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Elastic Properties and Mechanical Stratigraphy in a Potential Geothermal Reservoir in the MH-2B Borehole Near Mountain Home, Idaho, USA.

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Summary

The western Snake River Plain is a region of high crustal heat flow with the potential for commercial geothermal energy development. A high temperature (~140°C) artesian flow zone was encountered in basalt at a depth of 1,745 m (5,726 ft) in the MH-2B borehole on the Mountain Home Air Force Base, Mountain Home, Idaho, USA. Elastic and mechanical properties of rocks are paramount to understanding fracture permeability in crystalline reservoirs. Unconfined uniaxial compressive stress experiments on 110 core samples over a 480 m (1,576 ft) interval of the borehole are used to describe the variability in physical properties, elastic properties, and compressive strength of the rocks surrounding the geothermal reservoir. We describe 9 mechanical stratigraphic units in intervals. Three sections of ductile, low-permeability, highly altered, reworked basalt and basalt sands are present that vary from 21 m (70 ft) to 49 m (160 ft) thick. Samples from the ductile lithology have a mean density of 2.09 ± 0.01 g/cm^3, a mean uniaxial compressive strength of 43.5 ± 7.7 MPa, a mean Young's modulus of 10.3 ± 0.77 GPa, and a mean Poisson's ratio of 0.09 ± 0.03. The ductile units are interbedded with three intermediate units and three brittle units of unaltered basalt that contain the geothermal reservoir and vary in thickness from 62 m (205 ft) to 93 m (340 ft). The brittle basalts have a mean density of 2.89 ± 0.07 g/cm^3, a mean uniaxial compressive strength of 149 ± 15.1 MPa, a mean Young's modulus of 68.9 ± 22.8 GPa, and a mean Poisson's ratio of 0.25 ± 0.04. Pneumatic permeability measurements were taken parallel to the axis of compression as a first-order estimate of matrix permeability. Matrix permeability of the ductile units is typically ~ 5 mD while the brittle units are < 5 mD. It is common practice to calculate compressive rock strength and elastic moduli in pilot and exploration wells from shear and compressional ultrasonic acoustic velocities and rock density. The borehole was logged with a full suite of borehole geophysical tools that measured a variety of lithological properties including full wavetrain sonic velocities from which we calculate dynamic properties. We also calculate dynamic properties from acoustic velocities measured in the lab on the samples used in the UCS experiments from which we calculated the static properties.

Introduction

The geological formations studied here are obviously not sedimentary. However, this study is of interest for unconventional resource exploration and exploitation in the sense that, like many of the 'shales' undergoing stimulation, the rocks studied here are strong and of low permeability. As such, their behaviour is similar to many unconventional reservoirs and studies of in situ stress and fractures can be a useful analog particularly because of the paucity of materials available for study from unconventional reservoirs.

The MH-2B borehole is located in the western Snake River Plain, Idaho in an oblique-extensional basin that has formed during complex interaction of the North American plate passing over the Yellowstone Hotspot in the mid-Miocene and initiation of extension in the Basin and Range. High angle normal faults bound the basin to the north-northeast and to the south-southwest. The MH-2B borehole was cored between June, 2011 and February, 2012 on the Mountain Home Air Force Base outside Mountain Home, Idaho. Whole-rock core was recovered from the entire depth of the borehole with greater than 90% recovery. A large set of fracture data and core samples are available for analysis. A zone of interest (ZOI) is identified from ~ 1,200 m (~4,200 ft) bgs to a total depth (TD) of 1,821 m (5,976 ft) bgs that includes the artesian thermal zone. 110 core samples are collected over the ZOI at 55 different depth locations. Two samples were collected at each location in order to determine the reproducibility of the test results to measure mechanical properties and describe the variability of mechanical properties between adjacent samples. The static elastic properties calculated from results of the UCS experiments will provide the foundation for a subsequent in-depth geomechanical analysis that will compare the static elastic properties to dynamic elastic properties calculated from wellbore geophysical log data.

Method

Here we utilize strain measurements made during unconfined uniaxial compressive stress (UCS) experiments on core samples from the MH-2B borehole near Mountain Home, Idaho. The experiments took place at the Experimental Geophysics Group laboratory at the University of Alberta in Edmonton, Canada. From the strain data, we calculate uniaxial compressive strength (UCS), Young's modulus (E), and Poisson's ratio (ν). Those elastic properties provide the data needed to predict which samples in the MH-2B borehole will experience brittle failure and fracture catastrophically and those that experience ductile failure and do not experience brittle fracture under in-situ stress conditions. We also utilize sonic acoustic velocity data from full-waveform wireline logs over this interval. Below 1,670 m (5,480 ft) to TD where temperatures precluded logging, we use ultrasonic pulse velocities from laboratory measurements taken on samples that are the same as those in the UCS experiments described above. We lack bulk density logs in the wireline log suite so we use bulk density measured on the UCS samples in lieu of continuous log density data. The combination of compressional sonic velocity, shear sonic velocity, and bulk density is used to calculate Poisson's ratio (v), Young's modulus (E), and uniaxial compressive strength (UCS).

Results

The elastic properties and fracture data are distributed over the ZOI in the MH-2B borehole in 9 discrete mechanical units (Figures 1 and 2). The mechanical units are defined by the distribution with respect to depth of density, uniaxial compressive strength, Young's modulus, Poisson's ratio, pneumatic permeability, fracture density, and cumulative fracture intensity in the sample population. While the samples that failed catastrophically are confined to the most brittle rocks in the borehole, we consider the absence of catastrophic failure as a qualitative descriptor of the mechanical nature of the rocks in those zones. Generally, we consider an absence of catastrophic failure as an indicator of ductile behavior dominating the deformation process up to the elastic limit and until failure at the maximum sustained stress load. The lowermost brittle unit (unit 1) hosts the potential geothermal reservoir. The overlying unit (Unit 2) is a ductile unit and is considered as a caprock to the reservoir that may confine the fracture distribution in the lower brittle unit and may also contain thermal fluids. We also show that the method to measure the elastic properties using density and sonic velocities is effective in identifying the ductile units. The results of the calculations made from sonic velocities do not have the resolution do identify the intermediate brittle units from the strongly brittle units but do a good job of identifying the ductile units (Figure 2). We are currently working to show that similar calculations from ultrasonic pulse velocities made in the laboratory are as effective as using sonic velocities from borehole wireline log data.

Conclusions

Whole rock core recovery and borehole acoustic televiewer data provide an excellent opportunity to study the lithology, physical properties, and elastic properties in the MH-2B borehole and relate those properties to the natural fracture systems. Results of unconfined uniaxial compressive stress experiments on core samples provide measurements of uniaxial compressive strength, static Young's modulus, and static Poisson's ratio. Core samples provided us the opportunity to measure physical properties: dry bulk density and pneumatic permeability. We examined the variability of those properties and correlated the variations to fracture density and spacing, or cumulative fracture intensity, measured from both core and borehole acoustic televiewer data. Through interpretation of the correlations of all the data sets we identified 9 unique mechanical stratigraphic units. Three of those units (2, 5, and 7) exhibit ductile deformation under uniaxial compressive stress and did not demonstrate significant brittle failure in the UCS experiments. Fracture measurements from core and acoustic televiewer data indicate little to no natural fractures in Units 2, 5, and 7. We also used ultrasonic velocity measurements to make calculations of the elastic properties from wireline log data and ultrasonic pulse velocities measured in the laboratory. The calculations effectively identified the ductile units that demonstrate that the method can be used in future exploration wells to identify the unit 2 caprock that overlies the potential geothermal reservoir.

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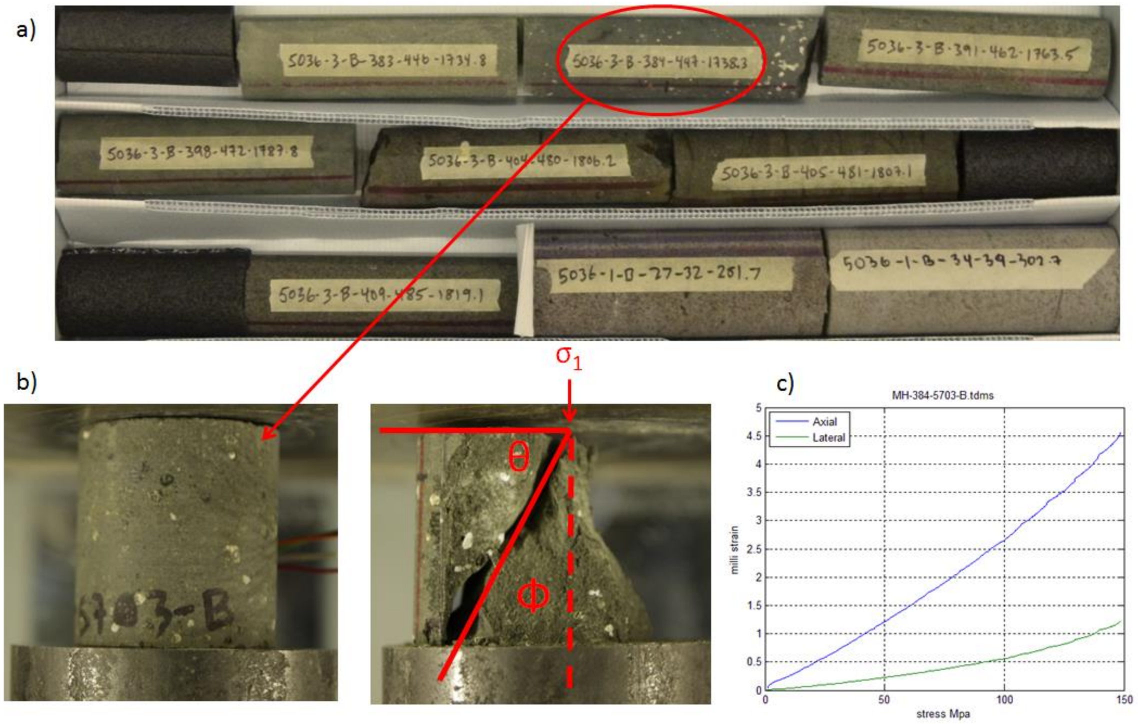

Figure 1. Sample photos showing failure angles for cohesion calculations and stress-strain relationship

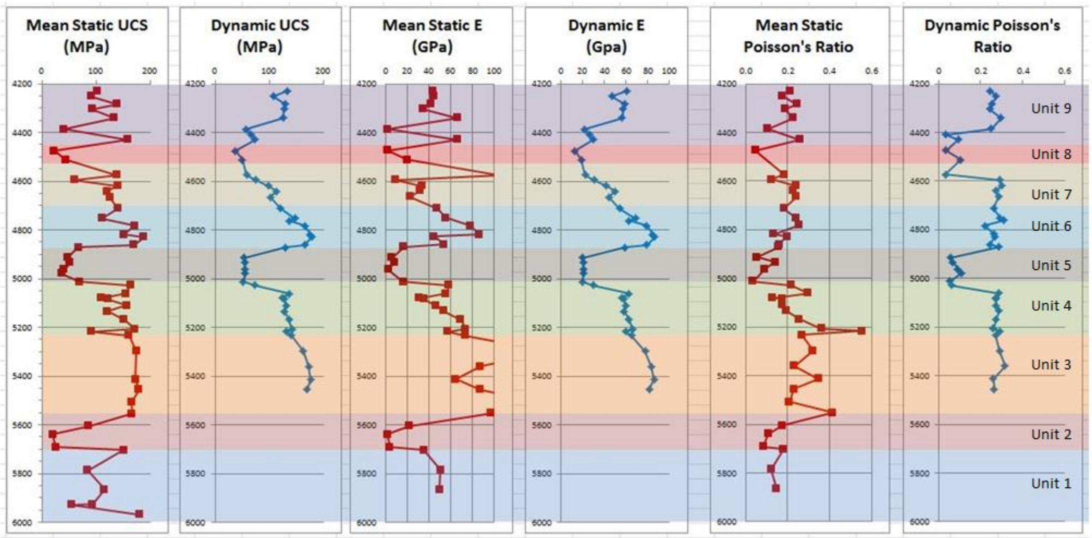

Figure 2. Static vs Dynamic Elastic Properties with Mechanical Stratigraphy