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Mechanical behavior of limestone undergoing brittle-ductile transition: experiments and model

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With increasing confining pressure, carbonate rocks can undergo the brittle-ductile transition at room temperature. In order to examine the brittle-ductile transition, we performed constant strain rate triaxial deformation and stress-stepping creep experiments on Tavel limestone (porosity 14.7%) under various conditions. The evolution of elastic wave velocities were recorded during each experiment and inverted to crack densities.

The constant strain rate triaxial experiments were performed for varying confining pressure from 5 to 90 MPa. For Pc≤55 MPa our results show that the behavior is brittle. The latter is characterized by dilatancy due to crack propagation, leading to a stress drop at failure. For Pc≥70 MPa, the behavior is semi-brittle with elastic compaction followed by inelastic compaction, then leading to dilatancy and eventual failure. The semi-brittle behavior is characterized by diffuse deformation. Inelastic compaction is due to intra-crystalline plasticity (dislocation motions and twinning) and micro-cracking. Constant strain rates experiments were modelled taking into account (1) crack propagation from pre-existing flaws, (2) plastic pore collapse and (3) crack nucleation from dislocation pile-ups. The obtained model predictions are in good agreement with our experimental data.

Stress stepping (creep) experiments were performed in a range of confining pressures crossing the brittle-ductile transition (from 20 to 85 MPa). In the brittle regime, the time-dependent axial deformation is coupled with dilatancy and a decrease of elastic wave velocities, which is characteristic of crack nucleation and/or propagation. In the semi-brittle regime, the first steps are inelastic compactant due to plastic pore collapse. All following stress steps are dilatant as a result of crack nucleation and/or propagation. In general, our results show that the axial strain rate is always controlled by plastic phenomena, until the last step, during which the axial strain rate increases significantly (tertiary creep) because of crack interactions leading to macroscopic failure.

Our results show the complex interplay between confining pressure, pore fluid and strain rate (i.e. time), which has an influence on the respective contributions of the active micro-mechanisms of deformation and thus on the macroscopic behavior of limestone.