Linking zircon ages to ages of metamorphism in high grade rocks: examples from Variscan granulites and eclogites (Bohemian Massif)

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High-grade metamorphism and plutonism is a fundamental feature of most major plate interactions over the history of the Earth. Metamorphic and igneous rocks produced and/or modified during such events contain, within their host minerals and mineral fabrics, a memory of the extremes of pressure (P), temperature (T), deformation (d) and fluid activity (f) pertaining during such crust-forming and mountain-building processes as well as critical information over the duration (time (t)) of the disturbance. Reconstructing the relationships between P, T, d, f and t in fossil orogenic belts is therefore vital to our understanding of the magnitude, and rate of change, of the dynamic processes operating in orogenic belts and should allow an insight into the possible processes active in the inaccessible depths of present-day collision zones.

In recent years, the significant advances made in microanalytical techniques combined with the results of high quality experimental studies on the thermodynamic properties of mineral and fluid phases, has made it increasingly possible to extract and decipher P-T histories from natural mineral assemblages and reaction textures in small 'equilibrium' domains within samples showing disequilibrium features on hand specimen or thin section scale. Deducing the sequential 'equilibrium' stages allow construction of P-T paths for rocks. In order to quantify the time scale of the P-T changes (T-t: heating and cooling rates; P-t: burial and exhumation rates) in such non-equilibrated rocks it is clearly necessary to be able to deduce age information for rock domains on the same scale as for the P-T data i.e. on a microscopic scale.

New and improved techniques for the isotopic analysis of microscopic amounts of material have also been developed: ion microprobes, ICP mass spectrometers and laser-sampling gas mass spectrometers. For low to medium grade terrains it is now possible to directly measure isotopic ratios in feldspars, micas and amphiboles - the important rock forming minerals and also the minerals from which P-T values have been estimated. In high grade rocks the situation is different because the retention of the geochronologically important isotopes in the rock-forming minerals during cooling is a much more significant function of temperature, time and diffusion processes. In minerals with very low diffusivities for important isotopes such as zircon (U-Pb system) however, diffusive lead loss is insignificant for geological temperatures and time scales and therefore, providing recrystallisation does not occur, such phases will provide mineral growth ages. Zircon, present in a wide variety of rock types but generally only in trace amounts, has thus become essentially the 'Gold Standard' for age determination of high grade rocks.

Two major problems exist with standard zircon dating. First, the common occurrence of multiple growth features in many zircons as evidenced by cathodoluminesence (CL) studies means that, in spite of the use of abrasion techniques, standard mass-spectroscopic analysis of zircon size fractions is fraught with possible errors. Second, the generally low concentration of zirconium in rocks has required that very large samples must be crushed, sieved and zircons hand-picked thus losing the direct relationship between zircon and host rock mineral phases. Use of the ion microprobe has revolutionised zircon dating. Now overgrowths can be dated as well as cores or other growth zones identified in advance by CL. We have overcome the second problem by extracting our zircons for ion microprobe study directly from the same thin sections from which P-T estimations were made. Zircons identified optically have been checked by CL for complexity before being drilled out of the polished thin sections, remounted in new resin blocks, repolished to ensure surface height, and then again checked by CL ready for ion probe spot selection. This technique has the enormous advantage in that zircons can be correlated with mineral growth stages (when they occur as inclusions for example), fabric development, fluid infiltration or vein formation: a feature impossible with standard preparation techniques. There is the added advantage that in samples where zircons are relatively rare, such as in eclogites for example (e.g. Gebauer, 1990), it is clear from the outset whether the measured zircon belongs to the eclogite (or pre-eclogite) stage or if it is tied to cross-cutting veins: a feature not possible when zircon is just the residue from 200 kg of crushed rock. The technique is also extremely useful where there are small samples available such as clasts in conglomerates, greywackes or just a single hand specimen.

In order to test if there was any difference between zircons separated by the standard crushing/hand picking technique and directly from thin sections we investigated samples of high temperature granulite from southern Bohemia (Czech Republic). Such kyanite-K-feldspar-bearing granulites, of granitic composition and showing a characteristic mylonitic fabric that formed during retrogression (and secondary biotite and sillimanite growth) along the exhumation path, are the most voluminous of the scattered relics of high pressure metamorphism in the crystalline core of the European Variscides. Three metamorphic stages at HighP-HighT (>15 kbar, >900°C), mediumP (6–8 kbar, 800°C) and at lowP (ca. 4 kbar, ca. 700°C) are visible petrographically. Near-spherical, multi-faceted zircons measured by SHRIMP (Kröner *et al.*, 1996) as well as by conventional multigrain and single grain evaporation techniques (standard preparation method: Wendt *et al.*, 1994) yield statistically identical ages around 340 Ma. Older detrital as well as *c.* 370 Ma magmatic grains were identified. The measurements undertaken on the sample block prepared by the new extraction technique reproduced these ages exactly. This shows that the considerable advantage in petrological control is not offset by any appreciable lack of reproducibility when compared to conventially prepared ion-probe samples even though the technique cannot ensure that grain cores are exposed and must cope with thinner polished grains than is the case for bulk separation techniques.

Eclogites associated with garnet peridotites in the granulites also yield Carboniferous ages (Medaris *et al.*, 1995) and have been interpreted as products of melting at deep mantle conditions. Rare, very small eclogite bodies exist within paragneisses close to the granulites where they have been described as tectonic outliers of the granulite massifs. However, based on zoning characteristics of garnet, this second eclogite group is clearly different although high temperature breakdown reactions are identical to those found in eclogites associated with granulites (O'Brien, 1997). Rare zircons extracted from thin sections and measured by ion microprobe reveal a lower Palaeozoic age and confirm that these eclogites, despite similarities, belong to an earlier orogenic phase than those in the granulites.

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