

Seismic reflection imaging of hydrostratigraphic facies in Boise: A tale of three scales

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Summary

We have acquired, processed and interpreted seismic reflection data from the Boise Valley at three scales to help build a hydrostratigraphic model for regional groundwater studies and to better understand the hydrostratigraphic significance of seismic boundaries. We use existing industry seismic reflection data to identify the structural and stratigraphic framework of the western Snake River Plain, a normal-fault bounded basin that contains more than 2 km of Neogene and younger sediments. To directly tie structure and stratigraphy to water well lithology and geophysical logs, we have acquired seismic reflection data throughout Boise to image near-surface sediments, where prograding delta and fluvial sediments control groundwater flow. To correlate seismic boundaries to hydrologic properties in Boise, we have also acquired seismic reflection data from a highly characterized wellfield. We find the seismic boundaries directly correspond to bulk changes in porosity at this site. Seismic reflection data from these three scales better define basin morphology and help map discrete hydrostratigraphic units necessary to understand hydraulic connectivity, groundwater flow directions, and aquifer capacity in the Boise Valley.

Introduction

Groundwater resources in the Boise Valley are limited. Mapping hydrostratigraphy and identifying hydraulic connectivity between and within sedimentary units is critical to assessing this valuable resource. Seismic methods are often used to assist with groundwater studies because large-scale permeability changes can occur at lithologic boundaries, and seismic velocity contrasts generally appear at these same boundaries.

The Boise Valley is part of the western Snake River Plain (WSRP), a fault-bounded extensional basin in southwest Idaho and eastern Oregon (Figure 1). The basin contains Neogene and younger fluvial and lacustrine sediments deposited from rising and falling lake levels of relic Lake Idaho (Figure 1). Sand layers and channels were deposited within deep-water mudstones (Wood, 1994). These sand units are targets for groundwater production in the valley. Unfortunately, the sands are often discontinuous and connectivity between aquifer units is poorly understood. In addition to the complex geometry of the sands, structural downwarping and faulting in the basin further complicate the stratigraphy. For example, a typical 4 degree dip shifts the stratigraphy approximately 70 m between wells spaced 1 km. Water wells rarely extend greater than 100 m depth

and are often at greater distances. In addition, faults with greater than 200 m of vertical offset are observed in the basin (Wood, 1994; Liberty, 1998), suggesting lithology between water wells may be complex and that each well may record a unique stratigraphic sequence.

To address the problems of mapping complex stratigraphy and structures in the WSRP for groundwater resource assessment, we are compiling existing seismic reflection data and geophysical and lithologic logs to gain a regional understanding of the depositional style of the basin (Figure 2a). We are also acquiring and processing new seismic reflection data (Figure 3a) to better understand and map the subsurface stratigraphy in the upper 500 m below land surface (BLS) where groundwater resources are economically viable. Finally, we are conducting a series of surface and borehole seismic studies at a highly characterized research wellfield in Boise to better understand the significance of seismic boundaries for detailed hydrogeologic studies. By combining the geology and geophysics at these three scales, we are building a geologic framework to support planning for future groundwater needs for the growing Boise metropolitan area.

Basin-Scale Studies

Interest in the WSRP for petroleum and geothermal resources in the 1970s has yielded several hundred km of seismic reflection data and has provided great insight into the depositional and extensional history of the basin. In particular, a 1972 Chevron USA Vibroseis seismic reflection profile through Boise (Figure 2) provides a

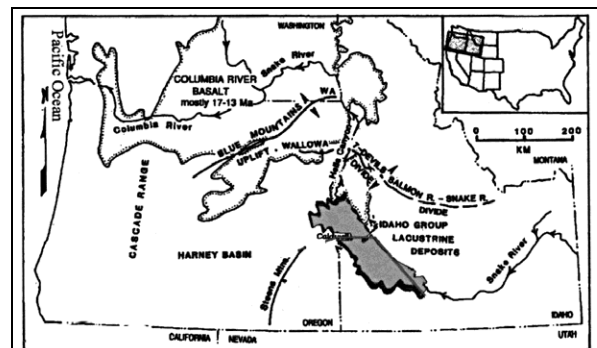


Figure 1. Regional map showing the location of the western Snake River Plain. We are acquiring new seismic reflection data primarily in the Boise metropolitan area.

A Tale of Three Scales

The seismic reflection data show that the hydrostratigraphy cannot be mapped between major water wells more than 1 km apart (Figure 3) and that the seismic reflection data are critical to mapping hydrostratigraphic and structural detail relevant to groundwater management in Boise.

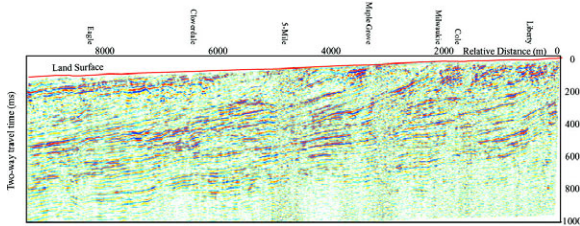


Figure 3a. Seismic reflection profile along the UPRR in southeast Boise. The profile parallels Chevron profile IB-2 further to the south.

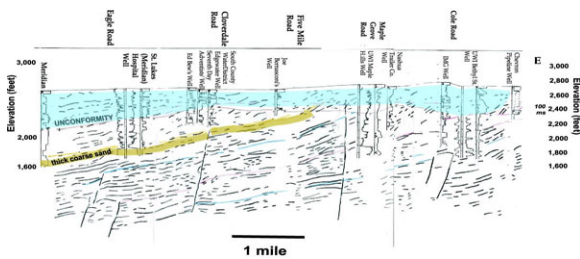


Figure 3b. Interpreted seismic reflection profile along the UPRR with well log information.

Meter-Scale Field Site

The Boise Hydrogeophysical Research Site (BHRS) is a research wellfield containing 18 cored wells which extend through a 17 m thick cobble-and-sand aquifer that is underlain by a continuous red clay layer. The BHRS is located on a gravel bar immediately adjacent to the Boise River where the river leaves a canyon and enters the WSRP. Ground penetrating radar (GPR) profiling indicates that the cobble-and-sand aquifer at the site consists of a sequence of deposits separated by subhorizontal bounding surfaces (Peretti et al., 1999). We established the BHRS to develop methods for mapping variations in permeability by combining information from hydrologic and non-invasive geophysical techniques (Barrash et. al, 1999; Clement et al., 1999). By identifying the seismic methods that can image lithologic boundaries in this difficult seismic environment, we can begin to map the three-dimensional distribution of lithologic and hydrologic properties at this site and better assess the role of seismic methods in mapping permeability in similar geologic environments.

To investigate the seismic character at the BHRS, we conducted a series of seismic experiments with a variety of source-receiver geometries, seismic sources, and receivers (Liberty et al., 1999; Liberty et al., 2000). Here we show a shot from a crosswell seismic survey at the BHRS (Figure 4) that correlates seismic velocities to borehole geophysical logs (e.g., neutron), and identifies the nature of reflectors that appear with both surface and borehole seismic studies.

Figure 4 shows an unprocessed and processed crosswell seismic shot from 21 m depth. We recorded shots at a 0.15 m depth spacing and receivers at a 0.10 m depth spacing below the water table (approximately 2.4 m below land surface) to the maximum depth in each well (approximately 20 m depth). Distinct first arrivals and reflections appear in the unprocessed shot from all downhole, source-receiver pairs (traces) below the water table. We picked all first arrivals for tomographic velocity analysis and used wave field separation techniques to separate upgoing and downgoing reflection energy for subsequent reflection processing.

The crosswell shot (Figure 4) shows three distinct reflections in the upper 5 m of the section, from the land surface, water table (at 2.4 m depth), and from approximately 4.5-5 m depth. Also, reflections appear later in the section at approximately 13 m, 17.5 m, and 21 m depth (reflection from 21 m correlates with the basal clay and does not appear on this shot gather due to source/receiver geometry). Each reflection is distinct and closely ties with hydrostratigraphic boundaries that appear on geophysical logs. For example, the transparent zone (no coherent reflections) that appears between 4.5-10 m depth corresponds to the high velocity/low porosity zone defined with the tomogram and the neutron-derived porosity logs (Figure 4). The zone between 10 and 21 m depth contains variable reflection quality that correlates with changes in porosity and the lithology of mostly cobbles with some sand lenses. When we invert the level run data set (source and receivers at the same depths between two wells), we see that seismic velocities strongly correlate with neutron-derived porosity values at this site (Figure 4).

A Tale of Three Scales

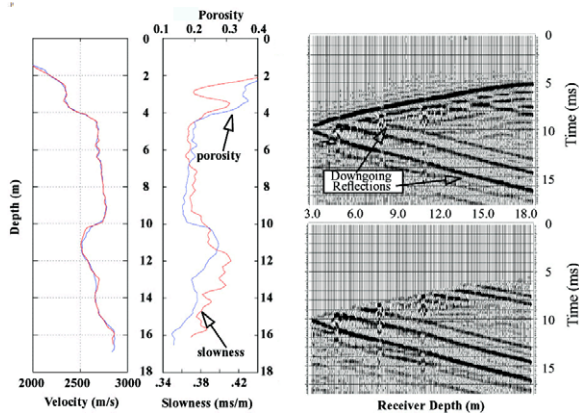


Figure 4. Results from a crosswell seismic reflection survey showing level run velocity logs, a comparison of slowness (1/velocity) vs. neutron-derived porosity values, and an unprocessed and processed (wavefield separation) shot gather from 21 m depth with 12.7 m borehole spacing. Note the strong correlation between seismic boundaries and porosity.

Conclusions

We show that seismic reflection methods are well suited for mapping hydrostratigraphy and structure on both a basin scale and aquifer scale to better understand the framework for groundwater flow in the WSRP. Also, we have successfully acquired seismic reflection data at the BHRS to map significant hydrostratigraphic boundaries in a shallow cobble-and-sand fluvial aquifer. The results of our study show that reflections are mainly controlled by changes in porosity. Although interbedded sands and mudstones dominate the deeper geology of the WSRP, this study shows that we can also map hydrostratigraphy at meter-scale at this shallow site.

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