Geophysical Research Abstracts
Vol. 14, EGU2012-11099, 2012
EGU General Assembly 2012

P-wave monitoring of an unconsolidated and partially saturated porous medium : an experimental study

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Nowadays, it is well admitted that hydrogeological properties of porous media (porosity, fluid saturation and permeability) can influence seismic properties. In geophysics, the major theory which links hydrogeological and seismic parameters is poroelasticity proposed by Biot (1956). The Biot relaxation process is due to the relative displacement of fluid in comparison to the solid which causes a significant attenuation of seismic waves, notably in unconsolidated and highly permeable media. Laboratory experiments are necessary to better understand the effects of fluids on velocity dispersion and attenuation of seismic waves but few ones are done in the low frequency range (1Hz to 10 kHz) where the wavelength is greater than heterogeneities size. In order to analyse the role of partial saturation on direct P-waves phase velocity and attenuation, we performed a laboratory experiment in the kiloHertz range to avoid scale effects between field studies and traditional ultrasonic laboratory measurements. This experiment consists in a sand-filled tank equiped with accelerometers and water capacitance probes, where seismic propagation is generated by hitting a steel ball on a granite plate. Several imbibition/drainage cycles were performed between the water and gas residual saturations. Seismic data were processed by a Continuous Wavelet Transform using the complex Morlet wavelet which was numerically validated using a viscoelastic 2D code for wave propagation (Specfem2D). Phase velocity of direct P-wave decreases with the increase of water content, that is quite consistent with Biot-Gassmann-Wood (BGW) limit of the Biot's theory both for imbibition and drainage. This behaviour indicates that the fluid mixture (gaz and water) can be averaged as an effective fluid, which is typical of field seismic applications. In this experiment, attenuation is very strong and cannot be fully explained by the macroscopic fluid flow of Biot's theory. It is necessary to introduce a viscoelastic contribution linked to the grain to grain overall losses, which are described by a constant Q-model. Moreover, hysteresis between imbibition and drainage are observed and explained by introducing an effective permeability of the mixture depending on water and gas relative permeabilities.