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Breakthroughs in Seismic and Borehole Characterization of Continental Flood Basalt Sequestration Targets

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Mafic continental flood basalts form an important, but undercharacterized CO_2 sequestration target. In the northwestern U.S., the Columbia River Basalt Group is up to 5 km (16,000 ft) thick and covers 168,000 km^2 (65,000 mi^2). Brecciated tops of individual flows form regional aquifers that locally have greater than 30 percent porosity and three Darcies permeability; aquifer-storage projects demonstrate annual injection rates of multi-million metric tons (up to 500 million gallons). Basalts are potential sites for sequestration of gigatons of supercritical (sc) CO_2 in areas where the flow tops contain unpotable water at depths greater than 800 m (2600 ft).

In laboratory experiments, basalts react with formation water and $scCO_2$ to precipitate carbonates, adding a potential mineral-trapping mechanism to conventional hydrodynamic and dissolution trapping mechanisms. The DOE's Big Sky Regional Carbon Sequestration Partnership has conducted a 3C surface seismic experiment and a bore-hole characterization study in support of a field test of capacity, integrity, and geochemical reactivity of basalt reservoirs near the town of Wallula in eastern Washington, U.S.A.

Surface-based seismic data are critical in reducing uncertainties associated with site selection, reservoir models, and time-lapse monitoring of injected CO_2 of commercial-scale projects. Traditional surface-seismic methods have had little success in imaging intra-basalt features in on-shore areas where the basalt has a thin sediment cover.

Processing of the experimental 6.5 km (4 mile), 5 line 3C swath included constructing an elastic wavefield model, identifying and separating seismic wave modes, and processing the swath as a single 2D line. Our most important findings are: - A wide variety of shear-wave energy modes swamp the P-wave seismic records.
- Except at very short geophone offsets, ground roll overprints P-wave signal.
- Because of extreme velocity contrasts, P-wave events are refracted at incidence angles greater than about 7-15 degrees.

The open- and cased-hole wireline log suite includes full waveform sonic and resistivity-based image logs, as well as a pulsed-neutron reservoir saturation log for comparison with post-injection saturation signatures. Analyses of the P and S wave form modes integrated with the image log data yield geomechanical insights. Of particular interest is the azimuth of the fast shear mode, which is parallel to the horizontal component of maximum compressive stress. The integrated data yield a record of basalt-flow orientation as well as changes in tectonic-stress regimes. This integration provides new bore-hole techniques for assessing basalt emplacement and cooling events that are related to the development of flow-top reservoirs and seals, as well as mapping of tectonic stresses and fracture systems that could affect CO_2 transport or containment.