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How much differential stress can a rock support?

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The complex microstructures of multiple phases containing chemical gradients in rocks present an incredible challenge to determining what non-lithostatic stresses can be developed and how much of the deviatoric stress state can be preserved. Examination of simplified systems can provide some constraints to this problem. However, until now, even the simplest elastic system of a single inclusion embedded in an isotropic host has not been properly addressed for geological systems, even though it is essential for determining the depths of formation of diamonds, and could also provide constraints on the prograde and retrograde stress-temperature paths of metamorphic assemblages. Previous analyses (as summarized in Zhang, 1998) have relied on the assumption of linear elasticity and invariant elastic properties of the minerals with pressure and temperature, or assume that the host material is completely rigid. These assumptions are not physically correct.

We will present a solution to the single-inclusion problem that incorporates non-linear elasticity and can be applied to determine the stress distribution in the host and inclusion that arises from any change in pressure and temperature. Our solution shows that the previous calculations of residual inclusion pressures are incorrect in the relaxation term. The errors are greater with softer hosts, and when the final conditions are not at ambient P and T. The general form of our solution allows it to be used in combination with any form of equation of state and/or thermal expansion, and is not restricted to linear elasticity or just invertible Eos. Numerical calculations have been performed with a new module of EoS routines (Angel et al. 2014) that has been added to the publicly-available CrysFML library.

A key result is that the strain field induced in the host falls to within 1% of the external value at less than five times the radius of the inclusion. This is true for all combinations of host and inclusion minerals. The question of preservation is then simple. If the inclusion is buried within the host to a depth of more than 5 radii from the nearest surface, there is the possibility that the entire stress field will be maintained. It will be maintained if it does not exceed the brittle or ductile limit of the host. For the Kulet whiteschist (Parkinson, 2000), calculations with realistic EoS show that at peak metamorphic conditions (760C and 38 kbar) an isolated quartz inclusion deep in the garnet cores would experience a pressure of less than 24 kbar and would thus remain in the stability field of quartz. The analysis suggests that at the peak metamorphic conditions garnet can support large stress gradients for geologically relevant times.

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