Treasure Valley Seismic Reflection Project - UPRR 2000 Profile

Report Prepared for the Idaho Department of Water Resources

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1.0 Summary

We have acquired approximately 12 km of seismic reflection data along the Union Pacific railroad in southwest Boise to help build a hydrostratigraphic model for regional groundwater studies and to better understand the hydrostratigraphic significance of seismic boundaries. High quality continuous reflections appear in the upper 900 m below the subsurface where we find prograding delta and fluvial sediments that influence groundwater flow and capacity. We find numerous faults that can inhibit lateral groundwater flow, a regional unconformity in the upper 150 m, fluvial channels, and reflections from sediments that contain apparent dips to the west of up to 10 degrees in the upper 300 m. By combining regional wells with the seismic stratigraphy, we can help parameterize aquifer capacities and flow directions for groundwater models and optimize placement of future water wells. The dip of many near-surface seismic reflections (1-10 degrees) and the presence of near-vertical faults (>65 degrees) that are often flow boundaries suggest deep water wells within this portion of the Boise basin are in several different dipping sands and that seismic reflection profiles provide critical information to the subsurface setting in the western Snake River Plain.

2.0 Introduction

Mapping stratigraphy and identifying hydraulic connectivity between and within sedimentary units is critical to assessing the groundwater resource. Seismic methods are often used to assist with regional and local groundwater studies because seismic reflection techniques can work at a variety of scales (Liberty et. al, 2001). Also, 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 both shallow and deep-water mudstones (Wood, 1994). These sand units are the principal aquifers for groundwater supply in the valley. 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 200 m depth and are often separated by 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.

The Idaho Department of Water Resources is conducting a major effort to map the groundwater resources within southwest Idaho. 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 2). We have also acquired and processed new seismic reflection data to better understand and map the subsurface stratigraphy at the depths where groundwater resources are economically viable. We have focused this year's effort on the region between southwest Boise and Meridian (Figure 3), where few deep water wells are located and the stratigraphy is too complex to tie major hydrostratigraphic boundaries between wells without additional information. The newly acquired seismic reflection data help correlate lithology and geophysical logs between regional water wells and allows us to better understand the subsurface depositional style in the Boise Basin. This report summarizes the acquisition, processing and initial interpretation of the seismic data that we acquired in the summer of 2000.

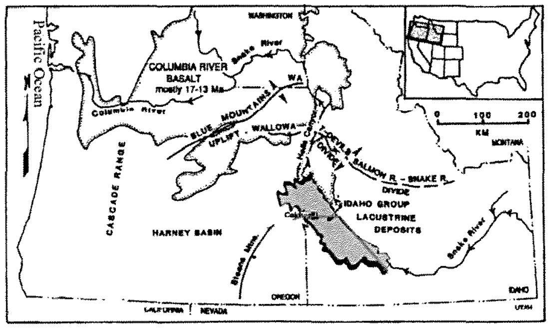

FIGURE 1. Location map of the western Snake River Plain where existing industry seismic reflection data and newly acquired seismic reflection data are being used to characterize the hydrostratigraphic aquifer.

3.0 Basin-scale studies

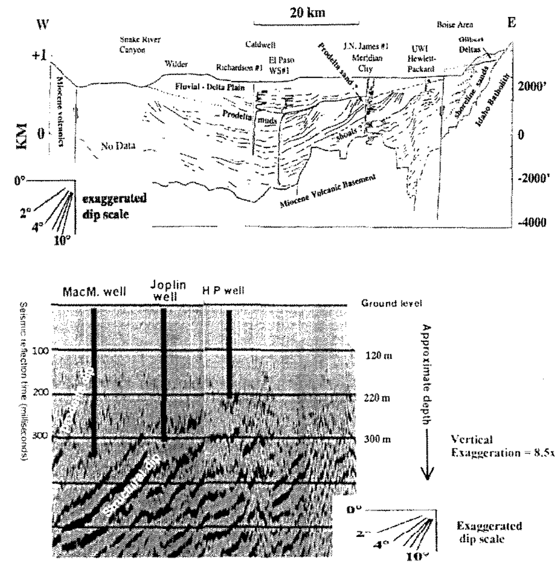

FIGURE 2. (A) Interpreted cross section of Chevron Line IB-2 profile across the western Snake River Plain. (B) A portion of profile IB-2 along the eastern front of the Boise basin. Note the absence of data above 300 m below land surface (figures from Squires and Wood, 2001).

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 (Figures 2 and 3) provides a concise picture of the basin structure and stratigraphy of the WSRP. The reflection data show a package of dipping and offset reflections that are typical of an extensional lacustrine basin. Neogene and younger basin sediments appear in nearby wells with a prograding delta sequence that extends up to 1 km below land surface (BLS). Numerous faults cut basin sediments and may extend to the surface or very near surface. The steep dips, large-offset faults, and varying stratigraphy all complicate the groundwater models for the basin, but provide the necessary framework to characterize the groundwater aquifer system. The industry seismic data offer insights into ground water resources by helping to identify major structural boundaries that may inhibit lateral groundwater flow. The data also shed light into the depositional style and sequence of mudstones, silts, and sands that may locally extend to the near-surface (Squires and Wood, 2001). Unfortunately the basin-scale seismic data do not image the upper 300 m BLS (Figure 2b) due to the acquisition design and processing interests, and much of the seismic data are not available for reprocessing to focus the images on near-surface sediment packages. As a result, we have acquired a series of seismic reflection profiles to provide detailed images of the upper km structure and stratigraphy in Boise to map both the cold water aquifer (e. g. , Barrash and Dougherty, 1997; Liberty, 1997; Liberty et al. , 1999) and the underlying geothermal aquifer (Liberty, 1998). The data summarized in this report add to the growing database of seismic data for the valley. Here we combine the seismic data and lithologic and geophysical logs from nearby wells to map hydrostratigraphy below southwest Boise, a region that has not been previously imaged with seismic reflection methods.

4.0 Union Pacific Railroad Seismic Profiling

4.1 Seismic Reflection Acquisition

In the summer of 2000, we acquired a 10 km seismic reflection profile along the Union Pacific Railroad (UPRR) main line through Boise and an additional 2 km along the northeast-trending spur through southwest Boise (Figure 3). The profile locations provided us

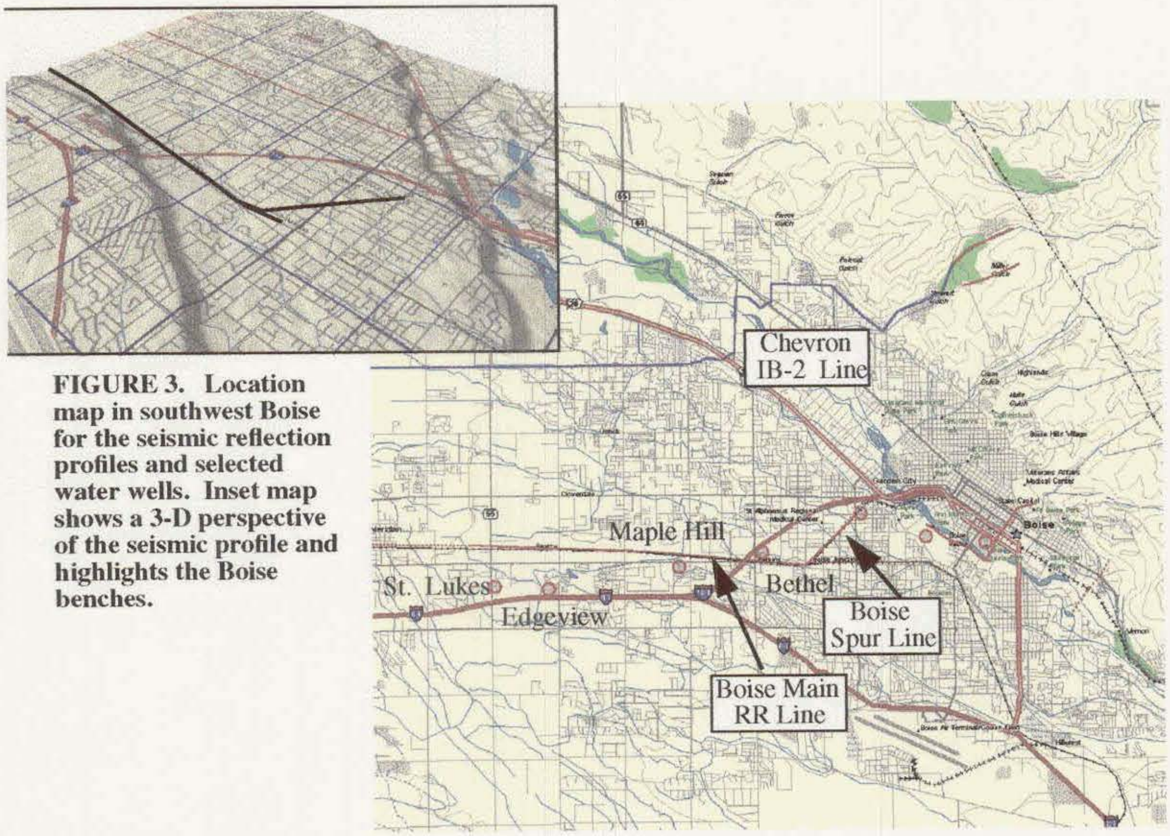

FIGURE 3. Location map in southwest Boise for the seismic reflection profiles and selected water wells. Inset map shows a 3-D perspective of the seismic profile and highlights the Boise benches.

the opportunity to collect straight seismic lines through an urban corridor in southwest Boise. Access for seismic reflection studies can be very challenging through urban areas (e. g. , Liberty, 1998), where either expensive seismic sources (e. g. , vibroseis, air gun, or explosives) are required to overwhelm cultural noise and operate on city streets, or else creative right-of-way access (e. g. , railroad line, irrigation canal lines) must be employed to gain access and to minimize cultural noise. The UPRR line provided this relatively quiet, straight-line access with a single land-access permit.

Railroads are often built up on a level grade to minimize topographic effects for rail traffic. Unfortunately the artificial grade can reduce source and receiver coupling and can also produce significant near-surface lateral velocity contrasts due to varying degrees of compaction. We present a noise test gather in Figure 4 that shows the high-quality of the seismic reflection data on a shot gather record. After initial field tests to optimize acquisition parameters for production seismic work and to test the validity of using the railroad easement for seismic profiling (Liberty and Wood, 2000), we acquired data along the UPRR using a trailer-mounted accelerated weight drop source (Figure 4) designed and built at

Boise State University. We used a 5-m source and receiver station spacing with a 120-channel Geometrics seismograph to produce a 60-fold seismic reflection section (Figure 5a). We used 10-Hz geophones, a 0. 5 ms sample rate, and recorded for 1 second. The

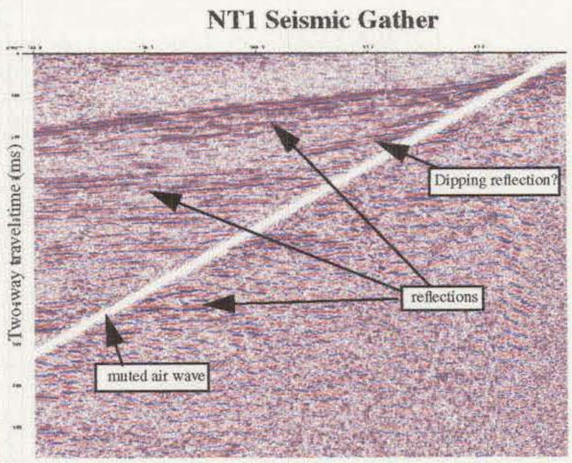

FIGURE 4. (A) The trailer-mounted seismic source used for the seismic reflection project. (B) Annotated shot gather from site NT1 along the downtown railroad spur near Orchard Road. Processing includes f-k and 40-150 Hz spectral whitening filters and air wave mute and shows the data quality of the raw field records.

initial field tests suggested that we could compensate for poor coupling and busy street crossings (up to 5 lanes at 55 m. p. h.) with high fold (redundancy of subsurface mid-points at varying source/receiver offsets) and that we also must pay special attention to static corrections during processing to address the large near-surface lateral velocity changes. In addition, due to excessive noise along portions of the profile, we crossed many busy streets (Table 1) and high noise areas at off hours (evenings and early mornings). A detailed topographic survey with a Topcon total station, coupled with GPS positioning, provided detailed elevation measurements to account for the near-surface static effects. Due to difficulties with access along the spur line, coupled with the poor signal quality from the observed data, only the main railroad profile is presented in this report.

TABLE 1. TVHP Main RailRoad Seismic Line Road Crossings

Location along UPRR	*CDP (internal use)*	Relative Distance (m)
Hartman Road	*4686-4692*	472. 5
canal	*4738-4742*	600
Liberty Street	*4768-4772*	675
Allumbaugh Street	*4928-4934*	1078
Bethel well (projected location)		1700
Cole Road	*5182-5196*	1725
I-80 Overpass	*5240*	1850
Milwaukie Road	*5412-5428*	2300
Benjamin Road	*5638-5646*	2855
Maple Grove Road	*5832-5844*	3345
Maple Hill well (projected location)		3375
Canal	*5898-5912*	3515
Five-mile Road	*6486-6496*	4980
Cloverdale Road	*7138-7146*	6605
Edgeview well (projected location)		6700
St Lukes well (projected location)		8200
Eagle Road	*7794-7806*	8250

4.2 Seismic Processing

We processed the seismic data with Landmark's ProMAX seismic processing software. This software is an oil-industry standard for seismic reflection processing. The basic processing steps are summarized in Table 2. We paid special attention to velocity and static complexities. The high fold and close station spacing enabled us to image detailed structural and stratigraphic information along the length of the UPRR profile.

TABLE 2. Basic processing steps included in the seismic reflection stack

Processing Step	**Comments**
Read raw data	SEGY data from seismograph
Apply geometry	From Topcon total station
Spectral shaping filter	30-150 Hz pass band
Kill bad traces	road crossings, bad channels
Apply Mutes	Ground roll and other coherent noise removal
Apply elevation statics	correct for changes in topography for each source and receiver
Sort to CMP	Place traces in correct spatial position (60 fold)
Normal Moveout Correction	Correct for subsurface velocity variations
Apply residual statics	Correct for near-surface velocity anomalies
CMP Stack	Find the mean of all traces for each common mid-point
F-K migration	Place reflections in the proper spatial position to account for dip

Boise Valley Main Railroad Unmigrated and Migrated Stack - Boise to Meridian

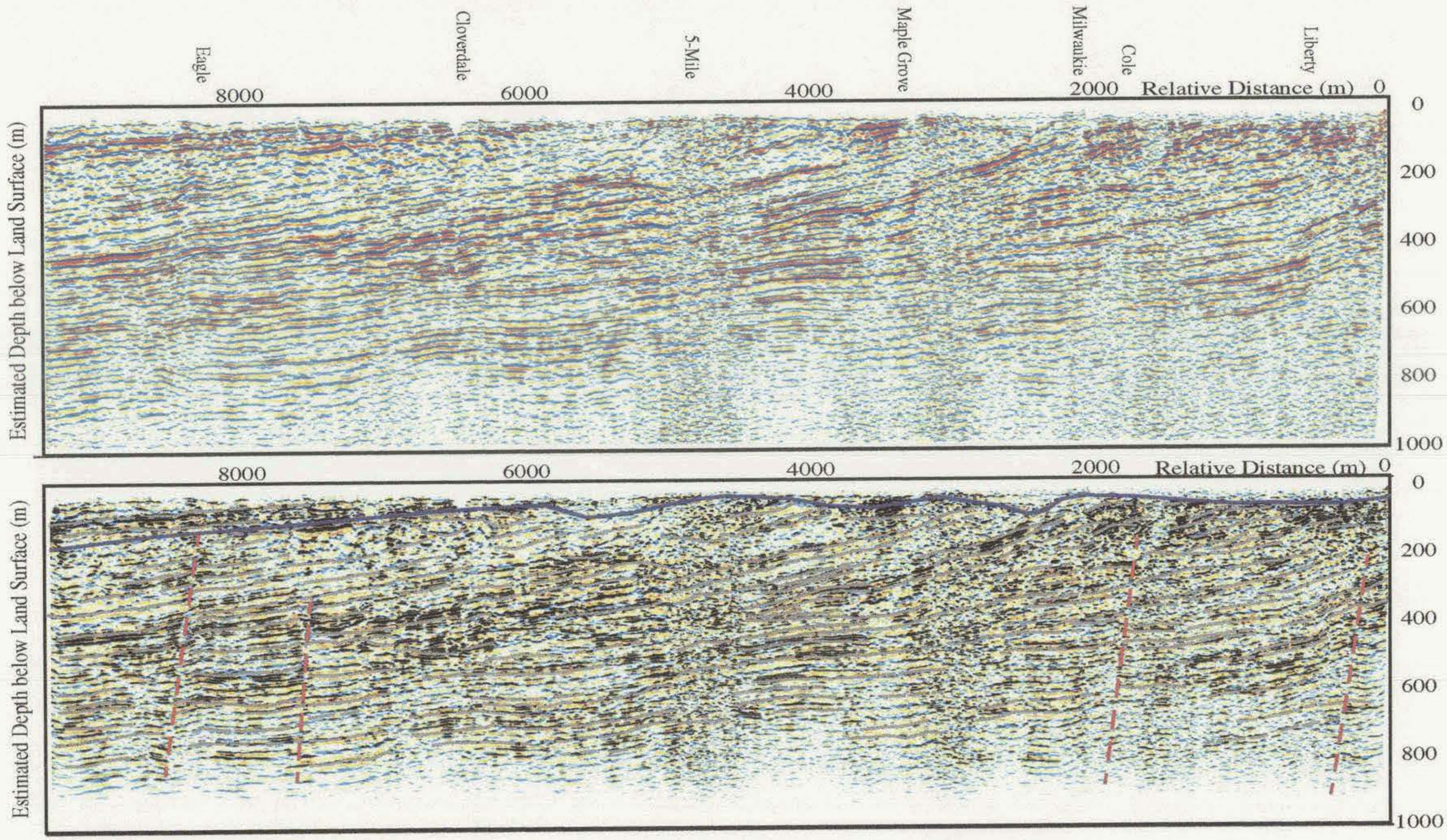

FIGURE 5. Main UPRR unmigrated and migrated seismic reflection profile. Vertical exaggeration ~2:1.

5.0 Discussion

The UPRR seismic data record a similar signature when compared to Chevron Profile IB-2 (Figure 2). However, we recorded reflections from approximately 20 m BLS and extending to upwards of 900 m depth (Figure 5). Although we acquired the seismic profile oblique to the primary dip direction in the basin (but parallel to the Chevron profile), we observe reflections with dips up to 10 degrees and numerous lateral breaks in seismic continuous seismic reflections. High quality data appear along most of the profile with the exception of the Fivemile and Maple Grove road crossings. These were the only two major road intersections that we did not cross at off hours and data quality suffered as a result.

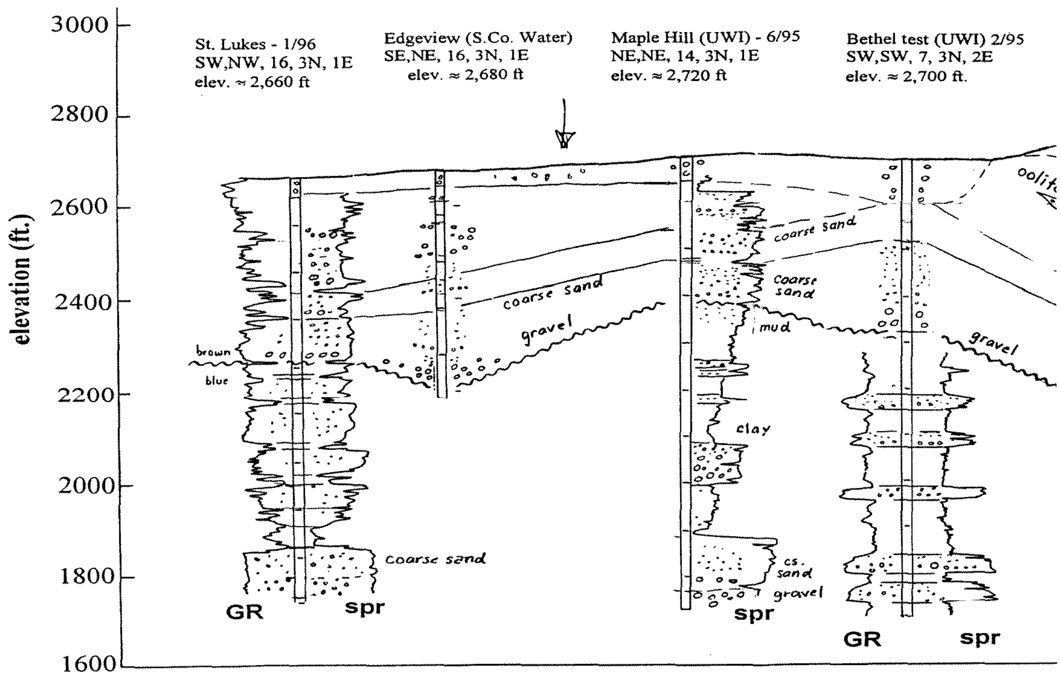

FIGURE 6. Four local wells near the UPRR seismic profile with inferred connection between aquifer units. The coarse-grained and finer-grained sediment contact correlates with the interpreted unconformity on the UPRR seismic section.

We present two views of the UPRR profile in Figure 5. We show the unmigrated seismic profile and the migrated seismic profile. The unmigrated seismic section helps locate faults due to the presence of diffractions (or overlapping reflections) from the edges of reflecting boundaries. The migrated seismic profile places each dipping reflection in the proper spatial position (assuming 2-D structures) and removes the effects of diffractions from abrupt lateral boundaries. We displayed each section in color to easily trace lateral seismic reflection packages. We also overlay black lines for large-amplitude signal on the migrated section to more easily interpret structural and stratigraphic patterns. Depths were calculated by converting sonic (interval) velocity measurements from the nearby

Higginson well to stacking velocities that can directly be applied to observed travel time measurements of seismic reflection data.

The overall pattern of the UPRR profile typifies a prograding delta sequence with basin extension (e. g. , Wood, 1994). Steep dips and fault offsets are common, but the faults do not appear to cut the surface. Reflections can be laterally traced for many km, suggesting that the lacustrine deposits are mappable for great distances and are preserved in-situ. Localized arcuate reflection packages in the upper portion of the section likely represent fluvial channels that have cut the lacustrine sediments (see Figures 7 and 8). These fluvial channels may be good aquifers and should be considered a target for future water wells. Also in the upper portion of the section is a clear unconformity that we inferred from nearby water wells (Figures 3 and 6) prior to seismic acquisition. Locations are projected onto the seismic section on Figures 7 and 8. This unconformity separates reflections from differing dips and represents a change from deep water deposition to shallow water fluvial and lacustrine deposition, as is noted on the geophysical and lithologic wells on Figure 6.

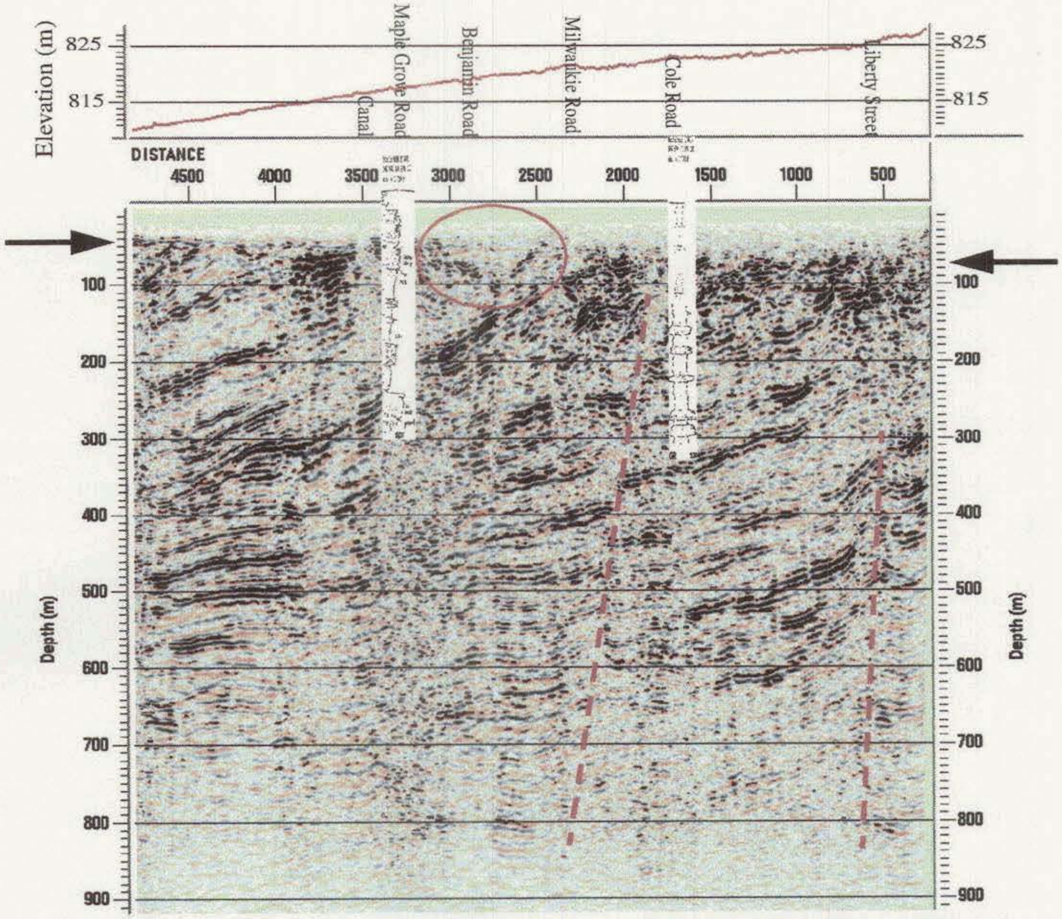

FIGURE 7. Migrated seismic reflection section with nearby well logs (locations on Figure 3) from the eastern portion of the UPRR railroad. Note the presence of faults (red dashed) and an unconformity (bounded by arrows) in the upper 50-100 m BLS with an interpreted sand channel (red circle). The zone above the unconformity correlates with a coarse-grained sand sequence that appears in the two wells. Vertical exaggeration ~4:1.

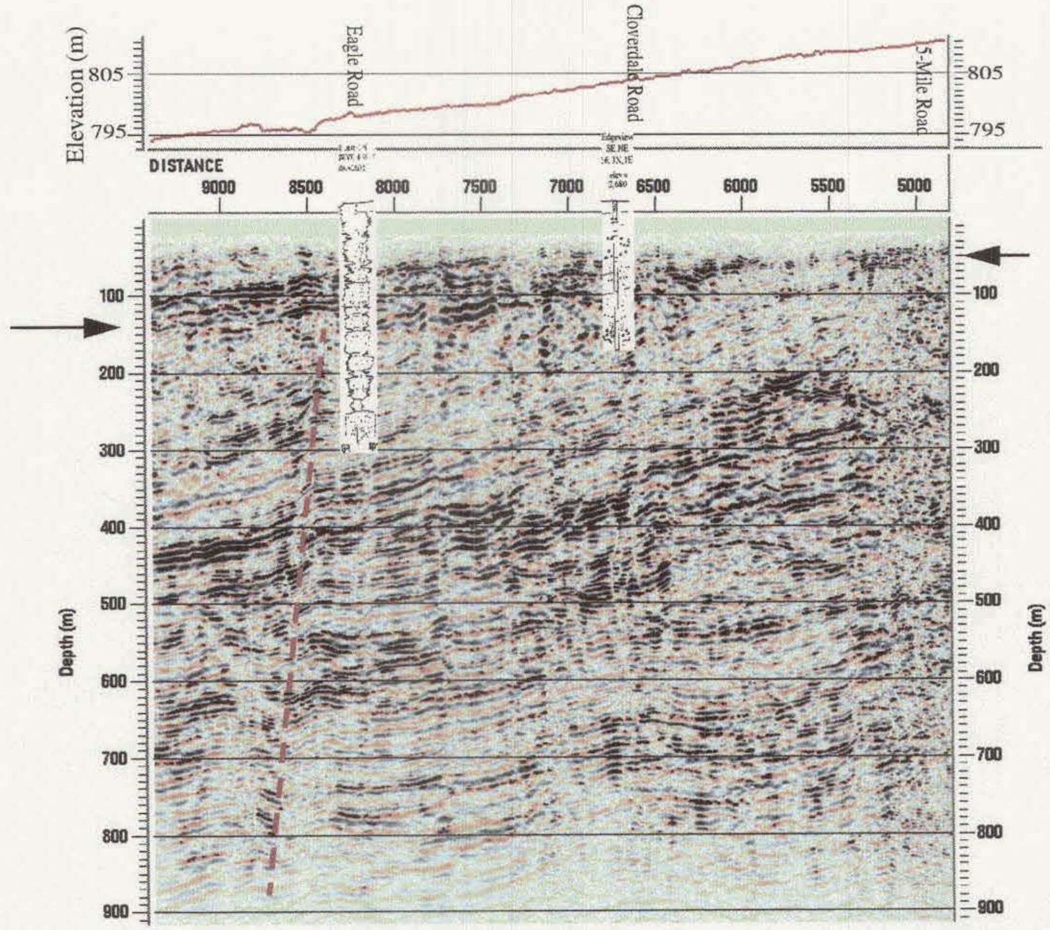

FIGURE 8. Migrated seismic reflection section with nearby well logs (locations on Figure 3) from the western portion of the UPRR railroad. Note the presence of faults (red dashed) and an unconformity (bounded by arrows) in the upper 150 m BLS. The zone above the unconformity correlates with a coarse-grained sand sequence that appears in the two wells. Vertical exaggeration ~4:1.

6.0 Conclusions

We show that seismic reflection methods are well suited for mapping stratigraphy and structure on both a basin scale and aquifer scale to better understand the framework for groundwater flow in the WSRP. We also show that we can map hydrostratigraphic and structural details with the UPRR seismic reflection section and when combined with regional well logs, we can map discrete lithologic sedimentary packages to better understand the depositional history of the sediments beneath Boise. The seismic reflection data show structural and stratigraphic details that well log information cannot solely provide and that the seismic reflection data provide key insights to mapping hydrostratigraphy in the western Snake River Plain.

7.0 Acknowledgments

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