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REPORT ON THE GEOPHYSICAL INVESTIGATIONS FOR THE HARPER-HINKLEY GAP AREA NEAR HINKLEY, CALIFORNIA

MOJAVE WATER AGENCY
VICTORVILLE, CALIFORNIA
MAY/2007

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INTRODUCTION

Aquifer Science and Technology (AST) has conducted a study for the Mojave Water Agency (MWA) to identify the geometry and hydraulic properties of the Harper-Hinkley Gap (the gap), located approximately 2.5 miles north of Hinkley, California. The gap is a shallow depression on the regional bedrock surface in the Hinkley Valley near Red Hill that allows ground water to flow from the Mojave River northward into the Harper groundwater basin (Harper Valley). This study used seismic refraction to map the depth to bedrock across the gap and electrical resistivity methods to estimate the composition and hydraulic properties of the saturated unconsolidated material above bedrock. The geometry of the gap as derived from the geophysical methods was used with the regional water table maps and published estimates of the hydraulic conductivity of the saturated unconsolidated materials to calculate the groundwater flux through the gap using standard Darcy analysis.

GEOLOGIC SETTING

The Hinkley Valley is a narrow northwest trending depression between uplifted igneous and metamorphic bedrock hills. The valley is about eight miles long and four miles wide, and is filled with alluvial sediments that consist of an upper layer of alluvial sand and gravel and a basal layer of coarse sand and silt. In some places these two units are separated by a Pleistocene-age lacustrine clay unit. The unconsolidated units are up to 300 feet thick. Buried channel deposits have been mapped from well logs that indicate remnants of an abandoned route of the Mojave River that has been covered by modern alluvium. Apparently during the Pleistocene the Mojave River split and flowed in part to the north into the Harper Valley trough a structural depression near Red Hill (the gap) as well as easterly through the Barstow Narrows. Modern groundwater levels, as illustrated by the 2002 USGS water table contours shown on **Figure 1**, indicate that groundwater flows through these channel deposits from the Mojave River into the Harper Valley.

The regional bedrock consists of igneous and metamorphic rock. In well logs, the bedrock is described as quartz monzonite, gneiss and schist. The bedrock generally has low permeability and forms the base of the aquifer below the unconsolidated deposits and the edges of the aquifer where the bedrock rises toward the surface in the hills. The Lockhart-Lenwood Fault System impedes groundwater flow through the Hinkley Valley. There is no surface expression of the fault in Hinkley Valley, however, a steep gradient on the southwest side of a cone of depression in the Hinkley Valley is believed to coincide with the location of the Lockhart fault (Mojave Water Agency, 1983). The location of two faults mapped by Dibblee (1967), and the depth to bedrock surface mapped by Crosby (1990) are shown on **Figure 1**.

The water quality in the unconsolidated materials of the Hinkley Valley was historically of good quality. However, heavy groundwater use caused a degradation of water quality (increase in TDS levels) in the upper portion of the unconsolidated materials above the lacustrine clay unit. The water quality in the bedrock of the Hinkley Valley is reportedly poor, exhibiting both elevated TDS concentrations and high fluoride levels (Mojave Water Agency, 1983).

RESISTIVITY SURVEY

Description of the Resistivity Method

The method of electrical resistivity incorporates the introduction of an electrical current into the ground through a pair of electrodes (current electrodes) while measuring the resultant voltage field in the ground at an offset pair of electrodes (potential electrodes). The purpose of the resistivity survey is to delineate lateral and vertical variations in the subsurface material. The change in electrical properties with depth is determined by taking measurements at increased electrode spacings and modeling the change in apparent resistivity with electrode spacing. This type of survey is referred to as a resistivity sounding. By making a series of soundings along a profile line, the lateral changes in layer resistivity can also be determined.

High resolution multi-node resistivity systems use a cable system with multiple conductors to connect many electrodes to a switching box. The switching box selects pairs of current and potential electrodes to make resistivity measurements. The spacing between current and potential electrodes, the spacing between the electrode pairs, and the position of the center of the electrode arrays are changed from one measurement to the next in a systematic way to provide resistivity measurements to different depths and different positions along a profile line. These systems can make hundreds of measurements in a matter of a few hours. The data can be interpreted to produce a relatively high resolution two dimensional section that shows the lateral and vertical changes in resistivity along the profile line.

The resistivity values measured in the field are called apparent resistivity values because they are a composite of the resistivity of all layers that the current traveled through. The field data must be modeled to distinguish the effects of each electrical layer penetrated in order to determine the thickness and resistivity of each layer. Multi-node resistivity data is typically modeled to produce a two dimensional resistivity section that shows the modeled resistivity of the subsurface beneath the profile line.

Substantial changes in electrical properties of the subsurface out of the plane of the resistivity line in close proximity to either side of the resistivity profile can introduce three dimensional effects into the data. The three dimensional effects introduce errors into a two dimensional survey and the resultant interpretation. Resistivity sections will show the position and orientation of major faults that are perpendicular to the line with a high degree of accuracy, but the modeled resistivity values may not be accurate.

Of particular significance is a phenomenon known as the paradox of anisotropy (Keller and Frischknecht, 1966), which causes conductive dikes to appear as high resistivity features due to the distortion of the current field created by the dike. The paradox of anisotropy makes faults with conductive clay rich fault gouge or conductive fluids filling fractures and voids associated with the fault appear as resistors when the fault plane is nearly vertical and cuts the resistivity line at an orientation close to perpendicular. As the orientation of the fault plane becomes more oblique to the survey line, the signature of the fault becomes more like a wide conductor. Given the limitations of imaging a three dimensional structure with a two dimensional survey method, these complexities must be kept in mind when interpreting the field data and processed sections. These effects can be eliminated or reduced by using three dimensional resistivity methods.

However, the cost and complexity of three dimensional survey methods are generally not justified for most surveys. For this survey, knowing the position and approximate orientation of the faults was adequate and three dimensional survey methods were not required.

ELECTRICAL PROPERTIES OF SOILS AND ROCK

The electrical resistivity method measures the electrical properties of the subsurface. The specific electrical property measured is electrical resistivity. Electrical resistivity is measured in units of ohm-meters (Ohmm), and is the mathematical inverse of the more familiar property of electrical conductivity.

Resistivity is a material property that can be used to determine the characteristics of the subsurface. The resistivity of a soil or rock horizon is determined by the degree of saturation and conductivity of the pore fluid and by the particular mineralogical composition of the material. Materials saturated with fresh water generally have lower resistivity values than unsaturated materials. Unstuarated sand and gravel typically has very high resistivity values (300 to 1,000 ohmm). Clay rich materials, such as lacustrine clays, generally exhibit very low resistivity (less than 30 Ohmm). Materials containing little clay, such as unweathered granite or monzonite and clean sand and gravel, generally exhibit very high resistivity values (greater than a few hundred ohmm). Porous materials saturated with fresh water, such as various sand and gravel mixtures, have intermediate resistivity values (between approximately 100 and 300 Ohmm). Porous units saturated with brackish or saline water have lower resistivity values (10 to less than 1 Ohmm). The more fine grain material present in a formation, the lower the electrical resistivity of the material. Very silty sand and sand/silt/ clay mixtures will exhibit resistivity values of between 30 to about 100 Ohmm. Schist is a metamorphic rock that contains laminations of clay minerals that provide electrically conductive layers. The clay laminations give schist a very low electrical resistivity (less than 50 Ohmm) value that is atypical for consolidated bedrock. Using these general relationships, resistivity measurements can be used to distinguish subsurface sediment types.

Description of the Resistivity Method

The method of electrical resistivity incorporates the introduction of an electrical current into the ground through a pair of electrodes (current electrodes) while measuring the resultant voltage field in the ground at an offset pair of electrodes (potential electrodes). The purpose of the resistivity survey is to delineate variations with depth in the subsurface material. This is based on the fact that the subsurface penetration of the electrical current is a function of the electrode separation. The change in electrical properties with depth is determined by taking measurements at increased electrode spacings and modeling the change in apparent resistivity with electrode spacing. This type of survey is referred to as a resistivity sounding. By making a series of soundings along a profile line, the lateral changes in layer resistivity can also be determined.

High resolution multi-node resistivity systems use a cable system with multiple conductors to connect many electrodes to a switching box. The switching box selects pairs of current and potential electrodes to make resistivity measurements. The spacing between current and potential electrodes, the spacing between the electrode pairs, and the position of the center of the electrode arrays are changed from one measurement to the next in a systematic way to provide resistivity measurements to different depths and different positions along a profile line. These systems can make hundreds of measurements in a matter of a few hours. The data can be interpreted to produce a relatively high resolution two dimensional section that shows the lateral and vertical changes in resistivity along the profile line.

The resistivity values recorded in the field are called apparent resistivity values because they are a composite measure of the resistivity of all layers that the current traveled through. The field data must be modeled to distinguish the effects of each electrical layer penetrated in order to determine the thickness and resistivity of each layer. Multi-node resistivity data is typically modeled to produce a two dimensional resistivity section that shows the modeled resistivity of the subsurface beneath the profile line.

Substantial lateral changes in electrical properties in close proximity to either side of the resistivity profile line can introduce three dimensional effects into the data, which will in-turn introduce errors into a two dimensional survey and the resultant interpretation. In particular, the resistivity sections will show the position and orientation of major faults that are perpendicular to the line with a high degree of accuracy, but the modeled resistivity values may not be accurate.

Of particular significance is a phenomenon known as the paradox of anisotropy (Keller and Frischknecht, 1966), which causes conductive dikes to appear as high resistivity features due to the distortion of the current field created by the dike. The paradox of anisotropy makes faults with conductive clay rich fault gouge, or conductive fluids filling fractures and voids associated with the fault, appear as resistors when the fault plane is nearly vertical and cuts the resistivity line at an orientation close to perpendicular. As the orientation of the fault plane becomes more oblique to the survey line, the signature of the fault becomes more like a wide conductor. The limitations of imaging a three dimensional structure with a two dimensional survey method must be kept in mind when interpreting the field data and processed sections. These effects can be eliminated or reduced by using three dimensional resistivity methods. However, the cost and complexity of three dimensional survey methods are generally not justified for most surveys. For this survey, knowing the position and approximate orientation of the faults was adequate and three dimensional survey methods were not required.

<u>Description of Resistivity Field Procedures</u>

A geophysical survey consisting of six high-resolution resistivity profiles was conducted along Burnt Tree Road between October 25th and October 27th, 2006. **Figure 2** shows the location of the survey lines. The resistivity data were collected using a SuperSting™ model R1 IP, with a Swift™, multi-node resistivity imaging system.

The Sting system consisted of a transmitter/receiver, switch box, four 450-foot long electrode cables, each with 14-takeouts spaced 10 meters (approximately 32.8 feet) apart, 56 metal stakes (electrodes), and a 12-volt deep cycle marine battery to power the transmitter. The system was laid out with the transmitter/receiver, switch box, and battery in the middle of the four cables. Using four cables and 56 electrodes, the total line length was approximately 1,800 feet. For each sounding, steel electrodes were pounded into the ground and attached to the cable at each 10-meter takeout. The electrode spacing was controlled by the transmitter's internal switching system. The switching system selects various electrodes to form dipole pairs of current electrodes and potential electrodes with different dipole spacings, dipole offsets, and array centers. Hundreds of measurements were made along each profile line to measure the lateral and vertical changes in subsurface resistivity.

The modeling package Earth Imager was used to model the field data. This program models the field data to image the lateral and vertical changes in subsurface resistivity. Available subsurface geologic data was used to provide estimates of the depth to bedrock and soil types in order to improve the accuracy of the resistivity models. The modeled resistivity sections are provided in **Appendix A**.

SEISMIC REFRACTION SURVEY

Description of the Seismic Refraction Method

Seismic refraction requires the input of seismic waves into the subsurface and instrumentation to measure and record the waves at different points along the ground surface. Refraction surveys are typically conducted to determine the depth to different geologic layers, most commonly to find the depth to bedrock. Critically refracted seismic wave paths cross boundaries between materials in a way that energy travels from source to receiver in the shortest possible time. The first arrival travel time of source to receiver and the corresponding geometry of the geophone spread are used to calculate layer velocities and thicknesses. The seismic velocities are characteristic of the type and density of unconsolidated material or bedrock encountered.

It should be noted that the refraction method has limitations when looking at steep dips or when thin or slower velocity zones are present at depth. These conditions can create erroneous depths in the interpretation of the data. Additionally, the weathering surface of bedrock can be highly variable and the change to competent rock can be gradational. This variable and gradational change in the competency of the rock can make it difficult to pick the transitions from weathered to competent rock. High noise conditions due to windy conditions can create strong seismic noise that can make it difficult to pick the first arrivals and create errors in the interpretation of the data.

Eight seismic refraction lines were run along Burnt Tree Road between October 25th and October 27th, 2006, as shown on **Figure 2**. The lines were typically located near the center of the resistivity lines unless unusual conditions were observed in the seismic or resistivity data, in which case additional seismic lines were conducted to provide more detail on the bedrock surface. The refraction survey was collected using a 24-channel Seistronics Ras-24 Digital Seismograph, with 10 Hz vertical component geophones and a 20 foot spacing between geophones. A "Betsy Seisgun" (Betsy) was used as the seismic source. The Betsy fires 8 gauge industrial grade shotgun shells in a shallow hole to impart sound waves into the subsurface. Forward, reverse, and midline shots were collected for each seismic line to allow dipping or irregular layers to be resolved.

The data was interpreted using SIP delay time methods with the Rimrock seismic modeling package. The seismic data is interpreted to select first arrival times and calculate the seismic velocities and the depth for each layer detected. This process provides high-resolution seismic refraction interpretations providing depth information under each geophone to various geologic layers. The processed depth sections for the seismic refraction lines are included in **Appendix B**.

SURVEY RESULTS AND DISCUSSION

Resistivity Survey Results

Data quality was very good on all six resistivity lines. Each of the resistivity profiles achieved a depth of penetration of about 400 feet. Each of the modeled profile lines are plotted with a uniform resistivity scale of 20 ohm-meters as the lower limit and 2,000 ohm-meters as the upper limit to allow the lines to be easily compared. The processed resistivity lines are included in **Appendix A**.

The processed resistivity lines were plotted on the base map to show the lateral and vertical changes in the resistivity of the subsurface across the survey area. **Figure 3** presents the resistivity plots hung from the surface trace of the resistivity line. The vertical scales of the plots are all the same. The full thickness of the resistivity plots represents approximately 400 feet of penetration into the subsurface. Each line is approximately 1,800 feet long, giving each plot a relatively mild vertical exaggeration of about 1.3 to 1.

Refraction Survey Results

Review of the seismic refraction data indicates that all eight seismic refraction lines exhibited good to very good data. Three geologic layers were detected on lines 1, 5, 7, and 8, which is typical for a refraction survey to map bedrock. The upper layer in the gap is generally 30 to 50 feet thick and has a seismic velocity of between about 1,200 to 1,800 feet/second (ft/s). This layer is interpreted to represent unsaturated unconsolidated material. The second layer is typically about 50 to 150 feet thick and has a seismic velocity of about 5,400 to 9,140 ft/s. A distinct shift in the velocity of the second layer was observed between seismic lines 3 and 5 near the center of resistivity line 3. This is the location of a fault mapped by Dibblee (1967) as shown on **Figure 3**. The second layer is interpreted to represent saturated unconsolidated deposits on the west half of resistivity line 3 where the seismic velocities are generally below about 6,000 ft/second. On the east half of resistivity line 3 where the seismic velocities are generally over 8,000 ft/second the second layer is interpreted as likely weathered bedrock or a basaltic intrusion. A third layer was detected on lines 1, 5, 7, and 8 at a depth of between about 100 to 250 feet with a seismic velocity of between about 11,000 to 19,400 feet/second. This layer is interpreted to represent competent granitic bedrock. The results of the seismic survey are summarized on **Table 1.**

The interpreted top of the bedrock surface from the seismic data is shown on the resistivity plots on **Figure 3.** The bedrock surface appears to correlate to the base of the high resistivity material in the west half of survey area (seismic lines 8, 1, 2 and 4), and the base of the low resistivity material in the east half of the survey area (seismic lines 3, 5, 6, and 7).

INTERPRETATION OF RESULTS

Resistivity lines 6, 1, and 2 detected a high resistivity (over 400 Ohmm) layer from near the surface to depths of about between 150 to 300 feet. This layer is interpreted to represent unconsolidated coarse-grained sand and gravel and probably represents a channel deposit from a former course of the Mojave River into Harper Valley. The saturated portion of this channel deposit is likely to be a major flow path for groundwater entering Harper Valley.

A low resistivity unit (less than 40 Ohmm) is present beneath this layer. The seismic data from lines 1 and 8 indicates that the low resistivity unit has a relatively high seismic velocity and represents consolidated bedrock. This unit is too deep to be detected by seismic lines 2, 3, and 4. The low resistivity and high seismic velocity of this layer indicates that it is likely electrically conductive bedrock. Several well logs from the area indicate that schist units are present within the bedrock. We interpret the low resistivity of the bedrock in this area to indicate the presence of schistose units within the bedrock.

Two inclined resistive anomalies cut the bottom layer on resistivity line 6 and one similar feature cuts the bottom layer on line 1. These anomalies have the characteristic response of faults. Dibblee (1967) mapped a fault between resistivity lines 1 and 6 (**Figures 1 and 3**). These features appear to represent the fault mapped by Dibblee. Based on the resistivity data, the fault may actually consist of several fault splays that form a fault zone in the approximate location mapped by Dibblee. The anomaly shows the fault planes to have a higher resistivity than the surrounding bedrock, but it is likely that the fault is actually a conductive feature due to clay-rich fault gouge and or fluid filled fractures. The higher resistivity response is assumed to be due to the paradox of anisotropy. The upper high resistivity layer shows a vertical truncation on the eastern half of resistivity line 2. This may indicate a fault with vertical offset.

The width of the faults and associated zones of alteration are probably thinner than the resistivity anomalies. The dip of the faults is probably consistent with the trend of the resistivity anomalies, though the dip of the resistivity anomalies are probably apparent dips because it is unlikely that faults cut the resistivity lines in perpendicular orientations.

A fault mapped by Dibblee (1967) cuts through resistivity line 3 as shown on **Figures 1 and 3**. Review of the seismic and resistivity data collected across this fault indicates the fault appears to cover a wide zone, beginning on the east end of resistivity line 2 (beneath the area covered by seismic line 3) and extends through the west half of resistivity line 3. Resistivity line 2 shows a sharp contrast between the modeled resistivity of layer two beneath seismic lines 3 and 4, even though the seismic velocities are very similar. Competent bedrock was not detected beneath either seismic lines 3 or 4. Resistivity line 3 shows more of a transitional response from the west half of the line to the east half of the line. On the west half of resistivity line 3, the upper material is predominantly low resistivity, with the material below exhibiting very low resistivity values. Resistivity line 3 also shows a moderately higher resistivity mass (100 to 200 Ohmm) in the interpreted bedrock near the center and eastern end of the line. Based on the seismic velocity obtained in layer two on seismic line 5, this material appears to be weathered bedrock. Resistivity line 4 shows a vertical low resistivity anomaly (under 100 Ohmm) at the western end of the line and higher resistivity bedrock over the rest of the line. It appears that the lithology of the bedrock changes on the eastern half of resistivity line 3 from a low resistivity rock type (probably schist) to a more resistive rock such as weathered granite or monzonite. The resistivity anomalies observed in the lower layer of resistivity lines 3 and 4 may represent the fault mapped by Dibblee (1967).

In the vicinity of resistivity line 3 the character of the unconsolidated material transitions from thicker more resistive sands and gravels in the western portion of the survey area to thinner lower resistivity clay and silt deposits in the eastern portion of the survey area. Based on the interpreted grain size and thickness of the unconsolidated materials from resistivity line 3 to the east, it does not appear that this portion of the survey area contains channel deposits and is probably not a significant flow path for groundwater entering the Harper Valley.

CALCULATED FLUX INTO HARPER VALLEY

The resistivity and refraction surveys appear to have mapped a former channel deposit of the Mojave River in the western portion of the survey area. The geometry of the channel deposit was calculated by making depth measurements along the resistivity and refraction profiles for the west half of the survey as shown on **Figure 3**. Based on 22 regularly spaced measurements between station 0 on resistivity line 1 and station 1345 on resistivity line 2, the average thickness of the channel deposits is 143 feet with a standard deviation of 54 feet across a width of about 5,000 feet. The channel is believed to extend at most a few hundred feet west of the western end of resistivity line 6 based on a bedrock hill located immediately west of Hinkley Road (**Figure 1**). The west half of the survey line is relatively flat and generally follows the 2120 foot contour line (**Figure 1**). The USGS measured the elevation of the water table in 2002 and the contoured values are presented on **Figure 1**. The 2050 foot contour line cuts the west half of the survey area indicating the depth to water is roughly 70 feet beneath resistivity lines 6, 1, and 2. This indicates that the saturated thickness of the channel deposits in this area averages about 73 feet.

Using the USGS 2002 water level contours on **Figure 1**, the water table drops about 50 feet over 10,500 feet across the gap on the west side of Red Hill. This provides an estimated gradient of 0.0048 on the water table across the gap. Assuming an average hydraulic conductivity of 100 ft/day for the saturated channel deposits, a width of 5,000 feet, and an average saturated thickness of 73 feet, we estimate the flux through the channel deposits at 175,200 ft^3/day, or 1.31 million gallons per day (mgd), which is equivalent to 478,331,000 gallons per year or 1,468 acre feet per year (af/yr).

Our estimate greatly exceeds the estimate provided by Mojave Water Agency (MWA 1983) of 22 af/yr, primarily because MWA used a cross sectional area for the channel deposits that was roughly one third less than our estimate, a hydraulic gradient that was roughly 10% of the value we used and a hydraulic conductivity value that was about 28% of the value we assumed. The hydraulic gradient value used by MWA may have reflected the large cone of depression created by past heavy agricultural pumping. Pumping in the area appears to have been greatly reduced, possibly in response to declining water quality, which may have allowed the gradient to recover to more natural conditions by the time the USGS made their measurements in 2002.

The Mark Group (1989) estimated the flux into Harper Valley using properties estimated from well logs. They estimated the groundwater discharge through the gap at 2,700 af/yr, which exceeds our estimate by about 84%. They used a saturated thickness of 150 feet, which is more than twice the saturated thickness of channel deposits we calculated from the geophysical data, a width of the channel deposits of three miles, which is more than three times the width measured by the geophysical data, and a gradient of 0.0038, which is very close to the value we calculated from the USGS water level data. They assumed a hydraulic conductivity of 100 ft/day, which is the value we used.

The USGS estimated the volume of groundwater flow into the Harper Valley at 3,071 af/yr based on 1994 conditions using a MODFLOW model of the entire Mojave River Basin (Stamos et al, USGS 2001). The model relied on transmissivity values to estimate groundwater flow on a regional basis. The modeled channel width was approximately 2,000 feet across with a transmissivity of 10,000 to 20,000 feet squared per day. It should be noted that the model was designed to predict large regional groundwater changes for the entire Mojave River Basin. The model was unable to account for localized changes in aquifer properties and basin/channel geometry, both of which are very sensitive variables to the flow volumes in the Harper-Hinkley Gap area.

Our estimate of groundwater discharge through the channel deposits into the Harper Valley includes new data on the width and saturated thickness of the channel deposits. As a result, we believe our estimate to be the most accurate produced to date. However, the accuracy of our estimate is directly related to the assumed value of hydraulic conductivity for the channel deposits. We used a value typical for sand and gravel. However, the actual value may vary by an order of magnitude higher or lower than our estimate. The flux estimate will vary linearly with the value of hydraulic conductivity used for the calculation. If the accuracy of our estimate needs to be improved, we recommend that the hydraulic conductivity of the channel deposits be measured directly by conducting one or more pumping tests near the center of the channel.

CONCLUSIONS

The results of the geophysical surveys conducted for this project provide a significant amount of information on the subsurface geology of the area and provided the geologic framework needed to provide a more accurate estimate of the groundwater flux into the Harper Valley. The former channel of the Mojave River appears to be limited to the area west of Red Hill. A fault near the center of the survey line appears to delineate a change in the depth and character of the local bedrock and a change from coarse-grained channel fill deposits west of the fault to finer grained and thinner clay or silt deposits above bedrock east of the fault. The groundwater flow into the Harper Valley is estimated at 1,468 af/yr. The accuracy of this estimate is limited by the accuracy of the hydraulic conductivity value assumed for the calculation. The resistivity data also detected indications of faulting in the bedrock on the west half of the line.

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Figures

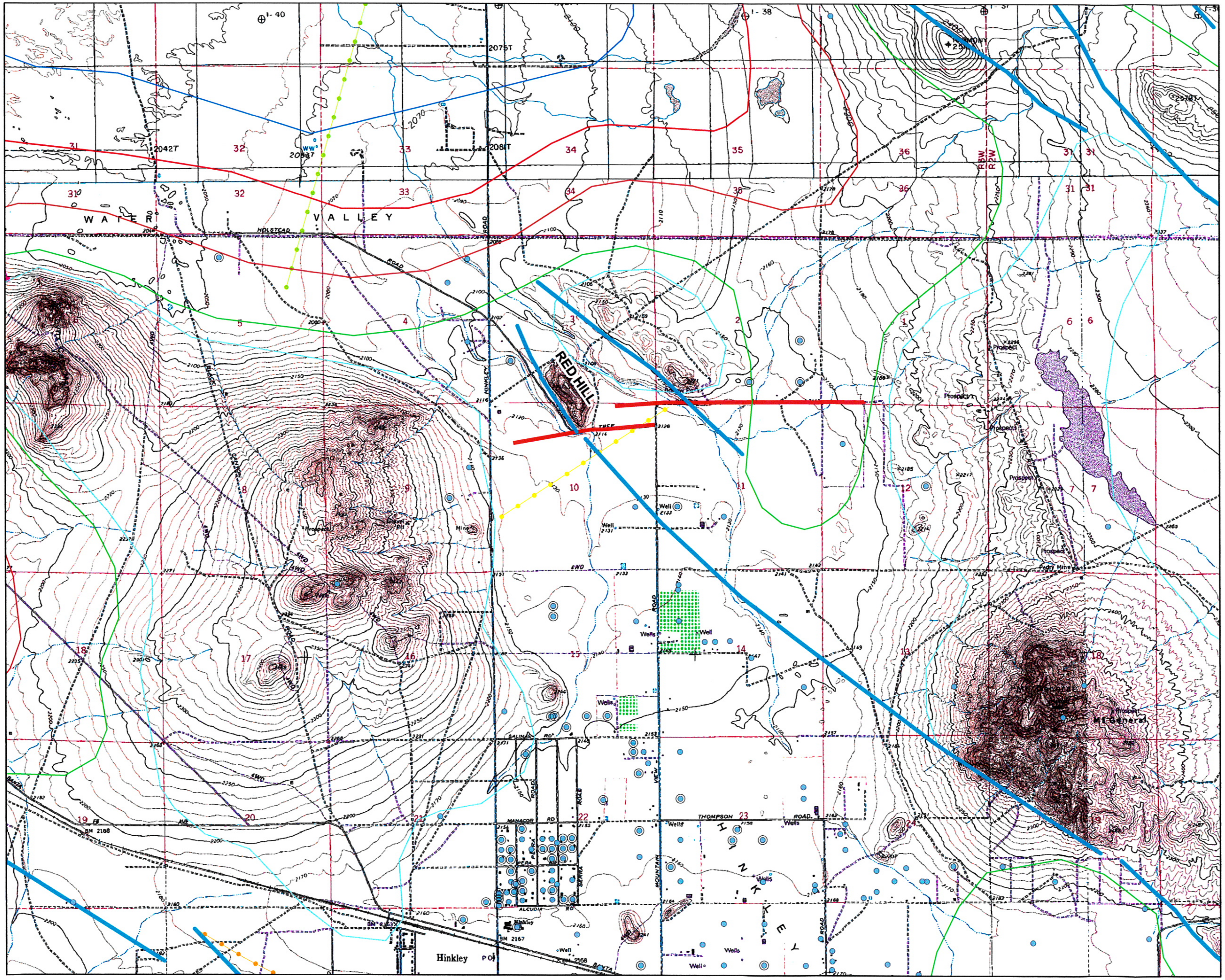

FIGURE 1

GEOPHYSICAL SURVEY LOCATIONS, DEPTH TO BEDROCK AND WATER TABLE MAP

HARPER-HINKLEY GAP AREA

HINKLEY, CALIFORNIA

Legend

- Wells with Well Completion Reports
- Wells with Well Completion Reports 2

Crosby 1990 Depth to Bedrock

- 0
- 500
- 1000
- 1500
- 2000
- 2500

USGS 2002 WL Contours

- 1900
- 1950
- 2000
- 2050
- 2100
- 2150
- Resistivity and Seismic Survey Lines
- Faults (Dibblee, 1967)

N W E S

0 1,500 3,000 6,000
Feet

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I:\ACAD_DWG\4092533\102\BEDROCK.mxd

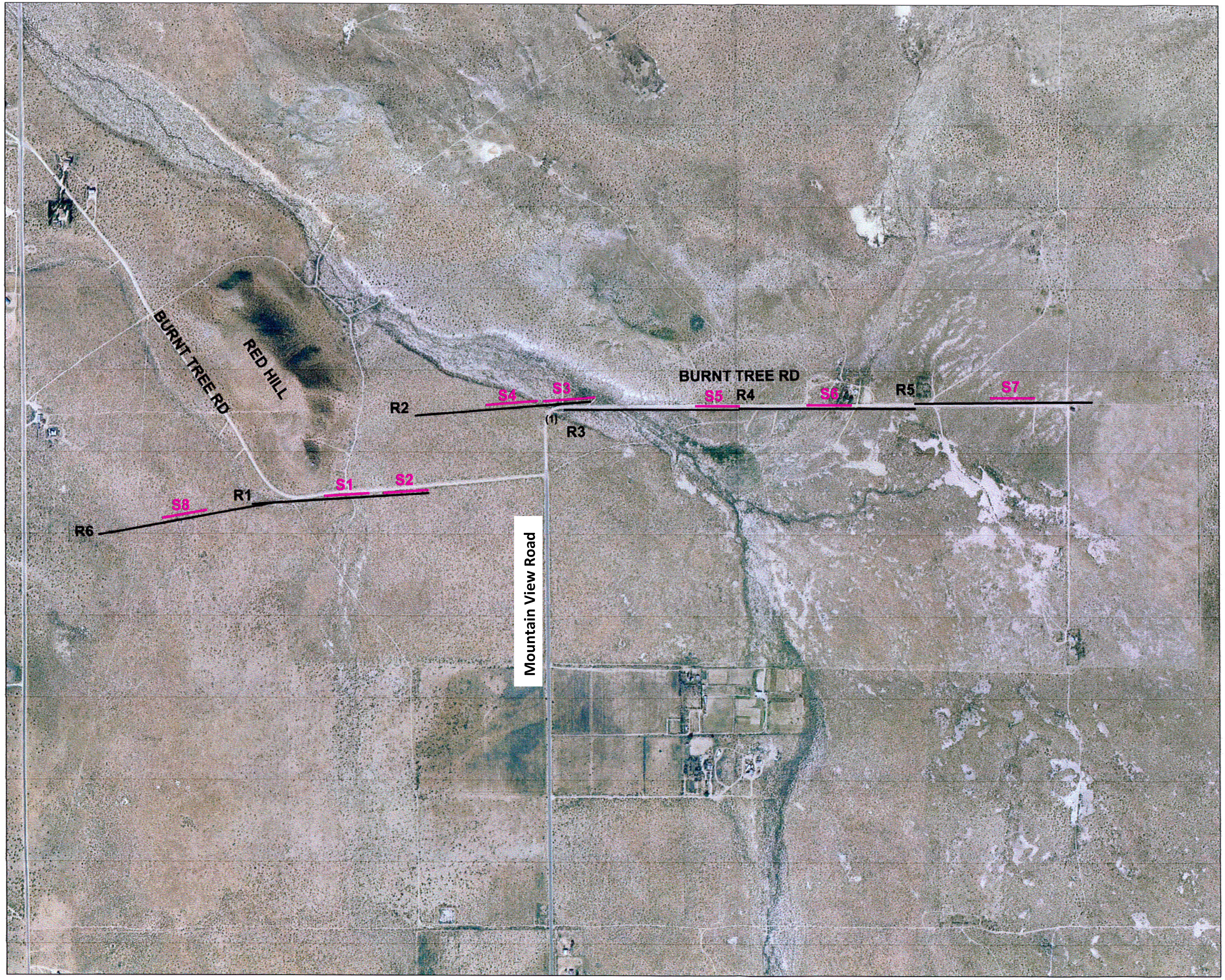

FIGURE 2

GEOPHYSICAL SURVEY LOCATIONS

HARPER–HINKLEY GAP

HINKLEY, CALIFORNIA

LEGEND

R1 — RESISTIVITY LINE (ELECTRODE NO.)

S1 — SEISMIC LINE (GEOPHONE NO.)

N / E / S / W

0 500 1000 2000
SCALE IN FEET

0 1/8 1/4 1/2
SCALE IN MILES

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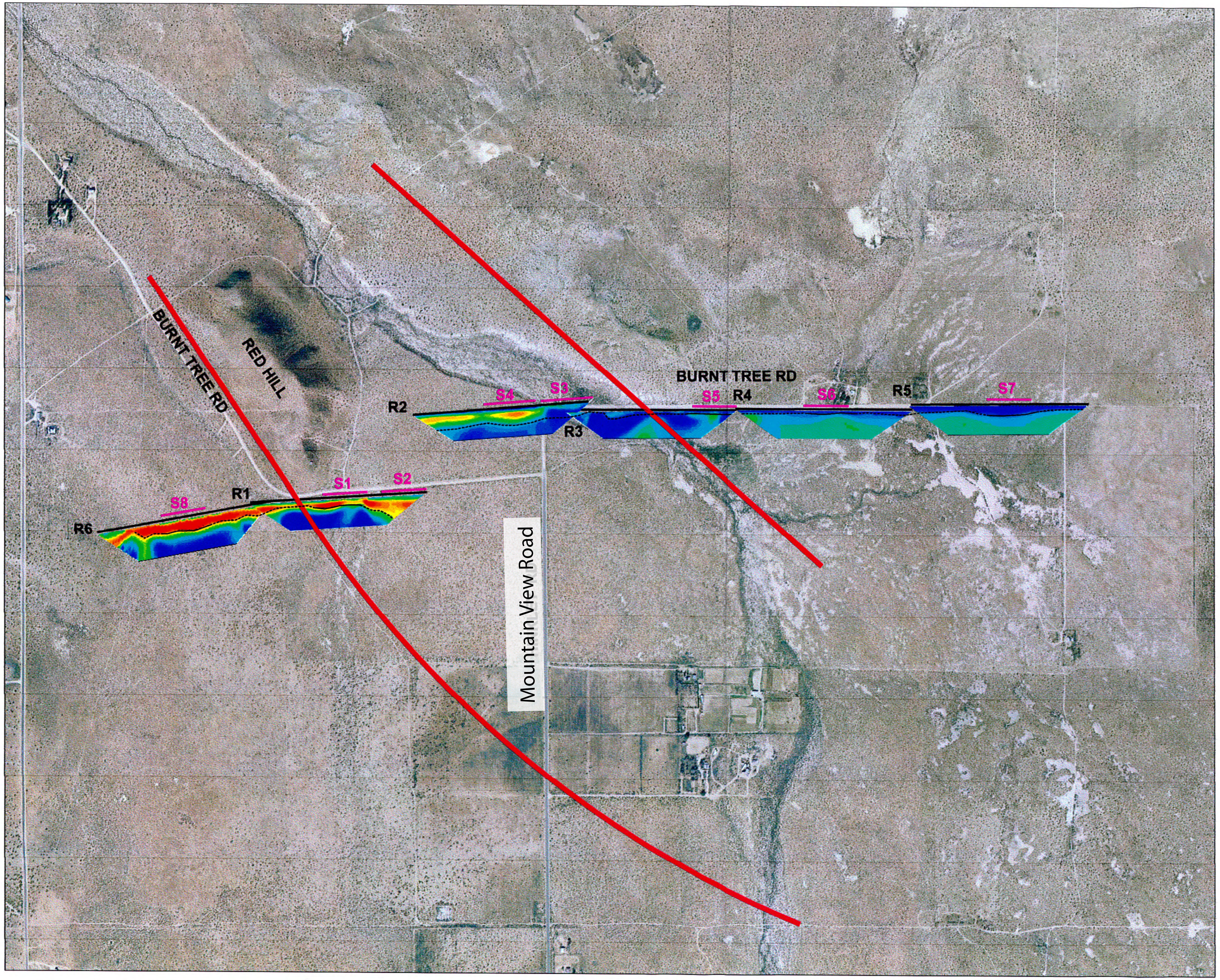

FIGURE 3

PROCESSED GEOPHYSICAL DATA

HARPER–HINKLEY GAP

HINKLEY, CALIFORNIA

LEGEND

R1	RESISTIVITY LINE (ELECTRODE NO.)
S1	SEISMIC LINE (GEOPHONE NO.)
	PROCESSED RESISTIVITY PROFILE
	BEDROCK SURFACE FROM SEISMIC DATA (DASHED WHERE INFERRED)
	MAPPED FAULT (DIBBLEE 1967)

N
W E
S

0 500 1000 2000
SCALE IN FEET

0 1/8 1/4 1/2
SCALE IN MILES

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Tables

Table 1

Summary of Seismic Refraction Data

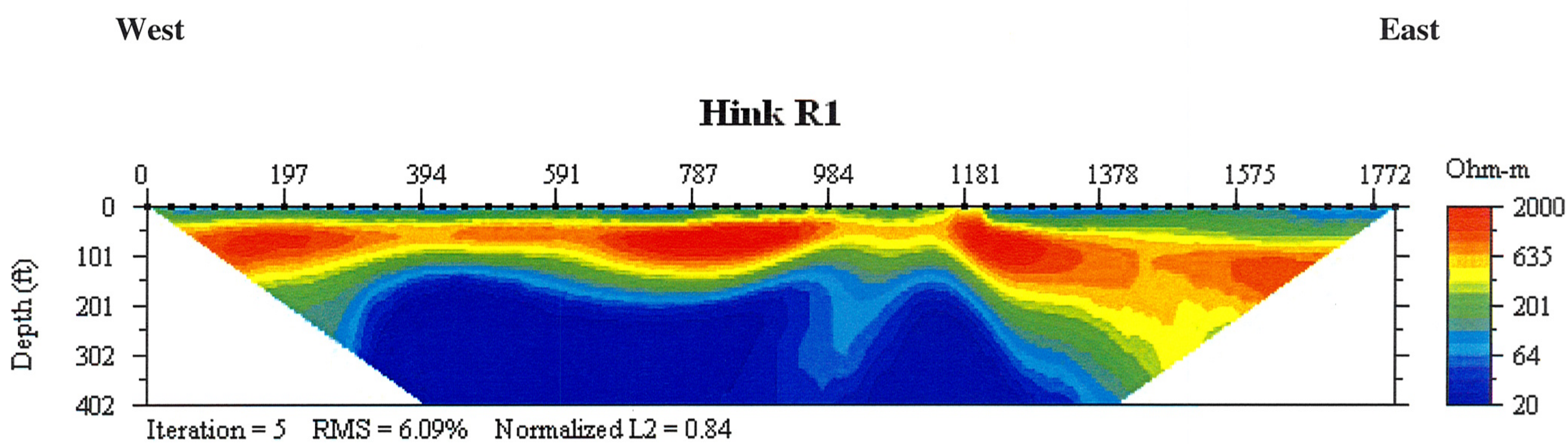
Line	V_1	Z_1	V_2	Z_2	V_3	Z_3	Approximate Depth to Bedrock* (ft)
1	1631	50	5593	50-100	11050	ND	100-160
2	1299	50	5432	ND			ND
3	1666	30-50	5376	ND			ND
4	1421	50	5547	ND			ND
5	1782	45	8126	50-100	12346	ND	45-50
6	1914	50	8412	ND			50
7	1660	45	9140	70-150	19444	ND	45
8	1181	50	6054	80-110	10058	ND	130-170

NOTE: All velocities in ft/sec and depths in feet.
V_n: Calculated seismic velocity of respective layer.
Z_n: Approximate thickness of respective layer.
ND: Bottom of layer not detected.
*: Depth to either weathered or competent bedrock.

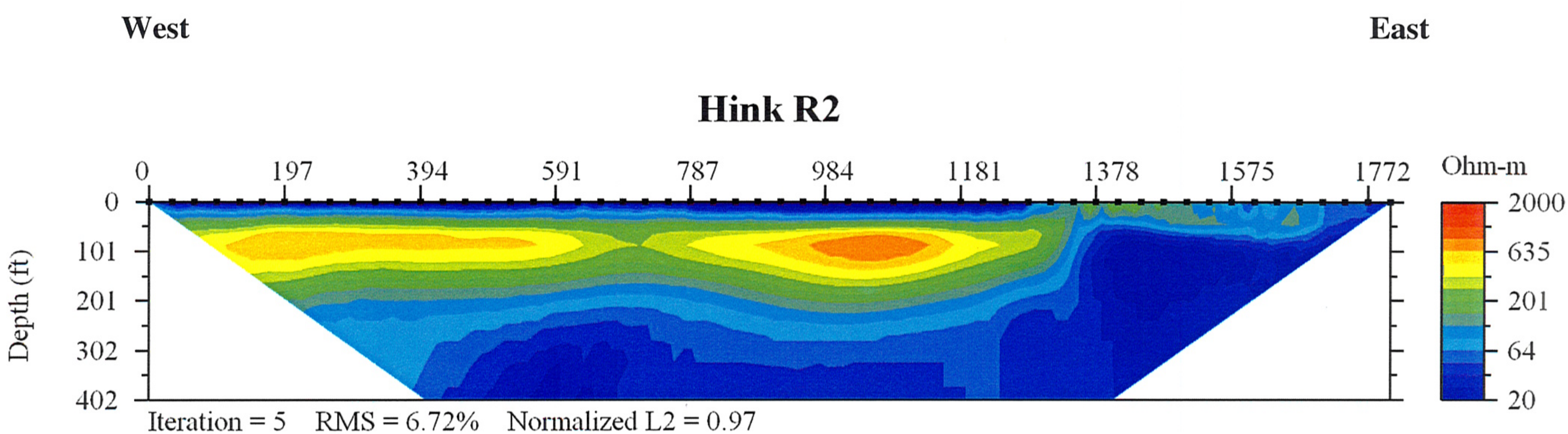
Appendix A

Modeled Resistivity Sections

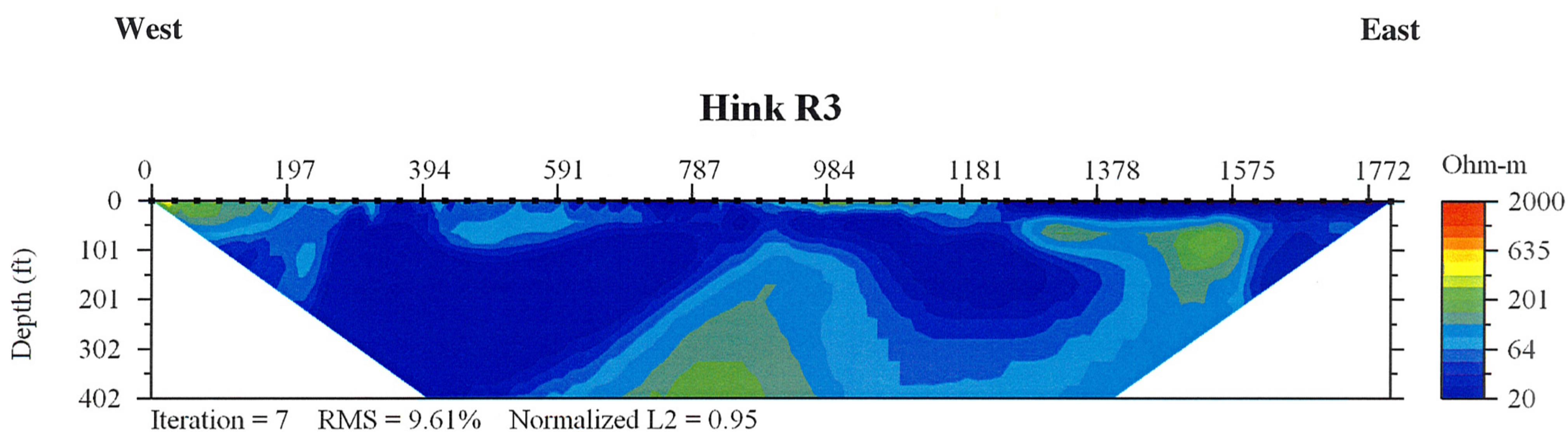
Harper-Hinkley R1



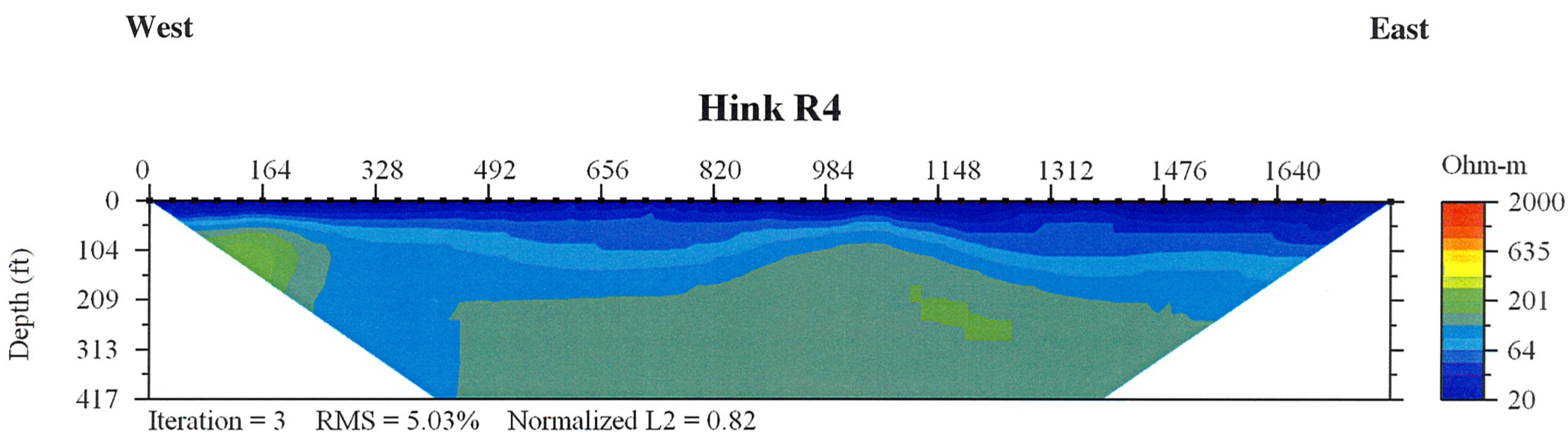
Harper-Hinkley R2



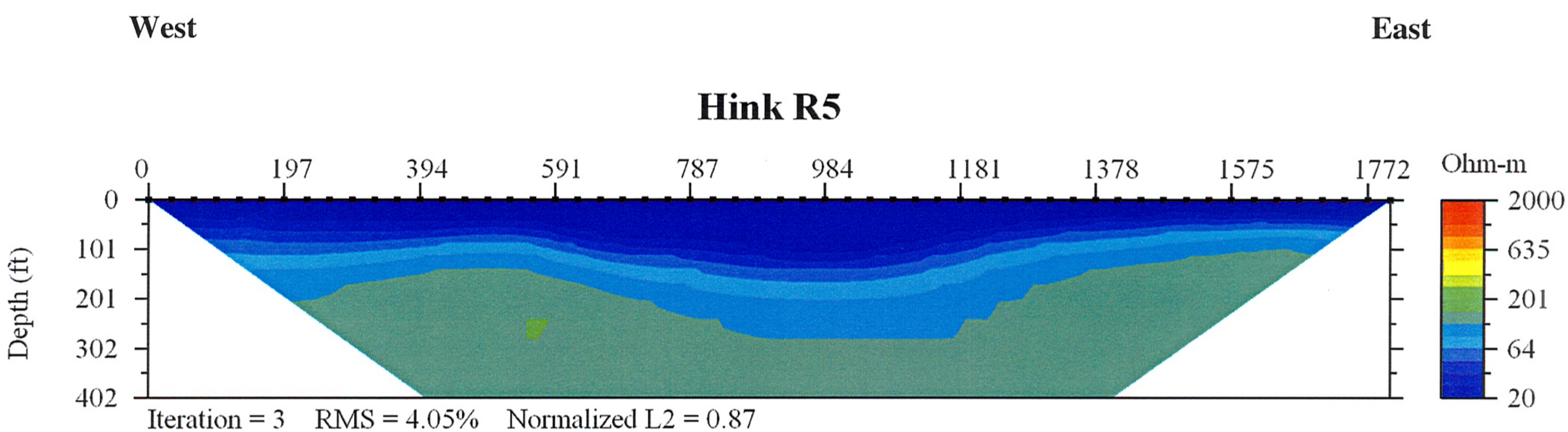
Harper-Hinkley R3



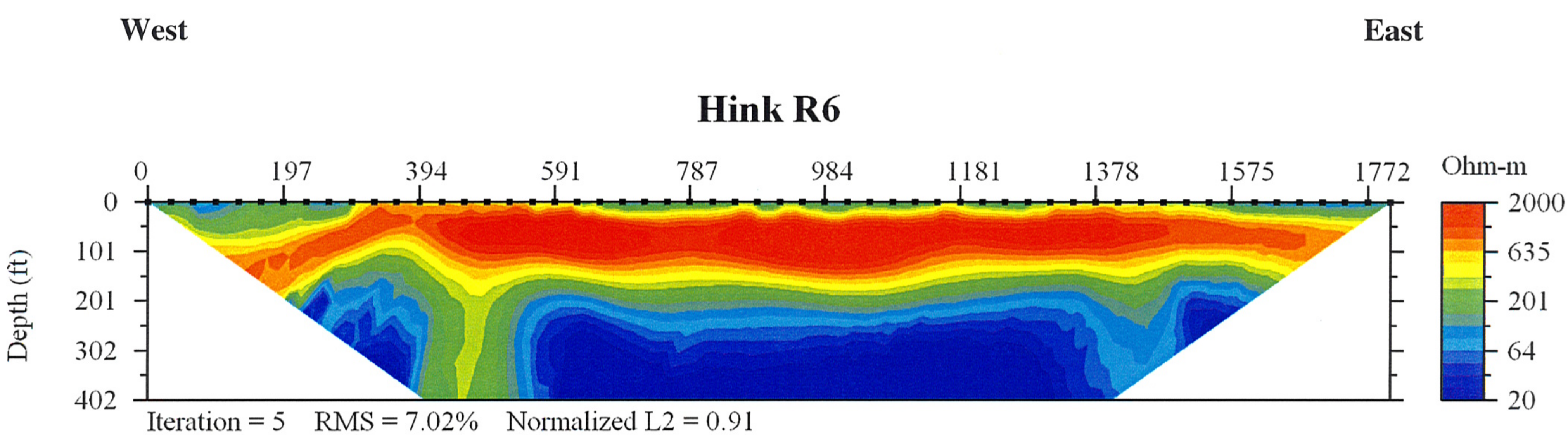
Harper-Hinkley R4



Harper-Hinkley R5



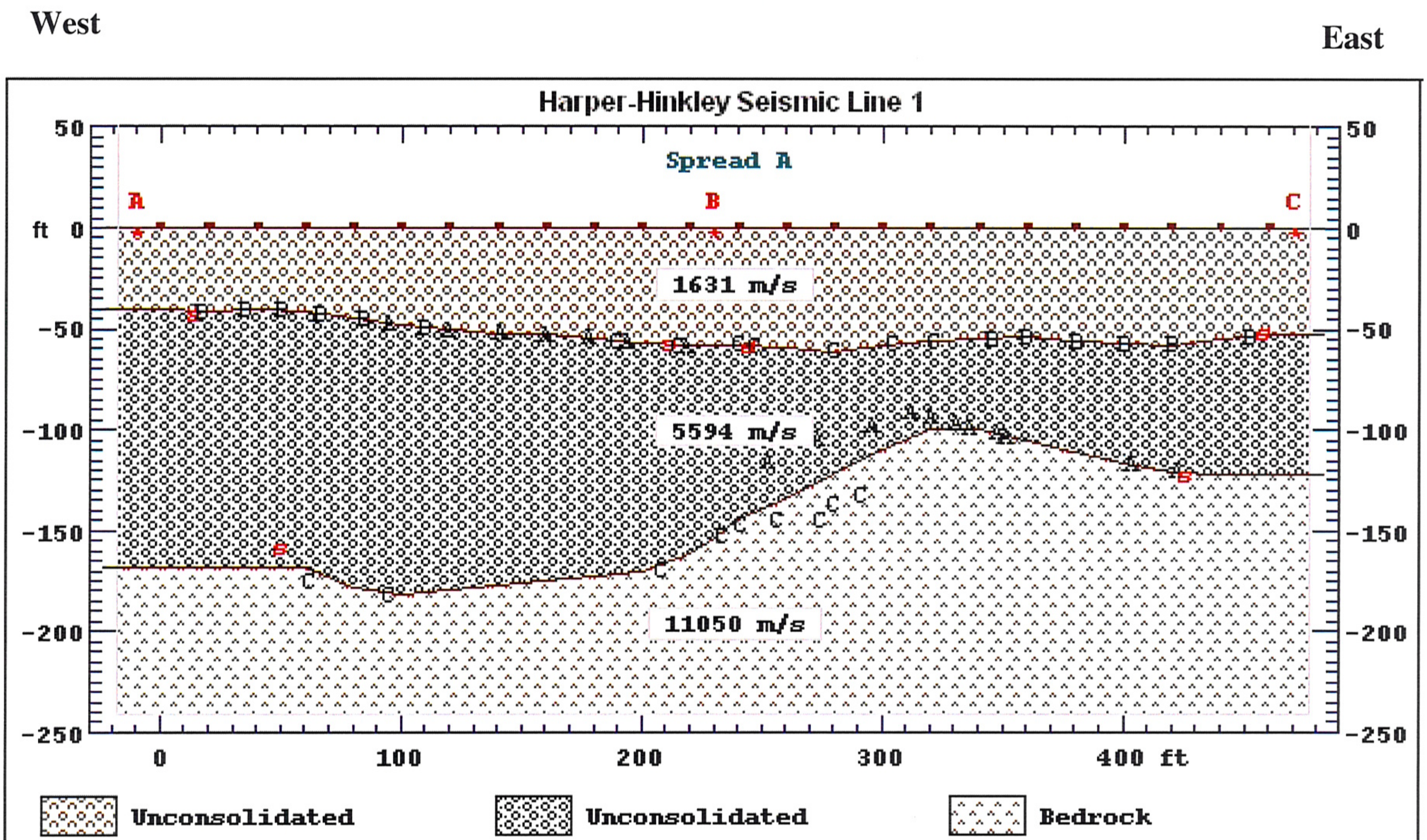
Harper-Hinkley R6



Appendix B

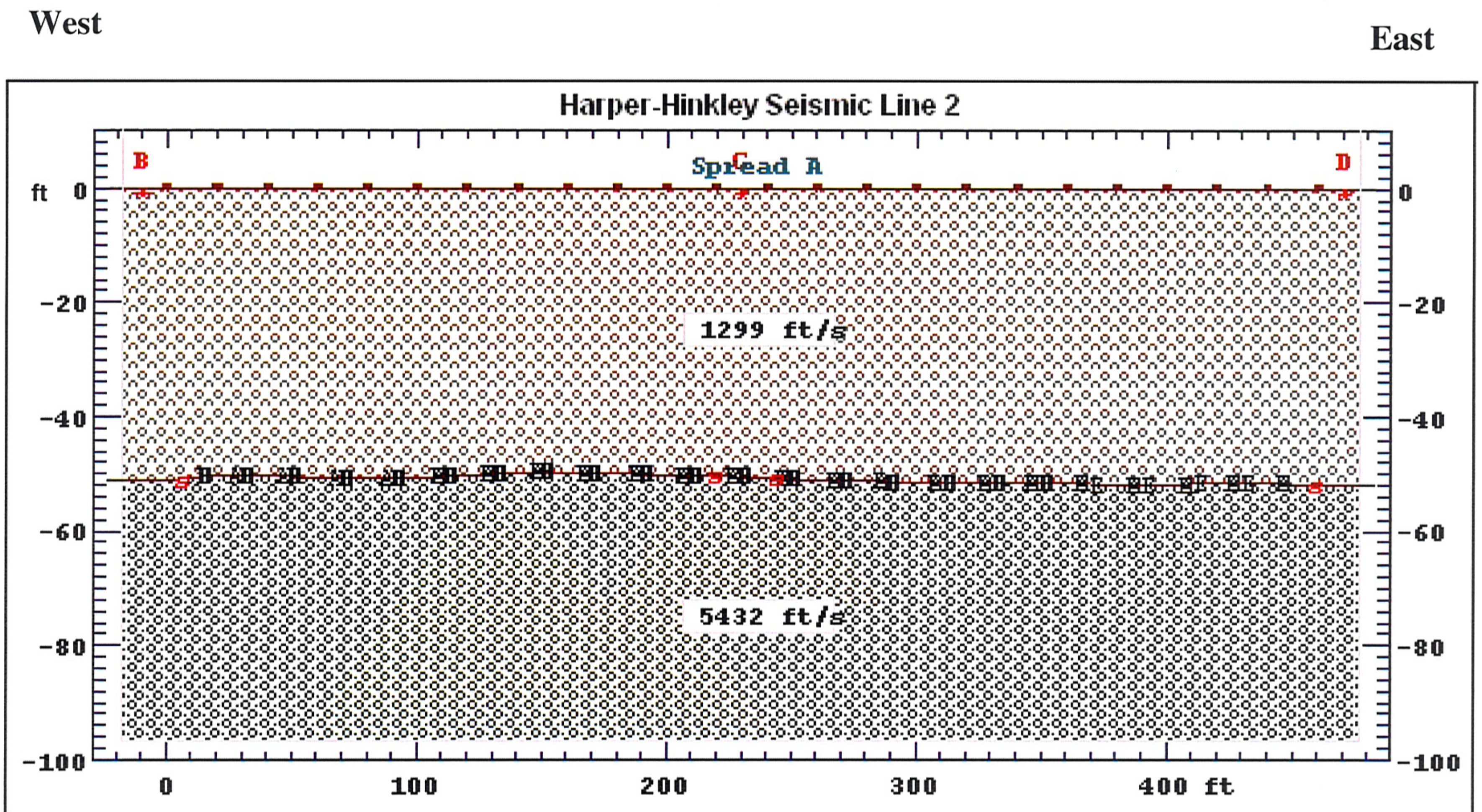
Processed Seismic Refraction Profiles

Harper-Hinkley S1



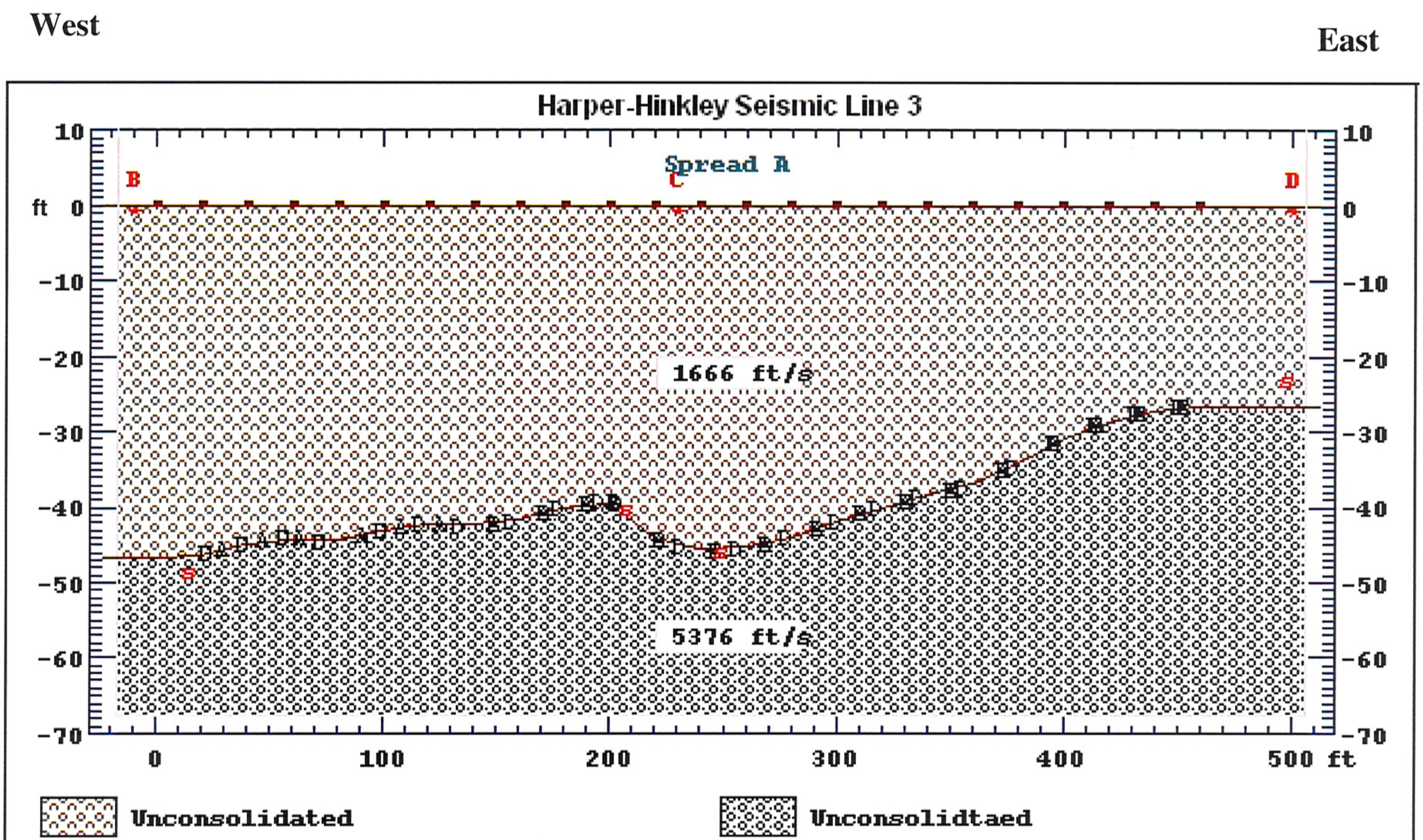
Prepared for	Prepared by
Mojave Water Agency	AST
Harper-Hinkley Gap	10/25/06

Harper-Hinkley S2



Prepared for	Prepared by
Mojave Water Agency	AST
Harper-Hinkley Gap	10/25/06

Harper-Hinkley S3



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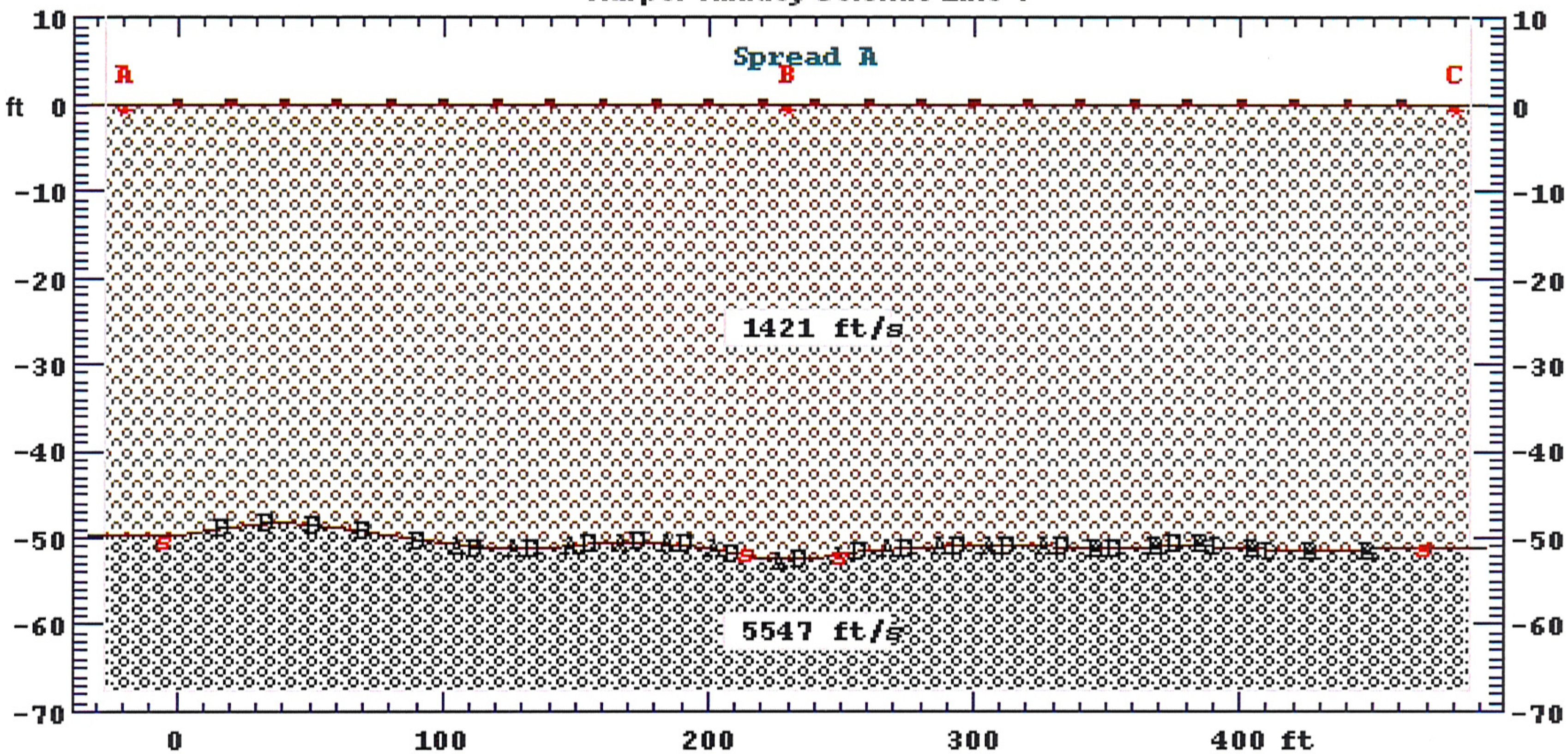
Harper-Hinkley S4

West

East

Harper-Hinkley Seismic Line 4

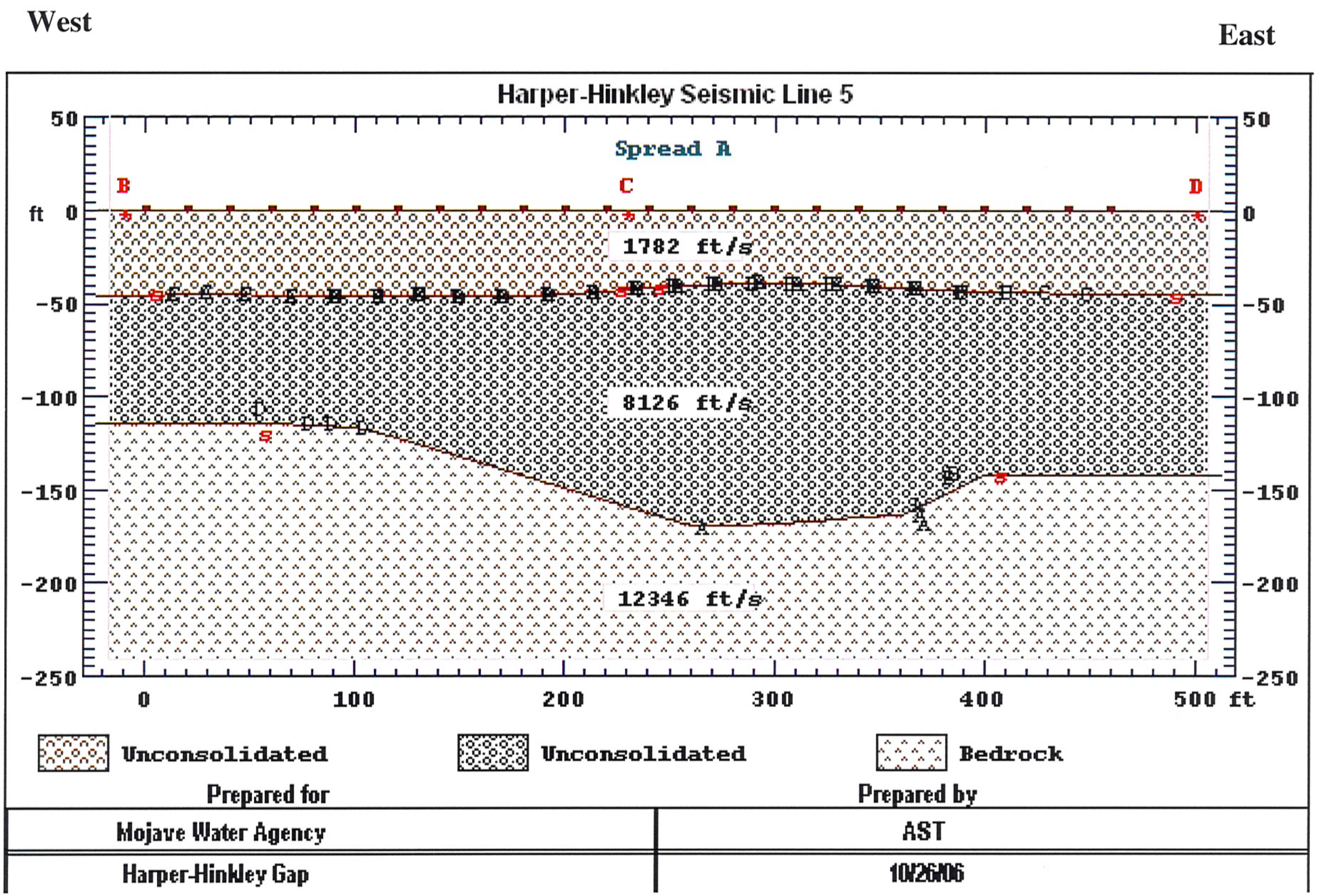


Unconsolidated

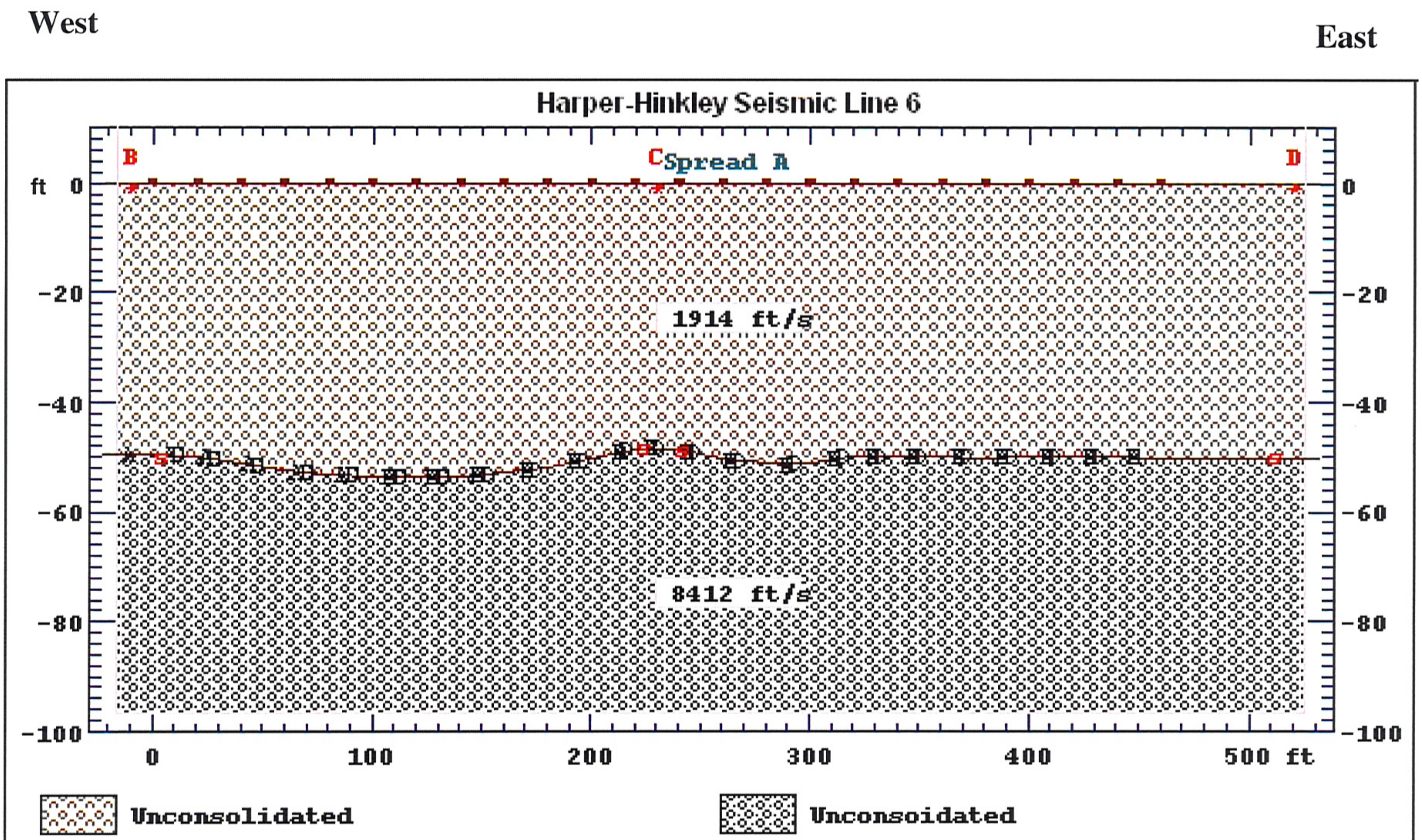
Unconsolidated

Prepared for	Prepared by
Mojave Water Agency	AST
Harper-Hinkley Gap	10/26/06

Harper-Hinkley S5



Harper-Hinkley S6



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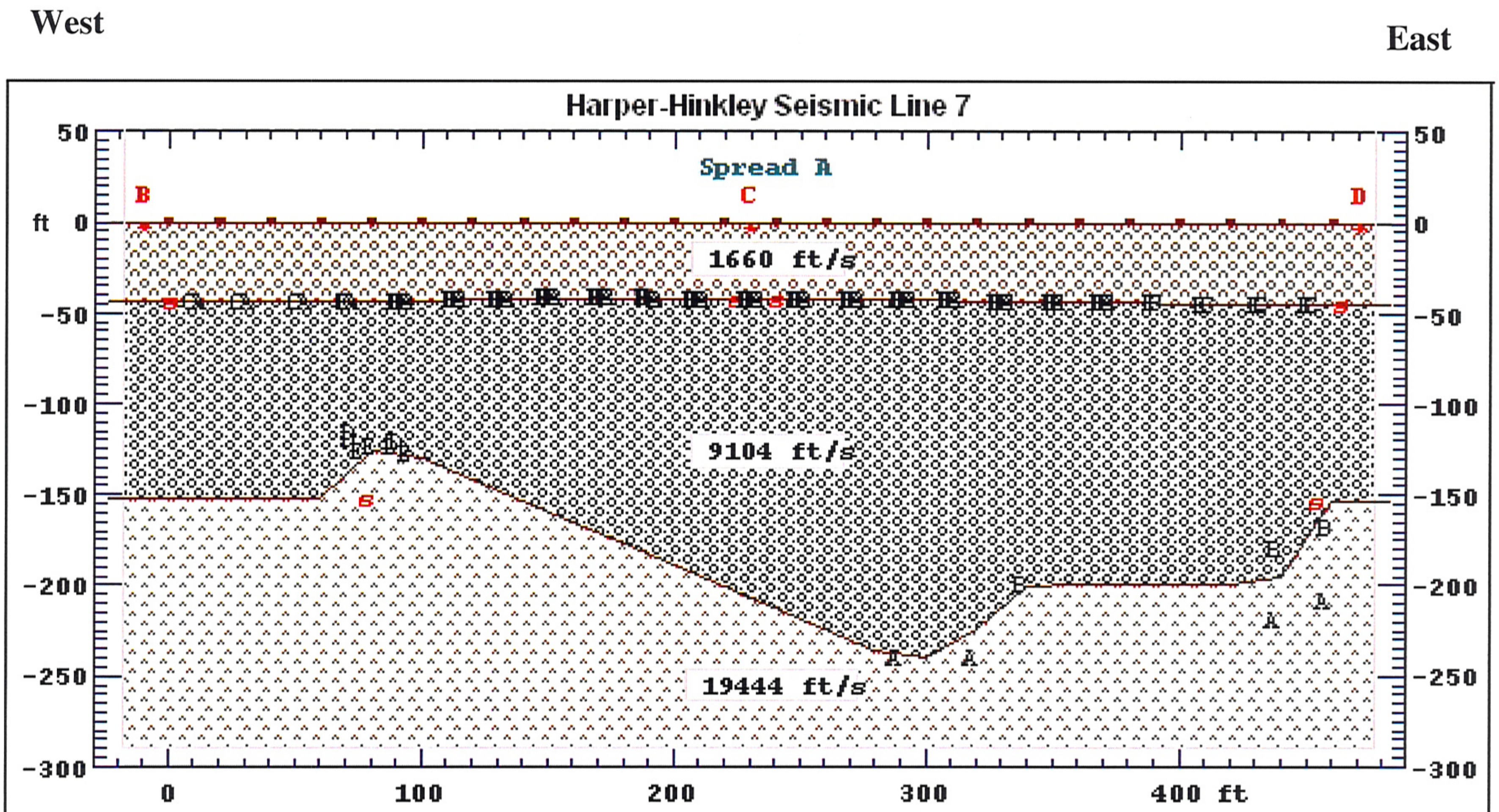
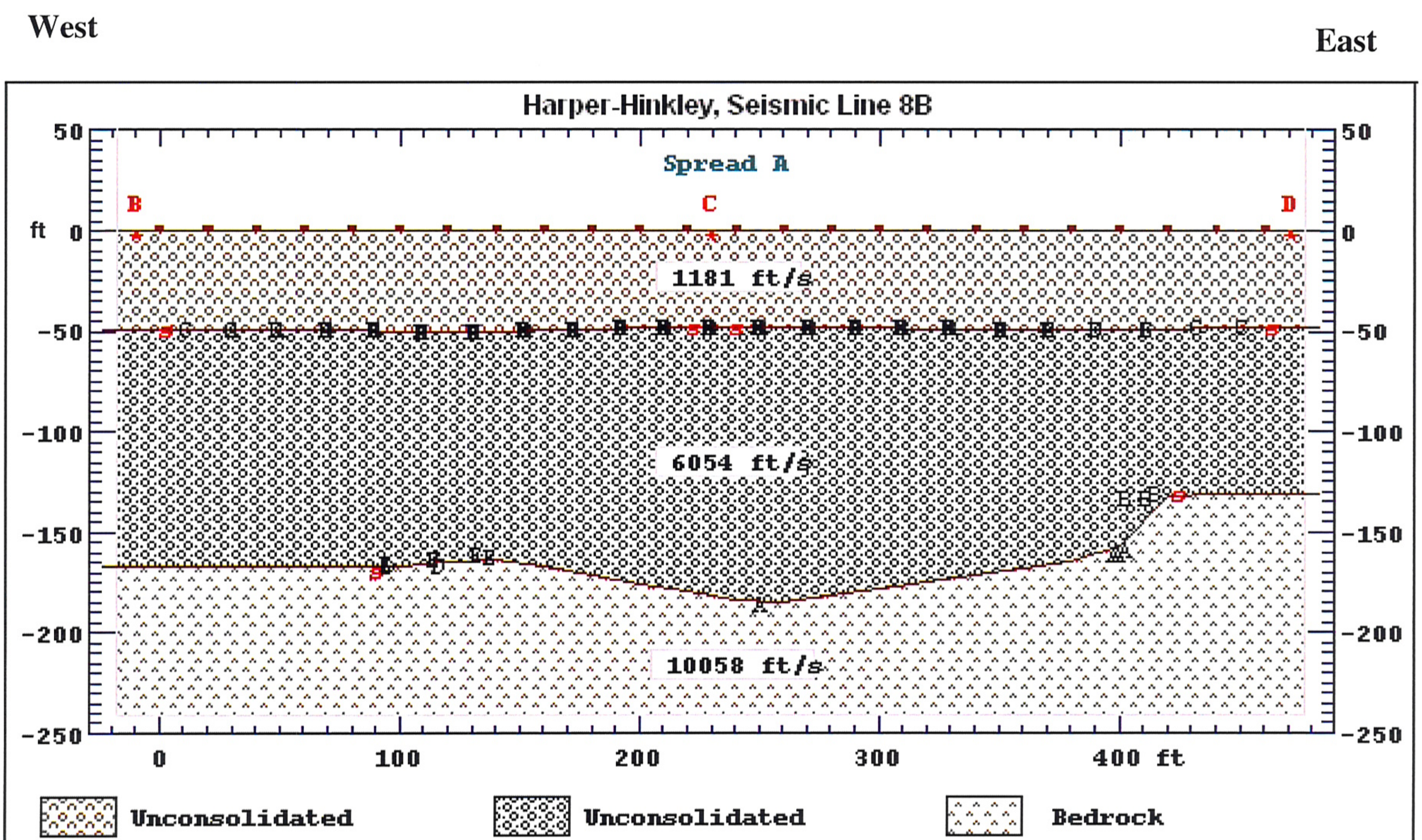
Mojave Water Agency	AST
	10-26-06

Harper-Hinkley S7



Prepared for	Prepared by
Mojave Water Agency	AST
Harper-Hinkley Gap	10/27/06

Harper-Hinkley S8



Prepared for	Prepared by
Mojave Water Agency	AST
Harper-Hinkley Gap	10/27/06