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From inversion of calcite twin data to paleo-differential stress magnitudes in the upper crust : state of the art and comparison with contemporary stress data

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Quantitative estimates of stresses and strength are central to many problems of tectonics and of crustal mechanics, and are also of first importance for applied geological purposes such as geological hazards, engineering activities and resource exploration. To date however, our knowledge of the actual stress levels sustained by rock masses remains poor.

Many techniques of measurements of contemporary stresses have been improved for a better understanding of current seismicity, active fault kinematics and crustal strength. Coevally, methods of paleostress reconstructions based on mechanical interpretation of various structural or petrographic elements in natural rocks have been set out in order to decipher the past tectonic evolution; among these methods is the study of mechanical twins in calcite.

In contrast to Turner's (1953) method which only yields sigma1 and sigma3 orientations and to the technique of Jamison and Spang (1976) which only provides values of (sigma1-sigma3) without any information on stress orientations and relative stress magnitudes, the computerized inversion of calcite twin data (Etchecopar, 1984) allows simultaneous calculation of principal stress orientations and differential stress magnitudes from a set of twin data; it therefore provides 5 parameters among the 6 of the complete stress tensor.

This contribution aims at reporting a compilation of currently available data on paleo-differential stress magnitudes in the continental crust (mainly from calcite twinning paleopiezometry) and at discussing and comparing them to the stress-depth relationships derived from in situ stress measurements. Collecting data on contemporary stress and paleostress magnitudes with depth is however fundamentally different. In drill holes, contemporary stresses are determined directly at a given depth, or at least in a narrow depth interval. In contrast, paleopiezometers are generally sampled and analysed after they have reached the surface, i.e. after exhumation from an unknown depth, from various settings, and establishing a differential stress versus depth relationship for paleostresses requires independent determination of differential stresses and depth.

Despite dispersion, both independent sets of stress data however support to a first-order that the strength of the continental crust down to the brittle-ductile transition is generally controlled by frictional sliding on well-oriented pre-existing faults with frictional coefficients of 0.6-0.9 under hydrostatic fluid pressure. Some ductile mechanisms may, however, relieve stress and keep stress level beyond the frictional yield, as for instance in the detached cover of forelands.

Concepts and techniques underlying determinations of contemporary stresses and paleostresses are inherently different, and both types of stress data do not have strictly the same geological meaning: contemporary stresses measured in situ reflect local, instantaneous ambient crustal stresses, while reconstructed paleostresses reflect ancient crustal stresses at the particular time of tectonic deformation, averaged over the duration of a tectonic event and over a given rock volume. Despite these differences however, analyses of contemporary stresses and paleostresses rely on the same mechanics, and both data sets can be combined to bring useful information on the strength and mechanical behavior of the upper continental crust over time scales of several tens of Ma.