Goldschmidt 2000
September 3rd–8th, 2000
Oxford, UK.

Journal of Conference Abstracts
Volume 5(2), 446

Dating of Subduction-Related Fluid Mineralizations: Constraints on the Life Span of a Paleozoic Subduction System in the Polar Urals, Russia

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Introduction

Fluid-rock interaction is of key importance for subduction zone processes. For example, eclogitisation reactions in the downgoing slab may be triggered by fluids. (e.g. Austrheim 1998) The changes of densities and rheological properties of rocks effected by these reactions may influence subduction zone dynamics. Fluid-related processes like re-amphibolitisation of high-pressure rocks during incipient uplift, or interaction of migrating, slab-derived fluids with rocks of the overlying mantle wedge are similarly important to the evolution of subduction systems.

Precise geochronological data are essential for understanding the dynamics of subduction processes. The fluid-rock interaction settings mentioned generate specific metasomatic rocks and mineralizations. Age dating of such fluid-related material is advantageous for several reasons: (1) Petrographic observation normally allows clear identification of the metamorphic processes caused by the fluids. (2) Assemblages of strictly cogenetic minerals can be identified. Such equilibrium assemblages provide material which has been in isotopic equilibrium and therefore is favourable for dating by internal mineral isochrons. In contrast, in many subduction-related rocks, like eclogites, textural disequilibria ascertain isotopic disequilibria which preclude precise dating of metamorphic reactions by isochron methods. (3) In many mineralizations, modal composition favours postcrystallisational closed-system-behaviour, so that true crystallisation ages can be determined. For example, eclogite facies vein assemblages are often by far dominated by quartz; additional phases may be garnet, omphacite, white mica and others. After crystallisation, the Sr- and Nd-bearing phases are armoured by quartz. Postcrystallisational diffusional isotopic exchange between the Sr- and Nd-bearing phases through the quartz matrix or by way of the intergranular space must have been irrelevant because of the diffusion lengths involved and the expected low diffusivities of the elements in quartz.

Study site and results

In the Polar Urals, near the Arctic Circle, an east-dipping subduction system was active in Paleozoic time. Today, complexes of high-pressure metamorphic rocks including eclogites and blueschists in the west, representing remnants of the downgoing slab, are juxtaposed with a belt of oceanic, ophiolitic successions in the east.

The earliest signal of ongoing subduction is represented by age data from a metasomatic vein in ultramafic rocks of the ophiolitic Rai-Iz massif. The vein mineralization consists of albite, amphibole, phlogopite and corundum, and is surrounded by a serpentinization aureole. It is interpreted as a product of ascending subduction fluids which reacted with mantle wedge rocks. A perfect Rb/Sr-isochron yielding an age of 373 ±4 Ma was obtained. The high-pressure metamorphism in the rocks exposed along the western margin of the ophiolitic belt is significantly younger. In the HP-metamorphic (low- to medium temperature eclogite facies) Marun-Keu massif, eclogite-facies, quartz-dominated vein mineralizations are a common phenomenon. These veins are surrounded by eclogitisation aureoles which also may overlap, leading to continuous eclogite-facies metamorphic domains extending over hundreds of meters. However, locally the meta-igneous, amphibolite-facies precursor rocks of the eclogites remained unreacted. The fluid activity causing the extensive eclogitisation was dated at 358 ±4 Ma by several Rb/Sr internal isochrons for vein material. This age value is in accordance with age results (both Rb/Sr and Sm/Nd) for equilibrium assemblages in fresh, unretrogressed eclogites.

Termination of the subduction process is indicated by ages from fluid veins with re-amphibolitisation aureoles in the eclogites. For such veins, ages around 355 ±3 Ma were obtained. Rb/Sr biotite ages, which may be interpreted as cooling ages, delimit the uplift of the eclogites to mid-crustal levels to the time span between 357 and 347 Ma.

Conclusions

The age data derived from fluid veins in different settings constrain the lifetime of the Polar Urals subduction system to an age interval between (minimum age) 373±4 Ma and 355±3 Ma. Subduction occurred for at least 18±7 Ma.

Internal mineral isochrons from subduction-related vein assemblages have the potential for precise, direct dating of geodynamically important processes like eclogitisation, reamphibolitisation, serpentinisation and other fluid-induced- or fluid-triggered processes. Such age data directly linked to metamorphic reactions are indispensable for establishment of reliable chronologies for parts of metamorphic P,T paths as well as for understanding of mass transfer mechanisms and -velocities in orogenic systems.

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