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The geodynamic evolution of garnet-peridotites, garnet-pyroxenites and eclogites of Alpe Arami and Cima di Gagnone (Central Alps) from Early Proterozoic to Oligocene*

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Abstract

U–Pb zircon data obtained conventionally and by ionprobe (SHRIMP) demonstrate the polymetamorphic history of the garnet-peridotites at Alpe Arami (Cima Lunga – Adula unit). Partial melting of the peridotite immediately followed by high-grade, probably HP-metamorphism occurred at 1.72 Ga. A second event, probably also under HP-metamorphic conditions was Panafrican (ca. 650 Ma) and the present garnet-peridotite/eclogite HP-association was established at 28.5 Ma as derived from SHRIMP-data on zircons from a garnet-peridotite at Cima di Gagnone, also part of the Cima Lunga–Adula unit. This Oligocene age is compatible with the Late Eocene age (35 Ma) for the gabbroic protoliths of the eclogites at Alpe Arami which must also be inferred for the pyroxenitic protoliths of the garnet-pyroxenite veins within the Arami peridotite. A microcontinent model involving Cretaceous subduction of a southern ocean and Eocene/Oligocene subduction of a northern ocean is proposed to explain the existing radiometric data from the Lepontine Alps.

Keywords: U–Pb zircon dating, HP-metamorphisms, Cima Lunga–Adula unit, Central Alps.

Garnet-peridotite at Alpe Arami

A ca. 500 m wide garnet-peridotite boudin occurs together with minor eclogites in sillimanite-bearing gneisses of the southern Cima Lunga–Adula unit within the southern steep belt of the Central Alps (Alpe Arami, Ticino, Switzerland). Cathodoluminescence (CL)-studies of zircons of the garnet-peridotite reveal oscillatory, euhedral growth zoning of trace and minor elements (SOMMERAUER, 1978) as typically found for melt-precipitated zircons. These zircons are interpreted to have crystallized within trapped liquids which have formed by partial melting of the peridotite. Ionprobe-data (SHRIMP) generally gave concordant and subconcordant ages at 1724 +46/–35 Ma (95% confidence limits). These Early Proterozoic ages were obtained both within the dominating magmatic as well as within metamorphically altered zircon domains. The latter frequently cut the oscillatory growth zoning of the older magmatic domains, a phenomenon empirically found to occur only under higher than amphibolite facies P-T conditions (GEBAUER et al., 1988 and GEBAUER, unpublished).

Due to the small time interval between Early Proterozoic partial melting and high grade, probably HP-metamorphism of the peridotite, both events could not be distinguished analytically. Possibly, they were even part of the same P-T-t

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loop. Based on both the lack of Alpine open U–Pb zircon systems and on empirical findings on the metamorphic alteration of trace and minor elements in magmatic zircons, the Early Proterozoic subsolidus event was probably more severe than the Alpine subduction zone metamorphism. The latter is thought to have occurred at around 850 °C and at a depth of more than 80 km (EVANS and TROMMSDORFF, 1978; HEINRICH, 1986).

A second, Panafrican high grade metamorphic event at around 650 Ma only very locally caused significant lead loss in the trace element richer, metamorphically altered zircon domains while the magmatic domains remained closed systems for U–Pb since their formation 1.72 Ga ago. For similar reasons as for the Early Proterozoic subsolidus HP-metamorphism the Panafrican metamorphism is inferred to also have been of higher grade than the Alpine eclogite facies event which left the analyzed U–Pb zircon systems completely undisturbed.

Clearly, the garnet-peridotites at Alpe Arami are polymetamorphic rocks which probably suffered at least three HP-metamorphic events since 1.72 Ga. Based on the general evolution of the Central European continental crust one can speculate that they might have been further involved into orogenic activities around 1 Ga, an important event for the evolution of the continental crust of the European Hercynides (GEBAUER et al., 1989), as well as into the Caledonian and Hercynian mountain building processes.

Eclogite at Alpe Arami

Zircons of an eclogite sample from Alpe Arami are also multiply, euhedrally zoned as detected by CL-studies and, therefore, are interpreted to have crystallized within the protolithic melt of the eclogite. The concordant SHRIMP-ages of these magmatic parts of the zircons average 35 Ma for their $^{206}Pb/^{238}U$-ages and are interpreted to represent the protolith age of these eclogites. According to new data on the age and duration of the Priabonian stage (33.7 Ma to 37.5 Ma; ODIN et al., 1991), the gabbroic protolith of the eclogites at Alpe Arami has formed during the Late Eocene.

Garnet-peridotite at Cima di Gagnone

Preliminary SHRIMP data of 28.5 Ma were obtained on well equilibrated zircons of a garnet-peridotite boudin at Cima di Gagnone, also belonging to the Cima Lunga–Adula unit and situated some 15 km to the NW of Alpe Arami. As no magmatic zoning is visible in these zircons the obtained age is interpreted to reflect the formation of the garnet-peridotites from previously serpentinized peridotites (e.g. TROMMSDORFF et al., 1975; EVANS and TROMMSDORFF, 1978). This Oligocene HP-event within the Lepontine realm excludes the dating of the peak of Barrovian-type metamorphism (the so called "Lepontine event") at 35–38 Ma (e.g. JÄGER, 1973) at least for the studied rocks of the Cima Lunga–Adula unit. Instead, these new data are in line with previous U–Pb monazite and U–Pb xenotime data of KÖPPEL and GRÜNENFELDER (1975) as well as with K–Ar amphibole ages of DEUTSCH and STEIGER (1985). Both the U–Pb monazite and the K–Ar amphibole ages yielded a typical age range of 22 Ma to 28 Ma which was interpreted as approximating very closely the age of Barrovian metamorphism within the Lepontine area. Biotite ages (JÄGER et al., 1967) in the southern steep belt are about 18 Ma to 20 Ma and a fission track age on zircon from the garnet-peridotite at Alpe Arami, giving us cooling to about 220 °C, was found to be 17.4 ± 0.9 Ma (NAESER and GEBAUER, unpubl.).

The possibility of the existence of an earlier greenschist metamorphism at 35 Ma to 38 Ma at the periphery of the Lepontine dome, the area providing the main arguments for the existence of a "Lepontine event" in the sense of JÄGER (1973), is not excluded by our data. The Rb–Sr phengite data from the frontal part of the Suretta nappe within the stilpnomelane zone (STEINITZ and JÄGER, 1981) which provide the least arguable data for a Late Eocene metamorphism, are interpreted here as a consequence of low grade metamorphic overprinting initiated by continent-continent collision.

Conventional zircon data from two garnet-pyroxenites and one eclogite at Alpe Arami

Conventional multi-grain U–Pb analyses of zircon fractions from an eclogite and two garnet-rich pyroxenite layers within the garnet-peridotite of Alpe Arami are strongly discordant. Although the errors of the upper intercept ages are large, they are still in line with the mantle melting event at 1.72 Ga as detected by the SHRIMP data. The lower intercept ages, partly derived from slightly scattering data, range between 33 Ma and 31 Ma. They are interpreted as a result of mixing the age of gabbroic and probably also pyroxenitic protolith formation at ca. 35 Ma with the age of eclogite-facies metamorphism at ca. 28.5 Ma. Such mixing is due to the fact that both magmatic zircon domains and metamorphically altered zircon domains were – apart from Precambrian inherited cores – concurrently analyzed using the conventional multigrain technique. Although ionprobe-data are not yet available for the two conventionally analyzed zircon populations of the two garnet-rich pyroxenites, a Late Eocene age of magmatic formation is probable due to the similar U–Pb zircon systematics of both eclogite- and garnet-pyroxenite zircons. Based on field observations the pyroxenitic cumulates, the likely protoliths of the garnet-pyroxenites, were in magmatic contact with the presently exposed peridotite.

Geodynamic implications

Geodynamic models for the Alpine evolution have to incorporate the following new constraints imposed by the presented results:

1) The data from the garnet-peridotite at Cima di Gagnone argue for Oligocene HP-metamorphism within the Cima Lunga–Adula unit. This surprisingly low age is supported by the somewhat older (ca. 35 Ma) but also surprisingly young protolith age obtained for the eclogites at Alpe Arami which is also probable for the protoliths of the deformed garnet-pyroxenites layers within the garnet-peridotite of Alpe Arami. It has to be noted, however, that these new data are not in conflict with earlier (Cretaceous) ages of HP-metamorphism in structurally higher positions, e.g. in the Sesia Zone of the Western Alps (Hunziker, 1974).

2) The time interval between gabbroic protolith formation at Alpe Arami, HP-event, Barrovian-type overprint and cooling is very short. This suggests a single P-T-t loop related to subduction with the Barrovian-type metamorphism – often misnamed as "Lepontine event" – occurring during uplift (Trommsdorff, in press).

3) The zircon data from the garnet-peridotite of Alpe Arami demonstrate a long lasting, polymetamorphic history of this ultramafic rock. They rather argue against an origin of these peridotites as part of an oceanic mantle of Mesozoic (Tethyan) age. However, such a scenario, although improbable, can not be excluded completely as oceanization might not have led to the production of new zircon or to isotopic disturbances in the 1.72 Ga old zircons.

Undoubtedly, the age of the gabbroic and very probably also the ages of the pyroxenitic protoliths of the eclogites and garnet-pyroxenites of Arami exclude a Tethyan formation of these rocks. Ca. 15 km to the NW of Alpe Arami, however, the mafic and ultramafic rocks at Cima di Gagnone could be shown to represent relics of oceanic crust (Evans et al., 1979). Thus, a Tethyan origin, respectively a Tethyan depletion event is possible for these rocks. Nevertheless, the majority of the presently exposed rocks within the Cima Lunga–Adula unit certainly is of continental lithospheric origin and the garnet-lherzolite of Alpe Arami may well be part of it.

Additional constraints result from the present structural position of the Cima Lunga–Adula nappe complex, its inferred palinspastic position and the age of subduction within the framework of the metamorphic and magmatic evolution of the Alps. The majority of this nappe complex probably was rooted near the southernmost rim of the European plate to the N of the N-Penninic Valais basin. A recent study demonstrated the presence of ophiolites within this basin (Schmid et al., 1990) and thus the Valais basin was of oceanic origin representing an important suture. In its present configuration the Cima Lunga–Adula nappe complex is likely to contain also Mesozoic and/or older oceanic elements as well as tectonic fragments derived from the continental lithosphere of the mid-Penninic rise. The time of closure of this northern ocean, separated from the Piemont-Liguria trough by the mid-Penninic continental rise (Briançonnais), is substantially younger than closure of the Piemont-Liguria ocean related to Cretaceous subduction and HP-metamorphism also on sedimentological grounds. The cessation of flysch sedimentation in the Valais trough did not occur before Middle Eocene (e.g. Ziegler, 1956) and roughly coincides with the white mica ages at around 38 Ma at the periphery of the Lepontine area (Steinitz and Jäger, 1981 and Hunziker, 1969). Therefore, subduction of the Cima Lunga–Adula continental lithosphere must have been post-collisional and immediately followed by Oligocene Barrovian-type metamorphism as well as backfolding and backthrusting in the southern parts of the Lepontine dome.

Taking into account the above mentioned constraints, we tentatively propose the following scenario for the evolution of the Central Alps: Oblique closure of the Liguria-Piemont ocean occurred during the Upper Cretaceous and led to the superposition of the Austroalpine nappes over the ophiolitic remnants of this ocean (Arosa-Platta and Combin zones) and possibly parts of the mid-Penninic rise (Briançonnais) by W to NW-directed thrusting (Ring et al., 1988). The northern oceanic domain (Valais) did not close before Middle Eocene times when continental collision during S-directed subduction of oceanic lithosphere led to the cessation of flysch deposition. This time coincides with a major episode of nappe piling in the middle Penninic realm (Tambo – Suretta). The latter is associated with N–S to NW-SE-directed lineations (SCHMID et al., 1990) also characteristic for contemporaneous and later nappe formation in the Lepontine area (MERLE et al., 1989) as well as with a possible first metamorphic overprint in the peripheral parts of the Lepontine dome. During ongoing plate convergence and in an essentially post-collisional stage beginning in the Middle Eocene those parts of the Cima Lunga–Adula unit representing the southernmost margin of the European foreland started to be subducted.

It is important to note that all units of continental crust adjacent to the Mesozoic oceanic basins are part of Gondwana-derived continental lithosphere. This is characterized, for example, by the presence of Panafrican detrital zircons in sediments and metasediments of the European plate as far to the S as the Gotthard Massif (GEBAUER et al., 1989; GEBAUER and QUADT, 1991) as well as in metasediments of the Adriatic plate as far to the N as the Strona Ceneri Zone (GRÜNENFELDER et al., 1984). Similar to the microcontinent-, respectively terrane model as suggested for the multisubduction evolution of the European Variscides during the Palaeozoic (e.g. GEBAUER et al., 1989), the Alpine orogen might best be interpreted as a result of successive post-Carboniferous rifting of Gondwana-type continental crust followed by successive docking of the thus formed microcontinental fragments in the Upper Cretaceous and Eocene.

We conclude that the protoliths of the Alpe Arami eclogites and pyroxenites were formed during latest Eocene subduction from a peridotitic mantle with a complicated and long prehistory. Unfortunately, there are no unambiguous constraints for solving the perennial problem on the mode and relative timing of emplacement of the ultramafic/mafic rock association into the present metasedimentary and metaigneous country rocks which are clearly different at the two studied occurrences at Alpe Arami and Cima di Gagnone. As a result of partial melting of peridotite at 35 Ma, the pyroxenitic veins and eclogites at Alpe Arami formed from a mantle source with a similar prehistory as the garnet peridotite. The latter is plausible as both garnet-pyroxenites and eclogites contain inherited mantle zircons of probably the same Early Proterozoic age as those in the peridotite at Alpe Arami. As melting of the peridotite is likely to have occurred at significantly higher temperatures than experienced by the essentially unmelted felsic country rocks, tectonic juxtaposition of the garnet-peridotite–eclogite–garnet-pyroxenite assemblage with the felsic country rocks must have taken place after melting of the peridotite at ca. 35 Ma. Most probably such a tectonic mixing happened during rapid and differential ascent of the subducted slab back to the surface (e.g. GEBAUER et al., 1985). Alternatively, melting of the peridotite above 1000 °C might have occurred due to fluid introduction from the upper part of the subducted slab into the overlying subcontinental mantle from which the peridotite has been detached. Due to rapid subduction this uppermost part of the subducted slab, mainly of continental crustal composition, never reached the high ambient mantle temperatures and thus these felsic rocks might have been mixed tectonically with the ultramafic/mafic mantle rocks already in the course of deep subduction.

For the Cima di Gagnone garnet-peridotite subduction of altered oceanic crust to at least 80 km (TROMMSDORFF, in press) and tectonic mixing with the felsic country rocks is likely to have occurred during the Oligocene assuming that the protoliths of the basaltic meta-rondingites are of Tethyan or older age.

Our best estimate for the time of maximum burial (28.5 Ma) is only very slightly older than the time of Barrovian metamorphism in the Lepontine area and the onset of backfolding and backthrusting (SCHMID et al., 1990). It fits very well with the uplift history of the southern steep belt as derived from mica and fission track ages (e.g. JÄGER et al., 1967; HURFORD, 1986 or HURFORD et al., 1989) and with observations made in other very young orogenic belts, e.g. in Papua New Guinea (BALDWIN et al., 1990).

For the notorious problem of uplift of HP-pressure rocks we feel that – apart from factors like buoyancy, normal faulting during extensional collapse and erosion – the corner flow model of COWAN and SILLING (1978) is especially attractive in that it provides a kinematic flow pattern which allows for contemporaneous subduction and exhumation in a compressive and converging environment. Furthermore, it provides a good explanation for the observed increasing pressures (HEINRICH, 1986) along the direction of subduction within the exhumed HP-rocks, i.e. from N to S in our case. However, a modern structural study aimed at resolving the kinematics of uplift of the Cima-Lunga unit in respect to its surroundings is not yet available in order to test this or any other uplift model for HP-rocks.

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