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SHORT COMMUNICATION

Time constraints on the pre-Variscan magmatic/metamorphic evolution of the Gotthard and Tavetsch units derived from single-zircon U–Pb results*

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Abstract

Polymetamorphic mafic-ultramafic rock associations preserving relic HP-HT mineralogy represent the oldest igneous remnants so far identified in the pre-Variscan Helvetic basement of the Central Swiss Alps. In order to establish time constraints on the origin of these important tracers of early basement evolution, three eclogitic metagabbro samples of island-arc affinity (Gotthard and Tavetsch units) and one basaltic eclogite of MORB affinity (Gotthard unit) have been dated by conventional high-resolution single-zircon U–Pb isotope techniques.

Zircons devoid of inherited cores from the three metagabbro samples yield overlapping linear U–Pb data patterns characterized by upper intercept and maximum apparent $^{206}Pb/^{238}U$ ages of ~ 467–475 Ma. The mid-Ordovician time interval defined by the results coincides with a previously published age of ~ 468 Ma assigned to the eclogite stage in the Gotthard area, whereas the lower intercept ages reflect substantial overprint by Variscan and partially, Alpine events. With the exception of few core-bearing zircons, pre-Ordovician age components are absent from the samples analyzed. Multiple internal zoning revealed by cathodoluminescence suggests at least partial preservation of primary *magmatic* mineralogical and isotopic features. The island arc-type gabbros therefore most likely have intruded within or closely before the 467–475 Ma time interval defined by the present data.

This result is in contrast to previous studies which suggested an extended oceanic evolutionary history beginning with late Precambrian (~ 870 Ma) island-arc magmatism.

The zircons from the MORB eclogite sample yield a slightly older maximal $^{206}Pb/^{238}U$ age of 481 Ma and a nominally older upper intercept age of 535 +150/–75 Ma. Anhedral crystal morphology and absence of multiple magmatic zoning probably reflect a *metamorphic* origin related to an *earlier intra-oceanic* subduction stage.

Conformable petrological information and age distribution patterns suggest that the Gotthard and Tavetsch basement units have undergone similar early evolutionary histories, characterized by island arc-type intrusive activity immediately preceding mid-Ordovician collision and therefore appear to have formed part of the same active plate margin environment during Caledonian times. The limited time interval of ~ 30–35 Ma bracketed by the intrusion of island arc-type gabbros and by the emplacement of Late-Ordovician (~ 440 Ma) granitoids which postdate HP-HT and subsequent granulite facies metamorphism, is indicative of a *fast coherent* evolutionary cycle.

Keywords: single zircon, U–Pb method, cathodoluminescence, pre-Variscan, Central Swiss Alps.

Introduction

Polymetamorphic basalts and gabbros occurring as lenses and intrusives in the Gotthard and Tavetsch units are the oldest remnants of igneous lithologies in the pre-Variscan Helvetic basement of the Central Swiss Alps (ABRECHT et al., 1991). On the basis of field relations and isotope-geochemical arguments the mafic-ultramafic associations can be divided into

1) a structurally older group of oceanic affinity, consisting of meta-E-N-MOR basalts, abyssal peridotites and minor metagabbros, and

2) a younger group of intrusive metagabbros and ultramafic cumulates probably generated in an island arc tectonic setting (BIINO, 1992).

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Both groups together with their country rocks (accretionary wedge-type metasediments) were metamorphosed at eclogite facies conditions (T = 650–750 °C and P > 1.8 GPa), and later at granulite facies conditions (T = 600–700 °C and P ~ 0.8 GPa; BIINO, 1994). The basement lithologies show varying degree of re-equilibration both at amphibolite and partly greenschist facies during the Variscan, and greenschist facies during the Alpine orogenies.

On the basis of ion-probe zircon U–Pb results and a Sm–Nd garnet – total rock age obtained for a retrograded eclogite of the Gotthard massif (Val Nalps), GEBAUER et al. (1988) and GEBAUER (1990, 1993) postulated ages of approximately 870 Ma for the magmatic formation of the protolith, probably an island arc derived gabbro, and 468 Ma for the eclogite event. This interpretation allows for extensive time separation between magma genesis and subduction, and thus for the possibility that the two processes were not related. GEBAUER et al. (1988) report that > 95% of the zircons in their sample were of irregular shape and yielded discrete primary ages in the range of 1.27–3.17 Ga, whereas the 870 Ma old subpopulation was characterized by magmatic morphology and multiple internal zoning. Zircons exhibiting ages > 870 Ma were interpreted to have crystallized during earlier melting events in the mantle source of the gabbro rather than representing contamination by sedimentary components.

A firm lower time limit for HP-HT metamorphism is given by the intrusion of post-granulitic granitoids ("Streifengneis") at ~ 440 Ma (436 ± 17 Ma, Rb–Sr total rock, recalculated using 1.42 × 10^{-11} y^{-1} decay constant: ARNOLD, 1970; 439 ± 5 Ma, single-zircon U–Pb: SERGEEV and STEIGER, 1993).

The current study re-examines and extends the pre-Variscan geochronological record of the Helvetic basement by presentation of single-zircon U–Pb isotopic results for four petrologically well-characterized garnet-bearing mafic rocks of the Gotthard and neighboring Tavetsch units, comprising members of both the structurally older, MORB derived, and the younger island arc-type mafic eclogites.

Rock description

Samples Gi69 and Gi55 are from the Kastelhorn pluton (Gotthard unit) and form part of the younger group of intrusives (ABRECHT and BIINO, 1994). In spite of polymetamorphic overprint, magmatic texture is still preserved in both samples. Gi69 is a coronitic melagabbro partially preserving a kyanite-bearing high-pressure assemblage (omphacite is replaced by oligoclase + diopside symplectite). Gi55 represents a leucogabbroic lithology forming a patchy melt impregnation-type texture with the melagabbro. Its metamorphic mineral assemblage suggests recrystallization under garnet amphibolite facies conditions; rare HP garnet and rutile are the only relics of the high-pressure assemblage.

Sample Zg1 is a partly retrograded gabbroic eclogite from the Tavetsch unit collected near Zignau. Whereas HP garnet, kyanite and rutile are still preserved, omphacite has been replaced by symplectite intergrowth of plagioclase and diopside. The rocks have undergone a syn-eclogitic phase of deformation resulting in a lineation pattern defined by kyanite, rutile and zircon. Field aspects and petrographic arguments suggest rather close affinity to the younger group of intrusives in the Gotthard unit.

Sample Ua0, a fine-grained eclogite derived from a N-MOR basalt, belongs to the older group of oceanic affinity.The sampling location is situated in the Unteralptal (Gotthard unit) approx. 3 km E of the Kastelhorn pluton. The eclogite facies mineral assemblage is well preserved in spite of minor retrogression to a symplectite eclogite.

Zircon preparation

In view of the complex metamorphic evolution of the samples and possible presence of multiple inherited components in their zircon populations, selection of well-characterized zircon crystals devoid of inherited cores and rejection of xenocrysts is of prime importance for quantitative interpretation of the isotopic results. Individual crystals were inspected by means of transmitted-light microscopy for absence of visible inherited cores. All samples were abraded in order to minimize the effects of metamorphic overprint by Variscan and Alpine events.

Zircon characteristics and U–(Th)–Pb isotopic results

METAGABBROS Gi55 AND Gi69 (KASTELHORN, GOTTHARD UNIT)

The relatively euhedral zircons from the Kastelhorn metagabbro samples (Gi69, Gi55) are characterized by multiple oscillatory growth zoning revealed by cathodoluminescence imaging (Fig. 1

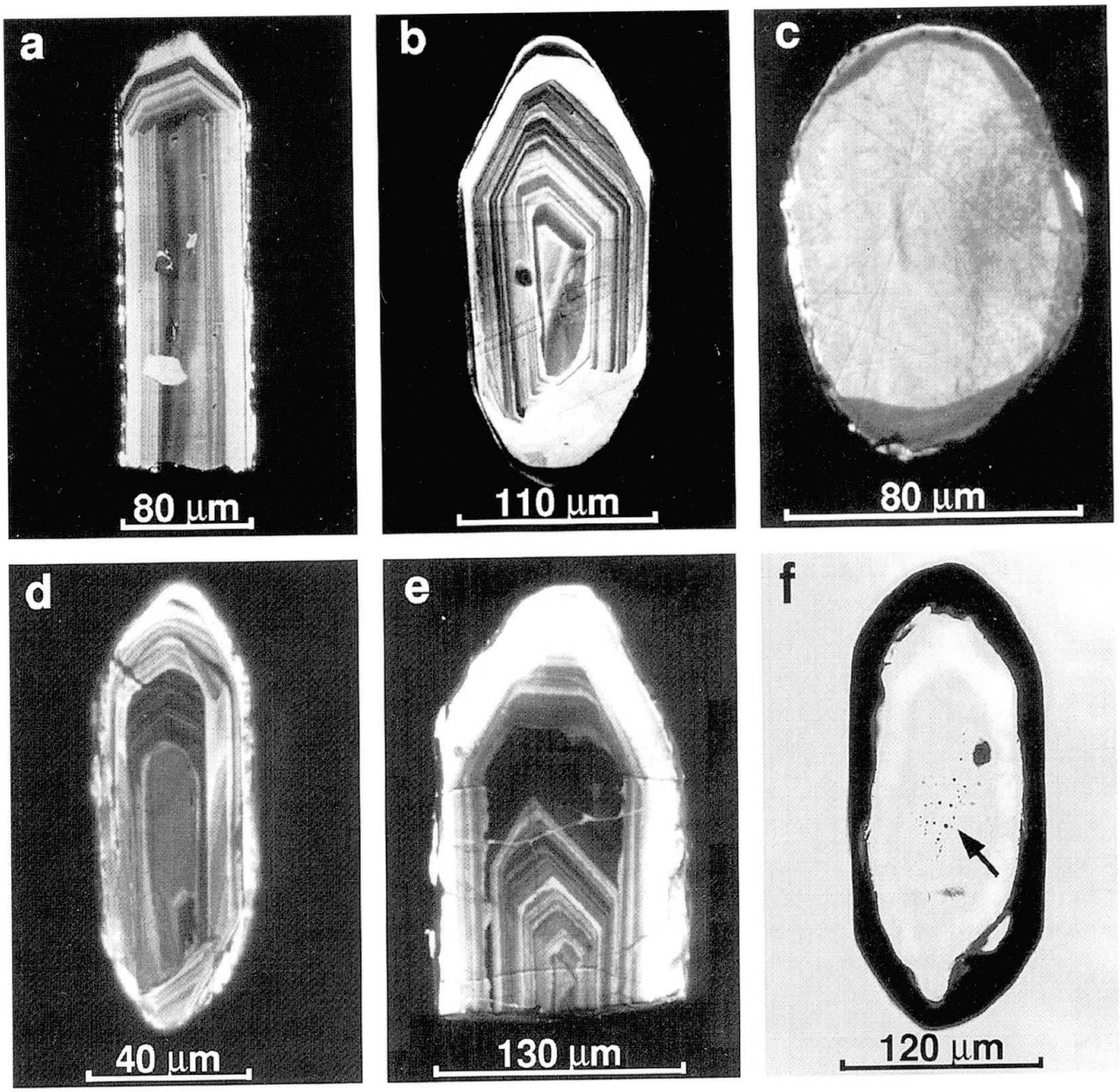

Fig. 1 a–e Cathodoluminescence images of representative zircons of the samples studied. Euhedral zircons from gabbroic eclogites Gi55 *(a)*, Gi69 *(b)* and Zg1 (*d*, zircon extracted from garnet; *e*, zircon from rock matrix) show multiple magmatic zoning, in contrast to the anhedral zircons from basaltic eclogite Ua0 *(c)* which are characterized by homogenous interiors and coarse marginal zonation. *(f)* Transmitted-light micrograph of zircon from sample Zg1 (matrix) showing "bubble core" structure (dark dots marked by arrow) indicative of inheritance.

a, b), show substantial spread in U concentrations (Gi69: 84–282 ppm; Gi55: 365–1087 ppm) and have Th/U ratios in the range of 0.39–0.72 (Gi69: 0.39–0.72; Gi55: 0.42–0.52). All these properties are compatible with zircon growth from a crystallizing melt. Many of the zircons display marginal zones of increased luminescence interpreted to represent recrystallization rims. In Concordia space the data points obtained for zircons from sample Gi69 and Gi55 define overlapping linear arrays within $^{206}Pb/^{238}U$ age intervals of 381–456 Ma and 416–459 Ma, respectively. The pooled data yield a well-defined upper Concordia intercept age of 467 +5/–4 Ma and a lower intercept at 304 ± 19 Ma (95% c.l. external; MSWD = 0.45; n = 15). The lower intercept age reflects partial resetting of the U–Pb isotopic system of the zircons predominantly by Variscan metamorphic overprint.

METAGABBRO Zg1 (ZIGNAU, TAVETSCH UNIT)

Examination of thin sections of metagabbro Zg1 revealed the occurrence of zircon both in HP garnet and in the rock matrix. The abundant zircons contained by garnet are distinctly smaller, have a higher length/width ratio and tend to be more euhedral than the zircons occurring in the rock matrix. The latter are typically associated with clusters of rutile. In order to investigate whether these differences in morphology might reflect asynchronous growth of the two subpopulations or whether garnet as a host mineral would have shielded zircon from later metamorphic overprint (e.g., during the Variscan or Alpine orogenies), single-crystal dating was performed on zircons extracted both from a garnet concentrate and from the rock matrix. The bulk subpopulation extracted from garnet was confined to < 75 μm sieve size and on average was characterized by lower U concentrations (122–524 ppm) as compared to matrix-hosted zircon (200–895 ppm). The rims of the latter are often irregular and display features of corrosion or overgrowth. Cathodoluminescence images of polished sections from both zircon subpopulations show multiple growth zoning frequently being replaced by broad recrystallization zones near the rims of the crystals (Fig. 1 d, e). In Concordia space the U–Pb isotope results plot on a discordia array within overlapping $^{206}Pb/^{238}U$ age intervals of 389–475 Ma (zircons from garnet) and 363–446 Ma (zircons from rock matrix), respectively. The upper Concordia intercept age of 471 +6/–5 Ma (95% c.l. ext.; MSWD = 0.31; n = 13) is identical within error limits to the age obtained for the Kastelhorn gabbro zircons. The lower intercept age of 272 ± 9 Ma postdates the climax of the Variscan orogeny and suggests that partial resetting of the U–Pb system of the (abraded) zircons occurred during both the Variscan and the Alpine events. This interpretation is in tune with the substantially higher degree of Alpine tectono-metamorphic overprint displayed by the Tavetsch lithologies as compared to the central part of the Gotthard unit.

A striking aspect of the present study is the scarcity of pre-Ordovician zircon components in the metagabbro samples analyzed, which contrasts the observation by GEBAUER et al. (1988) who showed that > 95% of the zircons in their sample were inherited yielding ages > 870 Ma. Whereas no pre-Ordovician inherited radiogenic Pb components were encountered in the zircons from Kastelhorn (Gi55 and Gi69), the occurrence of bubble core-type features (HANSMANN and OBERLI, 1991) revealed by transmitted-light microscopy in some of the garnet- and matrix-derived zircons of sample Zg1 suggested presence of rare cryptic inherited components (Fig. 1f). This was confirmed by isotopic data obtained on four of these grains which showed $^{207}Pb/^{206}Pb$ (minimum) ages of ~ 500–1460 Ma and (model) Concordia intercept ages of up to 2220 Ma. The result indicates that metagabbro Zg1 has incorporated a minor component of Precambrian origin. A possible source of inheritance are the accretionary wedge-type metasediments intruded by the gabbro. For the Gotthard unit GEBAUER and VON QUADT (1991) have shown such metasediments to contain zircons exhibiting a wide spectrum of Precambrian ages (0.6 to 3.4 Ga).

N-MORB ECLOGITE Ua0 (GOTTHARD UNIT)

The small, anhedral zircons of basaltic eclogite Ua0 have low U concentrations confined to a range of 24–37 ppm and relatively low Th/U of 0.11–0.20. The U–Pb data points form a linear array with a spread of $^{206}Pb/^{238}U$ ages of 331–481 Ma. The very low radiogenic Pb contents of the abraded zircon crystals (5–13 pg) are responsible for the poor precision of the data which yield ill-defined Concordia intercept ages of 535 +150/–75 Ma and 290 +90/–150 Ma (95% c.l. ext.; MSWD = 1.1; n = 9). The upper intercept age, although within error limits marginally identical to the ages of the metagabbro zircons and the maximal observed $^{206}Pb/^{238}U$ age of 481 Ma suggests that MORB eclogite Ua0 could be older than the island arc-type metagabbros which is in tune with field based relative chronology. Absence of multiple growth zoning from cathodoluminescence images (Fig. 1c) is interpreted to reflect a metamorphic origin, e.g. related to an earlier intra-oceanic subduction stage. Lack of resolvable inherited zircon components suggests absence of contamination by detrital sediments and therefore a more distal setting of ridge magmatism/subduction processes.

Summary and conclusions

1) Zircons of eclogitic metagabbros from the Gotthard and Tavetsch basement units yield overlapping upper Concordia intercept and maximal observed $^{206}Pb/^{238}U$ ages within a time interval of ~ 467–475 Ma. This interval coincides with the age of HP metamorphism (~ 468 Ma) previously postulated by GEBAUER et al. (1988) and imposes a lower limit for the magmatic age of the intrusive, island arc-type gabbros.

2) Rare pre-Ordovician zircon components are restricted to the occurrence of inherited cores in the zircons of the metagabbro from the Tavetsch unit. In view of the primary magmatic characteristics displayed by most of the metagabbro zircons, resetting of their U–Pb isotopic systems by HP-HT metamorphic overprint is not a plausible cause for the absence of pre-Ordovician components in the bulk zircon populations. Our results rather imply a *limited* time gap between the intrusion of the gabbros and the HP-HT metamorphic stage, probably of the order of 5–20 Ma, confining the oldest traceable period of island arc-magmatism to the *Ordovician.* Due to pervasive perturbation of the U–Pb systems of the (abraded) zircons by Variscan and Alpine overprint, resolution of the two processes has not yet been achieved. Nevertheless, the present age results, together with the lower time limit of ~ 440 Ma for HP-HT metamorphism imposed by the age of the post-granulitic "Streifengneis", suggest a *limited* time span for a *correlated* sequence of island arc-magmatism, suprasubduction/collision, burial and unroofing, associated with an active convergent margin setting.

3) Conforming petrological information and age results suggest that the Gotthard and Tavetsch basement units have experienced similar magmatic and metamorphic evolutionary histories, undergoing HP-HT metamorphism during a mid-Ordovician subduction event, and therefore have formed part of similar continental margin environments. The present results corroborate the prime importance of the Caledonian orogeny with respect to early basement evolution in the Central Alps, as first postulated by GRAUERT and ARNOLD (1968).

4) Except for the presence of oceanic crust of possibly late Precambrian–early Paleozoic age, our data do not provide evidence for the existence of pre-Ordovician magmatic crustal segments in the Gotthard-Tavetsch basement units. Except for the results obtained by GEBAUER et al. (1988), Proterozoic to Archean ages so far have exclusively been reported for zircon from paragneisses or for inherited components contained by granitoids, which are ultimately linked to detrital sources associated with Precambrian protoliths (e.g., GRÜNENFELDER et al., 1964; GRAUERT and ARNOLD, 1968; NUNES and STEIGER, 1974; GEBAUER and QUADT, 1991). A similar geologic situation is present in the adjoining Aar massif (ABRECHT, 1994), the northernmost segment of the Helvetic basement in the Central Alps, where pre-Ordovician zircon components were derived from late Archean-Proterozoic detrital sources (SCHALTEGGER, 1993, 1994). The oldest, in situ formed zircons were found in migmatites and in a metapsammite from the Erstfeld gneiss zone and yield Caledonian ages in the range of 456–445 Ma (SCHALTEGGER, 1993). These ages document an HT metamorphic stage essentially synchronous with the time interval defined by HP-HT metamorphism and the intrusion of the post-granulitic granitoids in the Gotthard unit. The similarities in the early evolution of both the Aar and Gotthard-Tavetsch units suggest that both basement units underwent the same Ordovician crustal amalgamation process.

5) The scale and complexity of accretion and orogenic processes involved in the formation of the Helvetic basement of the Central Alps and the presence of major Ordovician magmatic activity spread throughout central Europe suggest that the Caledonian event was neither localized nor minor. A paleogeographic restoration of central Europe for the Ordovician period by correlation of the Helvetic basement and the other pre-Variscan units, however, remains rather problematical. The Helvetic, Penninic, Austroalpine and Southern Alpine domains all show the same striking pattern of tectonic juxtaposition of oceanic units and wedge-type sedimentary sequences. These domains may have been formed in similar geotectonic positions during the Caledonian orogeny, but have repeatedly become separated and overprinted by post-Ordovician geological processes. Only detailed geochronological studies applying modern isotope techniques to conservative tracers of lithologic evolution will eventually establish a consistent framework for the pre-Variscan history of the central European basement domains.

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