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Sliding behavior of calcite and dolomite marbles at seismic deformation conditions

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Our understanding of earthquake physics is hampered by the poor knowledge of the evolution of the friction coefficient in rocks (μ or the ratio of shear stress over normal stress) at deformation conditions typical of the seismic source (normal stress > 40 MPa, slip rates V > 1 m/s, abrupt accelerations, etc.). Insights can be gained by experiments using a novel rotary shear deformation apparatus, SHIVA (Slow to HIgh Velocity Apparatus) which, by exploiting the large available power (300 kW), is capable of extending the performance of previous experimental apparatus to more realistic (i.e. natural) conditions. Here we present results from experiments performed on samples of Carrara (98% calcite) and dolomitic (98% dolomite) marbles. The two rocks were selected because (1) many earthquakes worldwide nucleate within and rupture through carbonates sequences (e.g., L'Aquila 2009 Mw 6.3) and (2), both rocks release CO2 during thermal decomposition; dolomite at about 550°C and 800°C, and calcite at 800°C; thus the different frictional evolution of the two rocks can be correlated to different decarbonation stages and temperatures.

Tests were conducted on hollow cylinders (50/30 mm ext/int diameter) at V of 0.1–6.5 m/s and normal stresses up to 40 MPa. Each experiment consists of three steps: (1) loading of the sample to the target normal stress; (2) acceleration to the imposed slip rate; (3) deceleration until the target slip or duration is reached.

At V < 0.3 m/s calcitic and dolomitic marble have a μ of about 0.5. At V $\geq$ 1 m/s, in both rocks, μ increases to a peak value ($\sim$ 0.6) in the first few mm of slip, followed by an exponential decay towards an extremely low steady-state value (« 0.1), as previously observed in experiments performed at lower normal stresses (< 13 MPa, Han et al., 2007; 2010). However, in dolomitic marble, the decay distance is shorter and complicated by a short-duration phase of re-strengthening (after about 0.5 m of slip): this complex weakening behaviour might result from the occurrence of two decarbonation reactions (at 550°C and 800°C, respectively).

At V < 0 .3 m/s, calcitic and dolomitic marble shorten significantly (0.2-0.3 mm of shortening per m of slip at 10 MPa normal stress) due to bulk fracturing and loss of gouge material from the sliding surface. Instead, shortening rate decreases with increasing slip rate. At V $\geq$ 1 m/s, shortening of calcitic marble is negligible (<0.05 mm per m of slip). Post-mortem sample observations (EDS-equipped SEM and Electron Probe Microanalysis) suggest that in calcitic marble, negligible shortening may be related to the formation of a 'protective' layer of CaO (lime) on the slip surface, resulting in very low wear rates and extremely thin slipping zones. In the case of dolomitic marble, shortening is <0.1 mm per m of slip and the slip surface is underlain by a tens of micrometers thick aggregate of nanoparticles (< 50 nm in diameter). The slip surface itself is lined by newly formed, polygonal grains 1-2 μm in size and 0.1-0.2μm thick. . This coating has been observed in other studies (for V = 1 m/s, Green et al., AGU 2010) but the process of formation remains enigmatic.