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A feasibility study of time-lapse seismic monitoring of CO_2 sequestration in a layered basalt reservoir

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A B S T R A C T

We investigate the potential of scattered seismic waves to remotely sense geological sequestration of CO_2 in basalt. Numerical studies in horizontally layered models suggest that strong scattering quickly complicates the wave fields, but also provides a sensitive tool to monitor physical changes in and around the reservoir. These results go hand-in-hand with recent laboratory work and rock-physics modeling that has shown significant changes in the seismic properties of a reservoir undergoing CO_2 sequestration, due to fluid substitution and mineral precipitation.

Contents

1. Introduction

Storage of carbon dioxide (CO_2) in the subsurface may provide a large-scale option to reduce its emission into the atmosphere. The effectiveness of sequestering CO_2 into deep reservoirs depends on the reservoir storage capacity, stability and risk of leakage (Benson and Cole, 2008; Davis et al., 2003; Holloway, 2001; Rochelle et al., 2004; Torp and Gale, 2004;). In basalt, rock–fluid chemical reactions leading to the precipitation of carbonate minerals would reduce the risk of leakage (Gislason et al., 2010; Matter et al., 2007; McGrail et al., 2006; Oelkers et al., 2008; Rogers et al., 2006; Schaef et al., 2010). When this reaction occurs, changes in the elastic properties of basalt will be the combination of fluid substitution of water with CO_2 and carbonate precipitation. Quantifying these elastic changes helps determine the feasibility of remotely monitoring the reservoir with seismic waves.

In addition to the apparently favorable chemical conditions for CO_2 sequestration, flood basalts are also widespread around the world and

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can potentially host large amounts of CO_2 (McGrail et al., 2006). Fig. 1 shows the extent and volume of the Snake River Plain Basalts (SRPB) and the Columbia River Basalts (CRB).

Seismic methods are widely used to remotely monitor changes in reservoir rock properties, and commonly applied in oil and gas reservoir characterization. However, layered basalts pose a considerable challenge to subsurface imaging, mostly due to strong scattering from the sharp impedance contrasts between basalt flows and sedimentary inter-beds (Jarchow et al., 1994; Kumar et al., 2004; Pujol and Smithson, September, 1991). In this paper we explore how scattered waves in such a high impedance contrast environment can be used to monitor elastic property changes within layers. We model our seismic data based on the elastic properties of basalt flows with inter-bedded sediments from well logs from CRB at the Hanford site (Washington State, USA, (Rohay and Reidel, 2005)). The values of velocity and density in each layer are from the blocked sonic and density logs. Fig. 2 shows the velocity-density model with the sonic log overlaid, and it can be seen that sedimentary interbeds (white layers) have a significantly lower density and velocity than the basalt flows (gray layers).

We first explore the anticipated changes in the seismic velocities due to fluid substitution. Second, we present the theory for monitoring velocity perturbations with scattered waves, and finally we model time-lapse seismic on three layered subsurface models, using the predicted velocity changes in the reservoir.

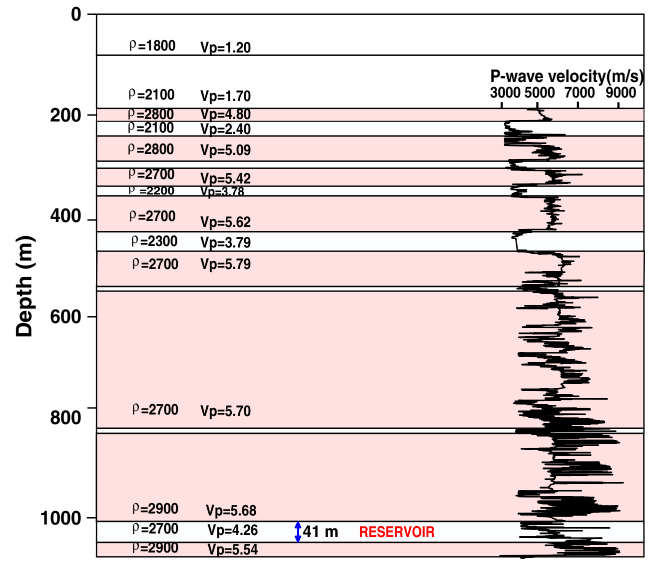

Fig. 2. Schematic diagram of multi-layered geological model. Units of density and velocity are in kg/m^3, km/s, respectively. The model parameters are estimated by averaging layers from the sonic log shown.

2. Changes in the elastic properties

Changes in the elastic properties of basalts undergoing CO_2 sequestration are a combination of fluid substitution of water with supercritical CO_2, as well as carbonate precipitation. Quantifying these elastic changes remotely with seismic waves will determine the feasibility of effectively monitoring the reservoir. Before we model the wave propagation, we first discuss the anticipated changes in seismic velocities.

2.1. Mineralization

Mineralization of CO_2 into carbonate minerals occurs from the combination of water-carbon dioxide mixtures and divalent metal cations (Ca^{2+}, Mg^{2+}, Fe^{2+}). These cations can be present in low concentrations in formation waters. However, host rocks rich in such metals with high dissolution rates are the target for long-term sequestration and mineralization. Basalt rocks are rich in Ca,

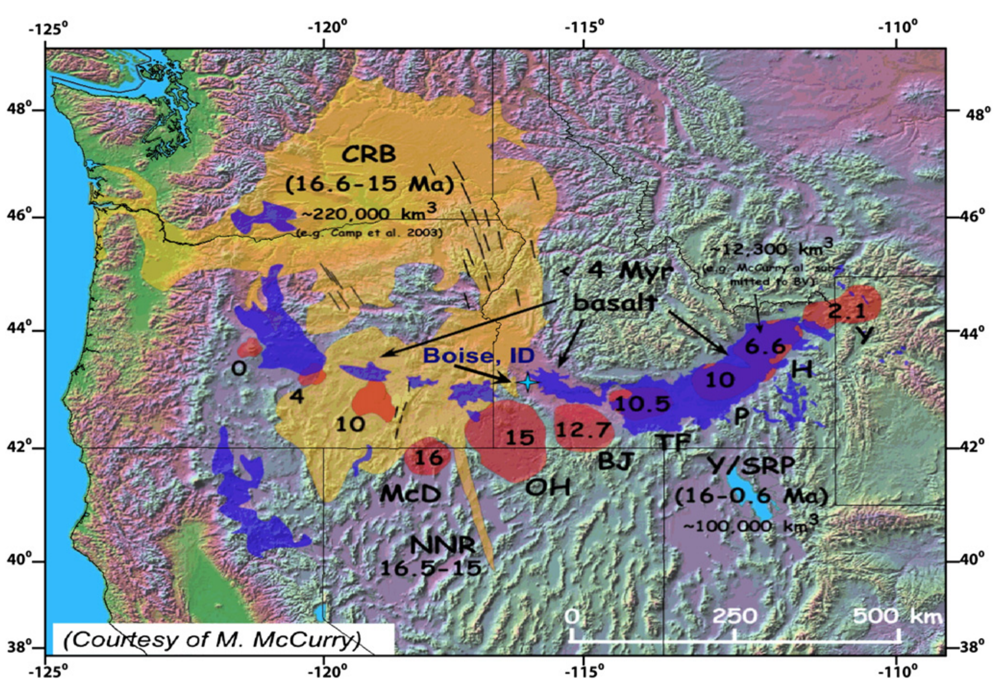

Fig. 1. Location and extent of the Snake River Plain (SRP) Basalt, Columbia River Basalt (CRB) and Northern Nevada Rift (NNR) Basalt. The numbers indicate the age of the basalt in millions of years. The sub-groups within the SRP Basalt are defined by time of eruption of the Yellowstone hotspot, from older to younger: McDermitt (McD), Owyhee–Humboldt (OH), Bruneau–Jarbidge (BJ), Twin Falls (TF), Picabo (P), Heise (H) and Yellowstone Plateau (Y). The volume of the CRB and the SRP basalt are referenced.