EGU21-12766
https://doi.org/10.5194/egusphere-egu21-12766
EGU General Assembly 2021

Fracture-generated frequency-dependent seismic Q measured from a VSP in granite

Victoria R. Bourne[1], C. Dario Cantu Bendeck[1,2], Mark W. Hildyard[1], Roger A. Clark[1], and William Wills[3]

[1]School of Earth & Environment, University of Leeds, Leeds LS2 9JT, UK
[2]now at: CGG, Crompton Way, Crawley RH10 9QN, UK
[3]Avalon Sciences Ltd, Somerton Business Park, Somerton, Somerset TA11 6SB, UK

We integrate two topics – seismic characterisation of fractures, and seismic attenuation quantified as the frequency-dependent Seismic Quality Factor Q, Q(f). The former is vital for predicting and monitoring fluid movement and containment in energy-related settings (hydrocarbons; geothermal; CO_2, hydrogen or compressed air storage; radwaste). Fractures control the fluid flow and structural behaviour of a rock mass, yet their expression in Q is poorly studied and not well understood despite it typically being more sensitive than wavespeeds as a rock physics parameter. The latter is long-recognised, little-studied, and a paradigm shift from frequency-independent Q ('constant-Q', a routine signal-processing and image enhancement tool in hydrocarbon exploration), despite theory, laboratory, and field data showing that Q must be frequency dependent due to varying scale-lengths of the physical-mechanical phenomena causing attenuation.

We therefore measure Q(f) from the downgoing direct P-wave arrival in a near-offset vertical seismic profile in granite at a former geothermal test site in Cornwall, SW England, where vertical and horizontal fracturing is seen at surface: horizontal fractures are confirmed at depth by well-log data. Sensors were 3-component 15Hz geophones at 15m depth spacing: the source was a single vibrator, linear 8-100Hz up-sweep, 30m offset from the wellhead in the azimuth of well deviation: record length was 1000ms at 1ms sample interval. We analyse only the deeper cased interval, from 700m to 1735m. Pre-processing was geometric spreading correction, hodogram-based component rotation toward the source, and wavefield separation using a 7-point median filter to suppress interference from upgoing energy. Measured attenuation Q_{eff} is the harmonic sum of intrinsic Q, Q_{int}, and apparent attenuation, Q_{app}. Q_{int} in massive granite is typically 500-1000, yet we find $Q_{eff}(f)$ is 50-70 at >60Hz and only ≈30 at <30-35Hz, features masked in the constant-Q result of 55±11 over our working bandwidth of 25-90Hz.

One contribution to Q_{app} is 'stratigraphic attenuation', forward-scattering interference of shortpath internal multiple reflections superimposed on direct arrivals, and quantifiable from sonic and density well-logs using O'Doherty-Anstey-Shapiro methodology. We find it is indeed frequency-dependent (peaking at ≈50-60Hz, 10-40% lower at our bandwidth limits) but its absolute magnitude is insignificant (Q≈20,000-30,000) and unable to explain the measured $Q_{eff}(f)$. We therefore investigate the effect of fracturing directly using finite difference models in which fractures are defined explicitly as displacement discontinuities with opposing surfaces connected by a normal and shear stiffness. An individual fracture acts somewhat like a low pass filter: more complex frequency behaviour emerges from multiple fractures, particularly when fracture stiffness, spacing and size can vary. We concentrate first on large horizontal fractures perpendicular to the borehole receiver array, and find that these can indeed influence effective attenuation within the 25-90Hz bandwidth. We then discuss the range of fracture spacings and stiffnesses capable of explaining the data and whether they are sufficiently physically credible as an explanation of the observed Q(f).