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Nonlinear elastic behavior of rocks revealed by dynamic acousto-elastic testing

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Nonlinear elastic behavior of rocks is studied at the laboratory scale with the goal of illuminating observations at the Earth scale, for instance during strong ground motion and earthquake slip processes. A technique called Dynamic Acousto-Elastic Testing (DAET) is used to extract the nonlinear elastic response of disparate rocks (sandstone, granite and soapstone). DAET is the dynamic analogous to standard (quasi-static) acousto-elastic testing. It consists in measuring speed of sound with high-frequency low amplitude pulses (MHz range) across the sample while it is dynamically loaded with a low frequency, large amplitude resonance (kHz range). This particular configuration provides the instantaneous elastic response over a full dynamic cycle and reveals unprecedented details: instantaneous softening, tension/compression asymmetry as well as hysteretic behaviors. The strain-induced modulation of ultrasonic pulse velocities ('fast dynamics') is analyzed to extract nonlinearity parameters. A projection method is used to extract the harmonic content and a careful comparison of the fast dynamics response is made. In order to characterize the rate of elastic recovery ('slow dynamics'), we continue to monitor the ultrasonic wave velocity for about 30 minutes after the low-frequency resonance is turned off. In addition, the frequency, pressure and humidity dependences of the nonlinear parameters are reported for a subset of samples. We find that the nonlinear components can be clustered into two categories, which suggests that two main mechanisms are at play. The first one, related to the second harmonic, is likely related to the opening/closing of microstructural features such as cracks and grain/grain contacts. In contrast, the second mechanism is related to all other nonlinear parameters (transient softening, hysteresis area and higher order harmonics) and may arise from shearing mechanisms at grain interfaces.