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Influences of the elastic anisotropy of minerals on deformation and metamorphism

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Rocks and minerals exhibit elastic behavior, which is important because it controls the transmission of acoustic waves through rocks, and precedes yield conditions for brittle and plastic deformation. Different aspects of elastic behavior are commonly represented by Young's modulus (E), shear modulus (G), and Poisson's ratio (ν). Minerals have directional variations in elastic properties (elastic anisotropy) that relates to their crystallographic structure. Elastic anisotropy is perhaps best utilized by geophysicists in calculations of seismic anisotropy. In structural geology and rock mechanics, minerals are commonly assumed to be elastically isotropic and scalar mean values of elastic moduli are used, and/or elastic strains are assumed to be small relative to plastic deformation and so ignored (e.g., in VPSC code). The effects of mineral elastic anisotropy is generally dismissed as insignificant and ignored in metamorphic petrology. This presentation investigates elastic anisotropy phenomena in minerals to stimulate discussion on their importance in geosciences.

Visualization of elastic anisotropy in minerals is vital in order to fully appreciate their complexity. For elastic materials in 3D, stresses and strains are related by a generalized Hooke's Law. Elasticity described by fourth rank tensors of stiffness and compliance – six by six matrices of elastic constants that relate the stress tensor to the infinitesimal strain tensor. These tensors are not easy to visualize, and even recent studies of elastic anisotropy tend to report just one component of the stiffness (or compliance) tensor. This presentation utilizes an open source toolbox of MATLAB scripts for visualizing elastic anisotropy in minerals (AnisoVis). The code produces linked 2D and 3D representations of E, G, and ν from elastic constant input data for any mineral to encourage investigation and deeper understanding of directional variations in these fundamental properties. AnisoVis renders directional variations as 3D surfaces, colour-contoured stereonets, and plots azimuthal variations along specific planar projections.

The results reveal complex 3D geometries that reflect the symmetric elements of the crystal system but are unique to each mineral. All minerals are elastically anisotropic - even optically isotropic minerals. Typically, the magnitudes of the anisotropy of E, G, and ν are significantly high for most minerals, and many minerals display negative Poisson's ratio (auxetic behavior) in some directions. Examples are presented to show the effects of P and T on elasticity (e.g., quartz, feldspar), the effects of mineral composition on elastic anisotropy (e.g., feldspars, pyroxenes, olivine), the effects of elastic anisotropy on polymorphic phase transformations (e.g., zircon-reidite, Timms et al., 2018), and links to deformation mechanisms (e.g., zircon, Timms et al., 2018). It is clear that the directional variations of elastic properties of rocks and minerals have significant consequences for their physical response to natural or imposed stresses. Yet, the effects on grain-scale processes such as the distribution of intra- and inter-grain stresses and strains in deforming rocks, consequences for deformation mechanisms, and ultimately the effects on metamorphic reactions has not yet been fully investigated.