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Attenuation and Dispersion in Earth's Materials

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One of the last challenges of Pr. Luigi Burlini has been to set up an experimental apparatus that would measure elastic wave attenuation under high pressure conditions. This project has since been developed by his colleagues and students at ETH. As a tribute to Luigi Burlini, this presentation aims at recalling why such measurements are important , how challenging such a project is, and what the main issues ahead are.
Most of our knowledge about either crustal layers (seismic exploration) or deeper layers (seismology) results from data related to elastic wave propagation inside the Earth. The large amount of available data as well as the huge capability of computers are such that descriptions in terms of isotropic homogeneous layers appear to be very crude today. Anisotropic, heterogeneous models are reported at various scales. In addition, accounting for wave attenuation (the Q factor) is potentially of great interest. The Q factor is highly sensitive to processes that involve some departure from perfect elasticity. Its knowledge may provide information on possible fluid content, temperature, etc. This is because various processes may dissipate energy (and thus lower Q value) as a result of fluid flow, solid flow, etc., depending on the precise P-T conditions at depth. This points immediately to the theoretical challenge of Q investigations: there are many possible ways for a rock to not behave as a perfect elastic body. To model these various mechanisms and identify in which conditions they can take place is a first major challenge. The second challenge is on the experimental ground. What is looked for is to get low frequencies (f close to seismic frequencies) Q data on crustal (or mantle) rocks at high pressure P-high temperature T. Experiments in such highT-high P-low f conditions are extremely difficult to perform. Only in Canberra (I. Jackson) and now in Zurich such conditions have been achieved.
Attenuation and dispersion (frequency dependence) of elastic waves are related through Kramers-Kronig equations. Using simple viscoelastic models such as the Zener model, one can show that Q-1 is maximum at a critical frequency fc, and, correlatively, that the wavespeed increases from low to high f by an amount [U+F044] V/V = (Q-1)max. This means that another (equivalent) way to look at attenuation is to look at dispersion. Experimentally, this implies to measure high and low frequency wavespeeds or elastic moduli. High frequency measurements have been performed for a long time (including high P-high T conditions) but low frequency measurements remain a challenge. Such data are however of major importance: seismic velocities data (1 H-1 kHz range) are obtained at much lower frequencies than laboratory data (MHz range). A difference by up to 6 orders of magnitudes in frequency exist between both set of data. Yet it has been mainly assumed that the frequency dependence can be neglected. Several set of experimental data show that it is not true. The implications for the crust and for the mantle will be discussed.