# Geophysical Investigations of Birch Creek Valley near the Northern Boundary of the INEEL - Year 1 Report

**Report Prepared for the Idaho Water Resources Research Institute**

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## 1.0 Abstract

The Center for Geophysical Investigation of the Shallow Subsurface (CGISS) at Boise State University (BSU) conducted geophysical studies in Birch Creek Valley near the northern boundary of the Idaho National Engineering and Environmental Laboratory (INEEL) as part of the Idaho Universities Consortium research effort to support and advance technologies to remediate the volatile organic contaminant plume in the Snake River Plain (SRP) aquifer at the Test Area North (TAN) site. CGISS reviewed existing gravity and aeromagnetic data, and removed the regional component from these data sets. Filtered complete Bouguer gravity data (i.e., influence of the SRP removed with a low-cut filter) provide information on the relative depth of basin fill along basin segments between ranges. These data suggest southern Birch Creek Valley contains a relatively shallow basin (a few hundred meters depth to bedrock) that is subdivided into local sub-basins along the axial trend of the valley. The relative depths of the sub-basins in southern Birch Creek Valley are anomalously shallow compared to nearby basins (i.e, central Birch Creek Valley; Little Lost River Valley). Anomalies in total field aeromagnetic data are strongest on the SRP and spatially correlate with near-surface basalt flows. CGISS also conducted seismic noise tests and short seismic profile lines that indicate: (1) shallow caliche greatly limits the ability to image bedrock and reflectors within the sedimentary fill, especially with a hitch-mounted weight-drop source; and (2) depth to a hard rock interface ranges from less than 20 m to greater than 200 m, and does not deepen systematically from southwest to northeast across southern Birch Creek Valley. Reflections were observed from a hard-rock interface (perhaps bedrock) and from the water table (confirmed by drilling). No intra-basin reflections were observed on the seismic records. This may mean that a relatively homogeneous package of gravels dominates the basin fill or that recording conditions (such as the shallow caliche) were inadequate for proper imaging. Seismic reflection results at the northern edge of the INEEL are consistent with the presence of near-surface basalt(s), perhaps related to Lava Ridge.

## 2.0 Introduction

The Center for Geophysical Investigation of the Shallow Subsurface (CGISS) at Boise State University (BSU) is investigating the southern Birch Creek Valley region near the northern boundary of the Idaho National Engineering and Environmental Laboratory (INEEL). This effort is part of the Idaho Universities Consortium program to contribute to the remediation of the organic contaminant plume in groundwater at the Test Area North (TAN) site. In particular, CGISS is using geophysical methods to provide control on the structure and stratigraphy of the subsurface at the transition from Birch Creek Valley to the Snake River Plain (SRP) immediately upgradient from the contaminant plume.

Several significant features that influence hydrogeologic conditions in the TAN area (Sorenson et al., 1996) are; (1) the anomalously low hydraulic gradient in the area between TAN and Birch Creek Valley (Figure 1); (2) the geometry and hydrology of the Birch Creek groundwater flux boundary to the SRP aquifer; (3) the anomalous orientation of the TAN organic contaminant plume with respect to the regional hydraulic gradient; and (4) the contribution of different water chemistries from underflows from Birch Creek Valley and the SRP north of the INEEL (e.g., Robertson et al., 1974) to microbiological communities in and possible bioremediation of the TAN organic contaminant plume. Better control on the structure and stratigraphy of the subsurface at the transition from Birch Creek Valley to the SRP immediately upgradient from the contaminant plume will help with modeling and design of remediation technologies at TAN. Sorenson et al. (1996) recently reviewed the state of understanding of the hydrogeologic system in the TAN area and factors which need to be evaluated for model development and effective remediation design. They noted that recharge from alluvial aquifers in the valleys adjacent to the SRP can have a pronounced effect on SRP aquifer levels in wet years, and that considering the low gradient at TAN, such fluctuations or trends can have a significant effect on remediation activities at TAN.

Objectives achieved during the 1996-1997 project year were (1) compilation and review of existing gravity, magnetic and seismic data for the region including the lower Lemhi Range, the lower Beaverhead Range and southern Birch Creek Valley (Figure 1), and (2) acquisition of seismic noise tests and a short seismic line in lower Birch Creek Valley. In addition, preliminary efforts were initiated to conduct seismic reflection experiments on the INEEL to provide subsurface information closer to the plume where thin basalt flow(s) are present in the subsurface but may be minor in the upper portion of the stratigraphic sequence.

## 3.0 Previous Investigations

Previously published geophysical studies focusing on Birch Creek Valley are very limited, although there are a number of more regional studies. Gravity and magnetic maps for the state (McCafferty et al., 1990; Mabey, 1982) and the INEEL region (Hadley and Cavit, 1984) have demonstrated the value of these data for mapping general basin structures and the extent of basalt flows related to the SRP. Previous seismic studies have focused on the crustal structure of the SRP (e.g. Sparlin et al., 1982; Elbring, 1984; Pankratz and Ackermann, 1982) and local near-surface features such as the thickness of surficial sediments and basin structures (e.g. Hadley and Cavit, 1984; Miller et al., 1988).

Birch Creek Valley is a northwest-trending extensional basin with interpreted basin-bounding faults (Beaverhead fault) along the northeastern basin margin (e.g. Kuntz et al., 1994). To the northeast are the Beaverhead Mountains and to the southwest is the Lemhi Range (Figure 1). Six major segments of the Beaverhead fault have been identified (Crone and Haller, 1991), with the 25-km Blue Dome segment extending along southern Birch Creek Valley. Southwest-dipping, sub-parallel intrabasinal normal faults offset Tertiary sediments and perhaps separate fault segments at the northern end of southern Birch Creek Valley (Rodgers and Anders, 1990). The latest movement on the Blue Dome fault segment is interpreted to be Pleistocene in age (older than 15 Ka) with a low Quaternary slip rate compared to adjacent segments (Crone and Haller, 1991).

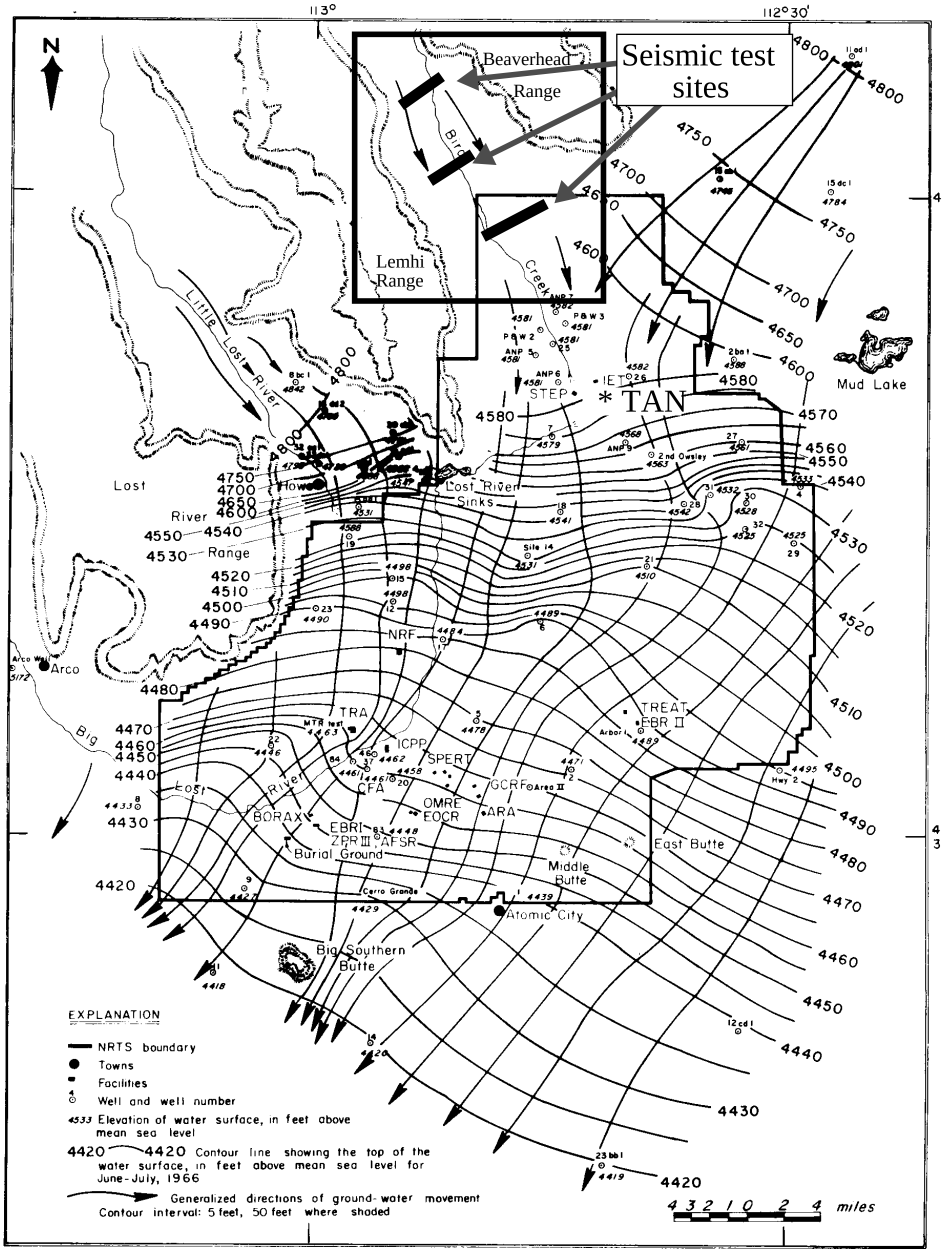


Figure 1. Location map for the study area. The three seismic test sites are labeled as well as the location of the Test Area North (TAN) facility. Figure modified from Robertson et al. (1974).

There are no fault scarps along the alluvial fans on the northeast range front and Paleozoic rocks outcrop on both sides of the interpreted Blue Dome segment. This may suggest the presence of multiple fault strands along the Blue Dome segment (Crone and Haller, 1991). There is less topographic relief along the Blue Dome segment of Birch Creek Valley (less than 1000 m) compared to adjacent basins and northern and central Birch Creek Valley, where more than 1500 m of relief is observed.

Cenozoic extension in the region began during Eocene time, coincident with the onset of Challis volcanism (~50 Ma). This extensional history continues to the present day, although extension directions did not remain constant during the past 40 Ma. The extensional history has produced mountain ranges that are faulted into complex horsts and grabens (Janecke, 1992). Faulting in Quaternary-to-Recent time has occurred primarily along range fronts of tilted blocks which are rotated to the northeast. Recent movement along the central portion of the Lost River Range (Borah Peak earthquake, 1983) was largely normal with a minor amount of lateral offset (Crone and Machette, 1984). This may be typical of faulting events in both the Lemhi and Beaverhead fault zones.

The oldest rocks exposed in the area are complexly folded Mississippian to Early Permian marine sedimentary rocks (Skipp et al., 1979). These rocks form the prominent northwest-trending linear mountain ranges which bound Birch Creek Valley. Much of the exposed coarse-grained sediment in Birch Creek basin is late Pleistocene gravel deposited during the late Pinedale glacial period (Pierce and Scott, 1982). Alluvial fans, which drape the sides of the valley, are also relics of that time since present-day stream flows are insufficient to transport these sediments. At the northern end of the southern Birch Creek Valley (Blue Dome) the underlying sedimentary rocks are uplifted and exposed. Interbedded Neogene conglomerates, fresh-water limestones, basalt, and rhyolite overlie the Paleozoic bedrock (Rodgers and Anders, 1990).

The broad SRP lays in stark contrast to the rugged mountain ranges and basins to its northwest and north. The eastern SRP is a northeast trending belt of volcanic rocks containing Miocene and Pliocene age rhyolite calderas and 2-10 Ma basalt vents along the track of the Yellowstone hot spot. Regional extension is parallel to the axis of the SRP and this extension is imprinted on the pattern of volcanic vents and cones. The orientation of major rift zones within the plain are parallel with the trends of adjacent basins and ranges (Kuntz, 1978; Kuntz et al., 1992). Modeling of seismic refraction and other geophysical data (Sparlin et al., 1982; Pankratz and Ackermann, 1982; Young and Lucas, 1988) suggests that the northwest margin of the SRP is a fault-bounded margin. Kuntz et al. (1994) have also mapped northeast-trending faults paralleling the eastern SRP margin, but suggest these faults may be related to caldera boundaries and not extension (Kuntz et al., 1992). Also, McQuarrie and Rodgers (1996) present evidence for a downwarping of Basin and Range crust 20 degrees toward the SRP within 20 km of the northern margin of the eastern SRP.

Surface water flows from present-day Birch Creek and the Big and Little Lost Rivers infiltrate into the SRP and rarely reach the playas in depressions at the northern edge of the plain (partly due to irrigation diversions). Fluvial sediments within the plain have been derived from these drainages for at least the past 580,000 years (Reed, 1994). Sediments recovered from exploration holes suggest that the sediment source for the region near the TAN has been from the Birch Creek drainage basin during that period (Bartholomay and Knobel, 1989).

# 4.0 Geophysical Data

## 4.1 Complete Bouger Gravity

The gravity data used in this investigation were taken from McCafferty et al. (1990). These authors compiled and processed data from a number of local surveys. The processing included projecting the data onto a 2 km regular grid using a minimum curvature interpolation technique, and a Bouguer correction using a density of 2.67 g/cm$^3$. Terrain corrections were applied for each station. The complete Bouguer gravity data from the INEEL region are displayed on Figure 2 with a colormap to represent the Bouguer gravity values. Red colors represent regions of high relative density and blue colors represent regions of low relative density. To emphasize variations in the mid-range of the gravity scale, very high and very low anomaly values were given the end-member red and blue colors respectively. Between the end-member colors, the scale is linear. A similar map is presented as Appendix A with geologic contacts from Kuntz et al. (1994) superimposed.

The unfiltered data in Figure 2 show the characteristic Bouguer gravity high (red) associated with the SRP, the lows (blue) associated with sedimentary basins, and the intermediate values (yellow) associated with Paleozoic rocks in the ranges northwest of the SRP. Note that the gravity signature of Birch Creek Valley varies considerably along the axial trend of the basin. In the northern and central portion of the valley, a large gravity low is observed. This implies a large density contrast between the basin fill and the ranges, and/or a relatively deep basin in the central and northern part of Birch Creek Valley. The southern portion of Birch Creek Valley (south of Blue Dome) shows much less difference between the gravity response of the basin compared to that of the adjacent ranges. This likely suggests southern Birch Creek Valley contains a much more shallow basin fill sequence than central and northern Birch Creek Valley, but a portion of this raw gravity response may be attributable to the regional effect of the denser crust in the nearby SRP.

To remove the regional trend caused by the SRP and to bring out local details in the gravity field, the data from Figure 2 were input to a spatial filter. The filter (a finite impulse response 2-D filter) was designed to attenuate the component of the gravity field with wavelengths greater than 60 km. The resulting data are shown in Figure 3 (Appendix B shows this map with geologic contacts superimposed). We can see, from the filtered results, the shapes of local sedimentary basins in the region (e.g., Little Lost River, Big Lost River, Mud Lake, and Birch Creek). Within southern Birch Creek Valley, a local gravity low is observed near Peterson Canyon Road, the site of one of the CGISS walkaway seismic tests in this study. Further north, near the Eightmile Canyon seismic test, the gravity anomaly increases in magnitude, possibly indicating a shallower basement. This suggests the presence of a local basin depocenter near the northwest corner of the northern INEEL boundary. Whether this apparent graben-like anomaly is structurally controlled cannot be determined by the gravity data alone.

## 4.2 Magnetics

The total-field aeromagnetic data used in this investigation were taken from McCafferty et al. (1990). Preprocessing included projecting the data onto a 0.5 km grid using a cubic spline interpolation method and reducing the data to a constant datum. Figure 4 shows the gridded aeromagnetic data from the INEEL region; Appendix C shows these aeromagnetic data with mapped geologic contacts (from Kuntz et al., 1994) on the magnetic map.

Aeromagnetic data are more sensitive to near-surface geologic features than gravity data because dipolar magnetic anomalies fall off with the cube of distance. The data in Figure 4 primarily show the location of the near-surface basalt flows since these are magnetic compared to the Paleozoic rocks and basin fill from the adjacent basins and ranges. The most notable features on the aeromagnetic map are the strong contrasts in amplitude associated with basalts from the SRP. Although individual basalt flows cannot be identified within the SRP due to overlapping signatures

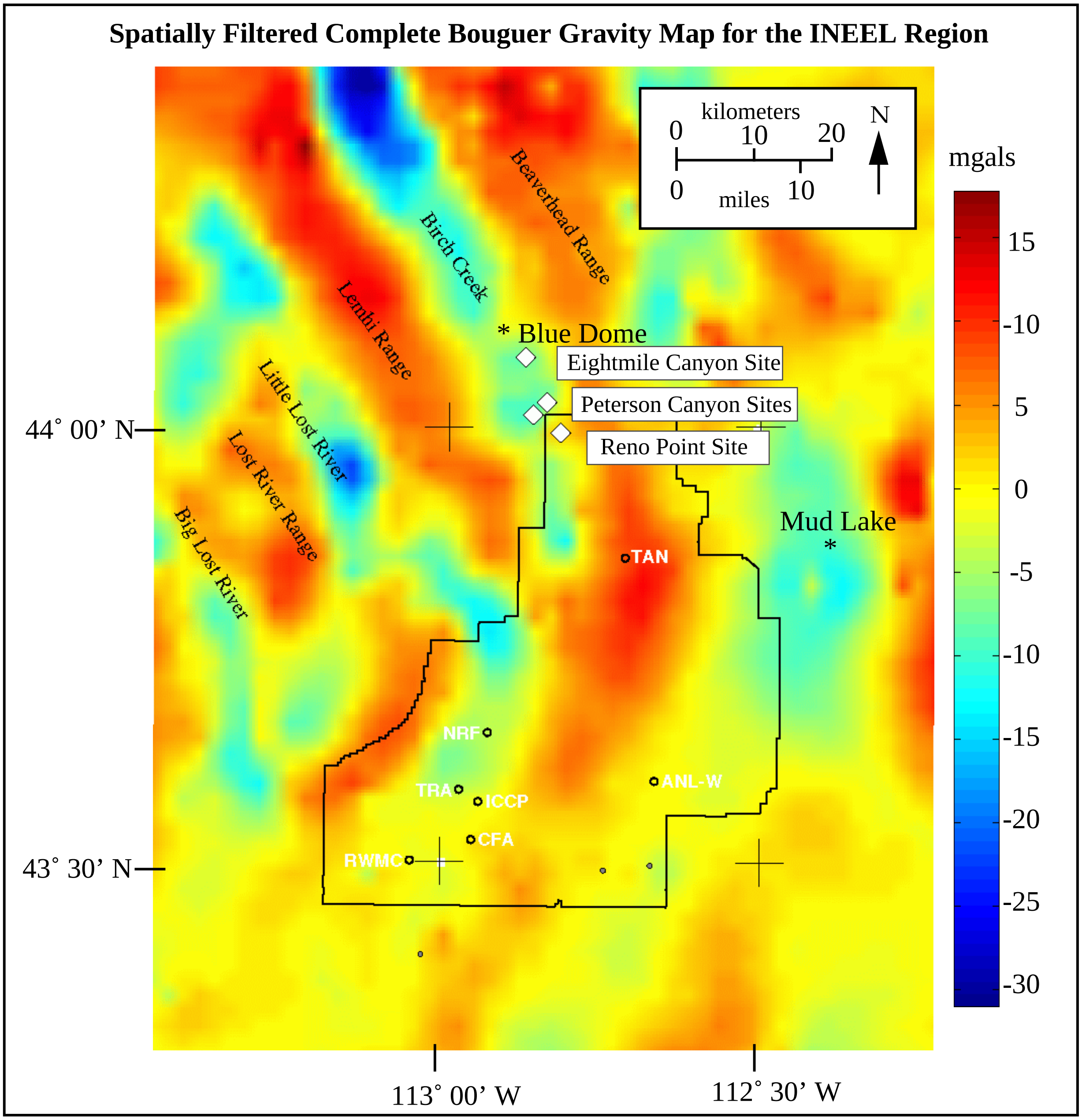
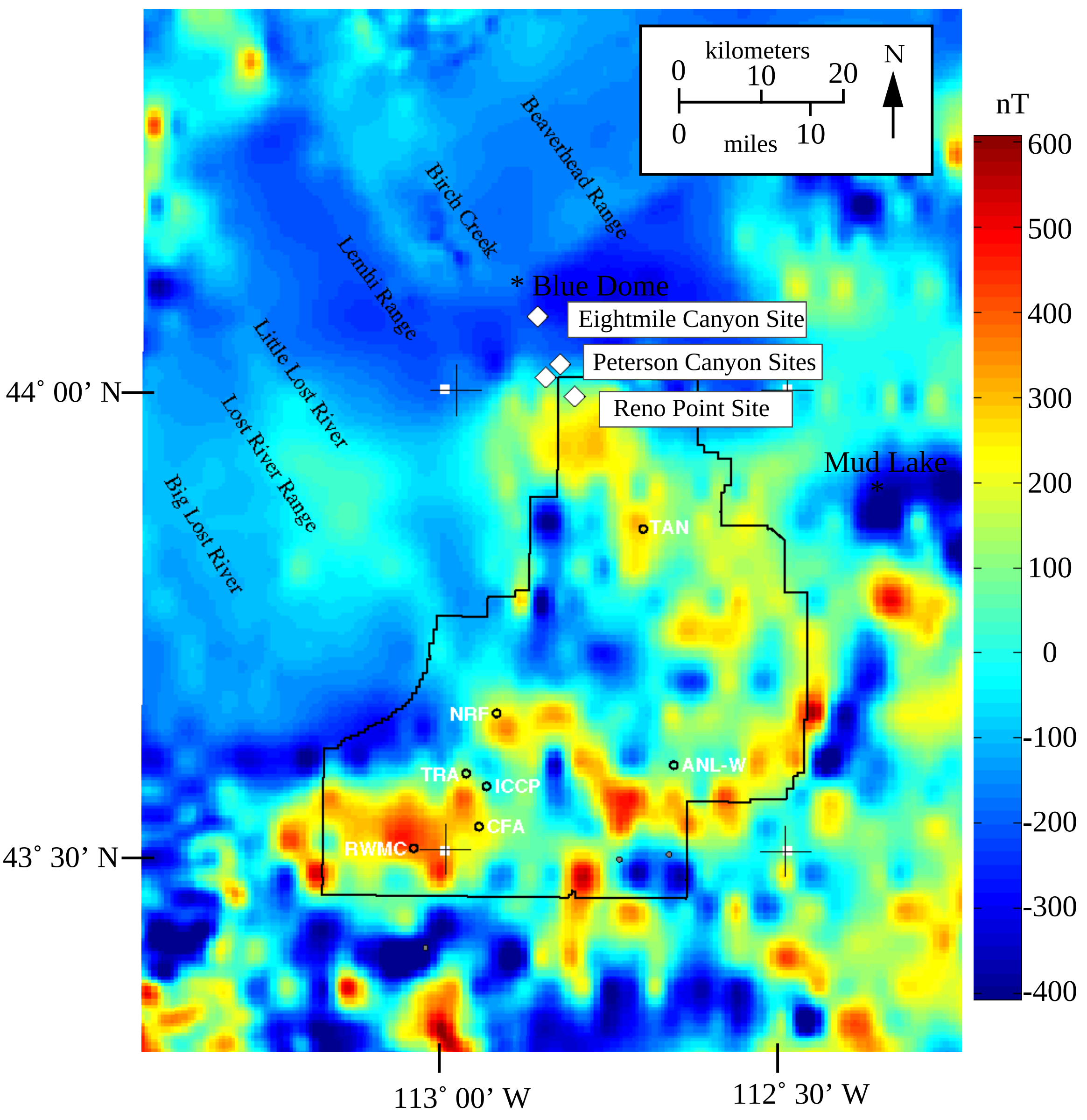


Figure 3. Spatially filtered Bouger gravity map for the INEEL region. Wavelengths greater than 60 km have been removed. Note the better resolution of the basin structures compared to the unfiltered data (Figure 2). CGISS seismic walkaway test sites from southern Birch Creek Valley are labeled with diamond shapes.



Unfiltered Total-Field Aeromagnetic Map for the INEEL Region

Figure 4. Total-field aeromagnetic map for the INEEL region. Regions of extreme fluxuations in the magnetic field are typically associated with areas of thick basalt flows. CGISS seismic walkaway test sites from southern Birch Creek Valley are labeled with diamond shapes

generated from each flow, the regional pattern clearly shows the extent of the basalts associated with the SRP. Northwest of the SRP, magnetic intensity is low and becomes much less variable. Generally, basins with unconsolidated fill and ranges with Paleozoic sedimentary rocks cannot be clearly differentiated with magnetic data because of the low contrasts in their magnetic signatures. One method for investigating a regional magnetic trend is to apply a low-pass filter to the grid of raw aeromagnetic data. However, we applied several low-pass filters, but did not find significantly different magnetic trends compared to the unfiltered results.

## 5.0 Seismic Results

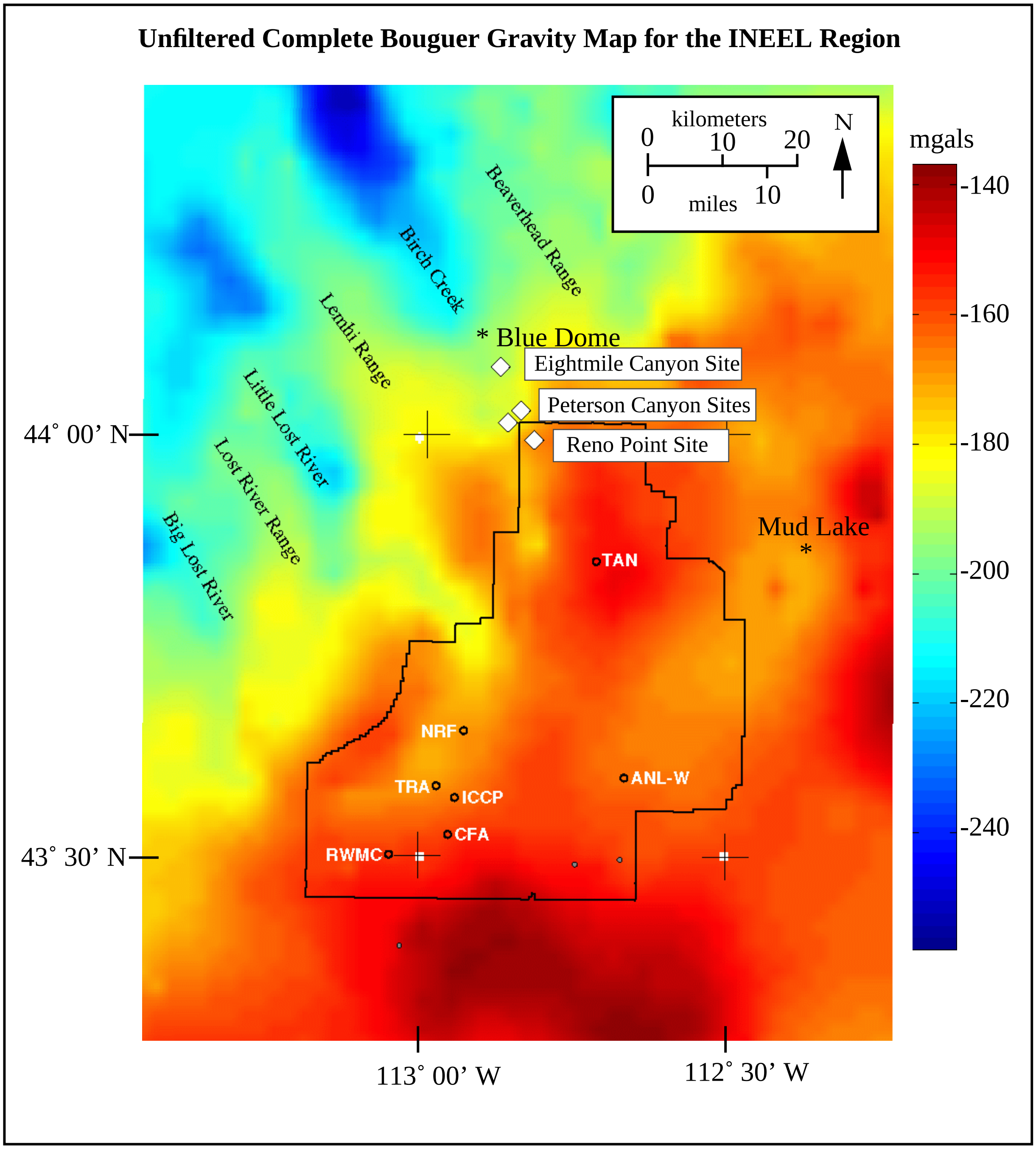
During August, 1996 we completed a series of seismic tests in southern Birch Creek Valley, north of the INEEL. The location of the seismic tests is shown on Figures 1-4. The purpose of these tests was to determine the optimal recording parameters for imaging the complicated volcanic and sedimentary stratigraphy in the area. We performed all of our tests with an accelerated weight drop source (Elastic Wave Generator (EWG-I) from Bison Instruments) mounted to a pick-up truck receiver hitch. Walkaway seismic tests were collected at four sites, and then we acquired two short seismic reflection profiles oriented at high angles to the axis of Birch Creek Valley.

A seismic walkaway experiment is a test to determine if seismic reflections can be recorded with various shot sources and a densely spaced spread of geophones. Recording parameters (analog filters, sample rate, recording time) are conservatively estimated to determine the optimum settings for a future seismic reflection profile. Once the raw data are collected, post-processing of the field records helps to identify reflections and define the optimum station spacing, source type, source size, source repetitions, and recording parameters for our 48-channel seismograph. Although we had planned to try both the EWG and an explosive (kinestik) as the seismic source, we were unable to use the explosive because of logistical problems.

### 5.1 Eightmile Canyon Road

The Eightmile Canyon walkaway experiment was centered approximately one mile east of Birch Creek along Eightmile Canyon Road, west of state highway 28. The experiment spanned approximately 400 m both east and west of a 48-channel geophone array (1 m spacing between geophones). The raw records (Figure 5) show little evidence for continuous coherent reflections through the section. The dominant energy on the seismogram is associated with strong surface waves. Within the “optimum window” of the walkaway data (Hunter et al., 1984) we see no obvious reflections with a characteristic hyperbolic shape.

Intercept times of the refractions or first break arrival data suggest that the depth to a high-velocity layer (interpreted to be “bedrock” - Paleozoic rocks or Tertiary volcanic rocks) is less than 100 m. Four different velocity legs can be interpreted from these data and are summarized in Figure 5. These data suggest the presence of a very shallow refractor (less than 2 m depth), perhaps associated with a caliche layer. Below this horizon, we have interpreted an additional transition zone at approximately 25 m depth (~1950 m/s velocity), consistent with an estimated water-table depth and velocity of underlying saturated sediments. We also interpret a bedrock refractor at approximately 97 m depth, with an approximate velocity of 3200 m/s, consistent with weathered basalt from the region (Pankratz and Ackermann, 1982). The depth to the last two horizons may be an



Unfiltered Complete Bouguer Gravity Map for the INEEL Region

Figure 2. Regional complete Bouguer gravity map for the INEEL region (extracted from McCafferty et al., 1990). Note the strong contrast between the Snake River Plain and the Basin and Range structures north of the INEEL. CGISS seismic walkaway test sites from southern Birch Creek Valley are labeled with diamond shapes.

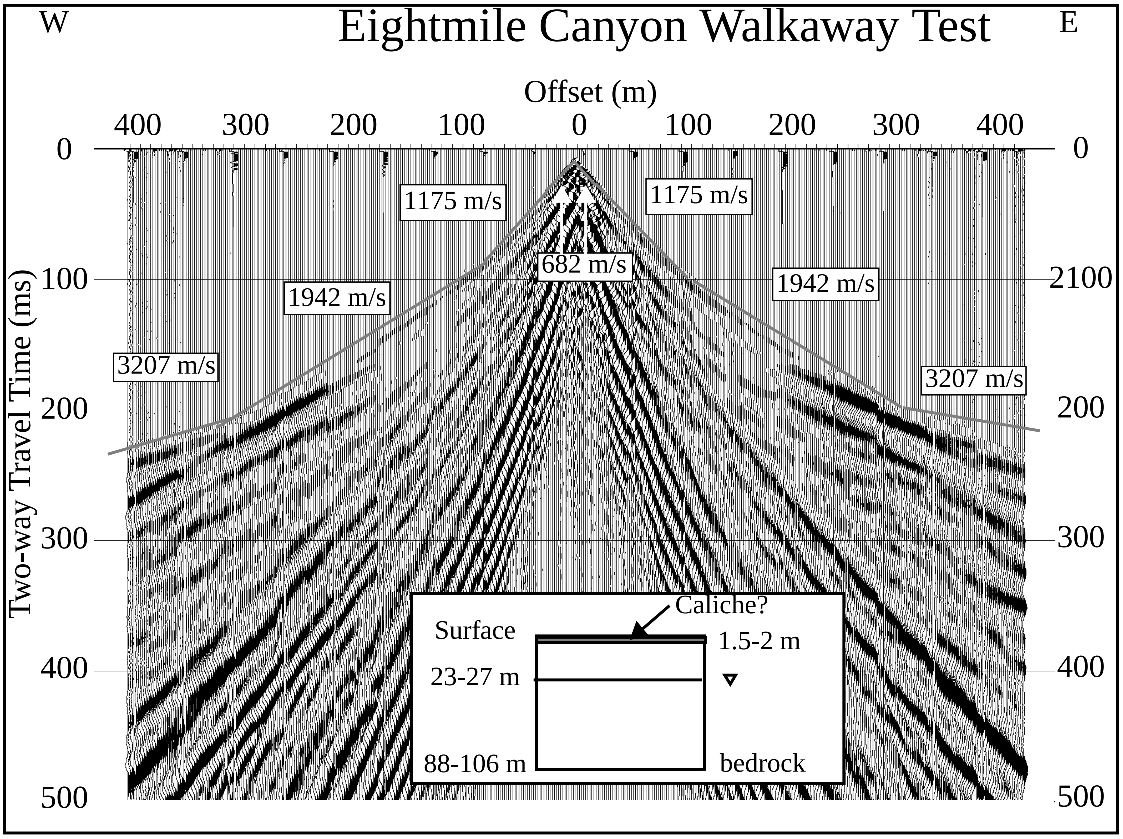


Figure 5. Walkaway seismic test results from Eightmile Canyon Road. Refractor velocities are superimposed on the first breaks. The depth model is derived from the first break picks and refractor crossover distances.

overestimate if a high velocity layer (i.e., caliche) is abnormally thick above a lower velocity zone (unconsolidated sediments) in the near surface.

The depth to the “bedrock” refractor is supported by reflection results seen after filtering the raw walkaway test records (Figure 6). After applying a 30-120 Hz spectral balancing filter to the raw data (to balance all energy within this bandwidth), we can interpret a strong amplitude reflection package that was masked by noise on the raw records. We have fit a hyperbola to this reflector and calculated a root mean square (RMS) velocity of 1825 m/s. The zero offset two-way travel time of this reflector (115 ms) suggests the presence of an interface at an approximate 104 m depth. This depth is consistent with the refraction results for the depth to bedrock.

## 5.2 Peterson Canyon Road

Two seismic walkaway tests were conducted along Peterson Canyon Road west of state highway 28. The first test was located approximately 1 mile east of Birch Creek and the second test was located approximately 1/2 mile west of Birch Creek. The creek was dry due to diversion for irrigation. The two walkaway tests produced similar results and will be discussed as one test.

Walkaway tests at this site (Figure 7) do not show a high velocity refractor out to the offsets acquired (400 m offset), as was noted on the Eightmile Canyon tests. We picked three layers from

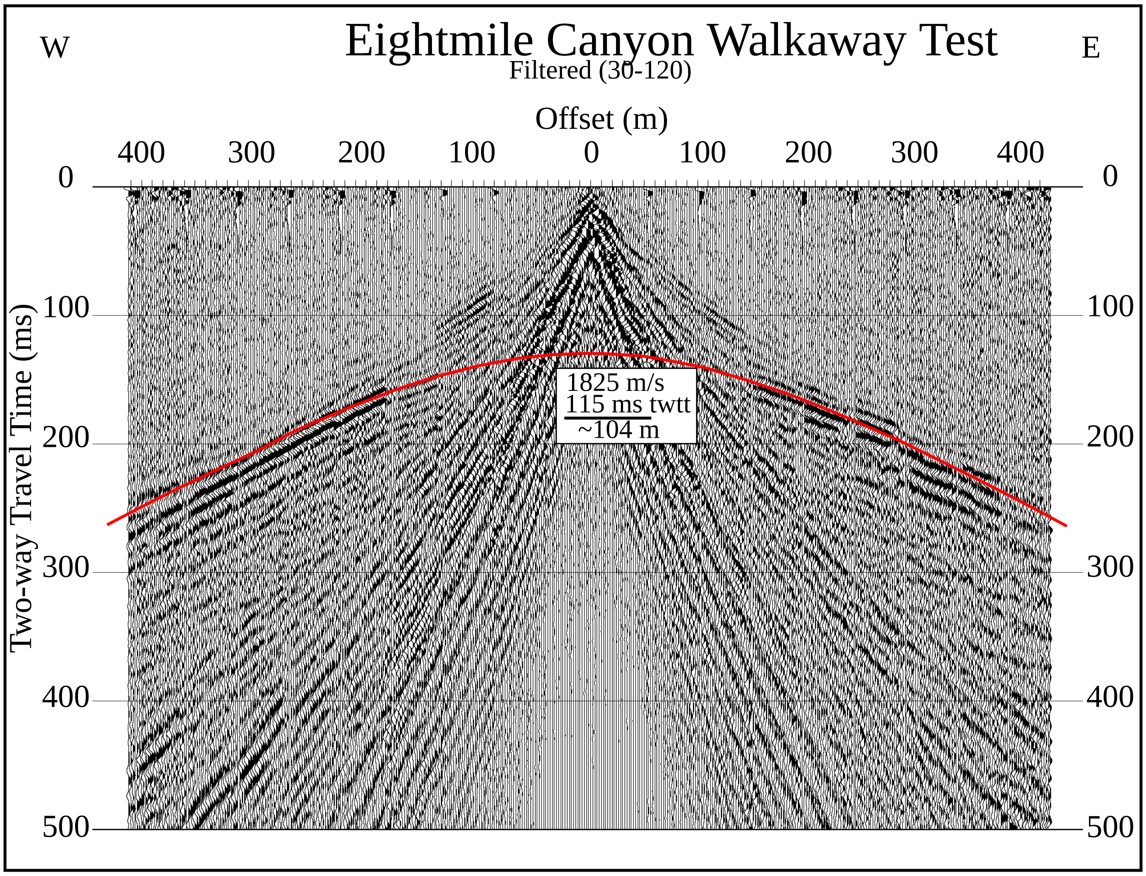


Figure 6. Filtered walkaway gather from Figure 5. Note the presence of a reflection package after filtering that correlates well with the depth of the bedrock determined from analysis of the refraction data.

the gathers, but the velocities associated with the second and third layers are not very different, suggesting a gradual increase in velocity with depth, as opposed to a strong, clearly defined velocity contrast. This velocity gradient is characteristic of a sedimentary basin, with increase in velocity with depth attributed to sediment compaction and cementation (Sheriff and Geldart, 1983). The depth to bedrock is greater than 100 m (increased offsets and a larger source would be needed to image bedrock at this site).

Again, the surface waves are strong in these data, possibly due to caliche in the upper 2 m of the section (based on attempts to drill along this road). The high-velocity surface waves infiltrate the “optimum window” reflection section, limiting the reflection data. With a 30-120 Hz spectral whitening filter, reflectors with RMS velocities consistent with basin fill sediments (Sheriff and Geldart, 1983) do appear in the section (Figure 8), but the signal-to-noise ratio is low. Different source and acquisition parameters may be needed to adequately image the section with reflection techniques.

## 5.3 Reno Point Road

The Reno Point walkaway test was acquired along a northeast-trending road on the northern edge of the INEEL. The profile was acquired west of state highway 28, approximately 1 mile

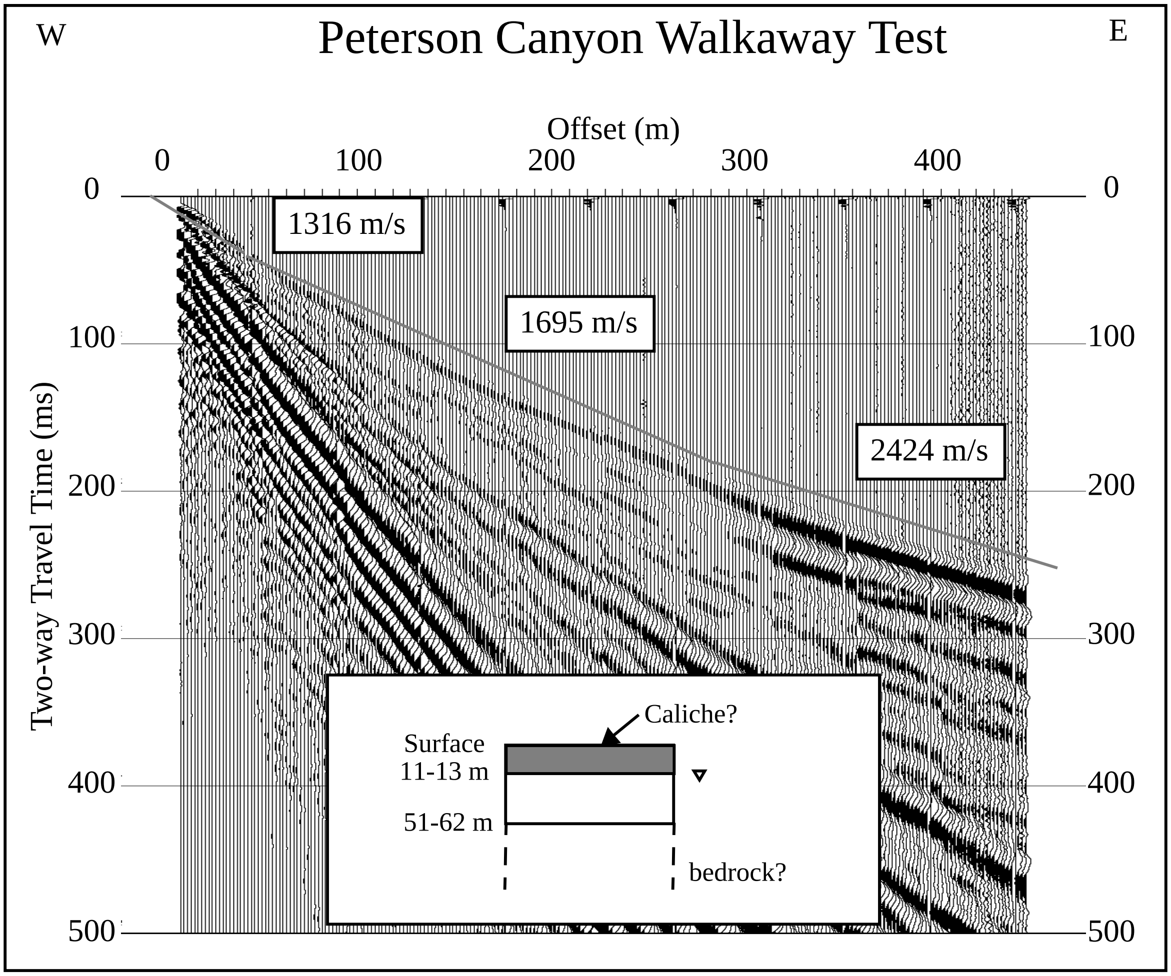


Figure 7. Walkaway seismic test results from Peterson Canyon Road east of Birch Creek. Apparent refractor velocities are superimposed on the first breaks. The depth model is derived from the first break picks and refractor crossover distances.

east of Birch Creek (which was dry due to water diversion to the north). We expected to image basalt at shallow depths at this location due to basalt outcrops at Lava Ridge to the south and the results of the gravity and magnetic maps discussed above. Results from the walkaway experiment (Figure 9) show a high velocity refractor (~2900 m/s) at approximately 18 m depth at the site. This velocity is consistent with the velocity of weathered basalt (Pankratz and Ackermann, 1982). Due to poor signal-to-noise ratio in the raw records, we could not confidently pick first breaks beyond 120 m offset. The results of filtering these data show no evidence for the presence of strong reflections at depths within range of this experiment, possibly due to an inadequate source and/or the presence of basalts in the near surface.

## 6.0 Conclusions

Complete Bouguer gravity data with the regional component removed (wavelengths > 60 km) may be interpreted in terms of basin dimensions and relative depth to bedrock. In particular, depth to bedrock appears to be relatively shallow in the southern segment of the Birch Creek Valley

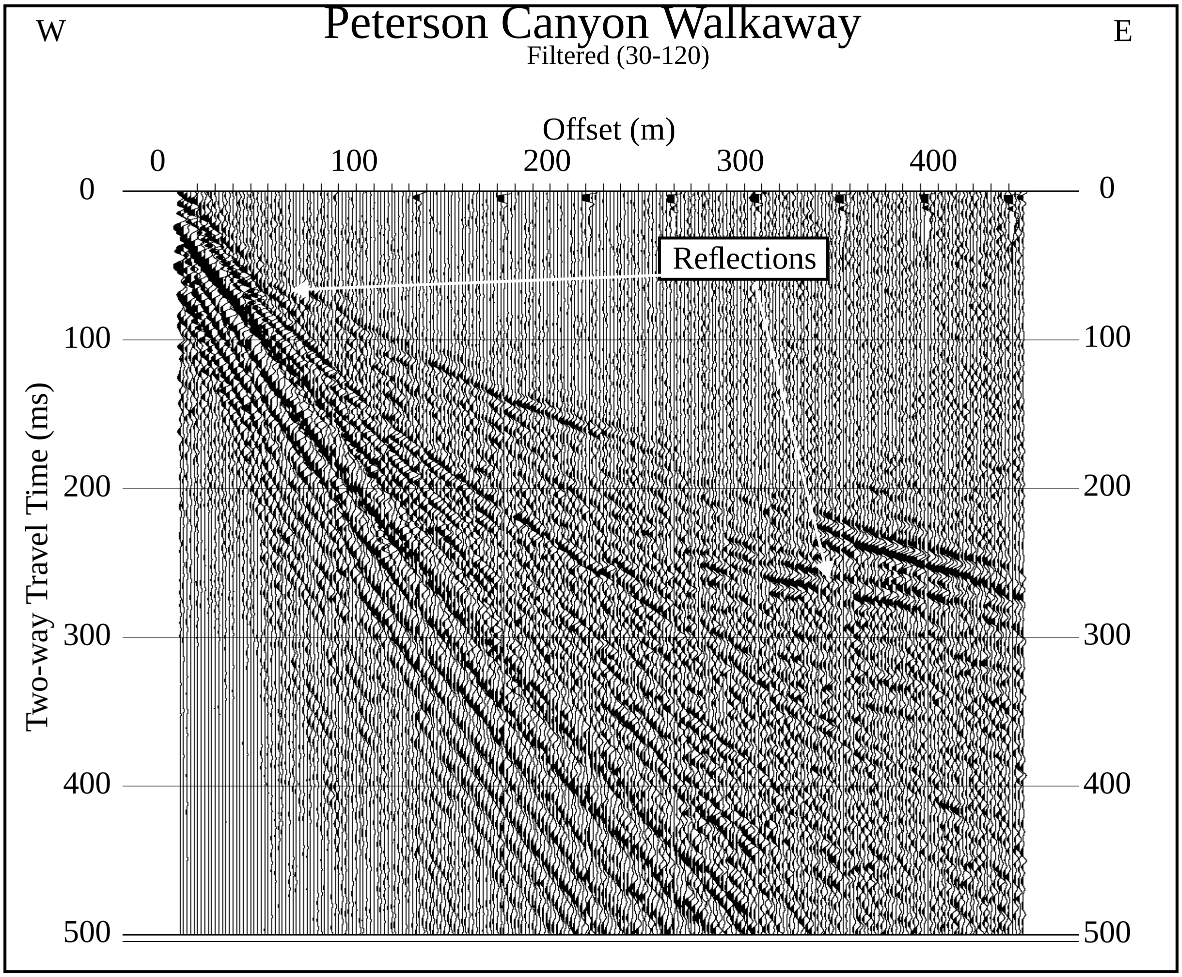


Figure 8. Filtered walkaway gather from Figure 7. Note the presence of reflections that correlate to intra-basin contrasts in the sedimentary fill.

between the Lemhi and Beaverhead Ranges. Anomalies in total-field aeromagnetic data are associated with near-surface basalt flows in the SRP, but do not contribute to our understanding of the geometry of structures in the Basin and Range province northwest and north of the SRP. Results from seismic noise tests and short profile lines in three regions of southern Birch Creek Valley are consistent with relatively shallow depth to bedrock interpreted with the gravity analysis. The results from seismic tests further suggest that southern Birch Creek Valley is not a simple northeast tilted half-graben basin. Drilling through the shallow caliche and use of a stronger source than the EWG-I weight drop used for this study are needed for acquisition of seismic reflection or seismic refraction data to provide a better image for the sediment fill, to reach bedrock in southern Birch Creek Valley, and to experiment with imaging through shallow, thin basalt within the sediment fill.

## 7.0 Recommendations

1. Off the INEEL site: (1) experiment with drilling through caliche and coarse cobbles to emplace an explosive such as kinestik (stronger source than EWG); (2) conduct noise tests to

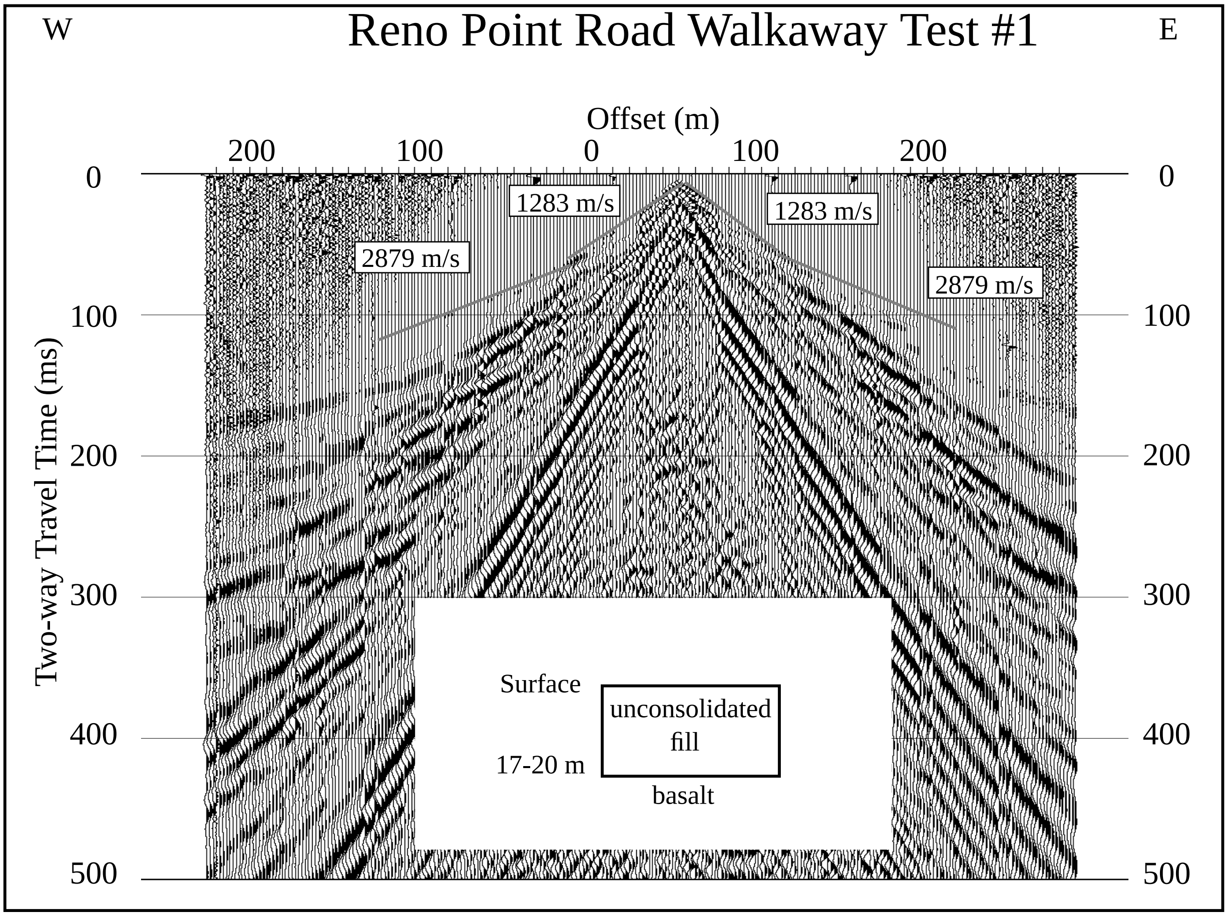


Figure 9. Walkaway seismic results from Reno Point Road on the northern border of the INEEL. Signal quality was poor due to near-surface geologic conditions.

determine acquisition parameters for seismic reflection data in southern Birch Creek Valley using an explosive as a source; and (3) complete a seismic reflection profile to image the basin fill and the bedrock reflector in a cross-section of the Birch Creek Valley.

2. On the INEEL site, conduct seismic reflection experiments using an explosive emplaced in shallow drill holes to: (1) better define subsurface geologic units and bedrock geometry at the transition from Basin and Range to the SRP; and (2) investigate the feasibility of seismic imaging below shallow, thin basalt flow(s) in the sediments between TAN and the northern boundary of the INEEL. If facies can be recognized in the sedimentary fill based on seismic reflection patterns (e.g., Barrash and Dougherty, 1995; Liberty, 1996), then relative hydraulic conductivity values may be estimated, based on depositional models for fault-bounded basins (e.g., McClosky and Finnemore, 1996; Leeder and Gawthorpe, 1987).
3. Examine locations of magnetic and gravity anomalies on the INEEL in conjunction with surface and near-surface geologic data (e.g., Anderson, 1991; Anderson and Bowers, 1995; Kuntz et al., 1994) to explain or develop hypotheses for the anomalies.
4. Install monitoring well(s) in southern Birch Creek Valley to record water levels immediately upgradient from the SRP aquifer. Analyze these water level data in conjunction with water levels in the low-gradient region of the SRP aquifer at and between TAN and Birch Creek Valley (Figure 1), and with flows in and diversions from Birch Creek to quantify the boundary

flux behavior and influence on the SRP. Also, lithologic data from the well(s) will provide calibration for subsurface lithologic and seismic stratigraphy.

## 8.0 Acknowledgments

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## 9.0 References

Anderson, S.R., 1991, Stratigraphy of the unsaturated zone and uppermost part of the Snake River Plain aquifer at Test Area North, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report, 95-4130, 47 p.

Anderson, S.R. and Bowers, B., 1995, Stratigraphy of the unsaturated zone and uppermost part of the Snake River Plain aquifer at the Idaho Chemical Processing Plant and Test Reactors Area, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report, 91-4010, 71 p.

Barrash, W. and Dougherty, M. E., 1995, High-resolution seismic reflection profiling and modeling of hydrogeologic system, Goddard2 well, northwest Boise, Idaho: Report prepared for the Idaho Water Resources Research Institute (University of Idaho, Moscow, Idaho), Technical Report BSU CGISS 95-17, 47 p.

Bartholomay, R.C., 1990, Mineralogical correlation of surficial sediment from area drainages with selected sedimentary interbeds at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 90-4147, 18 p.

Bartholomay, R.C. and Knobel, L.L., 1989, Mineralogy and grain size of surficial sediment from the Little Lost River and Birch Creek drainages, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 89-385 (DOE/ID-22082), 19 p.

Crone, A.J. and Haller, K.M., 1991, Segmentation and the coseismic behavior of Basin and Range normal faults: examples from east central Idaho and southwestern Montana, U.S.A., Journal of Structural Geology, v. 13, no. 2, p. 151-164.

Crone, A.J. and Machette, M.N., 1984, Surface faulting accompanying the Borah Peak earthquake, central Idaho: Geology, v. 12, no. 11, p. 664-667.

Elbring, G.J., 1984, A method for inversion of two-dimensional seismic refraction data with applications to the Snake River Plain region of Idaho: Ph.D. Dissertation, Purdue University.

Hadley, D.M. and Cavit, D.S., 1984, Geophysical investigations at the Idaho National Engineering Laboratory: Final Report, Contract No. EG&G 84-100GP, Sierra Geophysics.

Hunter, J.A., Pullan, S.E., Burns, R.A., Gagne, R.M., and Good, R.L., 1984, Shallow seismic reflection mapping of the overburden-bedrock interface with the engineering seismograph - Some simple techniques: Geophysics, v. 49, p. 1381-1385.

Janecke, S.U., 1992, Kinematics and timing of three superposed extensional systems, east central Idaho; evidence for an Eocene tectonic transition: Tectonics. v. 11, no. 6, p. 1121-1138.

Kuntz, M.A., 1978, Geology of the Arco - Big Southern Butte area, eastern Snake River Plain, and potential volcanic hazards to the Radioactive Waste Management Complex, and other waste storage and reactor facilities at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 81-689, 21 p.

Kuntz, M.A., Covington, H.R., and Schorr, L.J., 1992, An overview of basaltic volcanism of the eastern Snake River Plain, Idaho, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 227-267.

Kuntz, M.A., Skip, B., Lamphere, M.A., Scott, W.E., Pierce, K.L., Dalrymple, G.B., Champion, D.E., Embree, G.F., Page, W.R., Morgan, L.A., Smith, R.P., Hackett, W.R., and Rodgers, D.W., 1994, Geologic map of the Idaho National Engineering Laboratory and adjoining areas, eastern Idaho: U.S. Geological Survey, Miscellaneous Investigations Series Map I-2330.

Leeder, M.R. and Gawthorpe, R.L., 1987, Sedimentary models for extensional tilt-block/ half-graben basins, *in* Coward, M.P., Dewey, J.F., and Hancock, P.L. (eds.), Continental extensional tectonics: Geological Society Special Publication no. 28, p. 139-152.

Liberty, L.M., 1997, Seismic reflection results: Stewart Gulch region, Boise, Idaho: Proceedings of the 32nd Symposium on Engineering Geology and Geotechnical Engineering, Boise, Idaho, p. 365-380.

Mabey, D. R., 1982, Geophysics and tectonics of the Snake River Plain, Idaho, *in* Bonnichsen, B and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 139-153.

McCafferty, A.E., Bankey, V., and Cady, J.W., 1990, Digital aeromagnetic, terrace-magnetization, Bouguer gravity, isostatic gravity, terrace-density, and topographic grids for data centered on the Idaho batholith: U.S. Geological Survey, EROS data center release, magnetic tape.

McClosky, T.F. and Finnemore, E.J., 1996, Estimating hydraulic conductivities in an alluvial basin from sediment facies models: Ground Water, v.34, no. 6, p. 1024-1032.

McQuarrie, N. and Rodgers, D.W., 1996, Crustal downwarping of the eastern Snake River Plain, Idaho: Eos, Transactions of the American Geophysical Union, v. 77, p. F667.

Miller, R.D., Steeples, D.W., Treadway, J.A., and Hinschberger, S.T., 1988, Seismic survey over a topographic scarp in the Snake River Plain: Bulletin of the Seismological Society of America, v. 78, no. 1, 299-307.

Pankratz, L.W. and Ackermann, H.D., 1982, Structure along the northwest edge of the Snake River Plain interpreted from seismic refraction: Journal of Geophysical Research v. 87, no. b4, p. 2676-2682.

Pierce, K.L. and Scott, W.E. 1982, Pleistocene episodes of alluvial gravel deposition, southeastern Idaho, *in* Bonnichsen, B. and Breckinridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 685-702.

Reed, M.F., 1994, Mineralogy and depositional sources of sedimentary interbeds beneath the Idaho National Engineering Laboratory; eastern Snake River Plain aquifer, Idaho: Proceedings of the 30th Symposium on Engineering Geology and Geotechnical Engineering, Boise, Idaho, p. 153-164.

Robertson, J.B., Schoen, R., and Baraclough, J.T., 1974. The influence of liquid waste disposal on the geochemistry of water at the National Reactor Testing Station, Idaho, 1952-1970: U.S. Geological Survey Water Resources Division, Idaho Falls, Idaho.

Rodgers, D.W. and Anders, M.H., 1990, Late Tertiary and Quaternary faulting north and south of the eastern Snake River Plain; Part 3, Neogene evolution of Birch Creek Valley near Lone Pine, Idaho, *in* Geologic field tours of western Wyoming and parts of adjacent Idaho, Montana, and Utah., Roberts, S., ed., Public Information Circular - Geological Survey of Wyoming, no. 29, p. 27-38

Sheriff. R.E. and Geldart, L.P., 1983, Exploration seismology, data-processing and interpretation: Cambridge University Press.

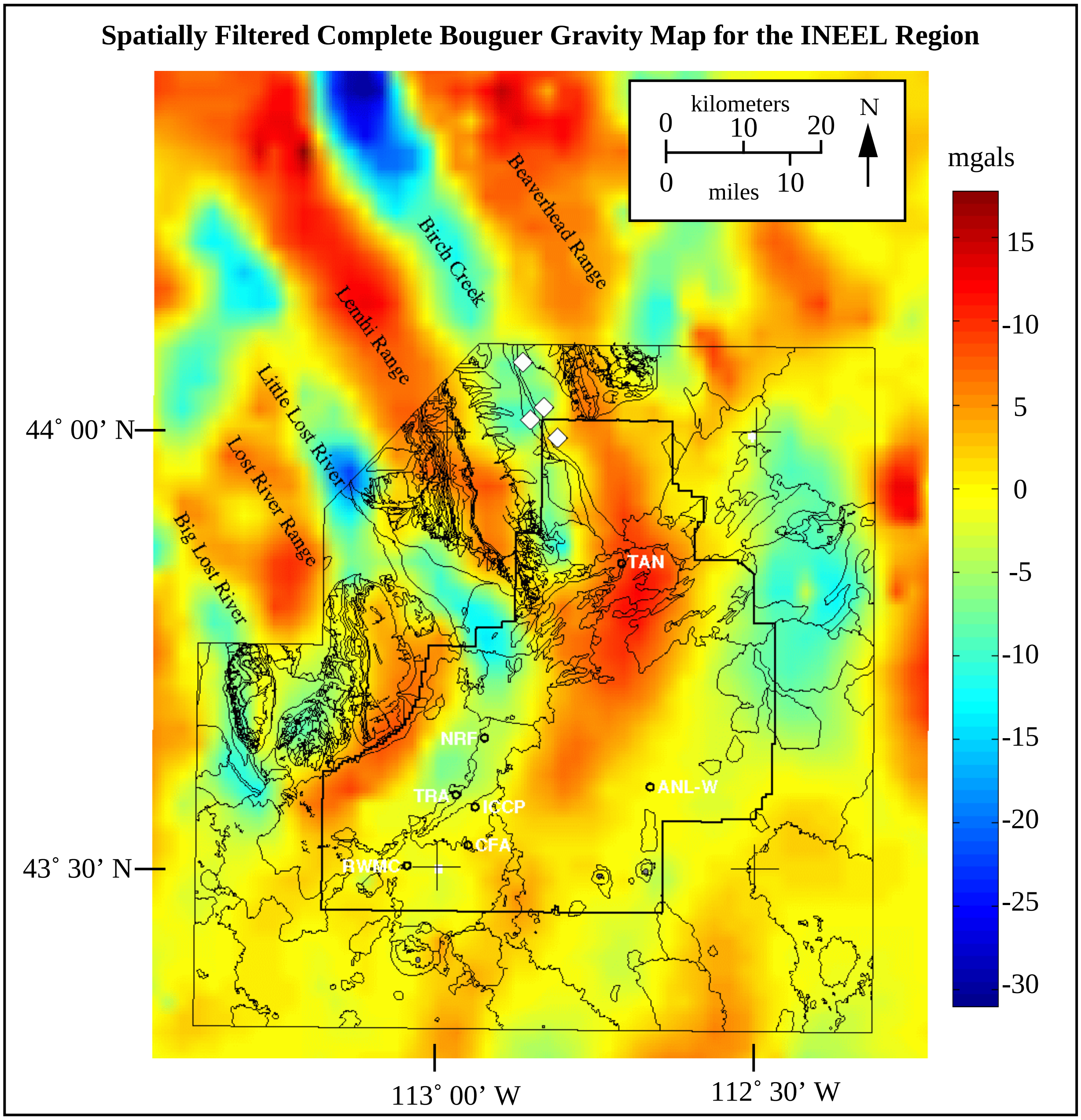
Skipp, B., Hoggan, R.D., Schleicher, D.L. and Douglass, R.C.,1979, Upper Paleozoic carbonate bank in east-central Idaho - Snaky Canyon, Bluebird Mountain, and Arco Hills Formations, and their paleotectonic significance: U.S. Geological Survey Bulletin 1486, 78 p.

Sorenson, K.S., Wylie, A.H., and Wood, T.R., 1996, Test Area North site conceptual model and proposed hydrogeologic studies, Operable Unit 1-07B: Parsons Engineering Science, Inc., Report INEL-96/0105, Parsons ES-25.9.9.31 to Lockheed Idaho Technologies Co. and U.S. Department of Energy, Idaho Falls, Idaho.

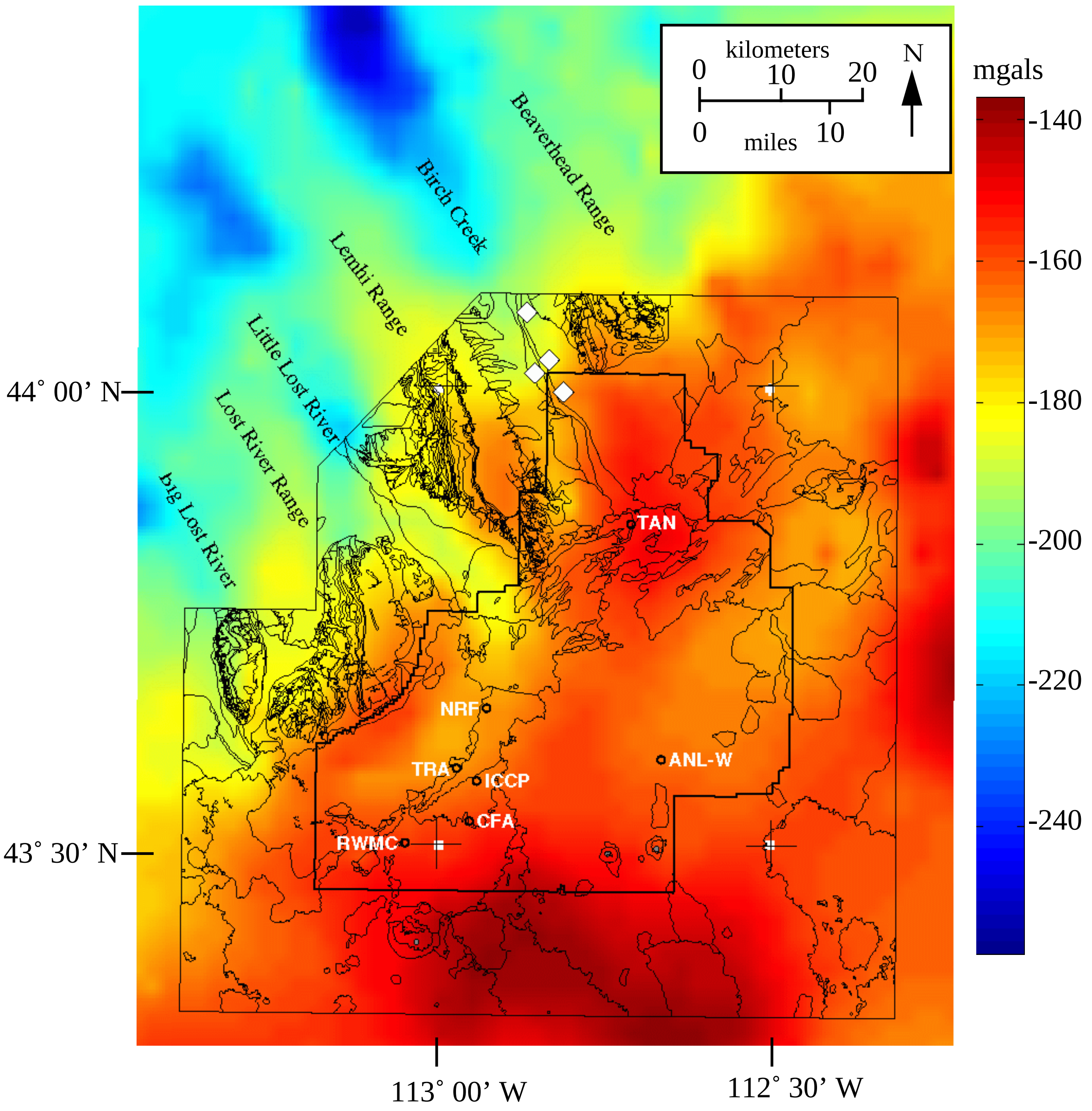
Sparlin, H.T., Braile, L.W., and Smith, R.B., 1982, Crustal structure of the eastern Snake River Plain determined from ray trace modeling of seismic refraction data: Journal of Geophysical Research, v. 87, no. 4, p. 2619-2633.

Young, R.A. and Lucas, J.E., 1988, Exploration beneath volcanics: Snake River Plain, Idaho: Geophysics, v. 53, no. 4, p. 444-452.

# 10.0 Appendices

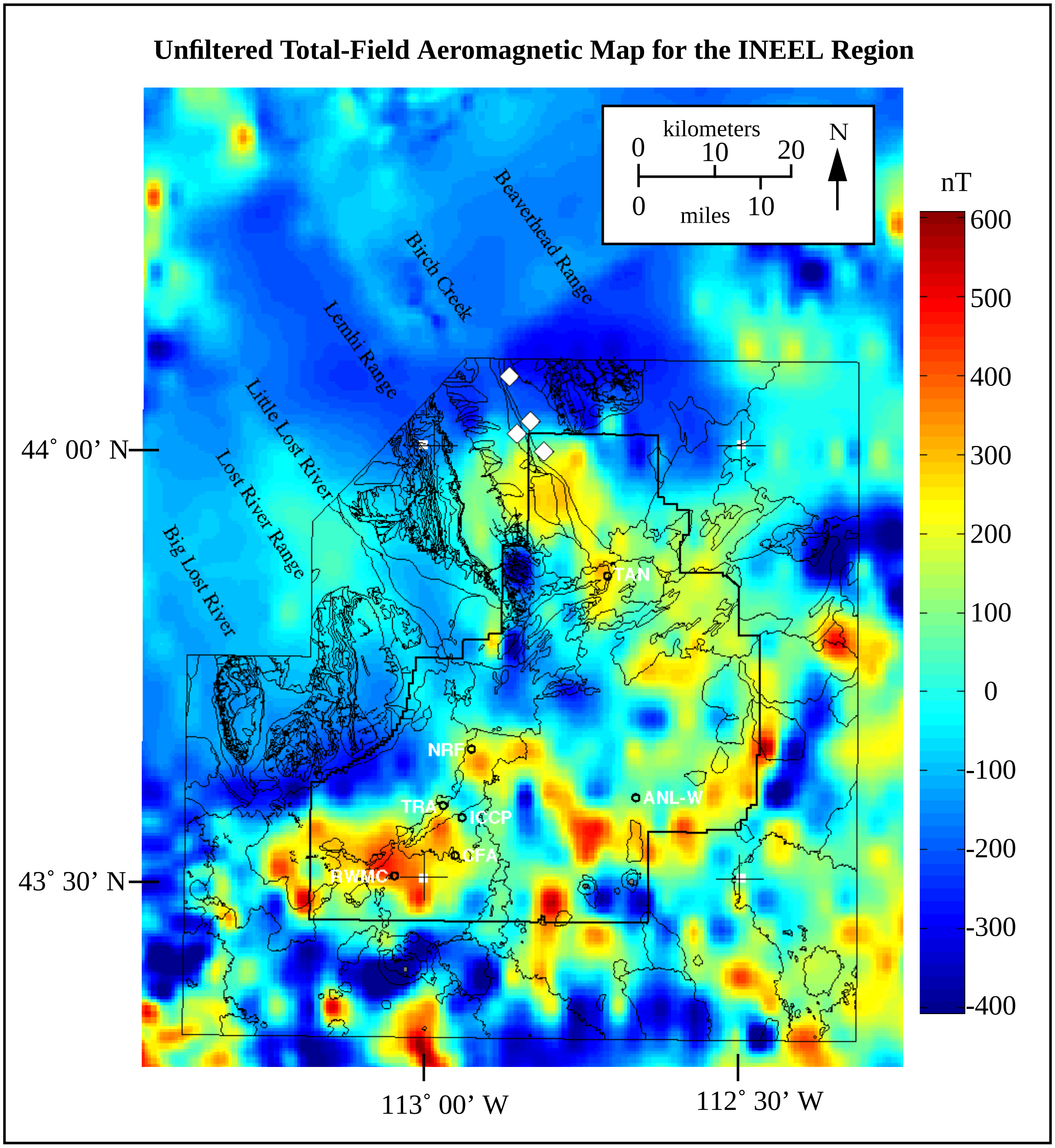


Appendix B. Spatially filtered Bouger gravity map for the INEEL region. Wavelengths greater than 60 km have been removed. Geologic contacts from Kuntz et al. (1994) are superimposed.



Unfiltered Complete Bouguer Gravity Map for the INEEL Region

Appendix A. Unfiltered complete Bouguer gravity map for the INEEL region (extracted from McCafferty et al., 1990) with geologic contacts superimposed from Kuntz et al. (1994). Note the strong contrast between the Snake River Plain and Basin and Range topography to the north of the INEEL.



Appendix C. Aeromagnetic map for the INEEL region with geologic contacts superimposed from Kuntz et al. (1994). The raw data are gridded at 0.5 km spacing and values are interpolated for a smooth grid appearance.