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Frequency dependent viscoelastic properties of quartz

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Quartz is one of the most abundant minerals within the Earth's crust. Hence, a profound understanding of its physical properties, including underlying processes and mechanics, is essential to understand geodynamic processes. In particular, the low to high quartz transition has been extensively investigated, since the discovery by Le Chatelier in 1889. This incommensurable phase transition around 573 ˚C (1 bar) strongly affects a number of physical properties.

In this study elastic and inelastic properties of quartz have been investigated as a function of frequency and temperature. Oriented samples, taken from a synthetic single quartz crystal, were examined with a three-point bending experimental setup. A set of rheological data is presented, acquired from dynamic thermo-mechanical analysis (Gabo EPLEXOR 1500N). The complex Young's modulus $E*$ is derived from dynamic stress-strain data in the frequency range between 1 and 20 Hz, from room temperature to 600˚C across the phase transition. Storage E' (elastic, real) and dissipationE'' (inelastic, imaginary) portions are deduced. The storage modulus of low quartz increases with frequency, approximating a constant value for high frequencies. In contrast, the dissipation modulus (energy lost as heat) shows a more complex behavior, while frequency rises. Towards the transition temperature a softening of elastic moduli is observed. Simultaneously, the angle δ of phase shift between applied stress and resulting strain enlarges from 0 to 10 ˚, which is a measure for the inelastic portion. Once the crystal system has changed and physical conditions entered the stability field of high quartz, the real part rapidly increases and the imaginary part declines significantly.

Furthermore, the real part is compared to published data and shows a very good agreement. A three element viscoelastic model, consisting of a spring and a dashpot, connected parallel, and another spring, connected in series, describes our experimental results. Model calculations yield the dynamic viscosity η and the classical Young's modulus E. Rising temperatures go along with a decrease in viscosity over several orders of magnitude. Anisotropy is temporarily lost, close to the phase transition. Modeling this development with the Arrhenius equation quantifies the activation energy E_A of the softening process to be in the order of 1.6 eV. Relaxation time τ, derived from viscosity and elastic properties, reaches about 0.5 s close to the transformation.

The ratio of storage and dissipation portionE'/E'' equals the seismic quality factor Q. Rising temperatures cause the quality factor to decrease by more than 80 %, indicating a strong attenuation of seismic waves in the range of the phase transition and seismic frequencies. This change in the seismic quality factor enables to discriminate quartz-rich rocks, close to the transformation temperature, from rocks with little or no quartz. Inversely, the attenuation of seismic waves can be used as an *in-situ* temperature probe in quartz-rich rocks.