Seismic Reflection Imaging of the Boise Geothermal Aquifer

Report Prepared for the City of Boise
Boise, Idaho

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Technical Report BSU CGISS 96-05
1 December 1996

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1.0 Abstract

Two seismic reflection lines acquired through downtown Boise, Idaho helped determine the optimal location for an injection well for the City of Boise geothermal heating system. The data acquisition using a land air-gun demonstrates the feasibility of collecting non-invasive, high-quality seismic reflection data through an urban setting for hydrogeologic and environmental studies. Annually, over 100 million gallons of water is drawn to provide heat to government buildings and residential homes in Boise. Artesian pressure in the geothermal aquifer has declined in recent years due to increased production. By re-injecting spent water, the City of Boise hopes to stabilize geothermal-aquifer pressure and properly dispose of high fluoride (~15 ppm) water.

Seismic reflection methods were employed to estimate the depth to and continuity of a rhyolite sequence. Two prominent basalt-within-mudstone units cap the rhyolite and confine the geothermal ground water. This basalt/rhyolite sequence dips (~8-10 degrees) away from the Boise range front, where geothermal water is artesian-flowing during non-producing months. Water is suspected to predominately flow along interconnecting faults that parallel the range front. Well siting was based on projected thermal impact of reinjection to existing wells, location of interpreted faults within the geothermal aquifer, drilling depth, surface piping costs, and public land availability. Seismic reflection results enabled interpretation of aquifer depths (> 2000 ft.) along the profiles and pinpointed an intepreted fault zone where injected water may encounter fracture permeability and optimally benefit the existing producing system.

2.0 Introduction

The first geothermal heating district in the nation was established in Boise, Idaho in 1892. Today, over 100 million gallons of water are drawn annually from the geothermal aquifer to provide heat to government buildings and residential homes in Boise. There are presently four separate geothermal-based heating facilities in operation in Boise (see Figure 1):

- Boise Warm Springs Water District
- State of Idaho (state offices)
- U.S. Department of Veterans Affairs
- City of Boise

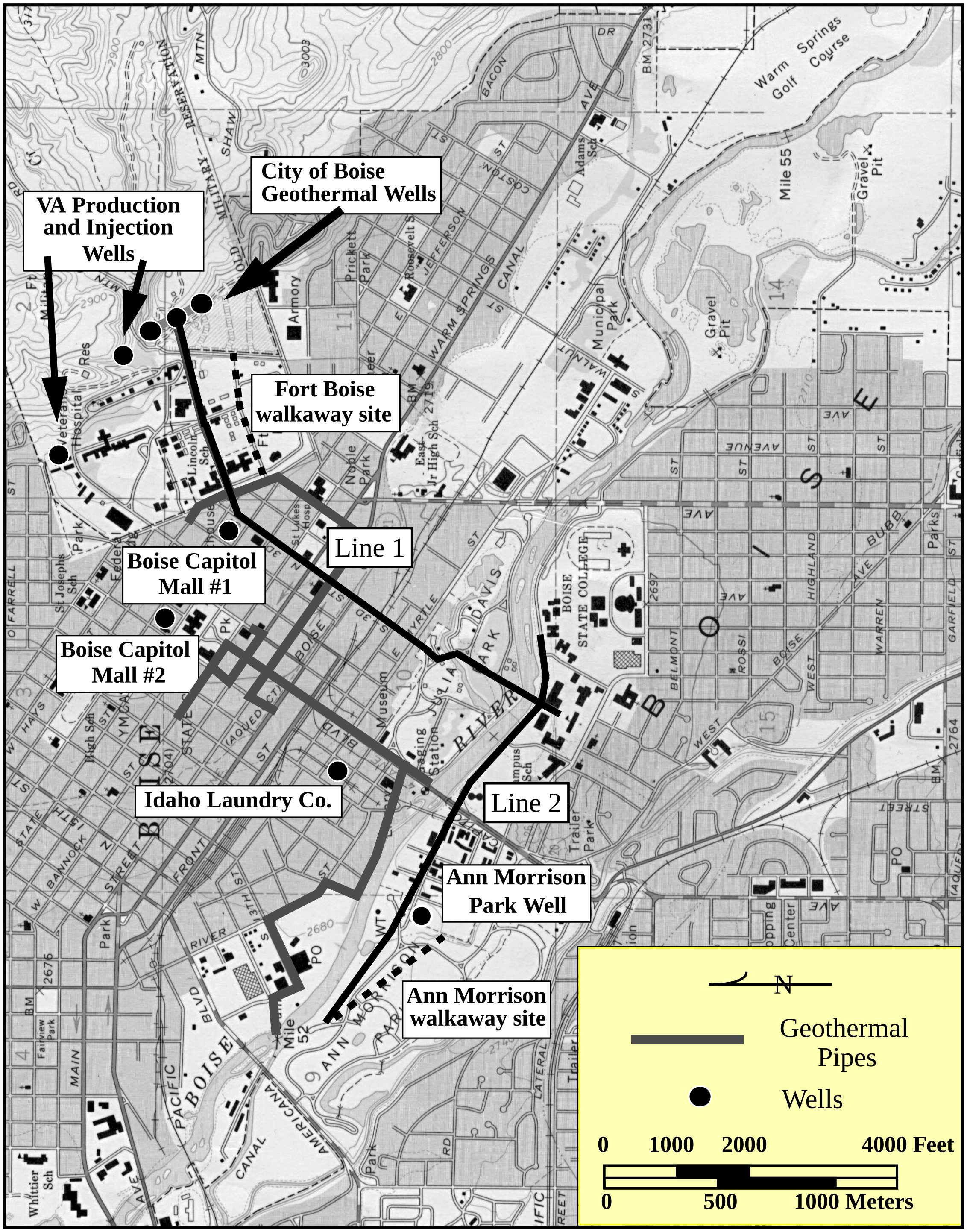


FIGURE 1. Location map of downtown Boise, Idaho. Seismic reflection line locations, walkaway test sites, Boise City geothermal pipes and relevant wells are shown.

In recent years, the increase in hot water extraction has resulted in a drop in artesian levels. The Idaho Department of Water Resources has imposed a moratorium on increased production from the geothermal aquifer until actions can be taken to stabilize the system. Since the Department of Veterans Affairs and the State of Idaho already inject spent geothermal water, and the Boise Warm Springs Water District has legal rights to the geothermal aquifer without re-injection (based on a historical precedence), the city of Boise and the U.S. Department of Energy have agreed to design and construct a new injection well.

3.0 Geologic Framework of the Boise Geothermal System

Each production facility extracts ~66^{o} C (172^{o} F) water from a rhyolite member of the Idavada Group (Figure 2). This geothermal water is confined to the rhyolite member,

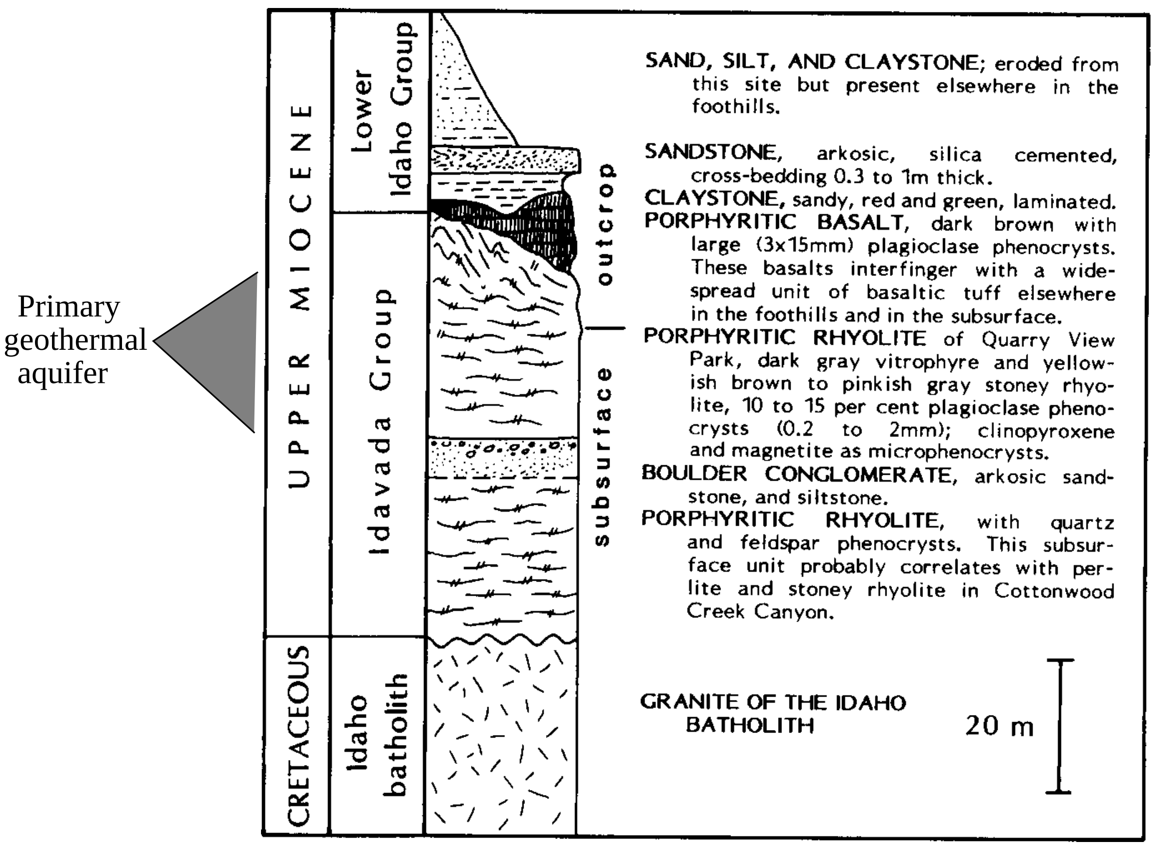


FIGURE 2. Stratigraphic section from rocks related to the geothermal system (from Wood and Burnham, 1987).

which is capped by a basalt unit and underlain by granitic rocks of the Idaho batholith. Fractures in the Idaho batholith are the presumed avenue for deep circulation and heating of the aquifer (Figure 3). The geometry of permeability in the rhyolite unit is unknown. Primary circulation of the geothermal water is thought to occur through predominately northwest trending faults.

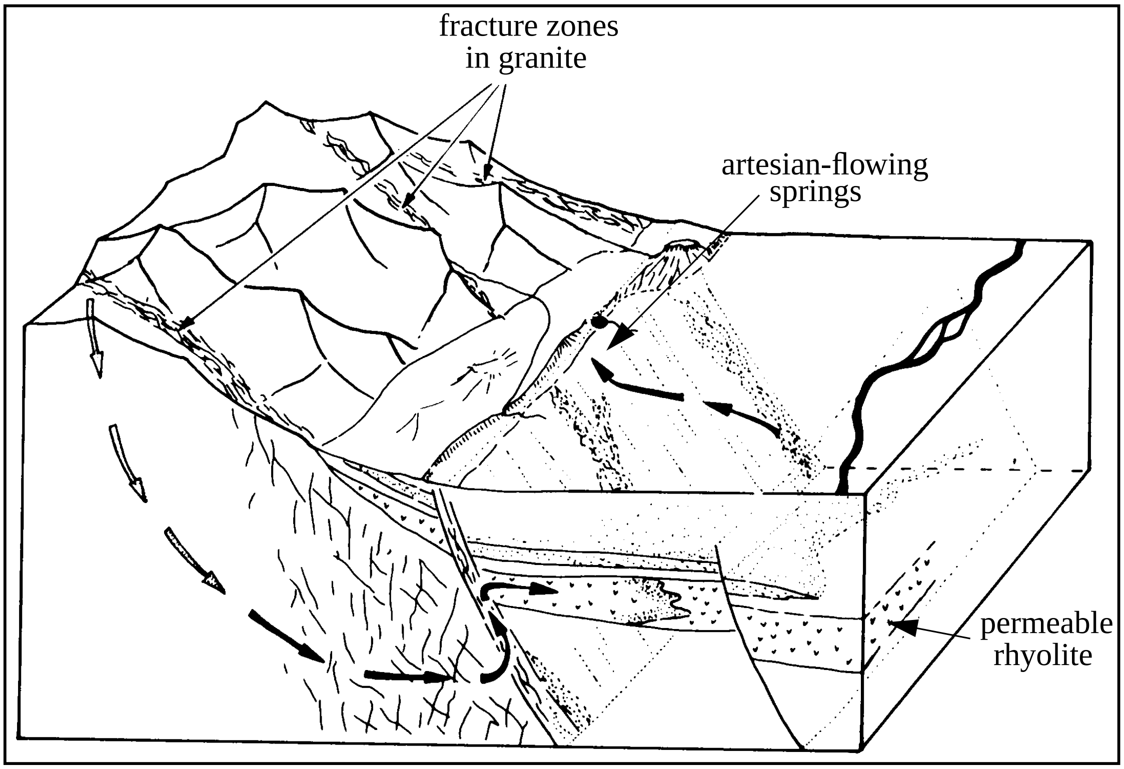


FIGURE 3. Conceptual model of the groundwater circulation system (from Wood and Burnham, 1987).

4.0 Project Scope

In order to continue to develop the Boise geothermal aquifer, steps must be taken to stabilize the pressure of the system without reducing the temperature of the extracted water. The current practice of dumping spent geothermal water into the Boise River reduces the system's ability to stabilize by extracting water faster than natural recharge. In addition, the spent geothermal water has a high fluoride (~15 ppm) and thermal load. Limitations on dumping the unprocessed water directly into the river may soon be set. By adding a new injection well, the city hopes to stabilize the geothermal system and lift the moratorium imposed by the Idaho Department of Water Resources, thereby allowing more customers to have access to this renewable energy resource.

Two seismic reflection lines (Figure 1) were designed to help determine an optimum location for siting a new geothermal injection well. The objective of the seismic survey was to determine the presence of, and the major structural style for, rocks associated with the geothermal aquifer. The first order goal was to estimate the depth to the geothermal aquifer, along the profiles, to constrain drilling costs. Since the footage costs for drilling match the footage costs for extending the surface piping system, seismic line locations were chosen to cover an area near the existing system and near well control. In addition to estimating depth to the geothermal aquifer, locating faults in the rhyolite unit were of interest. If an injection well were to penetrate a fault zone, an increased potential exists for recirculating the geothermal water back to the production site, assuming faults are conduits for geothermal water circulation. Also, a site was needed to minimize the thermal impacts to the existing production wells. This meant the new injection well needed to be placed as far from the production wells as possible without sacrificing drilling depth/surface pipe extension costs.

5.0 Acquisition Tests

City officials and utility representatives required that we demonstrate that no damage to city streets or buried utilities would occur from acquiring seismic reflection data in downtown Boise. The city selected a test site on a street where road resurfacing was scheduled and an old cracked sewer line was buried 4 feet beneath. We selected a land air gun from Bolt Technologies (Figure 4) as our seismic source. This source was chosen

FIGURE 4. Airgun source used for the Boise geothermal seismic experiment. Distance from the building was approximately 5 m.

because of its mobility, compatibility with our recording seismograph (a 48-channel Bison 9048 seismograph), repeatability, and energy output. We conducted systematic tests at this site to ensure the integrity of the buried utilities and the road surface. The city deployed a video camera in the sewer line (Figure 5), both before and after air gun shots, to monitor any changes in the sewer's cement wall. Also, we deployed a blast vibration monitor to measure peak particle velocities at various offsets from the air gun (Figure 6). These measurements could then be compared to a damage study (Siskind and others, 1980) to assess the risk of structural damage to nearby buildings (Figure 7). The tests demonstrated the air gun could be deployed on city streets with minimal damage (little to no damage on lined

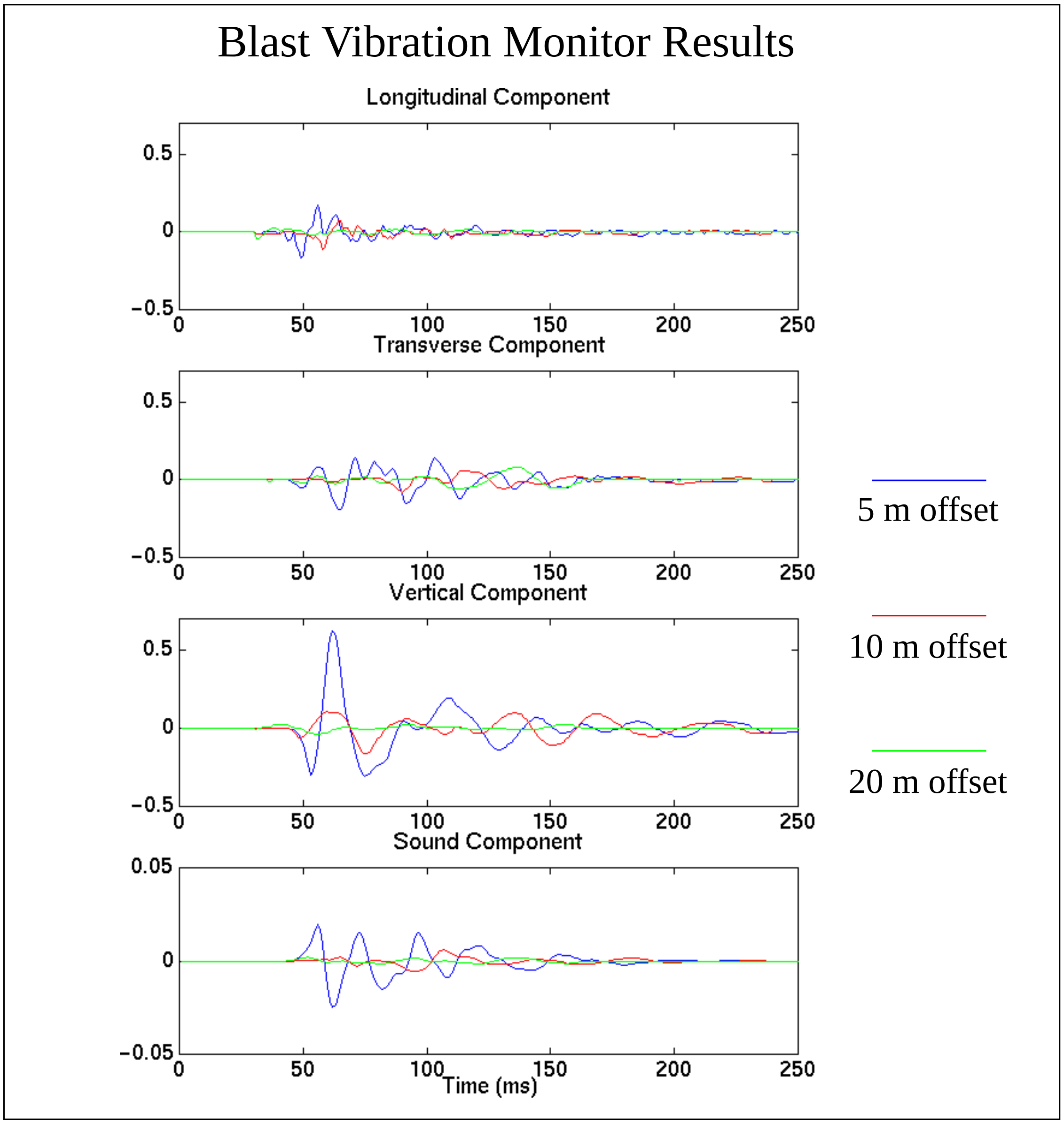
FIGURE 5. City officials deploy a video camera to monitor the air gun's effect on a sewer line. No damage was observed in the video after multiple air gun shots were fired over a heavily cracked region of the sewer's cement wall.

asphalt roads, but cracking after 1-2 shots on unlined asphalt and concrete roadways and sidewalks). An agreed upon distance of 5 meters from permanent structures and buried utilities and two air gun shots per location (to reduce risk of surface cracking) granted us full support from local officials.

We then compared the air gun's energy output with the results of a previously acquired test that used a buried explosive source (1/3 lb kinestik). We selected two walkaway test sites (Figure 1) at geologic end-member locations. Results (Figures 8 and 9) show a large amplitude reflection package near the predicted depth of the basalt/rhyolite sequence at both sites using either source. These predicted depths were projected from nearby geothermal wells (Figure 10). Thus, the walkaway tests suggested the existence of the basalt/rhyolite sequence at end-member sites, and also suggested that the depth to the rhyolite at the preferred injection site (at the present disposal site) may be beyond the drilling budget (based on an assumption that the thickness of the basalt/rhyolite sequence is constant as shown in Figure 10).

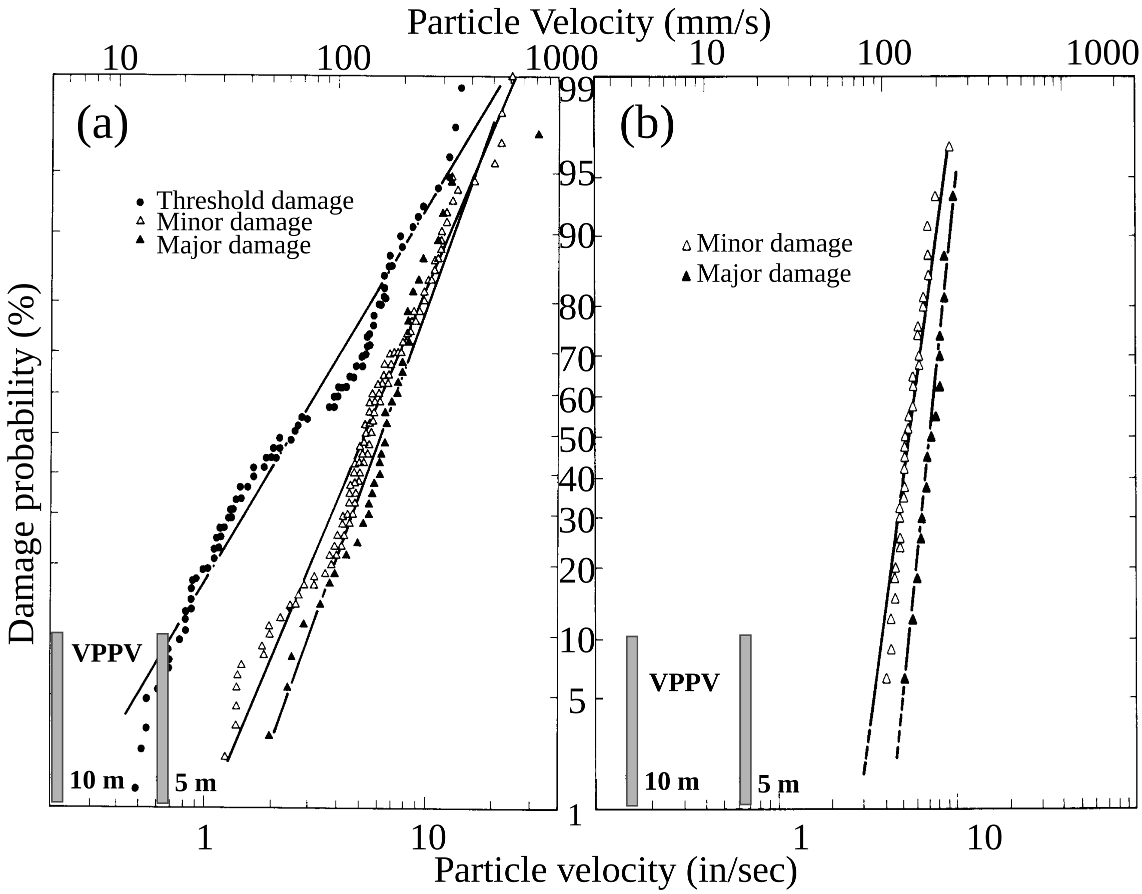
6.0 Seismic Reflection Acquisition and Processing

After the walkaway tests successfully demonstrated that the seismic reflection technique could help determine depth to rocks associated with the geothermal aquifer in downtown Boise, two seismic reflection lines were shot (Figure 1) to determine the struc-



Event #	Seismic Monitor Offset	Station Loc.	LPPV (in/sec)	TPPV (in/sec)	VPPV (in/sec)	LFRQ (Hz)	TFRQ (Hz)	VFRQ (Hz)	Peak Sound (PSI)
059	5 m	1006	0.86	0.19	0.62	50.0	55.6	41.7	.0049
060	10 m	1006	0.21	0.08	0.16	25.0	41.7	33.3	.0032
061	20 m	1006	0.07	0.08	0.04	31.2	23.8	35.7	.0012

FIGURE 6. a) Results from the blast vibration monitoring test. Note peak particle velocities (PPV) less than 1 in/sec for all three components (longitudinal, transverse and vertical) and frequencies exceeding 40 Hz at near offsets (5 m).



(c)

Threshold damage	Minor damage	Major damage
Loosening of Paint	Loosening/Falling of Plaster	Structural weakening
Small plaster cracks at joints between construction elements	Cracks in masonry around openings near partitions.	Rupture of opening vaults
Lengthening of old cracks	Hairline to 3 mm cracks	Cracks several mm in walls
	Fall of loose mortar	Fall of masonry (e.g. chimneys)
		Load support ability affected

FIGURE 7. a) A comparison of particle velocity with damage probability for a broad range of frequencies. b) Damage probability for just high frequency data (>40 Hz). c) Damage criteria. Note: (from Figure 6) frequency content for near offsets (5 m) is greater than 40 Hz for all components. Figures are modified from Siskind and others, 1980.

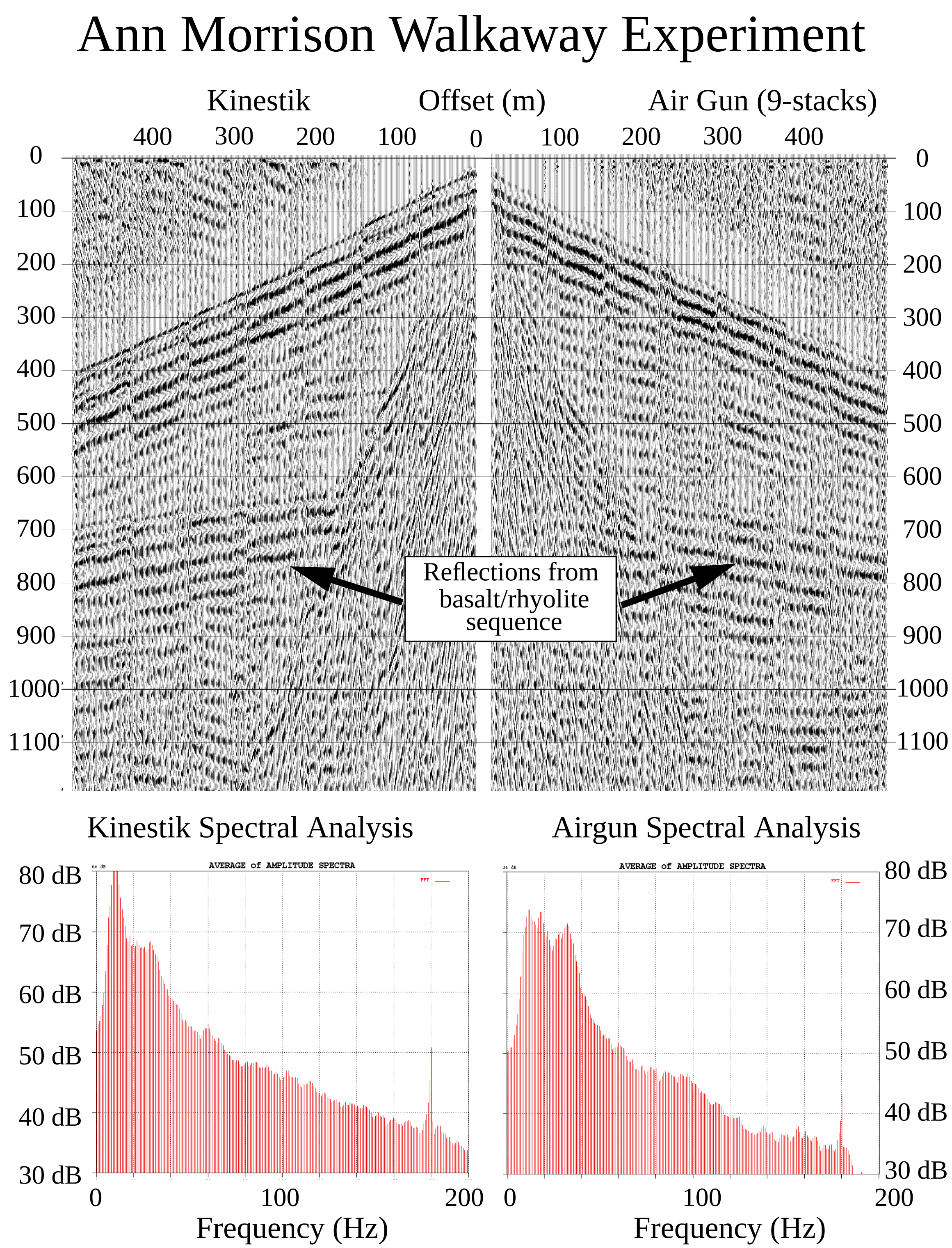


FIGURE 8. A comparison of kinestik vs. air gun sources at Ann Morrison Park. Both sources produced adequate energy to image the target zone. Spectral analysis plots are from the entire record lengths.

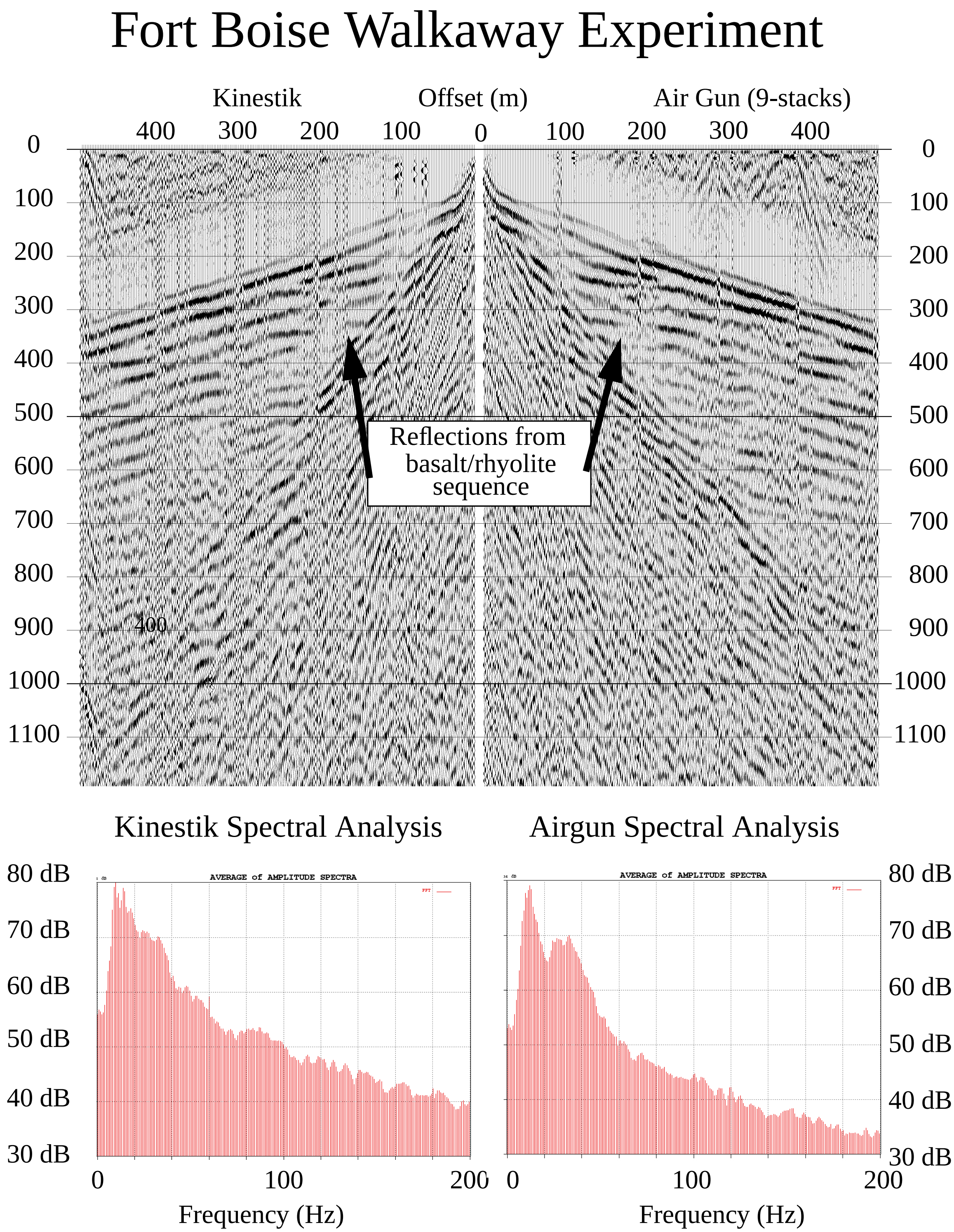


FIGURE 9. A comparison of kinestik vs. air gun sources at Fort Boise Park. Both sources produced adequate energy to image the target zone. Spectral analysis plots are from the entire record lengths.

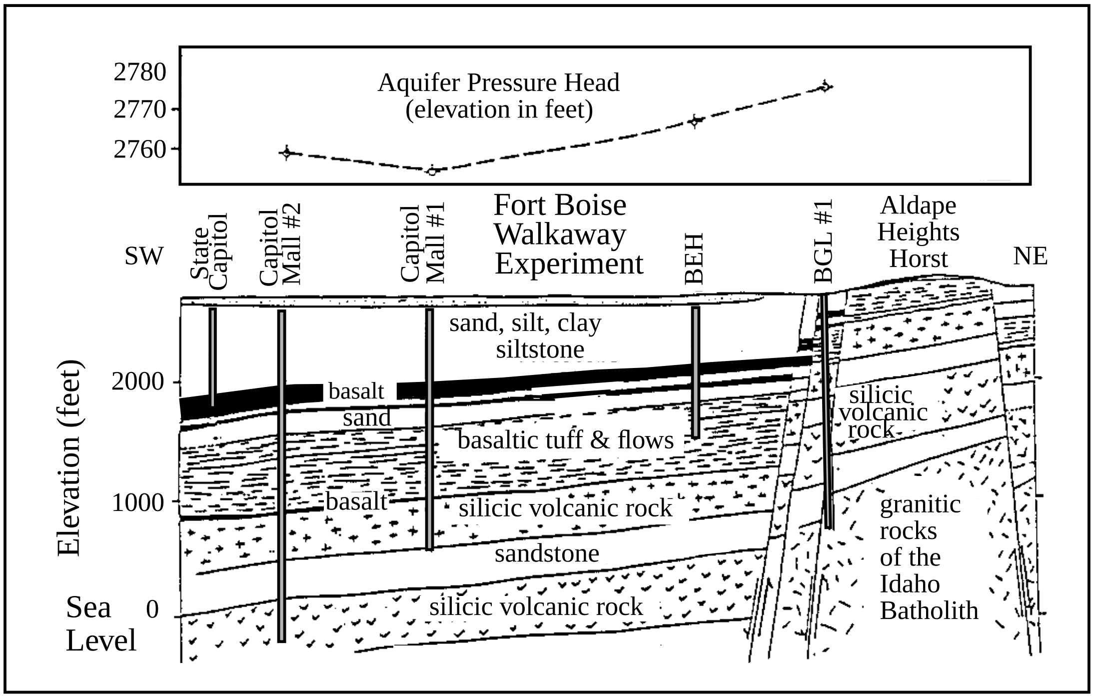


FIGURE 10. Geologic cross-section through downtown Boise based on local geothermal wells (from Burnham and Wood, 1985). The section has equal horizontal and vertical scales.

tural style of related rocks. We selected a 10 m station spacing to image the “optimum window” at the estimated depth of the target zone. At each station location, we recorded 8-16 air gun shots individually using a source array (moving the air gun source one pad length after 2 shots) and later summing individual shots for each station location to attenuate cultural noise (traffic, wind noise, etc.) and increase the data quality of the reflections.

Processing (summarized in Figure 11) on a DEC workstation using Landmark’s ProMAX seismic processing package enabled a fast, efficient turnaround time required by the city.

7.0 Seismic Reflection Interpretation

7.1 Line 1

The dominant feature on the unmigrated stack of Line 1 (Figure 12) is a reflector that dips (~11 degrees) to the south from 200-500 ms two-way travel time (twtt) between Myrtle Street and Fort Street. The dominant reflector south of Myrtle Street is more discontinuous and appears to dip north with a bow-tie feature near Myrtle Street. North of Fort Street, reflectors appear discontinuous to absent.

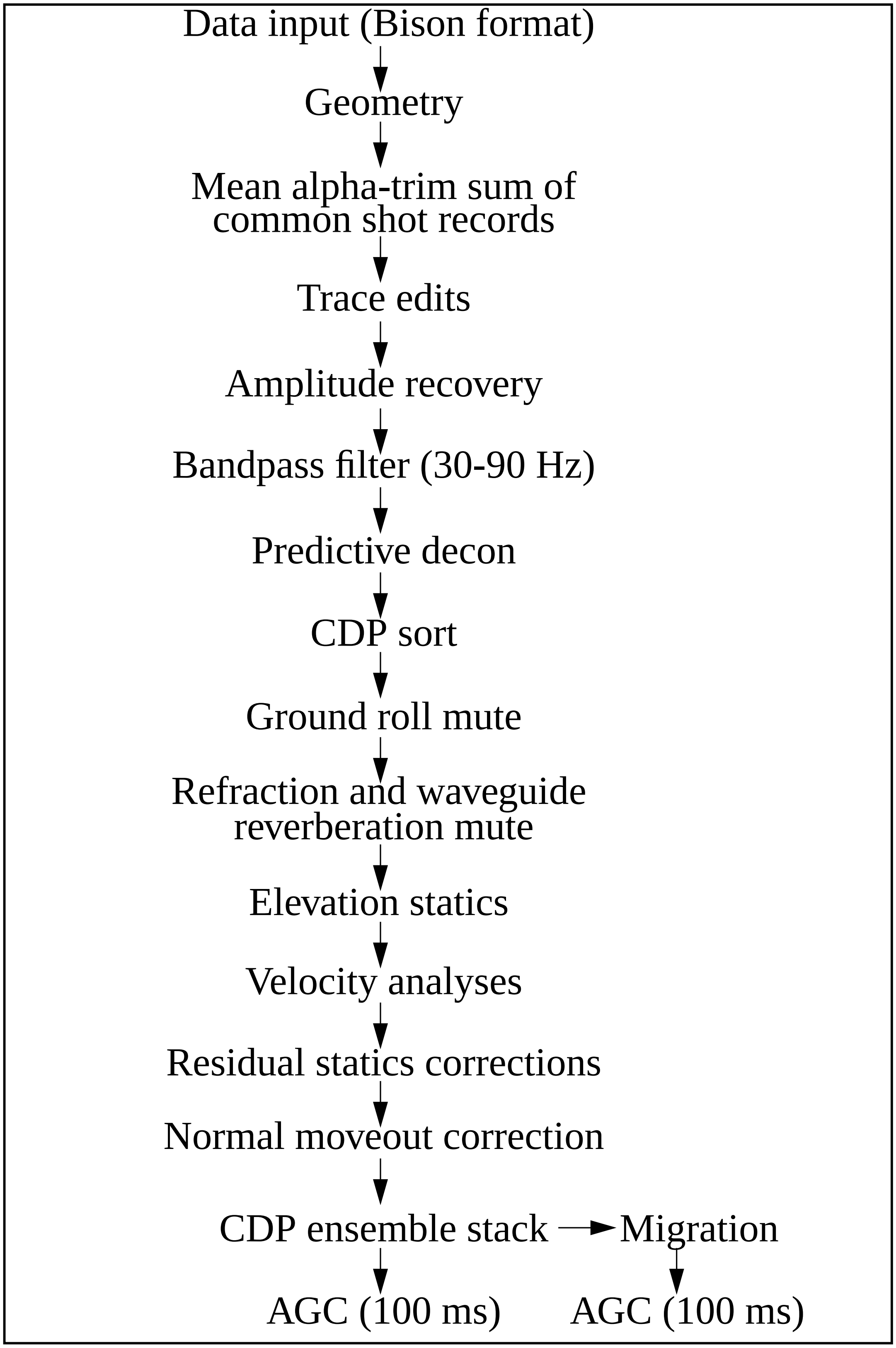


FIGURE 11. Processing flow chart for the Boise Geothermal seismic reflection data. Data were processed using Landmark's ProMAX seismic processing package.

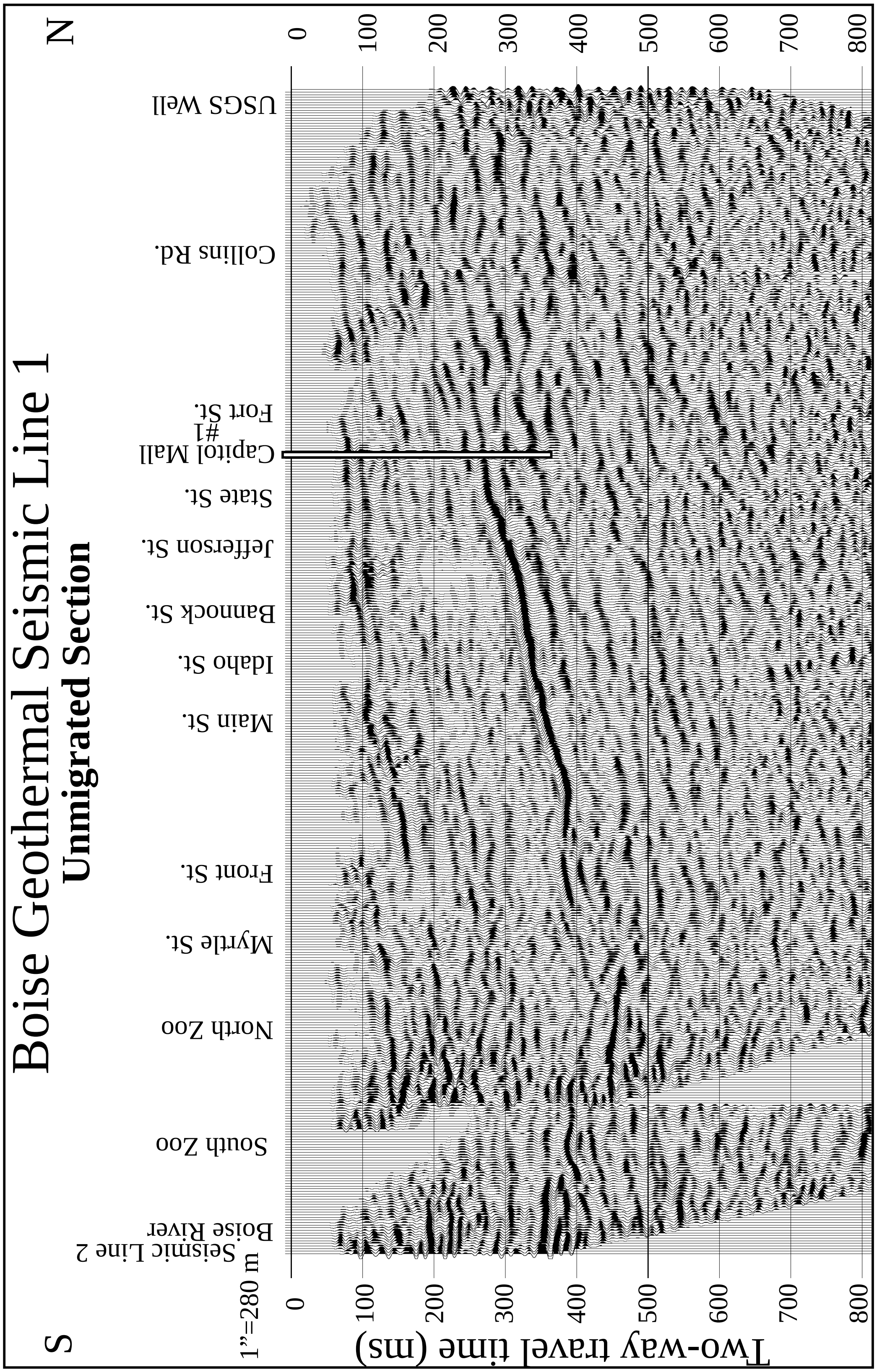


FIGURE 12. Unmigrated image of Line 1. This line extends from the Boise River to the Boise Front to the north. Note the large amplitude reflection package dipping south through the middle of the section.

Capitol Mall #1 is a geothermal injection well along Line 1. A synthetic seismogram generated from the sonic log (Figure 13) shows the expected arrival time to geologic units associated with the geothermal aquifer. The large amplitude reflection on Line 1 at the Capitol Mall #1 well site is at 260 ms twtt and matches the expected time of the upper contact of the basalt in the lower Idaho Group (Figure 14). The bow-tie feature near Myrtle Street suggests a change in dip in the basalt and underlying geologic units. The discontinuous nature of the reflector south of Myrtle St. and in the region north of Fort St. suggest faults cut the geologic units.

7.2 Line 2

Seismic Line 2 (Figure 15) crosses Line 1 at its south end, as shown in Figure 1. A similar strong-amplitude reflection package ties Line 1 to Line 2 and appears from 350-410 ms twtt east of 9th St. and from 580-700 ms twtt west of 9th Street.

The dominant reflection package is interpreted as the basalt unit in the Idaho Group (Figure 16) as interpreted in Line 1. A major offset fault (~200 m) is interpreted west of 9th Street and may be the Eagle-West Boise fault originally mapped by Squires and others (1992) to the west of downtown Boise.

8.0 Discussion

The ideal placement for the injection well is in fractured rhyolite, sufficiently distant from the production wells to avoid cooler-water breakthrough, where the depth to the aquifer is as shallow as possible, and the piping for the collection system does not need extending. The plan is to drill into a fractured zone in the rhyolite where permeability is high enough to accept the spent water that will be re-heated by the geothermal aquifer. An advisory panel, convened by the City Public Works department, jointly recommended placing the injection well along Line 1 south of Myrtle Street in the interpreted fault zone shown on Figure 14.

The main concern with locating the injection well north of the selected site was drilling into an unfractured, impermeable rhyolite that would not accept water. If the rhyolite did accept water, current production wells may be thermally impacted. To the south and west (on Line 2), the geothermal aquifer was interpreted to be deeper and the geology was more continuous (no major fracture zones), except for the main fault interpreted on Line 2 (Figure 15). The interpreted fault on Line 2 correlates with the Eagle-West Boise fault (Figure 16) documented on previous industry seismic data and outcrop exposure (Squires and others, 1992). This fault was not recommended for injection because of the increased depth to the aquifer, and the nature of this fault to the northwest, where the fault may act as an impermeable boundary to the cold water aquifer. Although the selected site is not along the current path of surface piping, future potential customers are located nearby and surface pipe extension into this area may be economically justified.

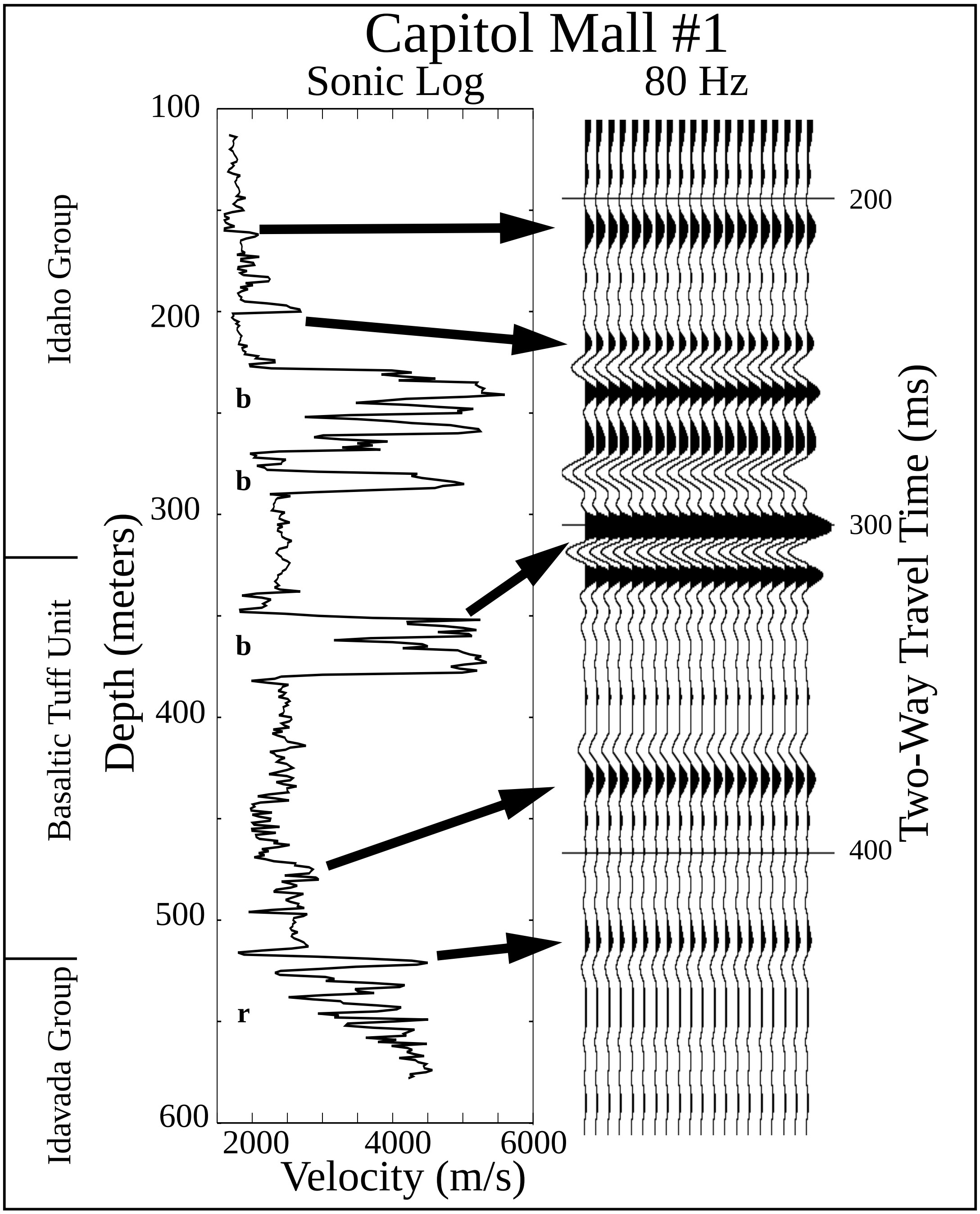


FIGURE 13. Sonic log from Capitol Mall #1 injection well with synthetic seismogram. The seismogram was calculated using an 80 Hz minimum phase Ormsby wavelet. Arrows point to the associated depth corrected times based on an RMS velocity model. High velocity layers are volcanic rocks: b=basalt, r=rhyolite.

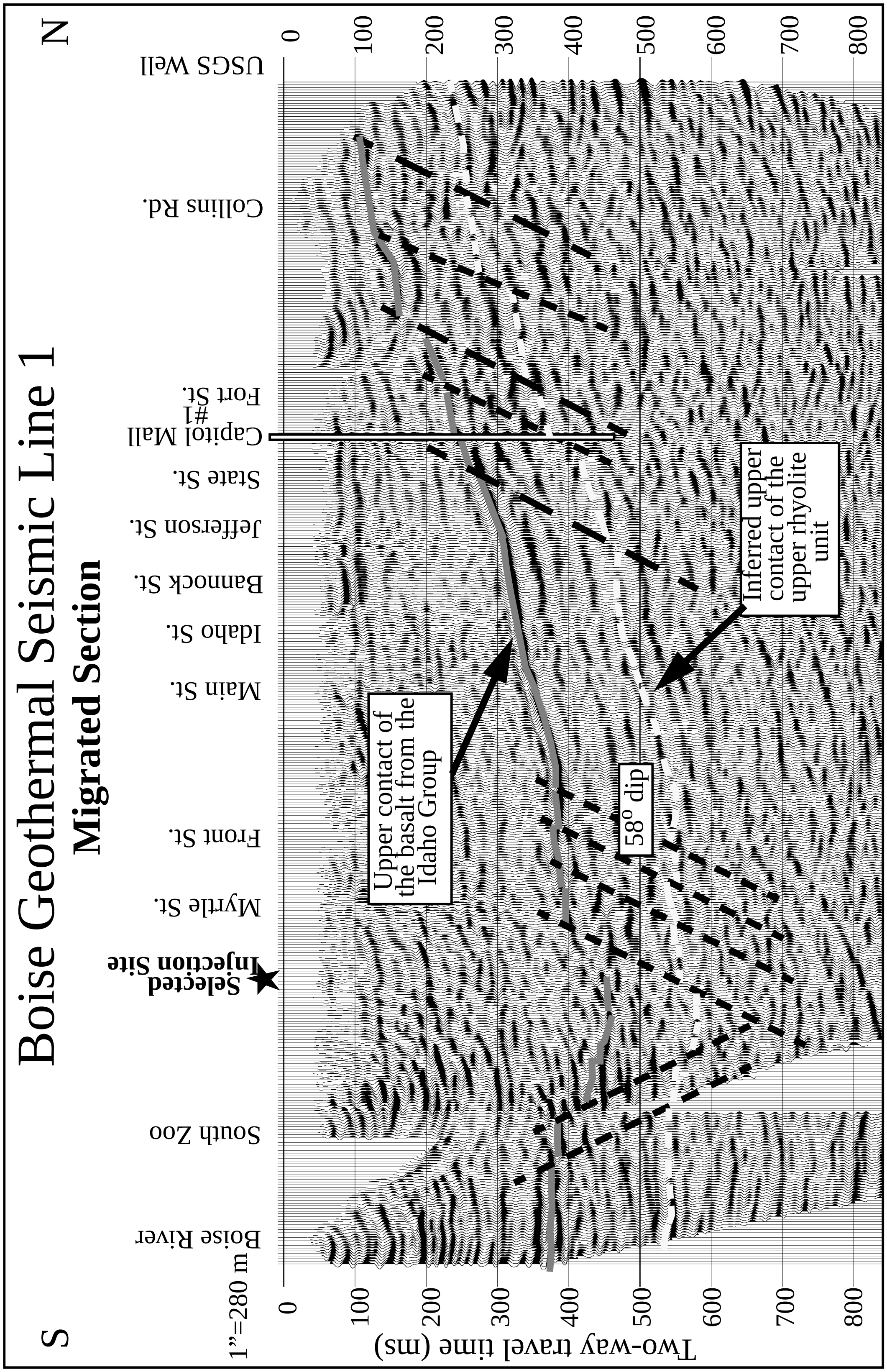


FIGURE 14. Line 1 migrated and interpreted section. The labeled site for the injection well is located in a region with suspected faults in the geologic units associated with the geothermal aquifer.

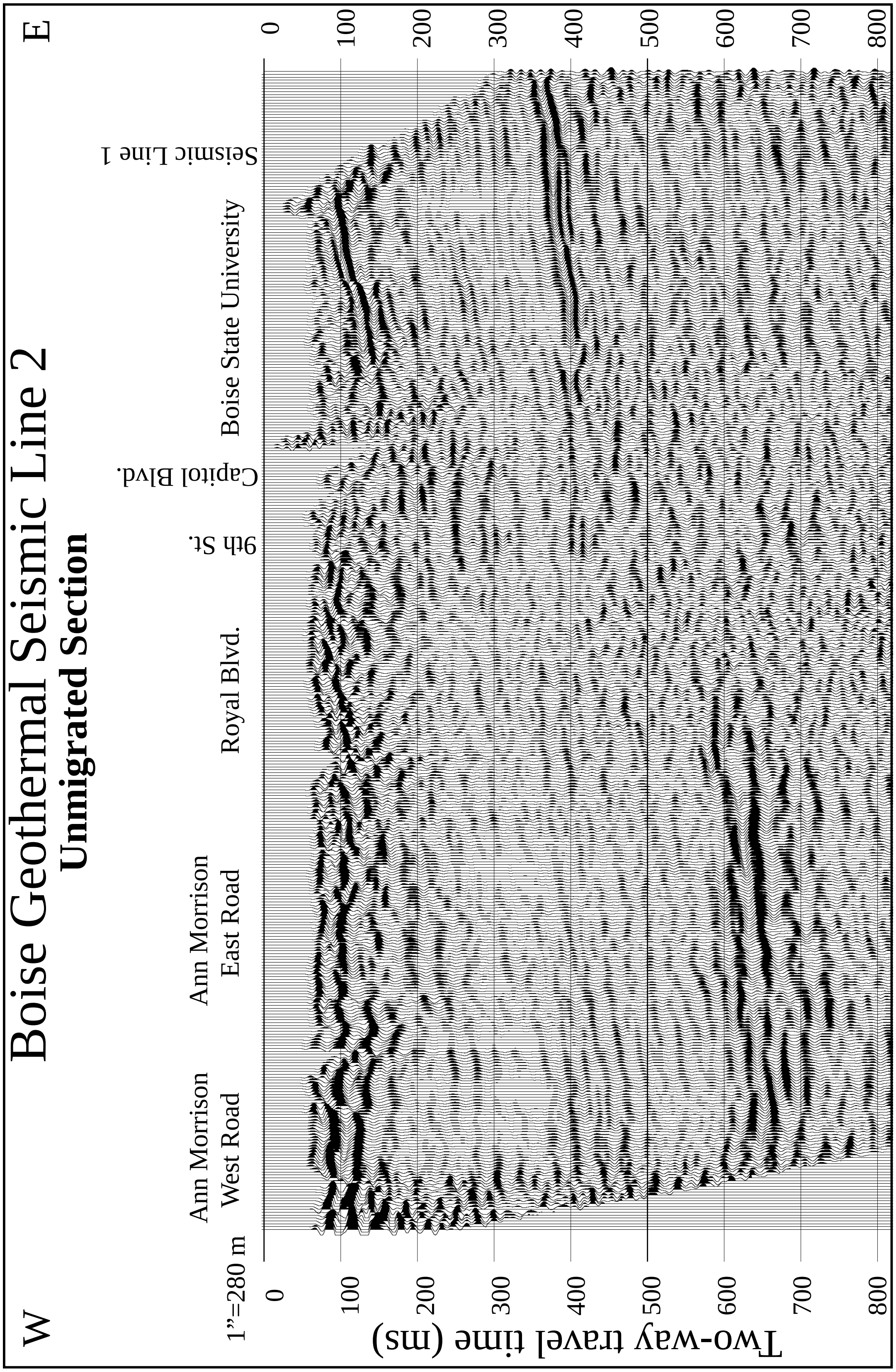


FIGURE 15. Unmigrated image of Line 2. Note the large amplitude reflection package on the east and west portion of the image from 350-750 ms. Also note the continuous reflectors above the large amplitude discontinuous reflection package.

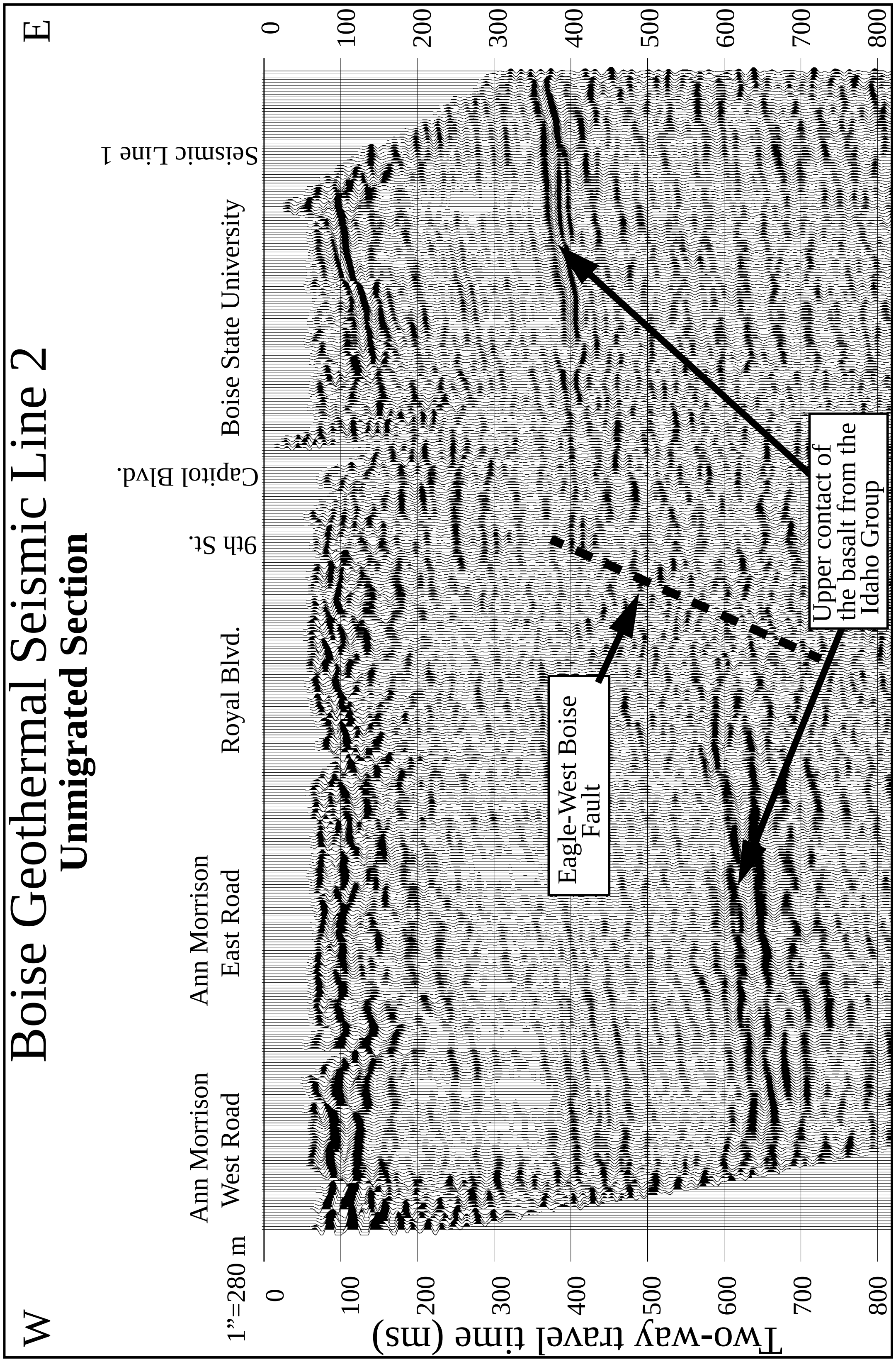


FIGURE 16. Interpretation of Line 2. The upper contact of the basalt from the Idaho Group reflector is inferred from the Line 1 tie. The Eagle-West Boise fault is also interpreted on past industry data and appears in a road cut northwest of downtown. Apparent fault offset is approximately 200m (650 ft.) down to the west on the Eagle-West Boise fault.

9.0 Summary

The Boise geothermal seismic project demonstrated that the seismic reflection method is a viable, non-invasive technique for imaging the near-surface geology in urban regions. A site for a re-injection well was selected based on the seismic results to:

- minimize the costs of constructing the well,
- stabilize pressure in the geothermal system,
- avoid thermal breakthrough of cooler injection into production wells, and
- increase production of the geothermal heating system for future customers.

10.0 Acknowledgments

Funding for the Boise Geothermal Seismic Reflection Project was provided by the U.S. Department of Energy in cooperation with the city of Boise. Terry Scanlan, representing Montgomery Watson, was the project manager for the Boise Geothermal Aquifer Study. Kent Johnson from the city of Boise, was the project manager for the Boise City Geothermal Injection Well Project. The author wishes to thank the field crew involved in the acquisition of the seismic survey and the advisory panel members, who directed the final site recommendation. Dr. Jack Pelton and Dr. Spencer Wood reviewed and contributed to this document.

11.0 References Cited

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