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Archaean zircons in a retrograded, Caledonian eclogite of the Gotthard Massif (Central Alps, Switzerland)

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Abstract

Ion microprobe U-Pb dating of zircons from a retrograded eclogite of the Gotthard Massif (Central Alps) has revealed a Late Riphean age of ca. 870 Ma for the eclogite's protolith, probably an island-arc-derived gabbro. More than 95% of zircon in that protolith was inherited and possibly of mantle origin, although a crustal origin, for example from subducted sediments, cannot be excluded. The U-Pb isotopic systems of four of the inherited zircons remained undisturbed by the formation and emplacement of the protolith ca. 870 Ma ago. Within-grain discordance lines for those zircons have upper Concordia intercepts at 3.17 Ga, 2.67 Ga, 2.45 Ga and 1.27 Ga, respectively. The lower intercept ages of these inherited, but also of the rare primary magmatic, multiply zoned zircons individually date the Caledonian eclogite formation at ca. 468 Ma. The latter is confirmed by Sm-Nd data, which give 461 Ma for the high-pressure metamorphism and an initial ε_{Nd} of +1.3 for the gabbroic protolith. This Caledonian eclogite is therefore the most reliably dated high-pressure rock in the European Hercynides. It gives further support to the microcontinent model for development of the European Hercynides, which is also based on the presence of differently old high-pressure events in different geological domains. The four events recorded by the inherited zircons coincide with continental crust-forming events detected by ion microprobe dating of detrital zircons from various (meta-)sediments of the European Hercynides (Gebauer et al., 1988 and in press). They may be mantle events or events in the crustal provenances of subducted sediments, although there is no chemical evidence for crustal contamination.

Both the lower intercept (400 Ma ± 3 Ma) and upper intercept (2.23 Ga ± .03 Ga) ages obtained from a conventional discordia line for the same zircon population are geologically meaningless, due to post-Caledonian lead loss in the first case and mixing of inherited zircons of different ages with the few primary co-magmatic zircons in the second.

It is likely that the eclogites (or their pre-high-pressure precursors) were emplaced into their present kyanite-bearing country rocks (or their low grade precursors) tectonically.

Keywords: Ion microprobe, U-Pb dating, Sm-Nd dating, zircon, eclogite, Gotthard Massif, Switzerland.

Analytical background

The reason for using an ion microprobe to date zircons is that ages can be obtained *in situ* on polished sections on a 30 µm (3×10^{-2} mm) scale. In this way it is possible to get information on the distribution of U-Pb and Pb-Pb apparent ages within single crystals and, for example, to date the formation of growth zones of different ages. There is only one ion microprobe presently operational that has enough sensitivity at high mass resolution to make such analyses. The development of the SHRIMP (Sensitive High Resolution Ion Micro Probe) was initiated by W. Compston at the Australian National University in Canberra in the early 1970s, the design was commenced in 1974 by S.W.J. Clement and the first data were ob-

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tained in 1981. Detailed information on the performance of SHRIMP is given, for example, in COMPSTON et al., 1985/86 or 1986. Fig. 1 shows the typically 20–30 μm big, 2–3 μm deep craters produced by the oxygen-induced sputtering of a zircon after 20 minutes, the typical time for a single analysis. All ion probe Pb-U ages referred to in the text of this summary paper are referenced to an age of 572 Ma for the SL 3 standard zircon used at the A.N.U.

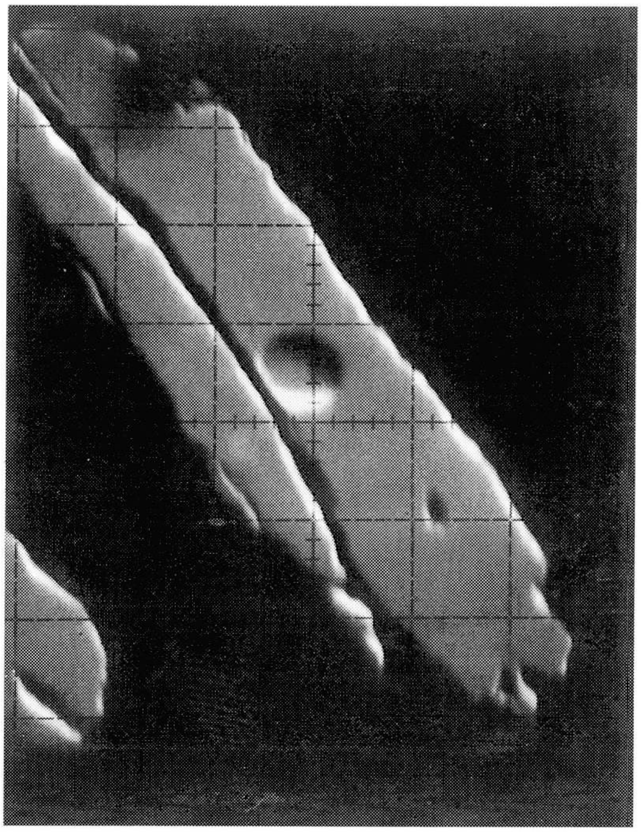

Fig. 1 Secondary electron image of a polished zircon formed co-magmatically at ca. 870 Ma in the gabbroic protolith of a retrograded eclogite of the Gotthard Massif. The 20–30 μm big and 2–3 μm deep crater was produced by oxygen-induced sputtering using SHRIMP. For cathode-luminescence distribution of this grain see Fig. 3.

Geological Setting, previous work and geochemistry

Retrograded eclogites occur together with serpentinites as lenses and layers up to ca. 100 m in thickness in pre-alpine gneisses of the Val Naps area of the Central Alpine Gotthard Massif (HUBER, 1943; NIGGLI, 1944). Major-, trace- and rare earth element data suggest that the protoliths of these former high-pressure rocks could have been calcalkaline to tholeiitic melts of island arc or even ocean floor affinity.

Early U-Pb zircon work by GRAUERT and ARNOLD (1968) on a kyanite-sillimanite gneiss only a few kilometres from the eclogite sample locality yielded a Caledonian age of ca. 440 Ma for the gneiss formation. A similar age of 436 ± 17 Ma (ARNOLD, 1970) was obtained on a strongly deformed granitic orthogneiss (Streifengneis) which probably also dates the high-grade Caledonian event (initial Sr: ca. 0.714) and not the protolith as originally suggested. As in many other areas of the European Hercynides a regional Hercynian amphibolite-facies metamorphism and emplacement of numerous Carboniferous granitoids has been identified already by early geochronological work as summarized by GRAUERT and ARNOLD (1968). The Alpine metamorphic overprint reached chloritoid-grade in the sampled area.

Analytical results

U-Pb analyses (GEBAUER et al., in prep.) of 15 spots on the rare, clear, euhedral zircons (average U ca. 300 ppm), which are interpreted to be formed magmatically in the protolith (Fig. 2), plot over the whole range of a discordia trajectory which intersects Concordia at ca. 870 Ma and around 460 Ma respectively. This wide range of discordance is found not only between grains but between different areas within single grains. Cathode-luminescence studies of the analysed zircons show areas of euhedral, oscillatory zoning of probably magmatic origin (Fig. 3), which give an age of ca. 870 Ma, and irregularly shaped areas possibly resulting from metamorphic recrystallization, which give ages at or close to the inferred age of eclogite facies metamorphism, ca. 468 Ma.

More than 95% of the zircons are irregularly shaped, often rounded and partly resorbed grains with a range of colour and clarity (Fig. 4). Unlike the rare euhedral, 870 Ma old grains, their original magmatic zoning can be cut by the present grain boundary (Fig. 5), indicating post-crystallization resorption. Recrystallization and/or new growth during the eclogite facies metamorphism is common (Fig. 5). Most such zones and domains were almost or completely reset during the Caledonian high-

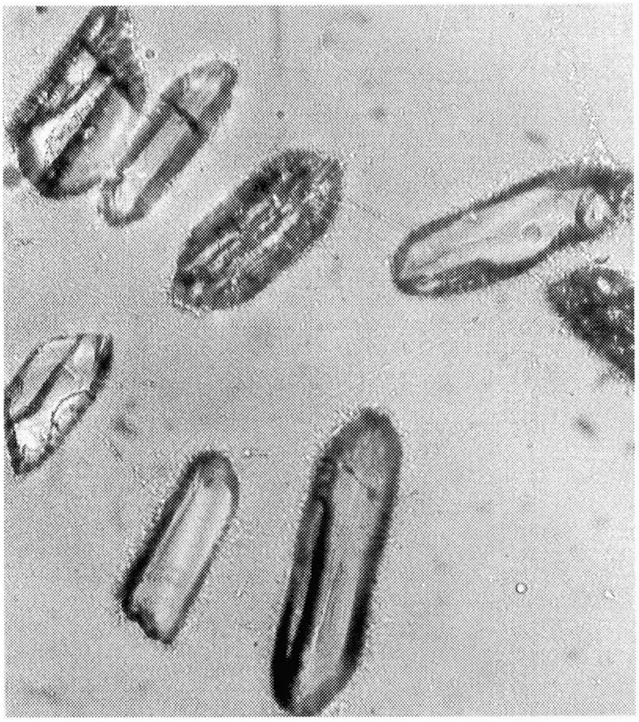

Fig. 2 Colourless and transparent zircons interpreted to represent the rare primary magmatic crystals of the protolith. The grains have a width of about 60 μm. Fracturing is a typical feature and is much more pronounced and frequent in the comagmatic than in the much more frequent inherited zircons (Fig. 4).

Fig. 3 Cathode-luminescence image of the grain shown in Fig. 1 (width ca. 60 μm). Multiple euhedral zoning is indicated by the different C.L. response which is largely based on variable sums of trace and minor elements. Probably, this grain grew under variable P-T-X conditions during formation and ascent of the gabbroic protolith.

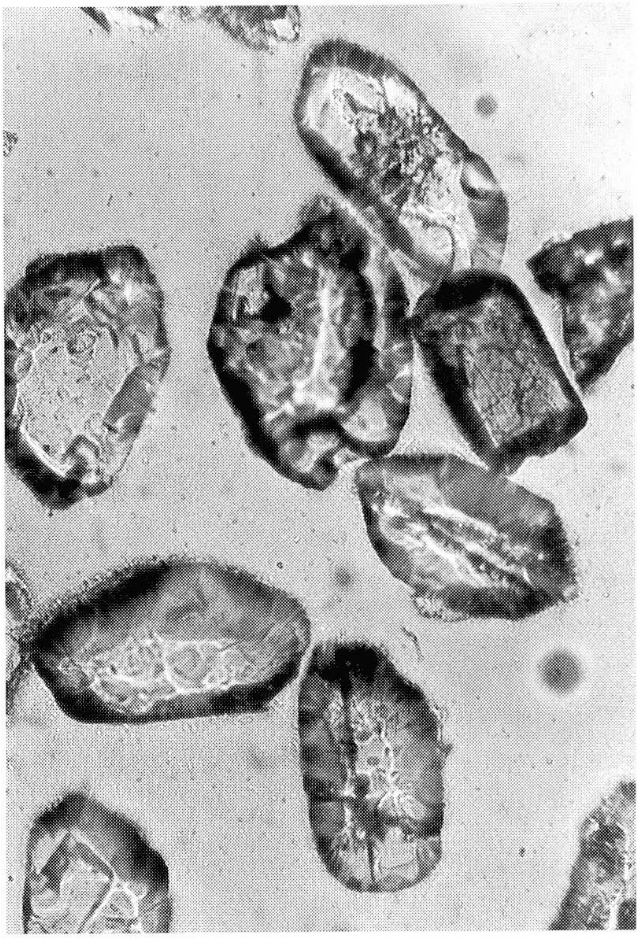

Fig. 4 Typical, probably mantle-inherited zircons representing almost the total zircon population of the analysed meta-eclogite. Average width: ca. 100 μm. Further explanation in text.

pressure metamorphism. They commonly are relatively U-rich and sometimes have lost variable amounts of radiogenic Pb during the Carboniferous overprinting. Four of the dozen grains of this type analysed still contain up to 90% of their pre-eclogite radiogenic Pb. Within-grain discordance lines defined by analyses of several areas on each of the four grains have lower Concordia intersections of ca. 468 Ma, the same age as indicated by the magmatic zircons. Errors in the intercept ages are between 3 Ma and 38 Ma. The upper intersection ages are at ca. 3.17 Ga, 2.67 Ga, 2.45 Ga and 1.27 Ga. None of the grains appear to have been affected by protolith formation at 870 Ma, extending the temperature range that zircons are known to survive from that of granite melts to that of gabbroic melts. Similar conclusions have been reached previously by COMPSTON et al. (1985/86) and KINNY et al. (1986).

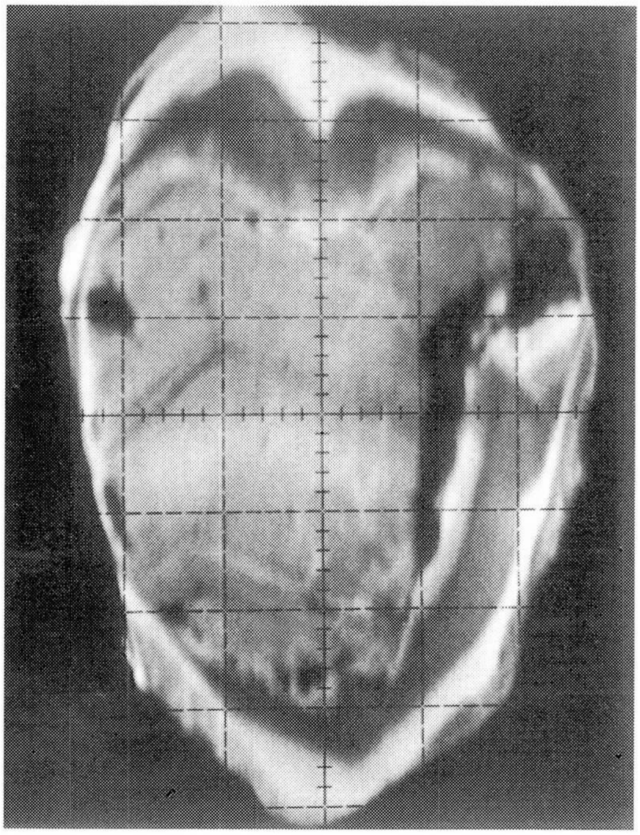

Fig. 5 Cathode-luminescence image of a ca. 1.27 Ga old, magmatically formed zircon of probably mantle origin. U-contents are around 250 ppm in the narrowly zoned, relict part of the crystal. The outermost, broader and more irregular zones (average U ca. three times the core) formed, probably by recrystallization, during eclogite facies metamorphism at 468 Ma.

Discussion

As none of the eclogite trace element analyses show any significant amount of crustal contamination, it is suggested that the inherited zircons were formed in the mantle. This would be consistent with their generally low U-contents. They probably formed during partial melting events (e.g. veining) and incomplete melt extraction at 3.17 Ga, 2.67 Ga, 2.45 Ga and 1.27 Ga and were incorporated into the mafic magma during the formation of the gabbroic protolith at 870 Ma. A second possibility might be that the irregular zircons, representing almost all of the zircon population, were brought into the mantle as a result of recycling of sediments along subduction zones. However, based on the geochemical data such felsic material, unless very rich in U-poor zircon, could only have played a very minor part and therefore the first hypothesis is preferred. Of course, zircons from gabbroic rocks or even plagiogranites of the oceanic crust might also have been brought back into the mantle via subduction zones. This possibility, however, does not change the implications of our preferred mantle contamination model. In case the protoliths of the eclogites were tuffs and/or basaltic lava-flows incorporation of zircon xenocrysts of continental origin is principally possible, but major- and trace element data do not support this.

The age of eclogite facies metamorphism at ca. 468 Ma is also supported by Sm-Nd analyses on whole-rock and garnet giving 461 ± 25 Ma (GEBAUER et al., in prep.). The initial ε_{Nd}-value at the time of emplacement of the protolith is about +1.3, a value within the lower range for rocks which probably originated in an arc environment. However, the inherited zircons suggest the presence of significant amounts of Archaean and Proterozoic trapped liquids in the eclogite's source rock which would have enriched that originally depleted source at least at 3.17 Ga, 2.67 Ga, 2.45 Ga and 1.27 Ga, progressively decreasing the Sm/Nd-ratio and lowering the rock's time intergrated ^{143}Nd content. The average age of the zircons inherited from the mantle is given by conventional multi-grain analyses as 2.23 Ga.

The significance of the coincidence between Archaean and Proterozoic events in the mantle recorded in the inherited zircons and those events detected in sedimentary and metasedimentary rocks of the European Hercynides should not be overemphasized. The continental crust of the European Hercynides, probably representing the African part of Gondwana, grew multi-episodically via many crust forming events. Periods of relative little or even missing orogenic activity are only indicated for the time periods of 100–200 Ma around 2.3 Ga and especially around 1.5 Ga (GEBAUER et al., 1988 and in press). Many mantle events are also to be expected, given the amount of new continental crust formed.

Assuming the deposition of the present country-rocks of the meta-eclogites to be syn- or post Pan African, as widely observed all over the European Hercynides (e.g. GEBAUER et al., 1988), it follows that the Late Riphean protoliths (at ca. 870 Ma) must have been emplaced tectonically, although the available data do not indicate when or under what P-T conditions this tectonic emplacement occurred. If it took place at low P-T conditions, at the earliest during a Pan African cycle, then both the eclogite precursors and the present day country-rock precursors suffered the same Caledonian high-pressure metamorphism. On the other hand, the eclogites and associatd mafic and ultramafic rocks could have been emplaced tectonically in a Caledonian or even Hercynian scenario, such as during the emplacement of pre-Alpine nappes.

An important conclusion from the present ion probe study is that the conventional analyses of zircon pupulations from the same sample give geologically meaningless intercept ages. Post-eclogite facies lead loss, as shown by analyses on areas frequently high in U or close to internal or external grain surfaces, clearly is responsible for the lower intercept age at 400 Ma ± 3 Ma. The Hercynian amphibolite facies overprint is responsible for some analytically concordant but geologically meaningless ages less than 468 Ma, and in at least one case an Alpine or even more recent lead loss must have occurred. The conventionally measured upper intercept age at 2.23 Ga ± .03 Ga clearly is the result of mixing inherited zircons of different ages with the few co-magmatic zircons 870 Ma old.

This study demonstrates the importance of verifying conventionally measured zircon ages by some other dating techniques, Sm-Nd or preferably ion microprobe analysis. The Caledonian eclogite facies metamorphism in the Gotthard Massif is now the most reliably dated high-pressure event in the European Hercynides, being defined by five independent zircon discordance lines in close agreement with Sm-Nd whole-rock and mineral data. In addition, it supports our microcontinent or terrane model which is based, at least in part, on the identification of high-pressure events of different ages in different domains of the European Hercynides.

Conclusions

1) Zircons incorporated into the protolith of an eclogite of the Gotthard Massif probably formed during several Archaean and Proterozoic melting events within the mantle.

2) The mantle chronology thereby obtained (3.17 Ga, 2.67 Ga, 2.45 Ga and 1.27 Ga) is synchronous with identified continental crust forming events in the European Hercynides.

3) The Late Riphean protoliths of the eclogites and related mafic and ultramafic rocks at ca. 870 Ma are probably older than the sedimentary precursors of their present country rocks, implying that the present association of country rocks and retrograded eclogites and peridotites (serpentinites) is of tectonic origin.

4) The eclogite facies metamorphism, probably related to subduction, is independently dated by five individual discordance lines and Sm-Nd mineral and whole-rock data on the same sample. Thus, it is the most reliably dated high-pressure rock within the European Hercynides. The age of 468 Ma supports the microcontinent or terrane model which is also based on the occurrence of high-pressure rocks of different ages in different terranes of the European Hercynides (e.g. GEBAUER, 1986).

5) Because the sample contains zircons of many different ages, the Concordia intersection ages measured on the zircons by conventional methods are geologically meaningless.

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