Rates of metamorphic processes constrained by petrology and single zircon U–Pb chronology: a case study on former *HP–HT* mafic rocks from the central Alps

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Introduction Polymetamorphic mafic rocks from the oldest part of the Gotthard and Tavetsch units (external part of the central Alps, Switzerland) have been studied by petrological and single-zircon U–Pb dating techniques in order to assess the reliability of these methods for quantification of the geological history of a complex polymetamorphic/polyorogenic unit. We present a tectonothermal model for the early, Caledonian geodynamic evolution of the Alpine orogenic belt dominated by a *HP–HT* event, which is only partially preserved in other domains of the mountain chain. Microstructures provide information on the sequence and type of reaction equilibria crossed by the metamorphic evolution path. The reaction equilibria are quantitatively described by thermobarometry and phase relations. The relative and absolute chronologies of the magmatic and metamorphic events have been established by field relations and by geochronology, respectively. The interpretation of the U–Pb results is complicated by variable, partially strong resetting of the U–Pb isotopic systems by Variscan amphibolite-grade metamorphism. This dominant overprint may mask additional effects caused by Caledonian unroofing at high temperatures and by Alpine metamorphism at greenschist grade and therefore seriously affects the time-resolution of the U–Pb dating technique.

Geological setting It is generally believed that the pre-Alpine evolution of the Gotthard and Tavetsch units can be compared to that of the central European basement (Mercolli *et al.*, 1994, with references therein). In the Gotthard and Tavetsch units relics of a pre-Caledonian ocean have been documented (Abrecht *et al.*, 1991; Meisel *et al.*, 1994, with references therein). The eclogites and the associated ultramafics are embedded in metasedimentary rocks whose structural setting of deposition is comparable to modern accretionary wedge systems. The closure of this oceanic domain involved both accretion and subduction. Prior to subduction the accretionary wedge was intruded by a younger generation of gabbros. The chemical and isotopic signatures of these metagabbros are typical for subduction-related magmas in island arc (IA) settings. After supra-subduction magmatism, the wedge and arc sequences experienced several phases of metamorphism, Late Ordovician granitoids crosscut the Caledonian metamorphic structures.

Metamorphic evolution According to Biino (1994) and Abrecht and Biino (1994) the metamorphic evolution of both oceanic and IA-derived mafic rocks can be summarized as follows: Pseudomorphs after lawsonite suggest that eclogite peak metamorphism is approached along a clockwise path. During the prograde part, lawsonite was replaced by an higher-temperature eclogite facies assemblage (at ~650-700°C). The stable assemblage at peak temperature is Grt-Omp-Ky-Qtz-Zo-Hbl-Ilm-Mt-Py and Rt. Estimated temperatures and minimum pressures at this later *HP* stage are ≈ 700-750°C and 1.8 GPa, respectively. During the subsequent unroofing, the mafic rocks re-equilibrated under granulite facies conditions. The granulite facies event is characterized by Grt-Di-Opx-Olig-Qtz-Hbl-Ilm-Mt-Py-Tit. This assemblage yields temperatures ranging from 600 to 700°C and pressures of approximately 0.8 GPa. The unroofing trajectory crosses the water-saturated melting curve leading to migmatization of the metasediments within the high-pressure part of the sillimanite field. Based on ion probe zircon U–Pb data and a Sm–Nd garnet–whole-rock age of 461 ± 21 Ma, Gebauer *et al.* (1988, 1990) postulated an age of ~468 Ma for the *HP* event. The *HT* metamorphic evolution ended with the intrusion of shallow-level Late Ordovician plutons. A Caledonian age for the emplacement of these granitoids has been established by a Rb-Sr whole-rock isochron (436±21 Ma, Arnold, 1970) and later been confirmed by single-zircon U–Pb techniques (439±5 Ma, Sergeev and Steiger, 1993; Bossart *et al.*, 1986). The initial Sr isotopic composition of these plutonic rocks (0.714 at 440 Ma) suggests presence of a major anatectic component.

U–Pb results Well-abraded, individual zircon crystals from rocks of oceanic and island-arc magmatic affinity have been analyzed by conventional U–Pb isotope techniques. Details on mineral separation, selection criteria and analytical techniques will be given by Oberli *et al.* (in prep.). The investigated samples which are undeformed and have undergone essentially similar metamorphic evolution paths, show different degree of rehydration after the eclogite facies event. The isotopic and chemical compositions of sample Ua0 (fine-grained eclogite facies rock) is typical for N-MORB; Sm–Nd, Rb–Sr, Pb and oxygen whole-rock isotope data (Biino and Stille, unpubl.) suggest very limited alteration by fluid infiltration. The eclogite facies mineral assemblage is still well preserved. Single-zircon U–Pb data scatter within a time-interval of 474–334 Ma, revealing considerable secondary overprint by Variscan (and/or Alpine) metamorphism. Multi-faceted crystal morphology and lack of multiple internal zoning revealed by cathodoluminescence imaging suggest a metamorphic origin, which is in tune with the absence of magmatic zircons in N-MORB. The highest observed U–Pb age, 474 $\pm$ 4 Ma may therefore be interpreted to define a lower time limit for the prograde part of the metamorphic path. Zircon data obtained for two cogenetic samples from an IA gabbroic pluton (Gotthard unit), a melagabbro preserving an eclogite facies mineralogy (sample Gi69) and a completely retrograded leucogabbro (Gi55) yield an upper Concordia intercept age of 466^{+5}_{-4} Ma. The lower Concordia intercept age of 297 $\pm$ 21 Ma reflects secondary overprint predominantly associated with the Variscan orogeny. Zircons from an eclogite-facies metagabbro from the Tavetsch unit show a rather similar U–Pb data pattern characterized by upper and lower Concordia intercept ages of 471^{+7}_{-6} Ma and 272 $\pm$ 11 Ma, respectively. The different degree of retrogression of the samples is not reflected by the discordance patterns of the zircons analyzed. The upper intercept ages can be interpreted to approximate the time of intrusion or, alternatively, metamorphic recrystallization. In the first case, intrusion, *HP* metamorphism and subsequent unroofing must have occurred within a 30 Ma time interval. Primary magmatic features of the zircons such as morphology, oscillatory growth zoning and highly variable U contents of the zircons suggest that the first alternative is more plausible. This conclusion is supported by ion probe results obtained for zircons from both an eclogitic metagabbro and its metasedimentary country rock originating from the Gotthard unit (Gebauer *et al.*, 1988, 1990; Gebauer and Quadt, 1991); extensive preservation of Precambrian radiogenic Pb components in most of the zircons analyzed points to rather limited resetting of the U–Pb isotopic systems during the Caledonian *HP–HT* events.

Tectonic evolution Based on *P–T–t* estimates derived from the petrologic and chronological data and field evidence, the following evolutionary path can be reconstructed for the Caledonian units in the central Alps: U–Pb data confine the age of *HP* metamorphism to a time interval of ~465-474 Ma. Magmatic emplacement of the IA gabbros must have taken place relatively shortly before this event. Unroofing of the area ended with the emplacement of ~440 Ma old granitoids. The resulting P-T-t path reflects the style and rate of unroofing. The *HP* event and the associated unroofing history are the result of collisional tectonics. The development of early Lw-bearing metamorphic assemblages is probably related to the thermal influence of the cool and wet sediments. The unroofing tectonics are constrained by the isothermal decompression path. The granulite event was driven by advective heat transfer related to the collapse of the orogenic belt. This interpretation is compatible with the large volumes of probably post-collisional, S-type granitoids emplaced during the Late Ordovician.Metamorphic petrology suggests that unroofing occurred without thermal relaxation. The radiometric age data indicate that the time span between IA magmatism, subduction and unroofing was rather small. Both, geochronology and metamorphic petrology propose a coherent evolutionary history characterized by a fast orogenic cycle.

Arnold, A. (1970) *Eclogae Geol. Helv.*, **63**, 29–30.

Abrecht, J., Biino, G.G., Mercolli, I. and Stille, P. (1991) *Schweiz. Mineral. Petrogr. Mitt.*, **71**, 295–300.

Abrecht, J. and Biino, G.G. (1994) *Schweiz. Mineral. Petrogr. Mitt.*, **74**, 53–64.

Biino, G.G. (1994) *Schweiz. Mineral. Petrogr. Mitt.*, **74**, 87–104.

Bossart, P.J., Meier, M., Oberli, F. and Steiger, R.H. (1986) *Earth and Planet. Sci. Lett.*, **78**, 339–54.

Gebauer, D. (1990) In *Eclogite facies rocks* (D.A. Carswell, ed). Blakie, New York, 141–59.

Gebauer, D., von Quadt, A., Compston, W., Williams, I.S. and Grünenfelder, M. (1988) *Schweiz. Mineral. Petrogr. Mitt.*, **68**, 485–90.

Gebauer, D. and von Quadt, A. (1991) *Terra Abstract*, **3**, 6.

Meisel, T., Biino, G.G. and Nägler, T. (1994) *Mineral. Mag.*, V.M. Goldschmidt Conference.

Mercolli, I., Biino, G.G. and Abrecht, J. (1994) *Schweiz. Mineral. Petrogr. Mitt.*, **74**, 27–38.

Sergeev, S.A. and Steiger, R.H. (1993) *Terra Abstract*, **5**, 394–95.