Temperature-Dependent Fluid Substitution Modeling of Geothermal Rocks

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Summary

In geothermal reservoirs, fluid-steam phase transition, fluid pressure and temperature are some crucial factors that potentially produce and/or contribute to seismic anomalies. When interpreting such anomalies, realistic assumptions based on validated rock physics models are important. An analysis of core scale properties of rock sample at in-situ reservoir conditions is useful to identify the role of temperature on the seismic velocity and attenuation.

An analysis of two rock samples, hyaloclastites and basalts, at in-situ reservoir conditions has been done to identify the role of temperature on the seismic velocity and attenuation (expressed as an inverse of the Q factor). The goal is to present the result of using Gassmann equation within the framework of Biot's poroelasticity for a fluid substitution analysis of geothermal rocks. The analysis of temperature-dependent wave attenuation is shown for hyaloclastites.

The result of P-wave analysis for both samples shows that the seismic velocities decrease with the temperature in a systematic way. The general decreasing trend of seismic velocity towards temperature may be related to the fluid characteristics with the temperature. Using Gassmann equation it has been shown that the presence of a small fraction of steam bubbles can reduce the effective elastic property of rocks which lowers the seismic velocity. The deviation of temperature-dependent fluid substitution modeling of hyaloclastites (compared to basalts) can probably indicate that the grain material of basalts exhibit more homogeneous structure than those of hyaloclastites.

The Q factor behaves surprisingly almost in the same way as the seismic velocity with temperature, except in the lower temperature range. In this range, the Q factor unexpectedly increases which is probably due to the coupled effect of a quick fluid viscosity decrease and of stiffening the rock skeleton due the increase of the fluid velocity. The decrease of Q factor may indicate the presence of steam bubbles due to the further temperature increase.

In the fluid-steam phase transition, the P-wave velocity and attenuation are also diagnostic towards the degree of steam build-up. The presence of steam seems to reduce the elastic property of the rock which reduces in turn the velocity and cause a strong attenuation.

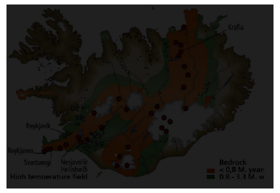
This finding demonstrates that the application of temperature-dependent Gassmann fluid substitution modeling may be used for the characterization of geothermal reservoir systems.

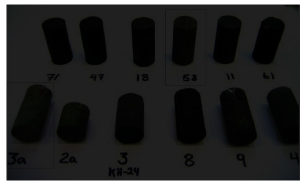
New Aspects Covered

1. Laboratory measurement of temperature-dependent seismic properties, i.e., velocity and attenuation, at in-situ geothermal reservoir conditions.
2. Application of temperature-dependent Gassmann equation for fluid substitution analysis of geothermal rocks.
3. Relationship of thermophysical characteristics of fluid to the temperature-dependent attenuation behaviour of geothermal rocks.
4. Seismo-acoustic signatures of temperature-dependent and fluid-steam phase transition of geothermal rocks at in-situ reservoir conditions.

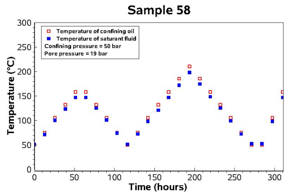
Samples

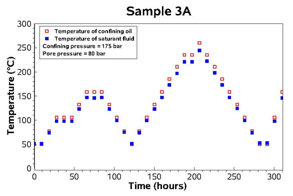
The rock samples came from the cores of geothermal well in Krafla (N-Iceland) and Hengill (SW Iceland). The sample from Krafla (sample 58) is a basalt rock with smectite alteration. The sample from Hengill (sample 3A) is a hyloclastite rock with a chlorite alteration.





Temperature-Dependent Experiment

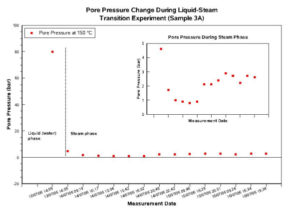


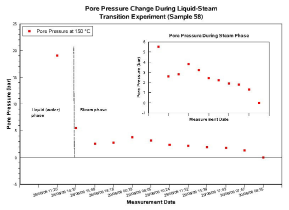


Sample	P_c*(bar)*	P_f*(bar)*
58	50	19
3A	175	80

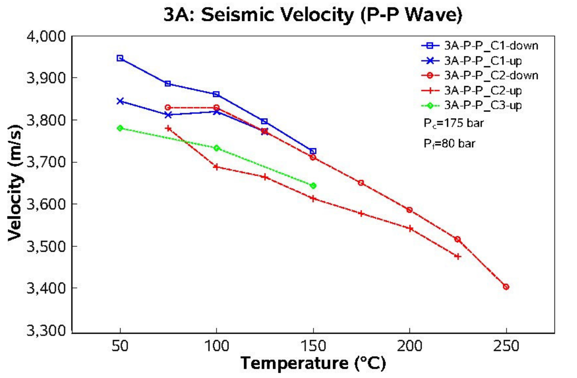
Fluid-Steam Transition Experiment

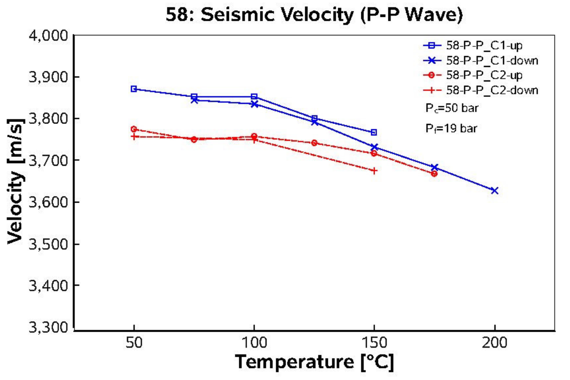
The experiment proceeded as follows: Ultrasonic transmission wave was measured during the course of steam-liquid transition at constant confining oil and pore-filling water temperature of approx. 150 °C.



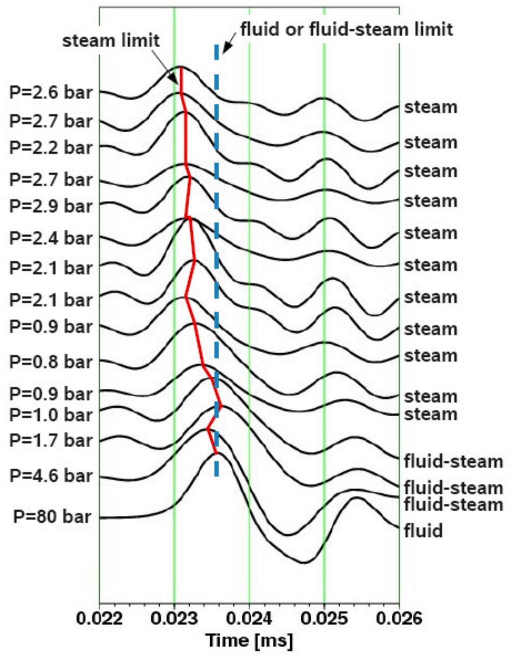


Temperature-Dependent P-Wave Velocity





Fluid-Steam Phase Transition



Fluid Substitution Analysis

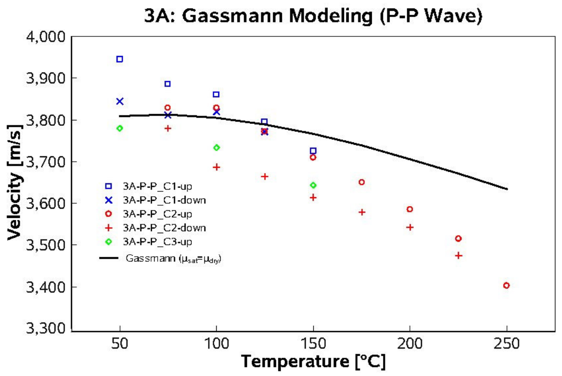
$$K_{sat} = K_{dry} + \alpha^2 \frac{K_g}{\left(1 - \frac{K_{dry}}{K_g}\right) - \phi\left(1 - \frac{K_g}{K_f}\right)}; \qquad \mu_{sat} = \mu_{dry}$$

$$\alpha = 1 - K_{dry} / K_g$$

$$\rightarrow \quad K_f = \rho_f(T)\left[v_f(T)\right]^2$$

$$\rightarrow \quad v_P = \sqrt{\frac{K_{sat} + \frac{4}{3}\mu_{sat}}{\rho_{sat}(T)}} \qquad \rho_{sat}(T) = \rho_{dry} + \phi\rho_f(T) > \rho_{dry}$$

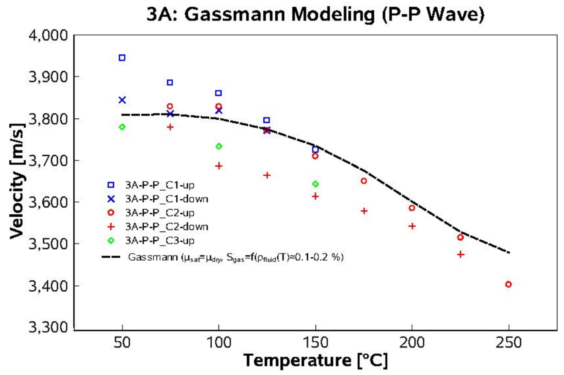
- **First Modeling:**
  - Sideromelane (basalt glass) is the dominant constituent of hyaloclastites (Furness, 1974)
  - Measurement of elastic properties of basalt glass of Pan et al. (1998)



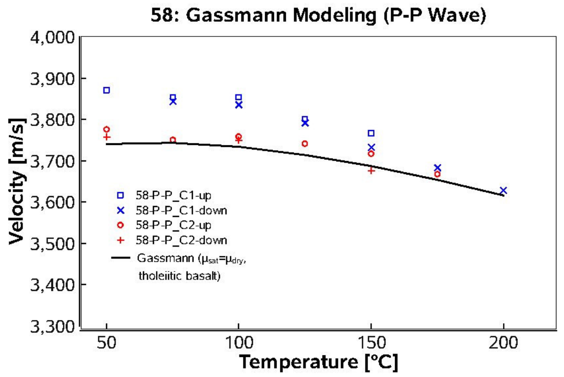
- **Second Modeling:**
  - Mixture of fluid water with a very small fraction of steam bubbles

$$K_f(T) = \frac{K_w(T)K_{gas}(T)}{(1 - S_{gas})K_{gas}(T) + S_{gas}K_w(T)}$$

$$S_{gas} = 1 - \left|\frac{\rho_f|_{T \geq 25°C}}{\rho_f|_{T = 25°C}}\right|$$

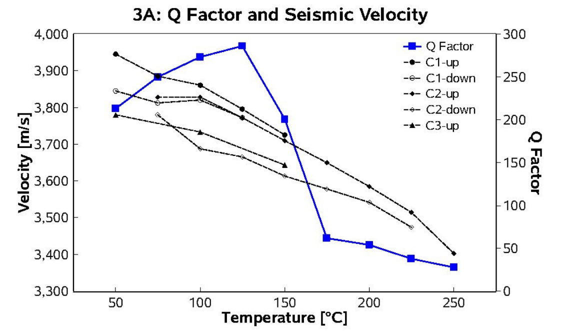


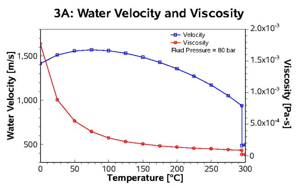
K_g *(GPa)*	K_{dry} *(GPa)*	μ_{sat} *(GPa)*	Φ *(%)*	ρ_{dry} *(kg/m³)*
66.38	12.313	11.13	20.7	2150

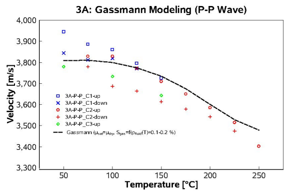


K_g *(GPa)*	K_{dry} *(GPa)*	μ_{sat} *(GPa)*	Φ *(%)*	ρ_{dry} *(kg/m³)*
92.18	13	11.16	20	2370

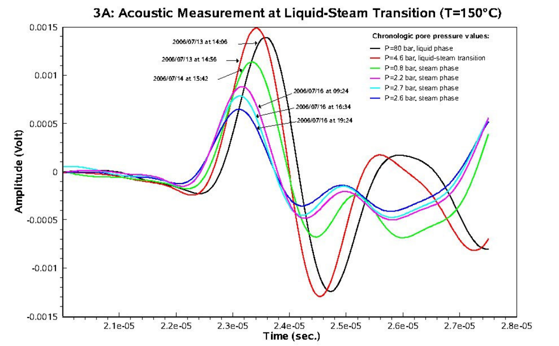
Temperature-Dependent Attenuation

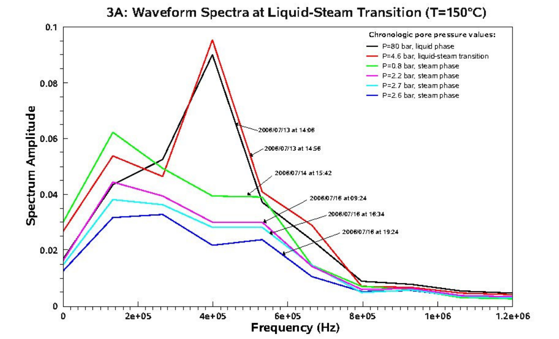






Attenuation at Fluid-Steam Transition





Acknowledgement and Contact Information

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