# Geophysical characterization at the North Ada and East Ada sites

## A 2012 Idaho Department of Water Resources report

Lee M. Liberty
Associate Research Professor
Center for Geophysical Investigation of the Shallow Subsurface (CGISS)
Boise State University
Boise, Idaho 83725-1536
Phone: 208-426-1166
Fax: 208-426-3888
lliberty@boisestate.edu
http://cgiss.boisestate.edu/~lml

## Contents

## Summary

This report summarizes new and existing geophysical data from areas in and around Ada County, Idaho. Geophysical data can help characterize surface and subsurface geologic features that can be used in basin characterization studies. In this report, I present results from new seismic reflection data from two locations; North Ada County and East Ada County. Both of these sites are located along the northern margin of the Western Snake River Plain. These new data provide detailed information that includes: (1) stratigraphy of major sedimentary units in the upper few thousand feet below land surface to delineate aquifers, (2) configuration and depth of basement rocks, (3) depths and locations of volcanic units, and (4) fault locations and vertical displacements. Additionally, I describe related industry seismic profiles and gravity/magnetic data in and around the study areas that provide the geological framework for both the western Snake River Plain and for each site.

## Introduction

Geophysical data have been used for aquifer studies throughout southwest Idaho (e.g., Wood, 1994; Barrash, and Dougherty, 1997; Liberty, 1997; Liberty, 1998; Liberty et al., 2001; Wood and Clemens, 2002). Seismic reflection methods are well suited for aquifer studies due to the acoustic properties within basin sediments and the contrast with adjacent and underlying hard rock interfaces. High resolution seismic reflection methods are often calibrated to image the upper few thousand feet below land surface while oil and gas industry seismic data are often calibrated for deeper and more regional studies. Gravity and magnetic data are useful to identify and characterize the regional-scale geologic framework due to the large physical property contrast (density and magnetic susceptibility) of basin sediments and hard rock. However, these methods also can address site specific targets when spatial sampling is sufficient for shallow geologic targets. Other geophysical methods including resistivity can also help characterize strata that control groundwater flow (e.g., Lindholm, 1996).

Here, I present data from a new geophysical campaign to identify and characterize geological and hydrogeological targets in the upper few thousand feet at two field areas in southwest Idaho. The first field site is termed the North Ada Study Area (Figure 1). This site is located near the Ada, Canyon, and Gem County line. The second field site, termed the East Ada Study Area, is located near the Ada and Elmore County line. New high-resolution seismic profiles for these sites, an analysis of existing gravity and magnetic data, and an assessment of nearby industry seismic data will help constrain geological and hydrogeological models that may predict groundwater flow directions and reservoir volumes. In this report, I will describe the geologic framework for each site, geophysical acquisition and processing methods, and interpretations from each site.

## Geologic Setting

The western Snake River Plain (WSRP) is a 40 mile by 180 mile intracontinental rift basin that extends across southwest Idaho (e.g., Wood, 1994; Wood and Clemens, 2002). The northwest-trending basin contains Neogene and younger strata upwards of 2 miles below land surface. Basin extension began in middle Miocene, where Idaho Batholith granite was likely replaced by intrusive diabase or gabbro rocks. Columbia River and younger basalts filled the extending basin and lie upon the intrusive rocks. Neogene and younger lacustrine and fluvial sediments lie above the basement rocks, deposited from paleo Lake Idaho that filled the WSRP to an elevation of approximately 3,600 feet. The lake remained until a spill point was created at Hells Canyon that eventually drained Lake Idaho down the modern Snake River (Wood, 1994). Wood and Clemens (2002) suggest faulting along the WSRP margins was most active from 11-9.5 Ma. Although extension within the WSRP continued after 9 Ma, basin-bounding faults do not dominate the northern margin of the WSRP; rather strata tend to gently dip southward to form sag basin style geometry.

The North Ada study area is located north of Eagle, Idaho along the northern margin of the WSRP at an elevation range from about 2,500-3000 feet (Figure 1). Here, a transgressive lacustrine sequence termed the Terteling Springs Formation (5-6 Ma) lies beneath coarse-grained deposits of the Idaho Group and primary aquifer (Figure 2; Wood and Clemens, 2002). The Miocene and younger shoreline sands interfinger with lake muds and alluvial deposits. Underlying and adjacent bedrock likely consists of Cretaceous granite of the Idaho Batholith and Miocene-age (~15 Ma) basalt flows. The proximity of the North Ada study area relative to the northern margin of the WSRP suggests Pliocene and younger faults may offset aquifer sands and influence groundwater flow. Groundwater flow directions are to the west/northwest toward the western limits of the WSRP and water depths range from 100 to 500 feet (e.g., Lindholm, 1996)

The East Ada study area is located along the Ada and Elmore County line at an elevation range of 3,100-3,500 feet (Figure 1). Due to the higher elevations relative to peak paleolake water levels, mostly near-shore Lake Idaho lacustrine and fluvial sediments are present. The surface geology is mapped as mostly Quaternary terrace gravels and interfingered Pleistocene basalt flows that lie above and adjacent to Cretaceous Idaho Batholith granitic basement (Phillips et al., in review). Water table depths extend to more than 300 feet below land surface in many locations and regional groundwater flow directions are to the southwest (Lindholm, 1996; Welhan, in review). The proximity of the East Ada study area relative to the northern margin of the WSRP suggests Pliocene and younger faults may offset aquifer sands and influence groundwater flow. Additionally, basalt flows extending from both the northern and central portions of the WSRP appear on both the surface geologic maps and borehole logs (Welhan, in review; Phillips et al., in review). Water well logs suggest thin (less than 100 feet) and interbedded basalts appear throughout the East Ada study area. The extent and influence of these basalts on groundwater flow are addressed in the Welhan (in review) report.

## Regional Geophysical Framework

The subsurface geology of the WSRP can be best characterized with a variety of geophysical methods with a tie to deep borehole information (Figures 1, 2 and 3). Seismic reflection and borehole data suggest the WSRP is a fault-bounded northwest-striking graben that is filled with lacustrine and fluvial sediments and interbedded basalt flows (e.g., Wood, 1994; Liberty, 1998; Liberty et al., 2001; Wood and Clemens, 2002; Figure 2). Deep exploration wells and a stratigraphic analysis from seismic data suggest near-shore and deep water facies can be mapped and correlate with Lake Idaho high-stand levels (e.g., Liberty et al., 2001; Wood and Clemens, 2002). Gravity anomaly maps show the difference between the observed acceleration of Earth's gravity and a value predicted from a simple earth model. Magnetic anomaly maps show the total magnetic field values that are influenced by changing susceptibility values. Magnetic susceptibility is the measure of the degree of magnetization of a material in response to an applied magnetic field. These maps suggest basement rocks vary considerably across the basin with granitic rocks dominating the boundaries of the basin and massive basalts underlie the western and central portions of the WSRP (e.g. Mabey, 1967, McCafferty et al, 1999; Wood and Clemens, 2002). Along the flanks of the WSRP near the North Ada and East Ada study areas, intermediate density and low susceptibility granitic rocks of the Idaho Batholith dominate the subsurface (Figure 2). Below the central portions of the WSRP, high-density and high-susceptibility basalts exceed 5,000 feet thickness (Figure 2).

### North Ada County study area

The topography of the North Ada study area shows the geomorphic and geologic expression for the northern margin of the WSRP. Northeast of the study area, high elevation topography represents granitic rocks of the Idaho Batholith (Figure 2). Along the northern margins of the study area, Tertiary sediments of the Idaho Group are mapped while the southern portions of the study area contain low elevation fluvial fan and terrace gravel deposits (Othberg and Stanford, 1992). Poorly developed alluvial fan deposits appear at the base of many of the narrow gulches and terminate at the main channel of the Boise River.

Gravity data can be useful to identify both regional density anomalies and more local geologic features. While the unfiltered complete Bouguer gravity map shown on Figure 1 suggests the density high (massive basalt) beneath the WSRP extends regionally and to great depths, filtered gravity data to remove regional trends show the sub-basin geometry for the North Ada study area (Figure 2). A northwest-trending gravity low that extends from downtown Boise to the Gem County line outlines the sub-basin (Figure 2b). The Julia Davis geothermal well lies within this depocenter and penetrates ~1,500 feet of lacustrine and fluvial sediments before encountering a very thin sequence of basalt overlying rhyolite and granitic rocks of the Idaho Batholith.

Aeromagnetic data tend to highlight variations in rock magnetic susceptibility in the near surface (Figures 1 and 2). By mathematically raising the elevation of the acquired data, upward continued magnetic images tend to highlight deeper geologic structures. Gravity and magnetic data within the central portion of the WSRP suggest the N60W-trending gravity high that spans western Ada County and eastern Canyon County line correlates with a magnetic low. The deep Halbouty-Chevron well, located near the center of the gravity high near the Ada/Canyon county line, penetrates ~5,000 feet of (dominantly) reversely magnetized Miocene basalt below ~2,000 feet of lake sediments (Figure 2). The transition between a massive basalt basement beneath the Canyon/Ada county line and a dominantly granitic basement to the east likely occurs near the NW-trending ~30 mgal gravity gradient along the southwest portion of the North Ada study area. Large-offset faults at depth are mapped along industry seismic profiles between the Halbouty-Chevron well and the Boise River/eastern sub-basin (Wood, 1994; Wood and Clemens, 2002; Figure 2). The faults diminish in offset towards the surface, suggesting little Quaternary motion, but may define the eastward limits of massive Miocene basalt rocks and may control and/or influence deep groundwater flow along the western limits of the study area.

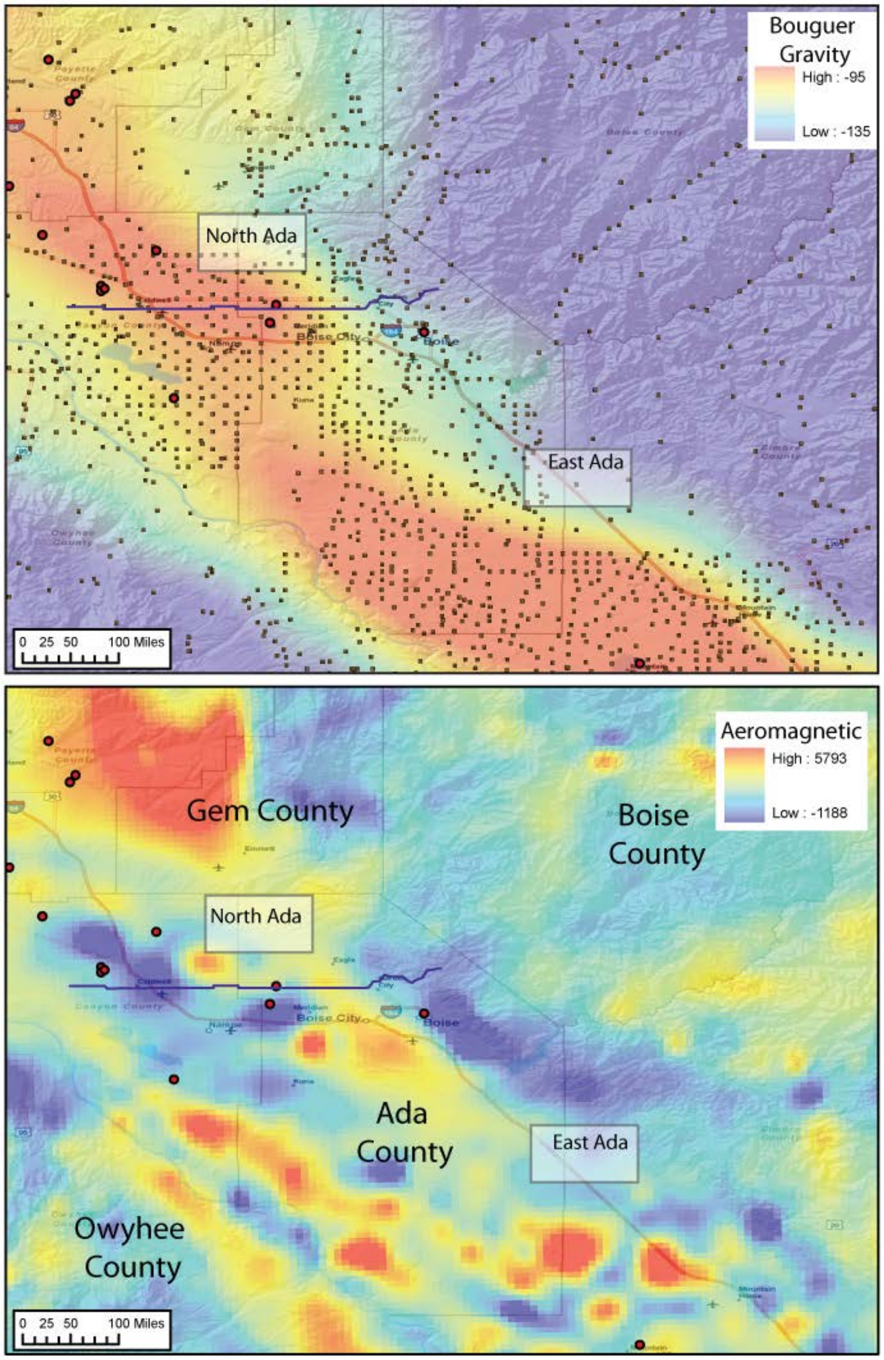



**Figure 1. (top) Bouguer gravity and topographic map for the WSRP area showing high-density basalts dominate the subsurface beneath lacustrine sediments of paleo lake Idaho. Black dots represent gravity station locations. (bottom) Total field magnetic and topographic map of the study area. High magnetic values (reds) correlate with surface and subsurface high-susceptibility basalt flows whole intermediate and low susceptibility areas (blue) represent either reversely magnetized basalt flows or relatively non-magnetic rocks (e.g sediments or granitic rocks). Northwest-striking lineations dominate the WSRP, suggesting volcanic emplacement during basin formation. Blue line on each map is the seismic profile IB-2 (see Figure 2) and North Ada and East Ada study areas are shown as boxes on each figure. Red circles represent deep boreholes that extend to bedrock depths. Data from McCafferty et al. (1999), Wood (1994) and Wood and Clemens (2002).**

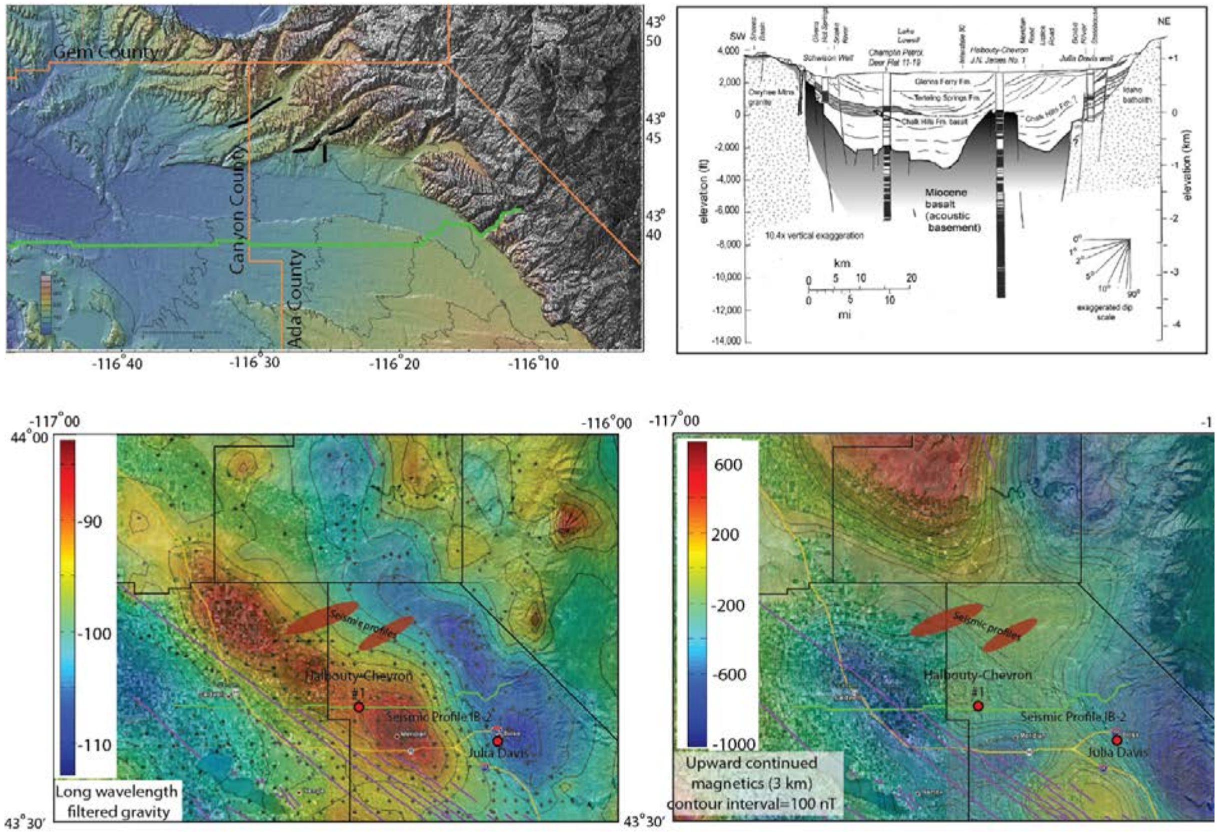



**Figure 2. (top left) Topographic map for the North Ada study area with seismic profile locations (black), county boundaries (orange), and seismic profile IB-2 (green). (bottom left) Filtered gravity contour map showing high-density (reds) basalt dominates the central portions of the WSRP (stations are black dots). Lower density portions (blues) are dominated by granitic rocks and overlying lake sediments. Deep boreholes (red circles), the location of industry seismic profile IB-2 (green), newly acquired North Ada seismic profiles (rust-colored oval areas), and mapped faults (USGS database) help constrain subsurface geologic interpretations. (top right) Cross section interpretation from industry profile IB-2 (from Wood and Clemens, 2002) (bottom right) Upward continued magnetic map contoured at 100 nT intervals highlighting regional magnetic features. Note the contour lines at the North Ada site parallel the gravity high. Gravity and magnetic maps show county boundaries with superimposed aerial photo. Industry seismic profile IB-2 and location of North Ada profiles are also shown.**

Ground-based magnetic measurements in the vicinity of the North Ada site show an approximate 100 nT change in total magnetic field from southwest to northeast (Wood, 2007). The aeromagnetic map shows a similar northwest-striking gradient, extending from north Boise, across the North Ada study area and terminating near the Canyon County/Gem County line (Figure 2). The magnetic, gravity, and seismic data from the region all suggest the lacustrine sediments associated with the northern margin of the WSRP increase in thickness from northeast to southwest. Gravity and magnetic lineations may tie to a regional fault system that has controlled sedimentation. Laterally changing stratigraphy and related faults may control groundwater aquifer properties along the northern border of the WSRP.

## East Ada County study area

The topographic map of the East Ada study area shows many of the geomorphic and geologic features that shape the area (Figure 3). High elevation hills to the northeast of the study area contain mostly granitic rocks of the Idaho Batholith (Othberg and Stanford, 1992; Phillips et al., in review). A relatively linear boundary that defines the northern margin of the WSRP separates the rugged Idaho Batholith high elevation topography from the lower elevation topography of the WSRP, defined by fluvial, volcanic, and tectonic processes. Although north-trending high susceptibility Miocene rhyolitic dikes appear north of the WSRP margin (Phillips et al., in review), intermediate density and low susceptibility granitic rocks dominate the Idaho Batholith. Low density and low susceptibility sedimentary rocks occupy the margins of the WSRP and high density/high susceptibility volcanic rocks appear within the central portions of the WSRP, along the southern margins of the study area. A N70W trending zone of high density/high susceptibility rocks appears near the southern portions of the study area and collectively has been referred to as Quaternary volcanic rocks of the Kuna/Mountain Home volcanic rift zone (Wood and Clemens, 2002). The geometry of sediments and bedrock is unknown near the Kuna/Mountain Home volcanic rift zone due to the lateral changes in subsurface physical properties. However, the young age of the relatively impermeable volcanic rocks relative to the older and more permeable Lake Idaho Group sediments suggests more complex groundwater conditions. Along the northern boundary of the WSRP and within the study area, ~0.9 Ma basalts of Slater's Flat are mapped and appear as a relatively flat region in topography. The lack of magnetic and/or gravity expression from this region is consistent with mapped thicknesses of this unit of less than 30 feet (Phillips et al., in review). Additional subsurface basalt flows are identified in water wells throughout the area (Welhan, in review), but the regional gravity and magnetic maps show no consistent pattern of volcanism north of I-84. Although gravity and magnetic maps suggest low density/low susceptibility rocks dominate the northern margin of the WSRP within the study area, inverting these data for sediment thickness (a common technique in sedimentary basins) would likely result in large errors due to the unknown distribution of buried high density/high susceptibility basalt flows .

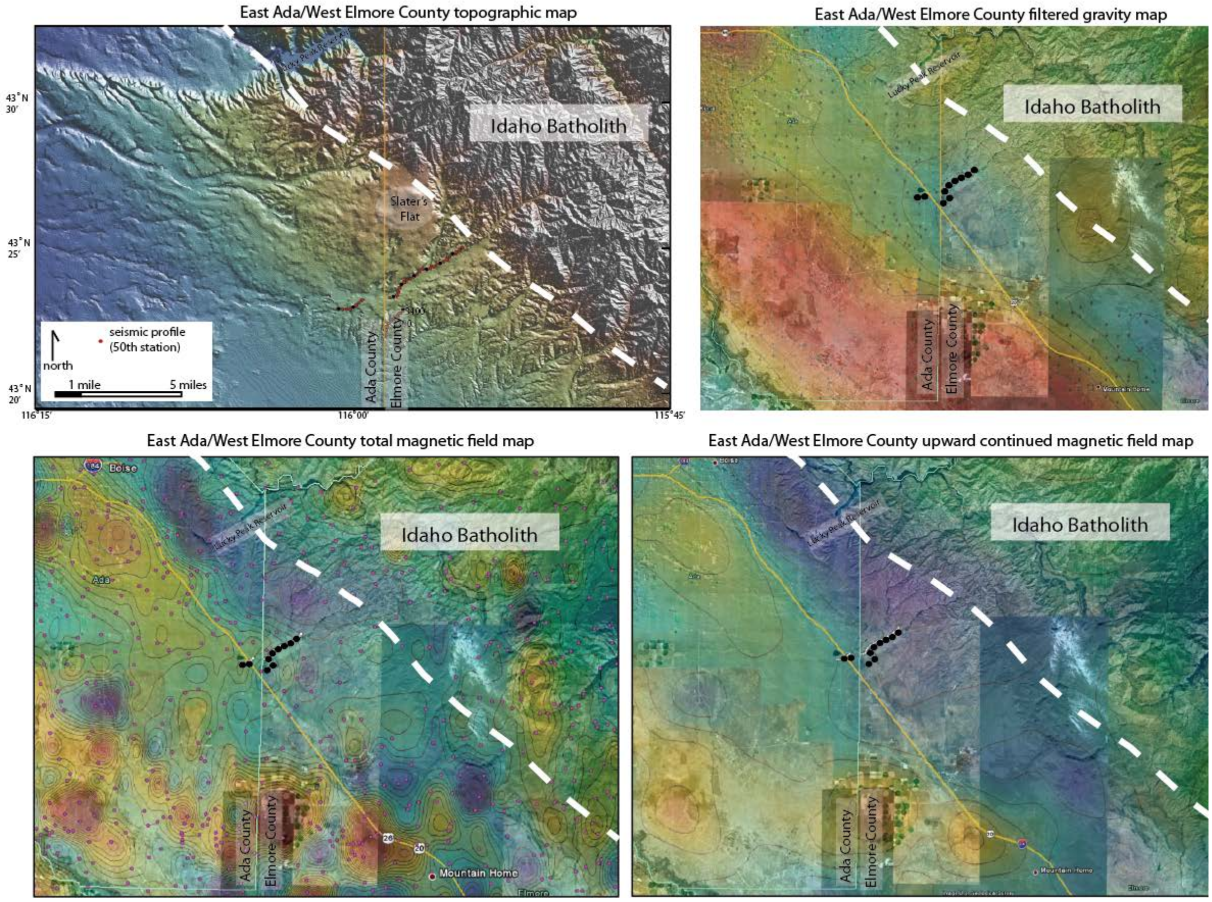



**Figure 3. (upper left) Topographic map of the East Ada study area showing the transition from Idaho Batholith rocks to WSRP. (upper right) Filtered gravity map showing dense volcanic rocks south of the study area, intermediate density rocks of the Idaho Batholith to the northeast, and low density rocks that dominate the northern margin of the WSRP. (lower left) Total magnetic field map for East Ada study area highlighting near surface volcanic rocks (magnetic high or red values) (lower right) Upward continued magnetic data showing regional distribution of high susceptibility basalt rocks relative to low susceptibility sediments and granite. White dashed line defines the approximate northern margin of the WSRP.**

## Seismic Reflection Methods

Seismic reflection methods are commonly used in exploration for hydrocarbons, coal, geothermal energy, and in shallow applications for engineering, groundwater and environmental targets. Seismic reflection data acquisition involves a seismic source and an array of sensors or geophones (Figure 4). The seismic source can range from explosives, hammers, and vibroseis sources, all coupled to the ground surface. The seismic source is intended to propagate sound waves through the subsurface. At each seismic velocity or density contrast in the subsurface, the seismic energy is partitioned. A portion of the seismic energy is reflected back to the earth's surface while another portion of the seismic energy continues to radiate away from the seismic source. The ground displacement, as the seismic energy returns to the earth's surface, registers on a geophone (similar to a motion sensor) as a change in voltage and the analog signal that represents ground displacement is digitally recorded with a seismograph. Seismic boundaries with large velocity and/or density contrast can include the water table, bedrock surface, and a significant change in porosity or grain size within a sedimentary sequence (e.g., clay to sand).

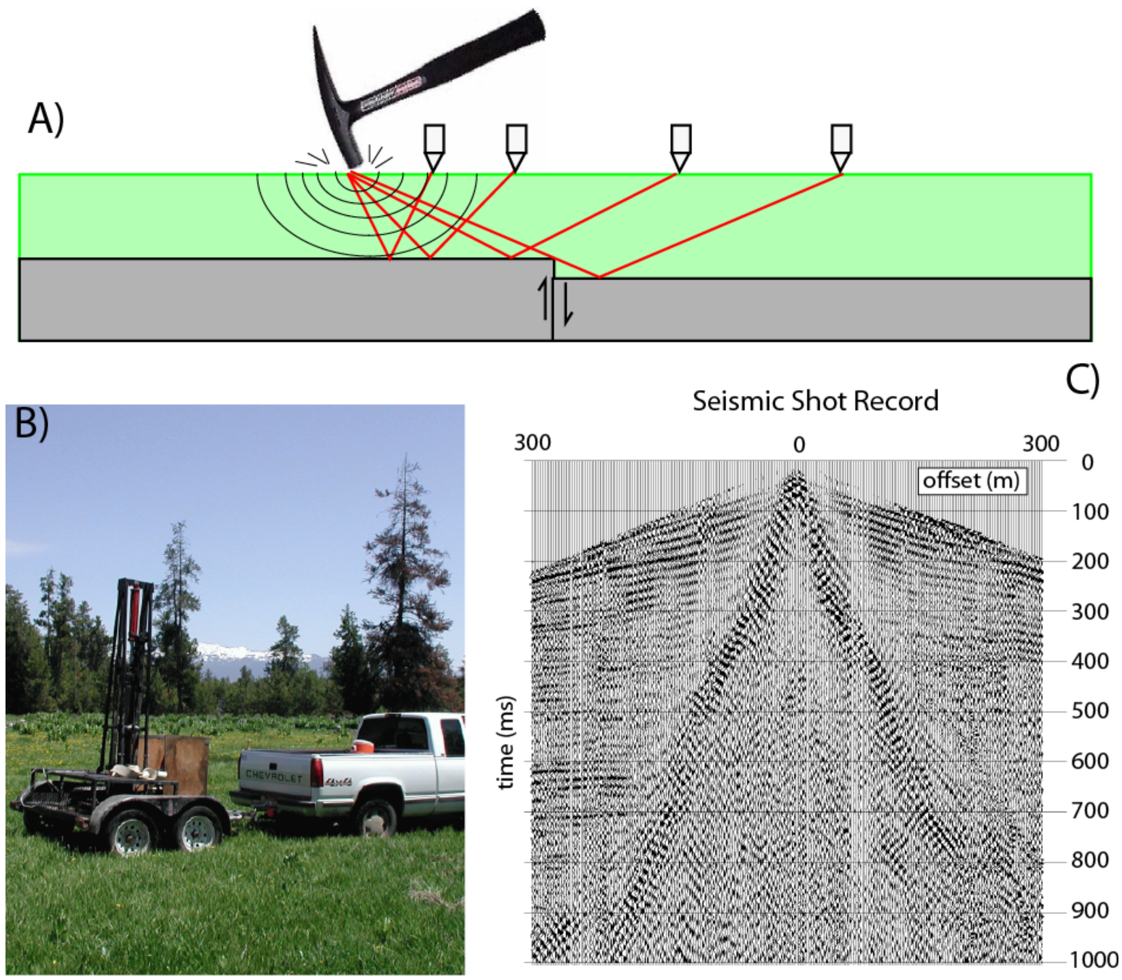



**Figure 4. A) Cartoon of acoustic waves transmitting from a hammer source through a subsurface layer and returning to geophone locations at the surface. B) A Boise State University 500 lb rubber band accelerated hammer source. C) An example shot record showing reflections and other coherent and random signals. Longer travel paths appear on the down side of the fault (on A). These longer travel paths result in delayed reflector travel times (on C).**

Once seismic data are recorded, seismic processing steps include removing or attenuating coherent and random signals not related to the reflection energy, a data sort from shot gathers to common midpoint gathers, a seismic velocity analysis and correction, elevation corrections to a common datum, and stacking data at varying ray geometries to produce a section that simulates a geologic cross section (e.g., Yilmaz, 2001).

Seismic reflection data interpretation involves identification of coherent reflectors, offsets in these reflectors, and the strength of the reflected signals. Tied to borehole information, seismic velocities, and geologic and other geophysical data, a geologic interpretation is formed. It is important to note that reflecting boundaries represent a change in physical properties at a measured travel time. A tie to borehole and geologic information provide the link between seismic data and a geologic interpretation. Depth estimates from seismic velocities alone are not precise, but serve as a reasonable first-order estimate of reflector depth. To more accurately tie seismic data to accurate depth estimates, extrapolation from borehole measurements are needed.

## Industry seismic data

Industry seismic data from southwest Idaho were obtained throughout the 1970's through 1980's. Some of these data are presently in the public domain and can be displayed and interpreted with few restrictions (e.g., Wood, 1994; Figure 2). Other datasets are available for purchase at a cost of $2,200 per mile (2009 cost estimate) through the Seismic Data Exchange brokerage (Figure 5). A visit to Seismic Data Exchange (Denver, Colorado – summer, 2009) by Spencer Wood (Emeritus Boise State Professor) and the author led to the conclusion that data in the study areas at target depths were not worth the cost of purchase. Reasons include the paucity of information in the upper 1,000 feet, the high cost of purchase relative to acquiring new seismic data, and the profile locations relative to the areas of present-day interest.

## North Ada County seismic reflection profiling

I acquired four seismic reflection profiles to characterize stratigraphy and faults in the North Ada study area. New data were acquired along Chaparral Road west of Hwy 16 and along Farmers Canal and Little Gulch east of Hwy 16 (Figure 6). A final north-south profile was acquired along Lanewood Road to determine whether a proposed fault extends to the northwest. Three of the 4 seismic profiles were acquired with the Boise State 500 lb trailer-mounted accelerated weight drop source (Figure 4). The Chaparral seismic profile was acquired with a 16,000 lb vibroseis truck rented from the University of Texas NEES facility (http://nees.utexas.edu). Although both seismic sources can image the upper few thousand feet below land surface, the vibroseis truck is more capable on city streets and imaging through dry sediments. All profiles were acquired with a 16 foot source and receiver spacing and a 120-channel seismic recorder. Source offsets varied for each profile, but generally each profile was acquired off-end with offsets up to 2,000 feet. A 10 Hz geophone frequency allowed a broad-band response to image to depths up to 5,000 feet. The following sections describe new seismic results from the North Ada area.

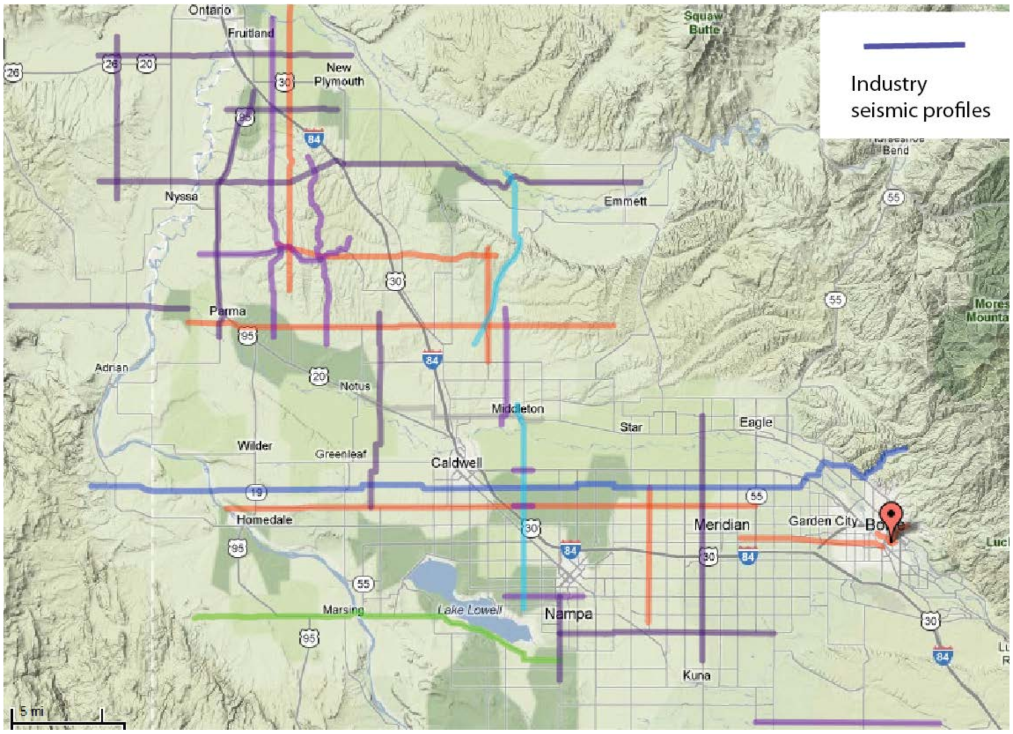



**Figure 5. A catalog of industry seismic profiles from the WSRP area. Data source is Seismic Data Exchange of Denver, Co. The line colors represent different vintage and/or data source (from Seismic Data Exchange database).**

## Chaparral Road seismic profile

The 3.4 mile long west-east Chaparral Road seismic reflection profile is located north of Eagle, Idaho along Chaparral Road/Edna Lane in Ada and Canyon Counties (Figure 6). The vibroseis seismic profile begins at the intersection of Blessinger Road/Edna Lane along the south shoulder of the paved road. The profile terminates near Hwy 30 at the end of Chaparral Road. Elevation increases approximately 130 feet from west to east (Figure 7). The profile was acquired in Canyon County from positions 1,000-1,380 and Ada County from positions 1,380-2,070. An approximate 30 degree bend in the road is located at position 1,800, a buried pipeline crossed the road at position 1,565 and overhead powerlines, drive ways, and cross streets provided difficulties with data acquisition and introduced noise into the final stack.

The unmigrated travel time seismic section and migrated, depth-corrected and interpreted Chaparrel seismic image is presented in Figure 7. The seismic data are corrected for a 2,625 feet datum and displayed at approximately 2:1 vertical exaggeration. At approximately 0.2-0.3 s two-way travel time (twtt), a generally flat-lying reflector appears across the profile. A non-reflective zone both above and below this reflector extends to approximately 0.3-0.4 s twtt from west to east respectively while a zone of highly reflective, west-dipping reflectors extend to approximately >1.0 s twtt.  Below 1.0 s, a zone of weak amplitude reflectors is present to more than 1.5 s twtt.

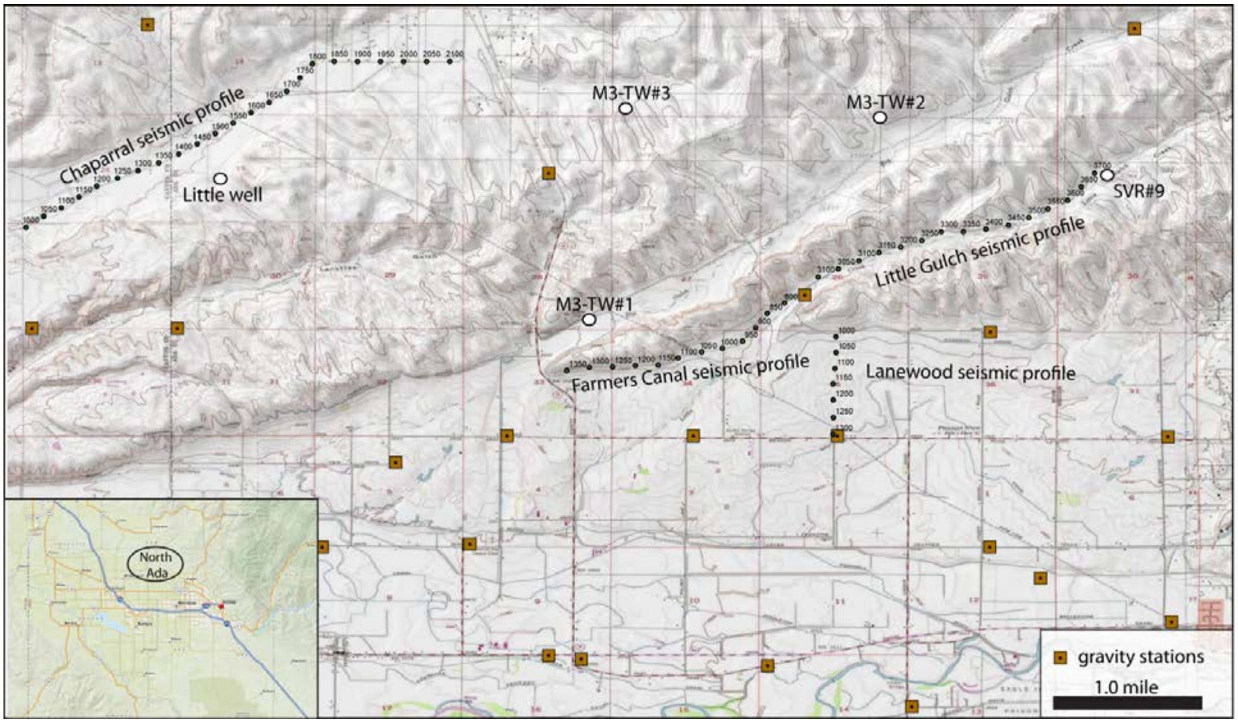



**Figure 6. Location map for North Ada seismic profiles. Gravity stations appear as gold boxes, water wells are open circles (Hydrologic, 2007; 2008a; 2008b; 2008c). Inset map shows the WSRP area with North Ada study site.**

Given measured seismic velocities of the near-surface layers (approximately 1,400-2,500 feet/s) and water depths measured in nearby wells, I interpret the 0.2—0.3 s reflector as the water table at approximately 2,400-2,500 feet elevation across the profile. The generally continuously dipping reflectors below and the relative flat-lying water table reflector suggest no major faults cross this profile. The non-reflective zone both above the water table reflector and immediately below suggests little lateral continuity of velocity and density values, consistent with sands of the Idaho Group aquifer. Given the ~260 feet of Idaho Group sand interpreted in the M3-TV#3 well (HydroLogic, 2007), alternating sands and clay in the upper 600 feet of the Little Well (Figure 7), and onset of west-dipping reflectors below this depth, I believe the seismic image captures the sand unit as a west-thickening unit that approaches 1,000 feet depth along the western portions of the profile.

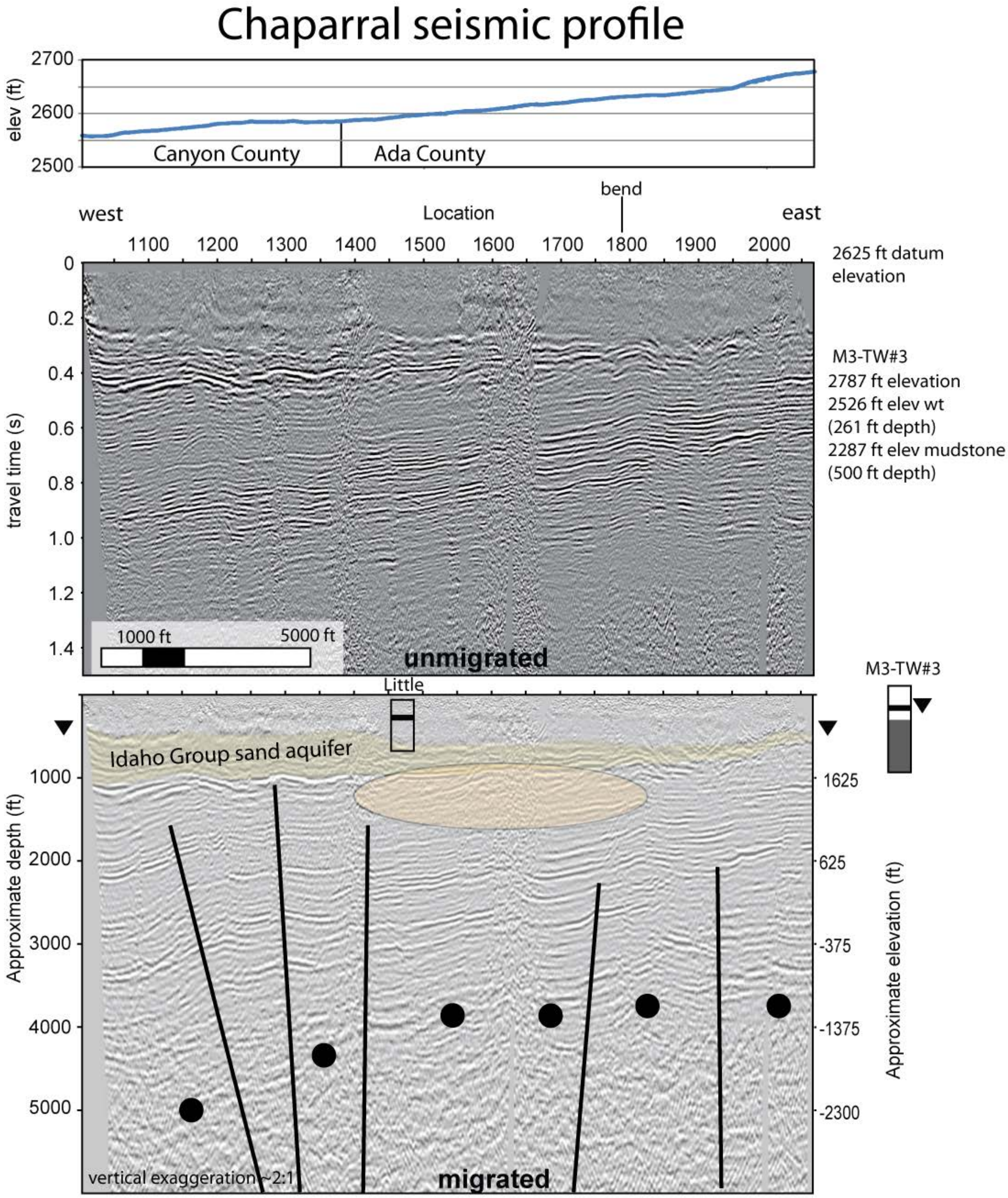



**Figure 7. Elevation profile, unmigrated seismic reflection profile, and interpreted, migrated, and depth converted seismic image from Chaparral Road, Ada and Canyon Counties. Interpreted image includes inferred faults from change in reflector dip and/or offset (black lines), bedrock depth (closed circles), seismically transparent Idaho Group sand aquifer below water table (yellow), and variable dip reflectors that represent a prograding delta sequence (orange). Seismic profile and M3 TW#3 well (HydroLogic, 2007) location and station numbers are shown on Figure 4.**

Below the interpreted boundary of the Idaho Group sand aquifer, a zone of highly reflective ~3 degree west dipping reflectors is consistent with Terteling Springs mudstone or deep water lake deposits from paleo Lake Idaho. Reflector discontinuities may indicate faults in the subsurface, however, there is no clear evidence that these faults extend into the upper 1,000 feet depth. Some reflectors show a steepening of dip immediately below the Idaho Group sand unit that may be related to prograding delta deposition. At depths below ~4,000-5,000 feet, a zone of lower amplitude and/or discontinuous reflectors likely represents bedrock. Although this boundary is poorly imaged with this profile, my interpretation is consistent with the basement reflector depth on nearby industry seismic profile IB-25 that clearly image to these depths (S. Wood, personal comm.). The bedrock surface does not appear bisected by faults. This implies that the interpreted faults that cut the overlying strata are not significant to basin development and likely these faults are not significant barriers to groundwater flow.

## Little Gulch seismic profile

The 2.3 mile long west-east Little Gulch seismic reflection profile is located north of Eagle, Idaho on Bureau of Land Management (BLM) property in the foothills adjacent to private property (Figure 6). The profile begins from a private residence along the bottom of the gulch, east-northeast along a dirt road to the eastern termination of BLM property, an increase in elevation of approximately 100 feet (Figure 8). A gap of approximately 1,500 feet separates the Little Gulch seismic profile from the Farmers Canal seismic profile (described below) to the west (Figure 6). The lack of cultural noise or infrastructure provided ideal listening conditions while seismic acquisition following a period of rain provided ideal source and receiver coupling. The seismic source was the Boise State trailer-mounted seismic source. Published borehole logs for nearby M3 wells, including the adjacent M3-SVR#9 well, assist in the interpretation of the seismic profile (Hydro Logic, 2008a).

Figure 8 shows the unmigrated travel time seismic section above a migrated, depth-corrected and interpreted seismic image. The seismic images are corrected for a 2,700 feet datum and displayed at approximately 2:1 vertical exaggeration. At approximately 0.2 s two-way travel time (twtt), a generally flat-lying reflector appears across the profile. A non-reflective zone appears both above and below this reflector to approximately 0.3-0.4 s twtt from west to east respectively while a zone of highly reflective, west-dipping reflectors appear to approximately 0.8 s twtt. Below 0.8 s, a zone of weak amplitude reflectors is present to more than 1.0 s while a set of discontinuous reflectors appears to approximately 1.5 s twtt.

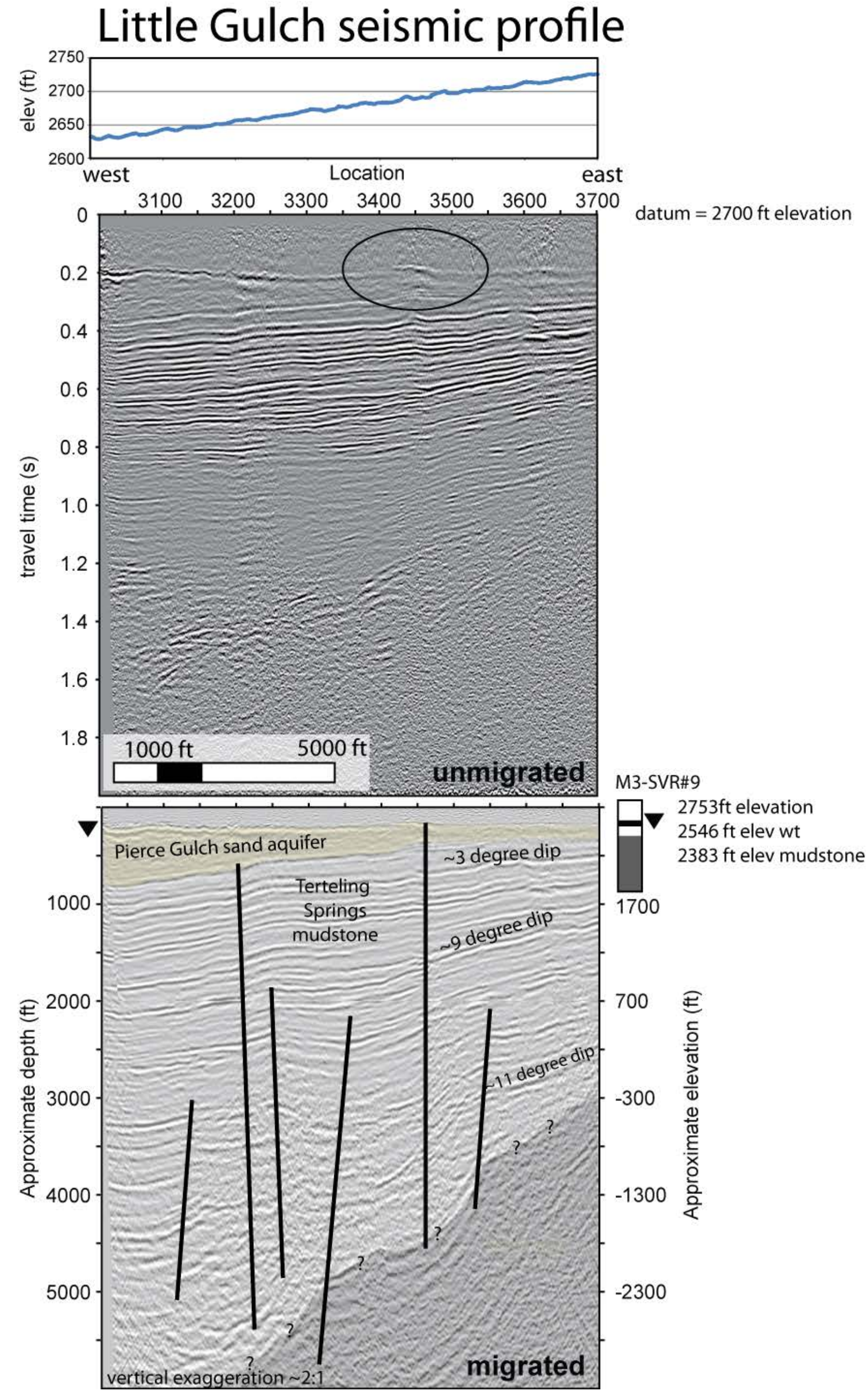



**Figure 8. Elevation profile, unmigrated seismic reflection profile, and interpreted, migrated, and depth converted seismic image from Little Gulch, North Ada County. Interpreted bedrock depth (?) is inferred from diffractions on the unmigrated profile. Seismic station number locations are shown on Figure 4, water well from Hydrologic (2008b).**

Given measured seismic velocities of the near-surface layers (approximately 1,400-2,500 feet/s) and water depths measured in nearby wells, I interpret the 0.2 s reflector as the water table at approximately 2,500 feet elevation across the profile. The generally flat-lying reflector shows the greatest topography near position 3450, coincident with a change in dip of deeper reflectors. The non-reflective zone both above the water table reflector and immediately below suggests little lateral continuity of velocity and density values, consistent with the Idaho Group sand aquifer. Given the ~370 feet of Idaho Group sand interpreted in the M3-SVR#9 well (HydroLogic, 2008) and onset of west-dipping reflectors below this depth, I believe the seismic image captures the Idaho Group sand unit as a west-thickening unit that approaches 600 feet thick along the western portions of the profile.

Below the interpreted boundary of the Idaho Group sand aquifer, a zone of highly reflective west dipping reflectors is consistent with Terteling Springs mudstone or deep water lake deposits from paleo Lake Idaho (Figure 8). Reflector dips generally increase to the east and with depth along the profile. A change in reflector dip with depth is consistent with basin subsidence with continued deposition. Abrupt changes in reflector dip, particularly noticed at positions 3,200 and 3,450 are consistent with normal faults that accommodate WSRP extension. The interpreted fault at position 3,450 likely extends to the Pierce Gulch sand aquifer, as evidenced by approximately 50 feet offset at the base of the Pierce Gulch sand and 20 feet offset across the water table. This water table offset may be related to a velocity pull-up from changing lithology above the water table, but given increased stratigraphic offsets with depth at position 3,450, a fault is likely present and influences groundwater elevations.

At depths below ~3,000 feet, a zone of lower amplitude reflectors likely represents additional Lake Idaho sediments (Chalk Hills Formation?) and either contain fewer physical property contrasts compared to the overlying strata (e.g., a sand unit), or that the seismic source did not have adequate energy to clearly image these depths. However, the presence of discontinuous high-amplitude reflectors at greater depths is consistent with a basalt bedrock surface increasing from ~3,000 to >5,000 feet depth from east to west across the profile. I interpret the bedrock surface to dip westward approximately 20 degrees. However, given the poor imaging capabilities of the source at these depths, detailed mapping of the bedrock surface is difficult.

## Farmers Canal

The 1.85 mile Farmers Canal profile was acquired along the south shoulder of the Farmers Union Canal between Hwy 16 and Little Gulch using the Boise State hammer seismic source (Figure 6). The canal road is relatively flat in elevation (Figure 9) and crosses Hartley Road at position 1,000. A bend in the canal road appears at position 960. Soft surface sediments and water pumps along the canal road added noise to the data, therefore data quality is poorer than the adjacent Little Gulch profile.

The seismic profile shows reflections to more than 1.0 second twtt, similar to observations along Chaparral and Little Gulch profiles (Figure 9). A prominent reflector between 0.1 and 0.2 s twtt overlies a dominantly west-dipping package of reflectors along the western portions of the profile and flat-lying reflectors along the eastern portions of the profile. Reflector topography along the profile may be hydrologically significant and is discussed below.

The shallowest reflector is a relatively flat-lying reflector that lies at approximately 100 feet depth that I interpret as the water table at approximately 2,500 feet elevation across the profile (Figure 9). Seismic velocities are consistent with unsaturated, unconsolidated sediments above this reflector and saturated unconsolidated sediments below. This horizon slightly shallows to the east with at least one large depth step. The largest change in water table depths appears near a bend in the seismic profile at position 960. Water table elevation change may be related to 1) the change in profile orientation and a bend in the irrigation canal or 2) a geologic fault.

Reflections below the water table are consistent with Neogene sediments of the WSRP. I interpret the top of the west-dipping reflectors as the top of Lake Idaho Terteling Springs mustones with Idaho Group sands above this depth. The mudstone reflectors dip upwards of 6 degrees to the west along most of the profile, consistent with the depositional dip of prodelta muds of the Idaho Group sediments. The apparent reflector dip of Lake Idaho sediments changes at the bend in the seismic profile at position 960. This is consistent with either a depositional dip oblique to the seismic profile orientation or a fault. Although this pattern of reflector dips is also consistent with geologic faulting, the coincidental location of changes in reflector dip with profile orientation does not necessitate geologic structure. I interpret a fault that surfaces near position 1100 where reflector offsets separate differing reflector dips. These offsets extend into the Idaho Group sands, but it is difficult to determine whether the sand unit is offset. Reflections below ~1.0 s twtt or > 4,000 feet are difficult to interpret on this section. Given the bedrock depth along the southwest limits of the Little Gulch seismic profile, bedrock depths may exceed imaging capabilities along the Farmers Canal seismic profile.

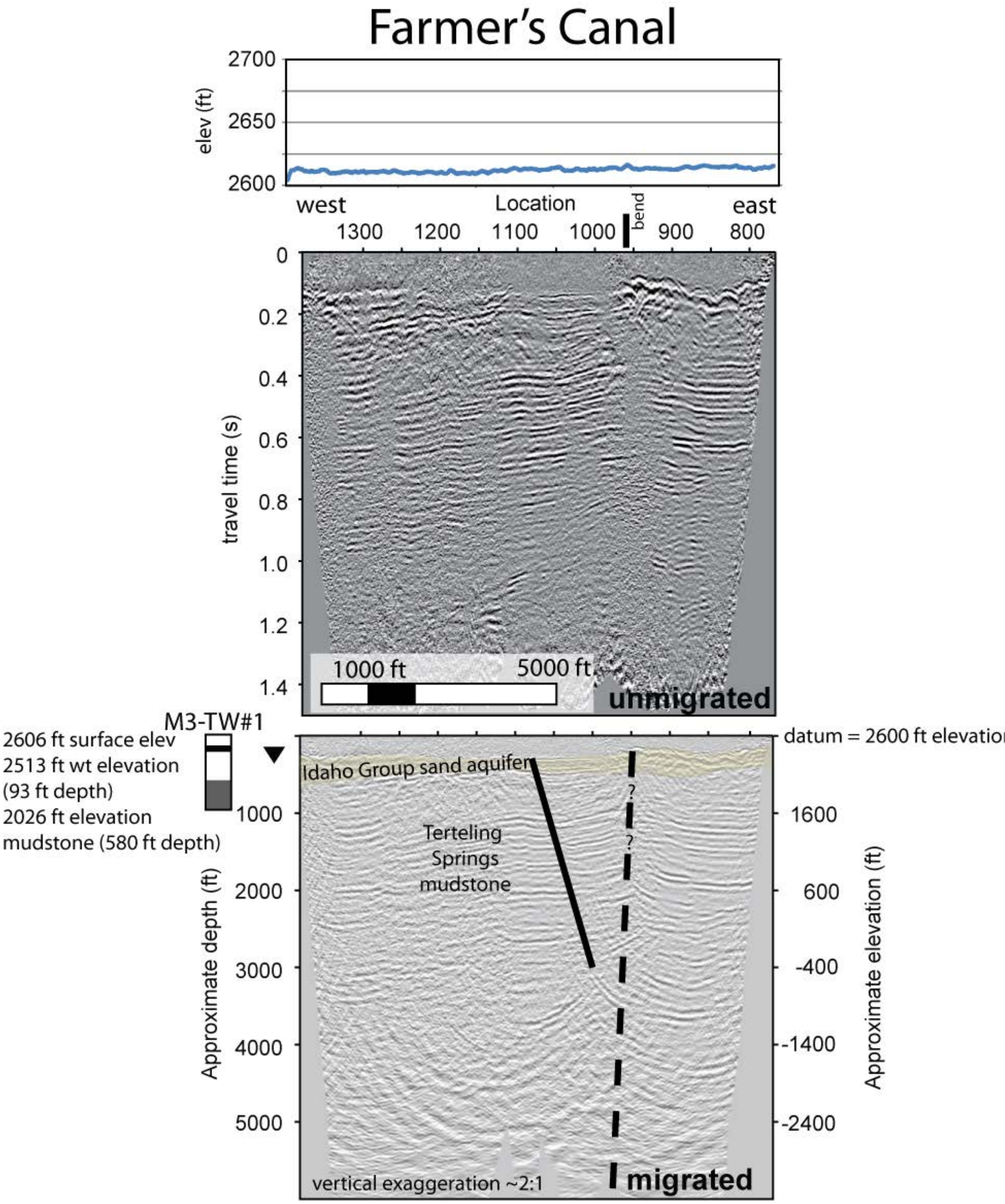



**Figure 9. Elevation profile, unmigrated seismic reflection profile, and interpreted, migrated, and depth converted seismic image from the Farmer's Canal, North Ada County. Note the bend in the profile at position 960 suggests depositional dip is oblique to the profile orientation. Seismic station number locations are shown on Figure 4. Well log for M3-TW#1 from Hydrologic (2008a)**

## Lanewood seismic profile

The 1.0 mile long north-south Lanewood seismic reflection profile is located north of Eagle, Idaho on a private property farm field and gravel road north of Beacon Light Road on Lanewood Drive (Figure 6). The profile begins at the Farmers Canal immediately south of West Homer Road, extends south across a farm field and gravel road to terminate at West Beacon Light Road, a decrease in elevation of approximately 45 feet (Figure 10). The lack of cultural noise or infrastructure provided ideal listening conditions while seismic acquisition following a period of rain and frozen ground provided ideal source and receiver coupling.

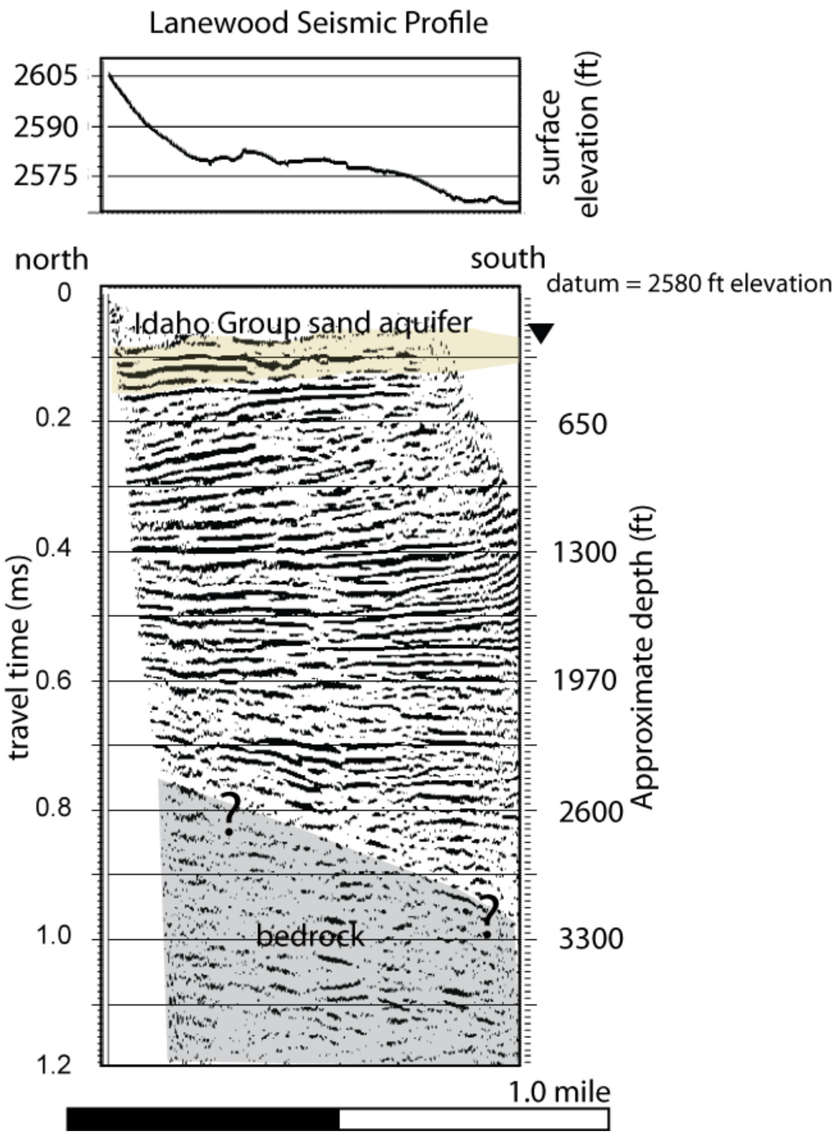



**Figure 10. Lanewood seismic profile, north Ada County. The seismic image shows mostly flat-lying reflectors with no indication of faulting. Moderate dips within the Lake Idaho sediments are likely depositional in origin. Seismic station number locations are shown on Figure 4.**

Figure 10 shows the unmigrated travel time seismic section for the Lanewood section. The seismic image is corrected for a 2,600 feet datum and displayed at approximately 2:1 vertical exaggeration. At approximately 0.1 s two-way travel time (twtt), a generally flat-lying reflector appears across the profile that I identify as the water table at approximately 75 feet depth. A zone of high reflectivity appears immediately below the water table reflector to approximately 0.8 s twtt, suggesting the Idaho Group sand aquifer is thin at this location and mudstones of the Lake Idaho unit appear within the upper 100-200 feet depth. Below 0.8 s, a zone of weak amplitude south-dipping reflectors is present to more than 1.0 s possibly related to bedrock. However, the weak signal returns places high uncertainties as to the bedrock character. Given the dominantly flat-lying reflection character within the Lake Idaho sediment, I do not identify any geologic faults that offset bedrock and overlying strata. The inferred fault that Wood (2007) projects (based on a 100-200 nT magnetic anomaly to the northwest) or the possible fault identified on the Farmers Canal profile (Figure 7) does not appear to cross this profile suggests 1) the fault does not extend to the southeast across the Lanewood Road, 2) the fault offsets deep bedrock, but does not extend into the near surface (explains the magnetic anomaly), or 3) the fault is farther south than this profile was acquired.

## East Ada County/West Elmore County geophysics

Three seismic profiles were acquired in easternmost Ada County and westernmost Elmore County (Figure 1). Additionally, a grid of magnetic profiles was acquired in the area near the Stagestop Plaza. This portion of the report describes the new seismic and magnetic data in detail.

The eastern Ada/western Elmore county study area is located along the northeastern margin of the WSRP. Pleistocene volcanic rocks and Quaternary gravel and terrace deposits appear on the surface immediately south of the Cretaceous granites of the Idaho Batholith (Phillips et al., in review). The Indian Creek road seismic profile is located north from the southern edge of the Idaho batholith south to the road termination at the county line (Figure 11). Immediately northwest of the profile, volcanic rocks from the ~0.9 Ma Slater's Flat volcanic system appear as a relatively smooth surface. These volcanic rocks are not seen at depths greater than approximately 30 feet and no gravity/magnetic signature is related to this feature (Figure 3). The two additional seismic profiles, Stagestop and Johnson profiles are located south of the Indian Creek profile on surface gravel deposits. Thin basalt layers are identified in adjacent boreholes and may be significant to groundwater flow (Welhan, in review). Northwest-trending lineations appear to cut the Slater's flat volcanic rocks and coarse-grained Plio-Pleistocene sediments of the WSRP (yellow arrows on Figure 11). These down to the south surface lineations extend westward into the Boise River terraces and eastward across the Indian Creek and Johnson seismic profiles and may represent regionally significant faults.

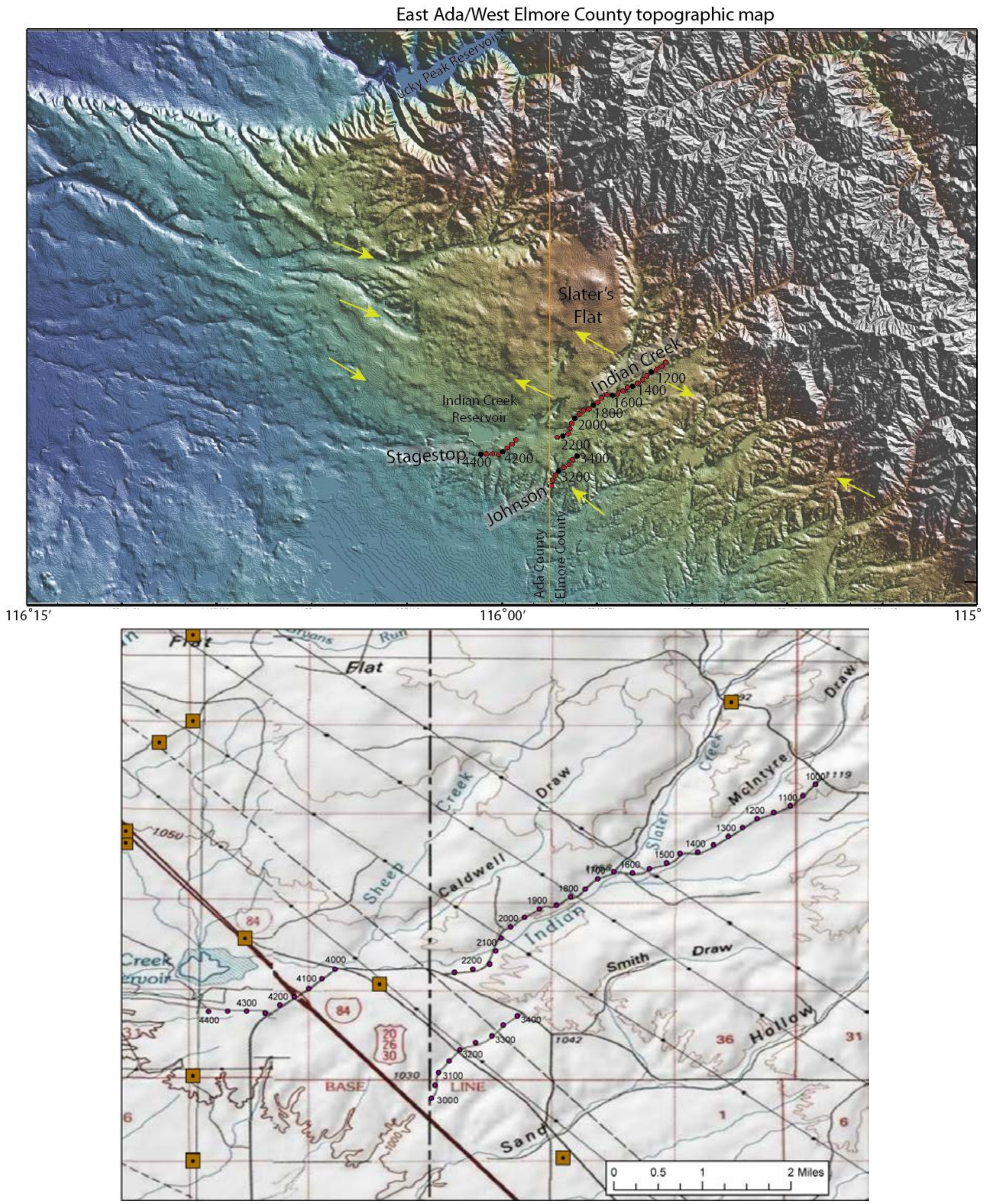


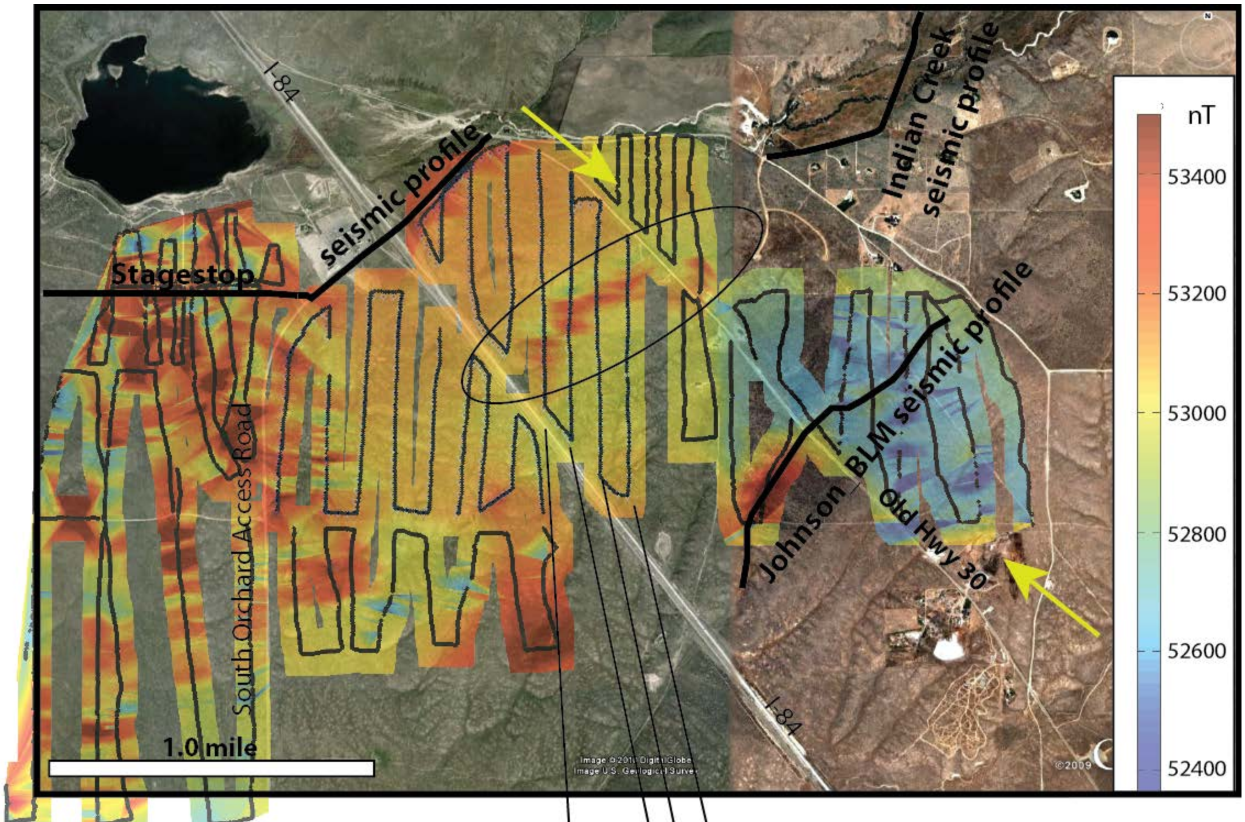

**Figure 11. (top) Topographic map from10 m DEM data of the East Ada Study Area (from GeoMappApp software). Seismic profiles are located as red dots (every 50 shot point). The high elevation Idaho Batholith is shown in white and light colors while sediments and volcanic rocks of the WSRP are shown in copper to blue color range. Yellow arrows highlight NW-trending lineations that represent surface elevation changes that may indicate surface faulting. (bottom) Map showing seismic positions for the 3 seismic profiles- Indian Creek, Johnson-BLM, and Stagestop seismic profiles. Dashed line represents the Ada/Elmore County line. Orange squares represent gravity stations for the area.**

## Magnetics of the Mayfield-Stagestop area

During the summer of 2009 and 2010, Boise State University geophysics students measured the total magnetic field along an approximate 2 sq mile area in eastern Ada County near the Mayfield exit and Stagestop rest area (Figures 11 and 12). The survey area was bisected by the South Orchard Access Road and Interstate-84. The Stagestop and Johnson seismic profiles also cross the survey area. The purpose of the survey was to identify geologic boundaries that may have a hydrogeological significance in an area with highly variable water levels, specifically the presence of buried basalt layers that may provide fluid flow barriers or conduits.

Background total field measurements were acquired at a basestation each day of acquisition with diurnal variations in the magnetic field measuring 10's of nT, with a median background level of approximately 53,300 nT. Total field measurements along the areas west of South Orchard Road were greater than background levels and greater than measurements east of this road, indicative of high susceptibility rocks (Figure 12). This observation is consistent with basalt outcrops mapped immediately north of the survey area where South Orchard Access Road intersects Old Hwy 30 and also consistent with water well logs from the Stagestop property where thin basalt interbeds were logged (Welhan, in review). In addition to the high total magnetic field along the west survey area, I observe a southwest-trending dipole that crosses the eastern portions of the survey, but does not cross the Interstate-84 (circled on Figure 12). Total field value changes of approximately 500 nT on four parallel profiles suggest a high susceptibility magnetic body within the upper hundred feet below land surface. I interpret this lineation as a southwest-striking buried basalt flow that terminates at or near I-84. This anomaly does not extend to the northeast or southwest and is best modeled as multiple thin flows buried at depth or a single basalt flow unit with a complex geometry. An additional feature of interest lies along the south end of the Johnson seismic profile. Again, the likely source of the high magnetic values comes from a buried basalt unit. However, the presence of overhead power lines may also contribute to this signal.

The terminations of the magnetic highs that dominate the western portion of the survey align with a northwest-trending lineation that I identify on Figure 11 (yellow arrows on Figure 12). If this lineation is related to Pleistocene faulting, there may be an influence on groundwater flow (see Johnson-BLM seismic section below).



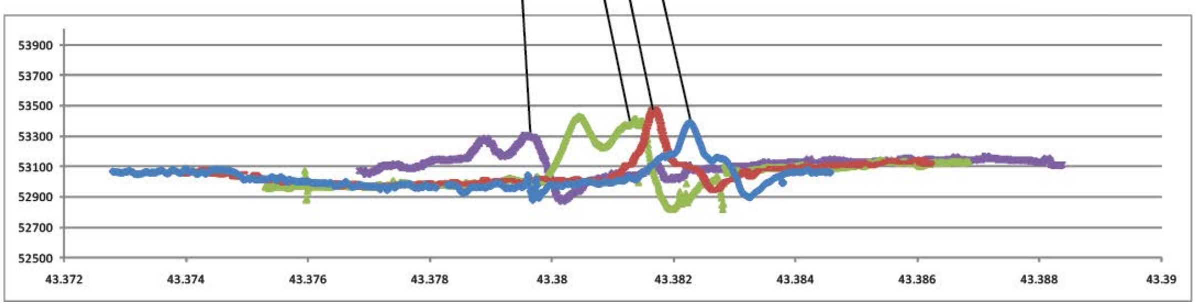




**Figure 12. Magnetic survey area in East Ada county adjacent to the Mayfield Stagestop and across I-84. Total magnetic field is high along the western, southeastern, and northern limits of the survey, mostly related to near-surface basalt flows. Along the central zone, I have circled a lineation that likely is affiliated with a buried basalt flow.**

## Indian Creek seismic profile

The 4.0 mile long northeast-southwest Indian Creek Road vibroseis seismic reflection profile is located along Indian Creek Road between Mayfield and Elmore/Ada County boundary in westernmost Elmore County (Figure 11). The profile begins from the intersection of the foothills access road near Mayfield along the north shoulder of the gravel road and was acquired with the NEES vibroseis truck. The profile terminates at the Ada County line (Figure 11), an increase in elevation of approximately 250 feet. Basalt outcrops appear immediately north of the profile and granitic bedrock appears approximately 1 mile to the north of the northern start of the profile.

Figure 13 shows the unmigrated travel time seismic section above a migrated, depth-corrected and interpreted seismic image. The seismic images are corrected for a 3,500 feet datum and displayed at approximately 2:1 vertical exaggeration. The seismic results from the East Ada profiles show a considerably different character compared to the North Ada profiles and all require additional processing to deal with these complexities.

The unmigrated Indian Creek seismic profile shows laterally discontinuous reflections that relate to large near-surface velocity contrasts. Zones of near-surface high velocities are best explained by shallow basalt flows (Phillips et al., in review). Two areas where these zones appear are at positions 1,300 and 2,050, where I interpret basalt beneath the profile that laterally extends for more than 1,000 feet (circled on Figure 13). The water table reflector generally increases in travel time (depth) to the south (Figure 13, bottom). However, the presence of shallow basalt flows from Slater's Flat may influence near surface velocities and therefore interpreted water table depths. An integration of nearby water well information may help calibrate water table depths.

Deeper in the seismic profile, a southwest-dipping reflector extends from approximately 1,000 feet depth to more than 5,000 feet depth at the Ada County line. The bedrock reflector is clearly imaged along the length of the profile, with diminishing quality to the southwest. The absence of significant bedrock offsets suggests the northern margin of the WSRP is best described by a sag or asymmetric basin geometry. Due to the lack of faulting along the basin margin, post deposition offsets of lithology are not common and tectonic drivers would not influence groundwater flow. However, changes in bedrock geometry at positions 1200, 1500, and 1600 are best explained by faults that alter the bedrock geometry. Consistent with this interpretation is offset of overlying strata and change in reflector dip of Idaho Group sediments. The 10 m DEM data show a regionally extensive lineation that crosses Indian Creek at position 1200 (Figure 11), consistent with late Pleistocene fault motion. The absence of continuous reflections between the near surface and bedrock suggests deep water paleo Lake Idaho sediments are limited in this area. This is consistent with lithologies identified in water well logs along Indian Creek Road that best describe the strata as near-shore sands. One important note is that the water table reflector does not appear near the interpreted faults, suggesting that these faults may not be barriers to groundwater flow.

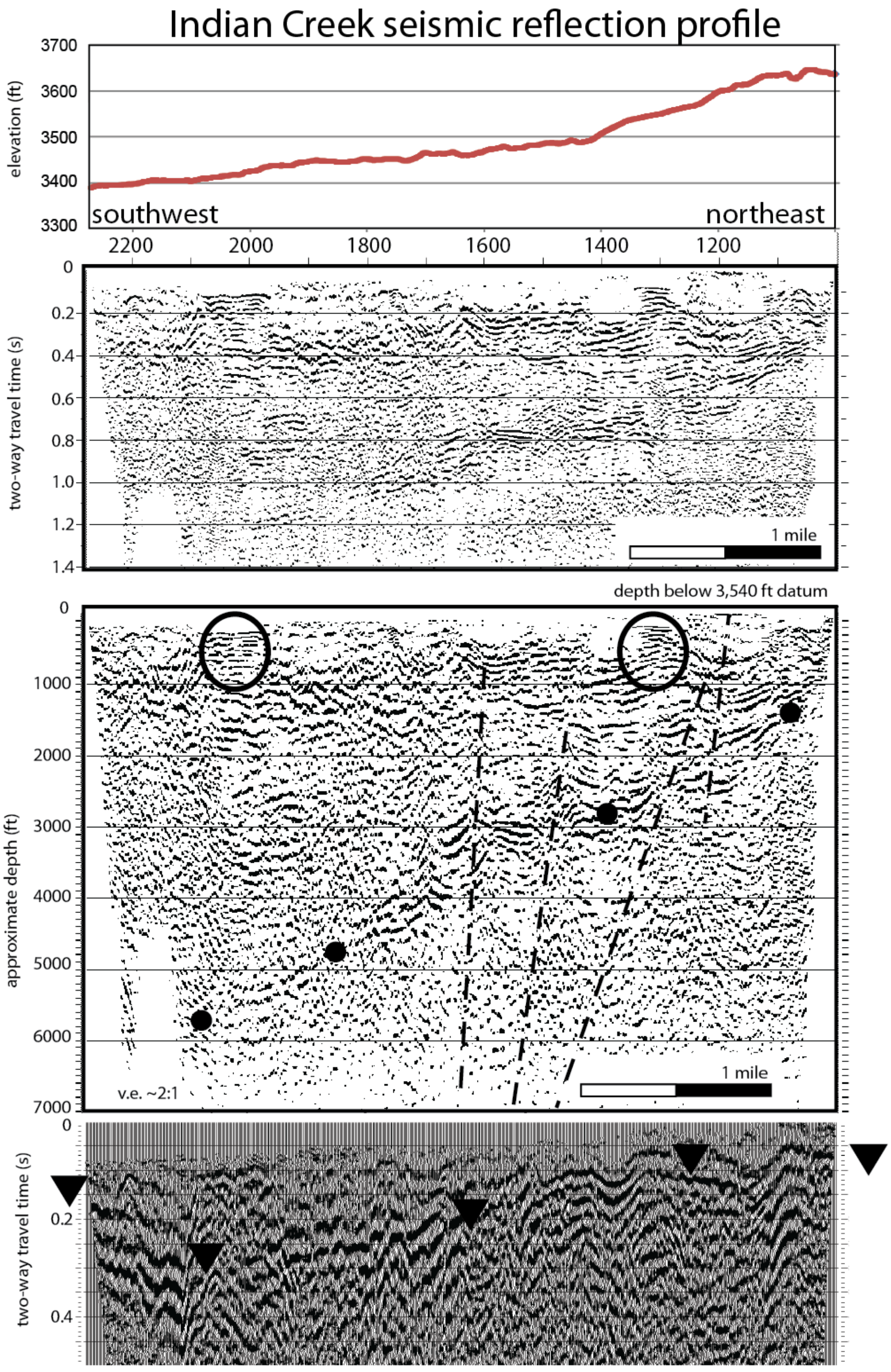



**Figure 13. (top) Elevation profile and seismic reflection section for the Indian Creek profile. The seismic profile is uninterpreted unmigrated section in travel time, (middle) interpreted depth converted migrated stack. (bottom) Upper few hundred feet to highlight the water table reflector. Black dots represent the interpreted bedrock surface, dashed lines represent interpreted faults. Triangles represent water table reflector and ovals represent high velocity zones that are best explained by surface or subsurface basalts. Seismic station number locations are shown on Figure 11.**

## Johnson-BLM seismic profile

The 1.3 mile south-north hammer seismic Johnson-BLM seismic profile is located north of Interstate-84 in Elmore County (Figure 13) along private property (Johnson family) and BLM property. The profile begins north of Interstate-84 along the southern termination of a dirt road. The road crosses old Hwy 30 near position 3,200. Total elevation gain is approximately 80 feet from south to north with the data processed at a 3,350 feet datum (Figure 14). Large power lines extended overhead from positions 3,050-3,200 but the remainder of the profile contained little cultural noise or interference. A large vertical velocity gradient made it difficult to display all information clearly on one figure, so I present an image that represents the shallow water table reflector and an image that represents deeper structures.

The Johnson-BLM seismic profile shows a dominantly south-dipping package of discontinuous reflectors across much of the profile below 0.4 s twtt (Figure 14). The shallowest reflector at 0.3-0.4 s twtt is flat-lying across much of the profile and dips to the south between stations 3000-3150 (Figure 14 right). The deeper reflectors are south dipping approximately 10 degrees along the northern portion of the profile and dip less than 5 degrees along the southern portion of the profile.

I interpret the shallow reflector as the water table, consistent with seismic stacking velocities of 2,000-3,200 feet/s. The change in water table dip at position 3,150 corresponds with a discontinuity and change in reflector dip below that may indicate a fault; however, stratigraphic offsets below 3,150 are not evident. Given the relatively constant seismic stacking velocities above the water table, I do not interpret large lateral variations in geologic conditions in the upper 300-400 feet depth that would misrepresent water table topography. Reflectors below the water table along the central and northern portions of the profile are consistent with changing lithologies within Lake Idaho Group sediments. An offset reflector at position 3250 at approximately 2000 feet depth may indicate a fault. Given the interpretation of magnetic rocks below the southern portions of the profile (Figure 12), subsurface basalt flows likely are present but poorly imaged at depth. The relationship of the surface lineation identified on Figure 11 to offset Idaho Group strata at position 3250 suggest a fault is present below the Johnson profile, and changes in water table geometry suggests the fault may influence groundwater flow.

## Stagestop seismic profile

The 1.5 mile northeast to southwest Stagestop seismic profile was acquired with a 12,000 lb vibroseis truck and begins at the South Orchard Road/Old Hwy 30 intersection, East Ada County (Figure 11). The profile crosses Interstate 84 at position 4,140 and extends west along a dirt road immediately south of the Stagestop Plaza at position 4,250. The profile has an elevation change of approximately 50 feet from the Interstate 84 crossing to the southwest line termination (Figure 11). The seismic profile was processed to a 3,350 feet datum.

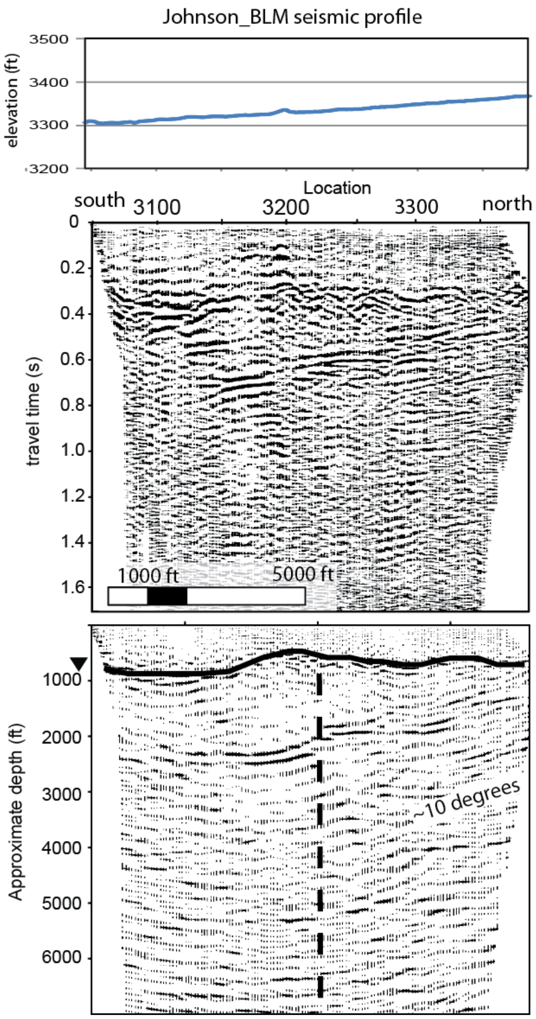
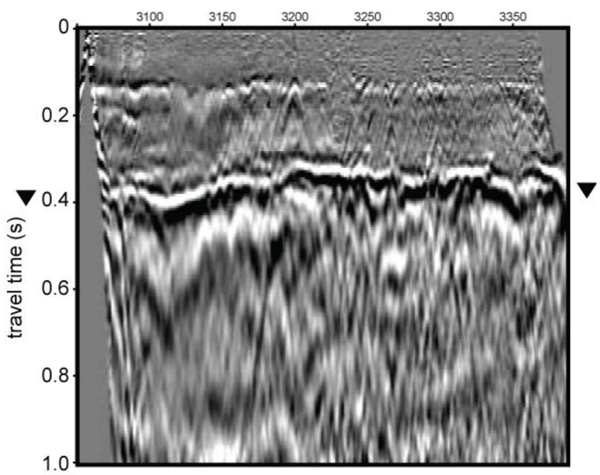



**Figure 14 . (left) Elevation profile, unmigrated seismic reflection profile, and interpreted, migrated, and depth converted seismic image for the Johnson/BLM profile, Elmore County. Note that a change in water table topography also matches offset dipping reflectors below. (below) Seismic profile processed to highlight the water table reflector. Note the flat-lying water table reflector along the northern portions of the profile and south-dipping water table reflector along the southern portion of the profile. Seismic station number locations are shown on Figure 11.**




The unmigrated travel time seismic image shows a south dipping reflector that ranges from 0.3 to 0.5 s twtt between positions 4,000-4,250 (Figure 15). At the bend in the seismic section (4250-4430), this reflector is near flat lying to east-dipping. Discontinuous, strong amplitude reflectors appear west of the profile bend (4250) that are not present along the north-south profile section. Seismic stacking velocities in the upper 0.4 s range from 1,500-2,500 feet/s along the northern portions of this profile while seismic velocities west of South Orchard Road (position 4250) are 2,500-5,000 feet/s. These slow velocities are consistent with unsaturated sediments above the south-dipping water table reflector at 300-400 feet depth across the section. The faster velocities and discontinuous reflectors that appear west of South Orchard Road are consistent with basalt interbeds in the upper few hundred feet, consistent with lithologies observed in the Stagestop Plaza water wells and also consistent with ground-based magnetic profiling (Figure 9). Reflections below the water table are poorly imaged on this profile, in part due to cultural noise, poor coupling of the sensors and vibroseis truck, and abundance of subsurface basalts.

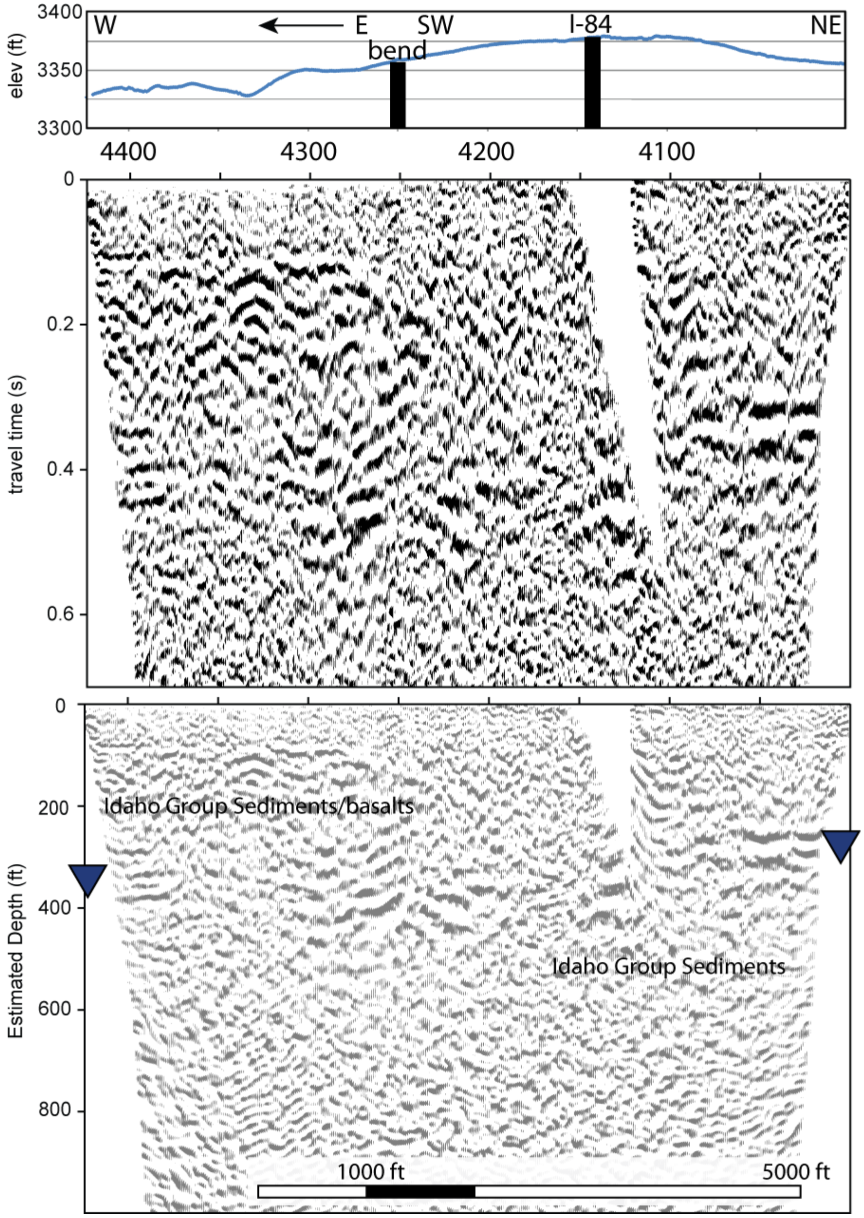



**Figure 15. Elevation profile, unmigrated seismic reflection profile, and interpreted, migrated, and depth converted seismic image for the Stagestop profile, East Ada County. Note the bend in the profile at position 4250 and the gap in near-surface coverage as the profile crosses Interstate 84. A significant change in seismic character west of the profile bend correlates with interpreted near-surface basalt flows. The south-dipping water table reflector is estimated at depths between 300-400 feet. Seismic station number locations are shown on Figure 10.**

## Conclusions

This report summarizes new and existing geophysical data from two areas in and around Ada County, Idaho. Seismic and well log data from the North Ada study area suggest dominantly southwest-dipping Idaho Group sediments fill the northern margin of the western Snake River Plain. Bedrock topography generally depicts a sag or asymmetric basin geometry for the WSRP with bedrock dips upwards of 20 degrees to the south. Regional gravity and magnetic data show the geometry of sediments and volcanic rocks within the WSRP. A shallow sand aquifer of the Idaho Group appears as zones of low amplitude reflections and extends to depths of 1,000 feet. Reflections from deep water Idaho Group sediments extend to more than 5,000 feet depth along the North Ada profiles. Seismic data from East Ada profiles suggest Idaho Group sands dominate the subsurface, increasing in thickness to the south. Increased depths to water table correlate with increasing basin depths and possibly to normal faults related to basin extension. Buried basalts are also identified with seismic and magnetic data and these units may locally control groundwater flow. Faults identified on seismic profiles match surface elevation lineations, suggesting that these faults contain late Quaternary (post deposition) motion. An inflection point in water table elevation at the location of one fault along the Johnson profile suggests faults may contribute to water table geometries.


## Acknowledgements

The author wishes to thank the Farmers Union Canal Company for site access at the North Ada site, the Johnson family for site access in Elmore County, the Stagestop Plaza in East Ada County and Ada, Canyon, and Elmore Counties for access along county roads. Boise State University field support was provided by Shaun Finn, Andrew Nies, Kyle Lindsay, Larry Otheim, Jason Compton, and Jennifer Parks.


## References


Barrash, W. and Dougherty, M. E., 1997, Modeling axially symmetric and nonsymmetric flow to a well with MODFLOW, and application to Goddard2 well test, Boise, Idaho: *Groundwater*, 35, 4, 602-611.

HydroLogic, 2007, M3 Eagle Test Well #3 Composite Diagram, http://www.idwr.idaho.gov/Browse/WaterInfo/NAC/consultant_reports/M3/M3%20Eagle%20Test%20Well%20%233%20Composite%20Diagram%20by%20Hydro%20Logic,%20Inc.%209-27-2007.pdf

HydroLogic, 2008a, M3 Eagle Test Well #1 Test Well Composite Diagram, http://www.idwr.idaho.gov/Browse/WaterInfo/NAC/consultant_reports/M3/M3%20Eagle%20Test%20Well%20%231%20Composite%20by%20Hydro%20Logic,%20Inc.%204-23-2008.pdf

HydroLogic, 2008b, M3 Eagle SVR #9 Test Well Composite Diagram, http://www.idwr.idaho.gov/Browse/WaterInfo/NAC/consultant_reports/M3/M3%20Eagl

e%20SVR%20%239%20Test%20Well%20Composite%20%20Diagram%20by%20Hydro%20Logic,%20Inc%2007-07-2008%20smaller.pdf
HydroLogic, 2008c, M3 Eagle Test Well #2Composite  Diagram, http://www.idwr.idaho.gov/Browse/WaterInfo/NAC/consultant_reports/M3/M3%20Eagle%20Test%20Well%20%232%20Composite%20-%20FINAL.pdf
Liberty, L. M., 1997, Seismic reflection results: Stewart Gulch region, Boise, Idaho, in, Sharma and Hardcastle, eds., *Proceedings of the 32nd Symposium on Engineering Geology and Geotechnical Engineering*, 365-380.
Liberty, L.M., 1998, Seismic reflection imaging of a geothermal aquifer in an urban setting: *Geophysics*, 63, 4, 1285-1294.
Liberty, L.M., Wood, S.H., and Barrash, W., 2001, Seismic reflection imaging of hydrostratigraphic facies in Boise: A tale of three scales, *Society of Exploration Geophysicists 71rst Annual Meeting, San Antonio, Tx*, p. 1393-1396.
Lindholm, G.F., 1996, Summary of the Snake River Plain regional aquifer system analysis in Idaho and eastern Oregon, U.S. Geological Survey Professional Paper 1408-A, 59 p.
McCafferty, A.E., R.P. Kucks, P.L. Hill and S.D. Racey, 1999, Aeromagnetic Map For The State of Idaho: A Web Site for Distribution of Data, U.S. Geological Survey Open-File-Report 99-37.
Othberg, K.L., 1994, Geology and geomorphology of the Boise Valley and adjoining areas, western Snake River Plain, Idaho: Idaho Geological Survey Bulletin 29, 54 p
Phillips, W.M., Lewis, R.S., Gillerman, V.S., Garwood, D.L., and Stewart, D.E., Geologic map of the Mayfield area, Ada and Elmore Counties, Idaho, Idaho Geologic Survey Digital Web Map, in review.
Welhan, J.A., in review, Hydrogeologic analysis of the East Ada project area, IDWR report.
Wood, S.H., 1994, Seismic expression and geological significance of a lacustrine delta in Neogene deposits of the western Snake River Plain, Idaho: *AAPG Bulletin*, v. 78, p. 102-121.
Wood, S.H., Qualitative interpretation of magnetic anomalies and progress report on geologic mapping in the foothills north of Eagle, Ada and Gem Counties, Idaho, Report prepared for Hydro Logic, Inc, May 20, 2007, 15 p.
Wood, S.H., and Clemens, D.L., 2002, Geologic and tectonic history of the western Snake River Plain, Idaho and Oregon: in  Bonnichsen, Bill, White, C.M., andMcCurry, M., eds., Tectonic and Magmatic Evolution of the Snake River Plain Volcanic Province: *Idaho Geological Survey Bulletin 30*, 35 p.
Yilmaz, Ö., (2001), Seismic data analysis, *Society of Exploration Geophysicists*, Tulsa, Ok, 2027 p.