



## Progress and pitfalls in dating deformation with carbonate geochronology

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Several isotopic systems can potentially be used to provide absolute chronology of carbonate minerals; these include Rb-Sr, Sm-Nd, U-Pb and U-Th. The production of a robust date requires incorporation of the parent isotope during formation, and ideally low abundance of the daughter isotope. Variable parent-daughter (P/D) abundance during formation additionally can increase the robustness of the resulting isochron. The ability to use high spatial resolution sampling via laser ablation (LA-) ICP-MS, makes it the most attractive technique, as varying P/D ratios can be sampled within single age domains, whether these be crystals, growth bands, or other textural domains. Of the systems available in carbonate, U-Pb is the only one that is commonly applied with LA-ICP-MS methods, although the others are all possible with modern instrumentation. Of note, collision-cell technology means that Rb-Sr is regaining popularity as an in situ dating method. Carbonate geochronology can be achieved at a range of timescales, with U-Th ranging from 100s yrs to ca. 500 ka, and U-Pb ranging from 100s ka to 100s Ma. The potential for isotopic disequilibrium effecting measured U-Pb ages, means that young (< 10 Ma) U-Pb dates are susceptible to inaccuracy. Published LA-ICP-MS U-Pb dates suggest that this method can be pushed well into the Precambrian.

The application of U-Th and U-Pb geochronology to provide direct timing constraints on deformation gained ground around 10 and 5 years ago, respectively. Because LA-ICP-MS instrumentation is relatively common, and because ancient carbonates provide undated material of significant interest, U-Pb in particular has become a rapidly growing technique. The biggest advance in LA-ICP-MS U-Pb dating has been the characterisation of matrix-matched calcite reference materials (RMs). The observation of minor matrix-related effects between carbonate matrices however, means that the availability of well characterised RMs for minerals such as dolomite and siderite, are a limiting factor in the accuracy of these non-calcite dates. In terms of deformation, most existing data corresponds to calcite.

Calcite precipitates from fluid at a range of temperatures in the upper crust, with fluid-flow typically being enhanced by brittle deformation, i.e. faulting and fracturing. To link calcite dates to

the timing of specific deformational events, such as fault slip or fracture-opening, various 'syn-tectonic' or 'syn-kinematic' vein types have been utilised. These include slickenfibres, breccia cements, and various types of vein arrays. Each of these structures has variable ability to faithfully record the timing of fault slip, and the ability to link calcite mineralisation to the timing of fault slip remains one of the most assumptive parts of this method. Detailed petrographic and compositional characterisation and documentation are required, for which a range of methods are available, such as cathodoluminescence and trace element mapping. Along with a summary of the advances in carbonate geochronology, various examples of vein structures and of methods for characterisation will be discussed, including examples where there is evidence for overprinting by later fluid-flow.