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Compressional wave velocities and attenuation of saturated geothermal rocks during a liquid-steam phase transition

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As geothermal reservoirs are exploited, a liquid water-steam phase transition controlled by fluid pressure draw-down can lead to time variations in seismic velocities and attenuation. To infer reservoir properties from measured seismic properties (velocity and attenuation) changes, validated rock physics models are essential.

In this work, both temperature dependence and liquid-steam phase transition experiments for an analysis of core-scale properties of rock samples at simulated reservoir conditions were performed to characterize the effects of both temperature and phase transition on the seismic velocity and attenuation behavior (Milsch et al., 2010, Kristindóttír et al, 2010, Jaya et al., 2010). One sample was selected from cores recovered from wells in the Hengill geothermal field, Iceland. During a temperature dependence experiment focussed on electrical rock conductivity, additionally, P-wave signals were recorded while keeping both confining and pore pressure constant. For the liquid-steam phase transition experiment both temperature and confining pressure were kept constant while pore pressure was decreased to boil the pore fluid in a controlled manner (Kristinsdóttir et al., 2007, Milsch et al., 2010).

The temperature dependence measurements showed that P-wave velocities decrease with increasing temperature in a systematic way that generally fits the predictions of the Gassmann relationship, implying that fluid characteristics, with modifications that allow for the presence of bubbles and microfracturing, account for much of the seismic velocity changes. The Q factor (inverse of attenuation) is affected by temperature through the viscosity of fluids and the formation of bubbles and thermal microfracturing. The observed increase in the Q factor at lower temperatures is related to a rapid drop in fluid viscosity as the temperature increases. A decrease of the Q factor at higher temperatures may be due to the formation of bubbles and microfractures that decrease the effective elastic moduli.

In the phase transition measurement, P-wave velocities did not increase immediately with a pore pressure decrease but with some retardation at the liquid-steam phase transition. P-wave velocities in the steam phase are higher than in the liquid. This is more likely due to the fact that the effect of a bulk modulus change is larger in the steam phase than in a liquid one as effective pressure (difference between confining and pore pressures) tends to increase. In contrast, relative P-wave amplitudes did not decrease immediately with a pore pressure decrease but with some retardation at the liquid-steam phase transition. P-wave amplitudes are smaller when the pore pressure medium is steam and greater near the phase transition. The decrease of the P-wave amplitude which indicates the attenuation behavior may be related to the viscosity change at the phase transition. Our results show that both seismic velocity and attenuation may be used as diagnostic tools to estimate the temperature and phase state dependence of seismic properties.

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