *Opx + Ca-Pl* may have formed at the expense of *Omp + Grt + Qtz.*

The high-P assemblage of the gabbros is altered by a subsequent transformation with *Oam + Na Cpx + Pl ± Hbl* (critical paragenesis). The older garnet is still stable and possibly indicates chemical rehomogenization. The new paragenesis defines slightly lower temperatures and medium pressures and can be related to the granulite event.

AMPHIBOLITE- AND GREENSCHIST-FACIES RETROGRESSION

The high-P and high-T assemblages are usually replaced by hydrous phases stable at amphibolite-facies conditions *(Hbl + Pl + Grt + Bt + Qtz + Ttn + Mrg + Ms)*. The amphibolite facies evolution occurred after the intrusion of the "Streifengneiss" magma. This intrusion produced spotted amphibolite *(Grt –> Pl + Zo + Bt)* in relatively undeformed volumes, or banded amphibolites in deformed volumes (relic assemblages and textures have been obliterated). However, in some places the transition from garnet-bearing mafic rocks to the present amphibolite is still evident. The pervasive amphibolite facies re-equilibration is associated with large scale isoclinal folding, predating the intrusion of the late-Variscan intrusives. Lower amphibolite to greenschist facies retrogression may be related to late-Variscan and is probably Alpine in age.

The last mineral transformations that occurred due to the Alpine greenschist metamorphism are of minor significance *(Act + Bt + Chl + Czo).*

GARNET-AMPHIBOLITES IN AAR AND TAVETSCH MASSIFS

Garnet amphibolites also occur in the Aar and Tavetsch massifs. In the Aar massif the garnet amphibolite mineral assemblages do not indicate high-pressure or granulite metamorphism, but are characteristic of amphibolite-facies conditions. An earlier event is recorded only by garnet and amphibole + oligoclase intergrowths. This genetic relationship between strongly altered common amphibolites and garnet-bearing high-P-T precursors is not observed in the Aar massif, most likely due to its stronger retrograde late-Variscan and Alpine overprint. This does not exclude a similar complex tectono-metamorphic evolution for these more external massifs. However, the significant lithologic differences between Gotthard and Aar massifs may also indicate that different crustal levels are exposed today. In Tavetsch massif the most recent research revealed the presence of high pressure parageneses. Samples formed by diopside and plagioclase symplectite probably replacing an omphacitic pyroxene were found. The possible sodic pyroxene was coexisting with the following high pressure paragenesis *Grt + Qtz + Ky + Zo + Rt ± Hbl.* The presence of this relic is consistent with the observed significant lithologic affinities between the Gotthard and the Tavetsch massifs. If this high-P evolution can be constrained more precisely, it may be possible to demonstrate a common pre-Alpine evolution of two massifs and their origin from the same crustal levels. In this case their present exposure as two separate units might be mainly due to alpine events.

ULTRAMAFIC ROCKS

In all three massifs the ultramafics still contain relics of high-T assemblages such as olivine, diopside I, Cr- and Al-rich spinel and phlogopite. The higher temperature parageneses evolved into tremolite, anthophyllite, diopside II, (Cr-)chlorite, talc, carbonates and serpentine assemblages.

Summary

According to the present field and petrologic data the following evolution is proposed for the Gotthard massif:

1) Pre-Palaeozoic or Lower-Palaeozoic crystallization of the mafic-ultramafic ophiolitic suite.
2) Pre-Variscan (or Early-Variscan?) eclogitic facies event.
3) Pre-Variscan (or Early-Variscan?) granulite event.
4) Ordovician intrusion of granitoid plutons.
5) Variscan amphibolite to greenschist-facies metamorphism.
6) Permo-Carboniferous intrusion of granitoid plutons.
7) Alpine greenschist-facies re-equilibration.

The age problem

While the relative ages of these metamorphic events can be established, their relationship to orogenic events is still very speculative. The Variscan age of the amphibolite-facies metamorphism was determined by Rb/Sr isotope age results (GRAUERT and ARNOLD, 1968; ARNOLD, 1970a).

A pre-Variscan age of the granulite- and eclogite-facies event is probable. This is supported by the presence of intrusive contacts between the "Streifengneiss" (U/Pb zircon age: 460–560 Ma, and Rb/Sr age: 436 ± 17 Ma, ARNOLD, 1970a), and the basement rocks with high-P assemblages. The high-P assemblages are usually retrograded when in contact with the "Streifengneiss" (garnet –> plagioclase + biotite).

U–Pb determinations on zircons from a mafic rock of the Gotthard massif (interpreted as eclogite) yielded an age of about 466 my (GEBAUER et al., 1988). This age was attributed to the eclogite-facies recrystallization related to subduction processes of a basaltic protolith formed some 870 Ma ago (GEBAUER, 1990). Although the Ordovician age of the granulite-facies event is purely speculative, it seems to be consistent with a reconstruction of the tectonic evolution during the Ordovician. Later, post-collision uplift of crustal rocks occurred, followed by the intrusion of the anatectic "Streifengneiss" magma (high Sr-initial: 0.714). Partial melting in the high-grade quartzofeldspathic rocks may be attributed to this high-T Ordovician event. The presence of granulite-facies rocks and structures in meta-sedimentary sequences (Val Nalps) was demonstrated by ARNOLD (1970b). This strongly implies a common evolution of country-rocks and mafic-ultramafic inclusions since at least the Early-Variscan. The lower intercept of GEBAUER'S (1990) zircon discordia lines at 468 Ma as well as his Sm/Nd ages of 461 ± 25 Ma (whole rock and garnet) can be interpreted as being in accordance with a granulitic event at Ordovician times. With the present available age data it is not clear if the two earliest metamorphic events are part of the same orogenic cycle.

Tectonic implications: discussion and conclusions

The presence of eclogitic rocks in the Helvetic domain (derived from upper-crustal protolith types) strongly infers a collisional tectonic regime with low associated thermal gradients typical for eclogite metamorphism. If the subsequent eclogite –> granulite evolution is related to the same polyphasic orogenic event, this constrains the possible tectonic models of the thermal evolution of the basement. On the other hand, if the eclogite event is related to an older event it must be part of the pre-Ordovician history of the European basement (thus an even more complex evolution of the Helvetic basement in the central Alps has to be envisaged).

In conclusion, the following tectono-metamorphic evolution of the Gotthard massif is discussed. Trace element and Sr–Nd isotope data from the Kastelhorn metagabbro support a subduction related origin in an island arc tectonic environment for some of the gabbros. A two-component melting-mixing model can be envisioned to explain the trace element and isotope characteristics of the volcanic arc magmas: in this model, basalt depleted peridotites (in a subducted lithospheric plate) were thermally equilibrated with the surrounding hotter mantle at a depth beneath an island arc, and thus became partially molten. These melts then rose diapirically and mixed with fluids or melts derived from the subducted oceanic sediments. They then intruded a sedimentary sequence of flyschoid character. The other basaltic and gabbroic melts were possibly generated in an island-arc or ocean floor environment (GEBAUER, 1990). Tectonic activity produced a melange of dismembered ophiolitic bodies and flysch sediments of Precambrian age (>1000 Ma, GRÜNENFELDER et al., 1964; NUNES and STEIGER, 1974). This flyschoid sequence with the melange (dismembered ophiolitic bodies) was attached to an accretionary wedge and intruded by gabbros. By continent-continent collision (approximately 460 Ma or earlier) this flyschoid melange was subducted to depths of at least 40 km and underwent eclogite-facies metamorphism. During the Ordovician (possibly earlier) the metamorphic rocks were transformed to granulite-facies conditions at medium pressure conditions (sillimanite field). During the Ordovician the basement was intruded by granitoid plutons. Then, during the Variscan orogeny, the complete sequence underwent amphibolite-facies metamorphism.

Finally, the Mesozoic to Tertiary Alpine metamorphism was not pervasive, leaving parts of the pre-Alpine basement mostly unaffected.

Acknowledgement

This study was supported by the Swiss National Science Foundation (Project no. 21-25282.88). The text was made comprehensible to readers by the careful revision of the English by John Chermak.

References

ABRECHT, J. (1980): Zur Bildung migmatitischer Schollenamphibolite aus dem Altkristallin des Aarmassivs. Geol. Rdsch. 69, 695–725.

ARNOLD, A. (1970a): On the history of the Gotthard Massif (Central Alps, Switzerland). Eclogae geol. Helv. 63, 29–30.

ARNOLD, A. (1970b): Die Gesteine der Region Nalps-Curnera im nordöstlichen Gotthardmassiv, ihre Metamorphose und ihre Kalksilikatfels-Einschlüsse (Petrographische Untersuchungen im Bereich der Anlagen der Kraftwerke Vorderrhein). Beitr. geol. Karte Schweiz, N.F. 138. Lfg.

BERMAN, R.G. (1988): Internally-consistent thermodynamic data for stoichiometric minerals in the system Na_2O–K_2O–CaO–MgO–FeO–Fe_2O_3–Al_2O_3–SiO_2–TiO_2–H_2O–CO_2. J. Petrology 29, 445–522.

BOSSART, P.J., MEIER, M., OBERLI, F. and STEIGER, R.H. (1986): Morphology versus U–Pb systematics in zircon: a high-resolution isotopic study of a zircon population from a Variscan dike in the Central Alps. Earth and Planetary Science Letters 78, 339–354.

ELLIS, D.J. and GREEN, D.H. (1979): An experimental study of the effect of Ca upon garnet-clinopyroxene Fe–Mg exchange equilibria. Contrib. Mineral. Petrol. 71, 13–22.

GEBAUER, D. (1990): Isotopic systems – geochronology of eclogites. In: Eclogite facies rocks, CARSWELL, D.A. (ed.), Blackie, Glasgow, p. 141–159.

GEBAUER, D., QUADT, A., COMPSTON, W., WILLIAMS, I.S. and GRÜNENFELDER, M. (1988): Archean zircons in a retrograded, Caledonian eclogite of the Gotthard Massif (Central Alps, Switzerland). Schweiz. Mineral. Petrogr. Mitt. 68, 485–490.

GRAUERT, B. and ARNOLD, A. (1968): Deutung diskordanter Zirkonalter der Silvrettadecke und des Gotthardmassivs (Schweizer Alpen). Contrib. Mineral. Petrol. 20, 34–56.

GRÜNENFELDER, M., HOFMÄNNER, F. and GRÖGLER, N. (1964): Heterogenität akzessorischer Zirkone und die petrographische Beurteilung ihrer Uran/Blei-Zerfallsalter. II. Präkambrische Zirkonbildung im Gotthardmassiv. Schweiz. Mineral. Petrogr. Mitt. 44, 543–558.

LABHART, T. (1965): Petrographische Untersuchungen am Südrand des Aarmassivs. Beitr. geol. Karte Schweiz, N.F. 124. Lfg.

NUNES, P.D. and STEIGER, R.H. (1974): A U–Pb zircon, and Rb–Sr and U–Th–Pb whole-rock study of a polymetamorphic terrane in the Central Alps, Switzerland. Contrib. Mineral. Petrol. 47, 255–280.

SCHALTEGGER, U. (1986): Voralpine und alpine Mineralbildung in der Gneiszone von Erstfeld (Sustenpass, Aarmassiv); der Mechanismus der K-Ar- und Rb-Sr-Verjüngung alpin umgewandelter Biotite. Schweiz. Mineral. Petrogr. Mitt. 66, 395–412.

SCHENKER, F. and ABRECHT, J. (1987): Prä-aargranitische Anatexis, variszische Kontaktmetamorphose und alpidische Regionalmetamorphose im Oberhasli (zentrales Aarmassiv, Schweiz). Schweiz. Mineral. Petrogr. Mitt. 67, 13–26.

Manuscript accepted March 5, 1991.