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Ductile strain rates measurements reveal continental crust long-term deformation modes

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Any discussion on the long-term crustal rheology is hindered by our poor knowledge of deformation rates in the deep crust. These rates have only been estimated to be ≤10-15 and ≥10-13 s-1 in the "stable" and highly deforming zones respectively, and measured in a few peculiar cases. Because quartz ribbons are ubiquitous in continental shear zones, the quartz-strain-rate-metry (QRS) method, based on experimentally calibrated quartz piezometers and ductile flow laws, could provide deformation rates measurements in many geological contexts. However, the results are highly sensitive on the deformation temperature that is difficult to measure. Furthermore, results vary by three orders of magnitude depending on the chosen piezometer and rheological law. If recent technical progress allow measuring more precisely the deformation temperature, it is still not clear what is the most accurate piezometer - rheological law association.

We solved that dilemma by comparing strain rates measured by the QRS method with a reference one measured with another method on the same outcrop of the Ailao Shan - Red River (ASRR) shear zone. At site C1, by combining dating of syntectonic dykes and measurements of their deformation, the strain rate is calculated between 3 and 4 x10-14 s-1 between 29 to 22 Ma, (Sassier et al., JGR, 2009). Quartz ribbons sampled in site C1 show large grains recrystallized by grain boundary migration (GBM), themselves recrystallized at lower temperature by sub-grain rotation (SGR). The mean recrystallized quartz grain size for the SGR event range between 74.0 and 79.3 μm. The associated stresses, measured with Shimizu (JSG, 2008) piezometer, range between 35.2 and 38.1 MPa. Conditions of deformation of P≈ 1.5 kbar and T≈ 430°C were inferred by combining several thermobarometers on quartz, such as TitaniQ, fluid inclusions microthermometry and crystallographic fabrics. The calculated strain rate with five flow laws and three piezometers range between 3.5 x10-18 and 4.3 x10-13 s-1. Strain rates of natural quartz ribbons deformation under mid-crustal conditions appear better approximated by the QRS method if using Hirth (J. Earth Sciences, 2001) power flow law and the Shimizu piezometer. Most other combinations underestimate the strain rate.

Applying the QRS method to major continental shear zones, we can quantify across-strike local strain rate variations and document where deformation localizes. For example, nine quartz ribbons sampled across the ASRR shear zone provided strain rates progressively increasing from the south-western border to the north-eastern border, from 2.5 x10-15 to 1.34 x10-12 s-1. The north-eastern border of the ASRR shear zone has been interpreted as the paleo-center of the shear zone, exhumed in the footwall of the active normal Red River fault. We conclude that strain localized at the paleo-center of the shear zone, as inferred by most of numerical models of shear zones deformation. Summation of the local strain rates yield global strain rates compatible with the fault rate deduced from geological constraints. This opens the way to extensive strain rate measurements, quantification of deformation localization and direct comparison with numerical models for continental lithosphere rheology and strain localisation.