Internal Friction and Mechanical Relaxation in Geomaterials

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The nature of mechanical losses and energy dissipation in geomaterials are manifold macroscopic and microscopic processes. As a result of differential straining, the geomaterials experience damping of mechanical energy according to 3 types of models: viscous damping, Coulomb damping (or dry friction damping), and structural damping (or hysteretic damping). Single crystals are also characterized by dislocation energy dissipation (Bordoni-peak). In polycrystalline solids grain boundaries can act as sink and source of vacancies affecting the internal friction $Q^{-1}$ under dynamic loading. In geomaterials during heating-cooling cycles elastic modulus relaxation and $Q^{-1}$ are characterized by a hysteretic behaviour reflecting the dynamics of formation and annihilation of relaxation centres. A pure Debye type of relaxations is very rare in geomaterials. The long-range interactions lead to a non-symmetrical broadening of the Debye peak. In glass-forming systems the mechanical relaxations can be subdivided into a strong primary relaxation ($\alpha$), i.e. the dynamical glass transition in the supercooled melt, or relatively slow relaxation of structural units above the thermal glass transition temperature $T_g$ defined due to the experimental conditions as well as several weak secondary relaxation processes in the vicinity of the thermal glass transition range ($\beta$) and in the glassy state ($\gamma$). The $\alpha$ relaxation in silicate melts is due to the hierarchically coupled mechanical relaxation processes with a weak correlation between the width of relaxation time distributions and the fragility index $m$. The $\beta$-relaxations are substantially masked by the $\alpha$ process as well as by the thermal glass transition range and correspond to the small scale structural adjustments as well as to the cooperative movement of divalent cations and non bridging oxygen. The $\gamma$-relaxation processes are linked to the low temperature cooperative movement of alkaline cations. Furthermore, all relaxation processes are influenced by water content and by water speciation. In partially molten rocks the macroscopic flow of melt and deformation of porous space contribute additionally to mechanical losses. The transition from anelastic solid behaviour to Bingham body or to Zener-relaxation model depends on the critical melt fraction and on the level of a shear stress relative to the yield stress of a solid material. In partially molten rocks grain boundary sliding mechanism has been expected to cause internal friction in the seismic frequency range and at the tidal deformation periods. For both melt-free and melt-bearing systems, the relaxation strength for bulk component in silicate rocks is much smaller than that for shear component, indicating that $Q_P^{-1}$ is controlled by only shear component of internal friction. The observed frequency dependence of $Q_S^{-1}$ is attributed to the viscoelastic behaviour and is due to the intrinsic diffusion mechanism and to the presence of a melt phase on grain boundaries. The first order effect of melt on internal friction above the melting temperature is supported by the onset of markedly stronger $Q_S^{-1}$ frequency dependence. The melt-related dissipation could be due to the melt squirt flow because the characteristic frequency for the fluid flow is $\omega_m \approx 0.2...200$ Hz when the melt pocket aspect ratio is $\approx 10^{-3}...10^{-2}$.