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Ultrasound P-wave velocities and amplitudes during triaxial deformation of three sandstone varieties: the chances to monitor different states of internal drainage

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Time-dependent variations in velocities and amplitudes of elastic waves are among the most important sources of information to monitor natural or induced subsurface processes at transient states of drainage. Laboratory experiments provide valuable information on the characteristic properties of elastic wave propagation associated with different mechanical states during deformation, in particular with respect to the role of variations in microstructure and effective stress. Triaxial deformation characteristics of dry and saturated sandstone samples (Ruhr sandstone, Wilkeson sandstone, Fontainebleau sandstone) at various confining pressures up to 150 MPa and strain rates ranging from 10^{-7} and 10^{-3} s^{-1} were investigated by simultaneously recorded ultrasound signals of P-waves propagating parallel to the applied deviatoric stress with the aim to monitor different states of internal drainage. During brittle deformation velocities and amplitudes initially increased, exhibited a maximum prior to failure and decreased, whilst the magnitude of variations decreased with increasing confining pressure and strongly differed between the three sandstones. Differences between the deformation characteristics of dry and saturated samples at equivalent effective pressures document the onset and magnitude of dilatancy hardening of saturated samples associated with the transition from effectively drained to undrained conditions at strain rates consistent with estimates from actual measurements of hydraulic properties. Monitoring strain-rate dependent variations of internal drainage with ultrasound P-waves was conspicuously limited for the three sandstones varieties due to an inherent ambiguity of velocities under the applied pressure and saturation conditions. However, the actual occurrence of insufficient drainage was associated with characteristic variations in velocity and amplitude. Effectively undrained conditions during deformation accompanied a reduced axial strain at maximum amplitudes compared to dry experiments at otherwise constant experimental conditions. The decrease in amplitudes at lower strains is likely attributed to pore overpressure inducing stable crack propagation, when hydraulic diffusion is too low to compensate for a reduction in pore space during the initial elastic compaction. Also, the reduction in velocity prior to failure was less pronounced for saturated samples under effectively undrained conditions than observed for dry and drained saturated samples documenting local pore pressure diminution during inelastic dilation resulting in dilatancy hardening. Critical strain rates for internal drainage independently deduced from properties of ultrasound waves agreed within an order of magnitude with critical strain rates estimated from both hydraulic and mechanical properties.