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Groundwater Resources Department
Water Resources Division

Audiomagnetotelluric Investigations in Selected Basins in White Pine and Lincoln Counties, East-Central Nevada

May 2011

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Audiomagnetotelluric Investigations in Selected Basins in White Pine and Lincoln Counties, East-Central Nevada

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May 2011

1. Southern Nevada Water Authority, Las Vegas, NV

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ACRONYMS

2D	two-dimensional
3D	three-dimensional
AMT	audiomagnetotelluric
CLWP	Clark, Lincoln, and White Pine County
GSLDFS	Great Salt Lake Desert Flow System
GWP	Groundwater Development Project
E	electric
EM	electromagnetic
H	magnetic
LGS	Layne GeoSciences
MT	magnetotelluric
POD	point of diversion
PSZ	Pahranagat Shear Zone
QC	quality control
RMS	root mean square
SNWA	Southern Nevada Water Authority
SR	State Route
TE	transverse Electric
TM	transverse Magnetic
US 6	U.S. Highway 6
US 50	U.S. Highway 50
US 93	U.S. Highway 93
USGS	U.S. Geological Survey

ABBREVIATIONS

asl	above sea level
bgs	below ground surface
Hz	hertz
KHz	kilohertz
km	kilometer
m	meter
ohm-m	ohm-meter (unit of electrical resistivity)

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1.0 INTRODUCTION

The Great Basin is a broad, region spanning Nevada and parts of the adjacent states. This arid, mountainous, and sparsely populated region is characterized by mostly north-trending basins and ranges that developed during late Cenozoic regional extension and normal faulting (Dixon et al., 2007). Even though surface water is confined to individual closed basins, regional aquifer systems (Harrill et al., 1988) contain groundwater that can flow between basins, and regional groundwater flow systems within the Great Basin and vicinity are composed of multiple basins (Harrill and Prudic, 1998).

Defining the distribution of basin-fill sediments, and volcanic rocks, as well as their association with the carbonate-rock aquifer system that underlies the entire eastern two-thirds of the Great Basin (Plume, 1996; Harrill and Prudic, 1998), is important for assessing groundwater resources in the region. Regional north-trending faults are the primary structural control of the groundwater in the valleys in eastern Nevada. These faults that bound and occur within the basins are in most places obscured by basin-fill sediments; therefore, geophysical investigations are needed to characterize both the subsurface faults and the stratigraphy that may influence groundwater flow.

As part of the Southern Nevada Water Authority's (SNWA) Clark, Lincoln, and White Pine Counties Groundwater Development project (CLWP GWP), audiomagnetotelluric (AMT) profiles were completed in Delamar (Figure 2-1), Dry Lake (Figure 3-1), Cave (Figure 4-1), and Spring Valley (Figure 5-1). AMT profiles are discussed below per basin, generally from north to south.

1.1 Purpose and Scope

Regional geophysical techniques, including gravity and aeromagnetic studies, were utilized in eastern Nevada prior to the SNWA CLWP GWP. With the start of the groundwater project, surface geophysical investigations have been used by SNWA to characterize the subsurface. These include AMT profiles, gravity, and limited ground magnetics.

This report describes many of the newly completed AMT surveys in eastern Nevada, including the development of two-dimensional (2D) resistivity models along the profiles. The AMT data and models presented here, combined with geologic mapping, are used to define the geologic framework in the vicinity of each AMT profile. AMT surveys have been completed in Delamar, Dry Lake, Cave, Spring, Hamlin, and Snake valleys (McPhee et al., 2006a, 2006b, 2007, 2008; Layne GeoSciences, 2009), but most of these AMT surveys and resultant 2D models were not geologically interpreted. In order to increase SNWA's understanding of the basin geometry and detailed subsurface geology in the valleys, and to help identify various subsurface faults, geologic interpretation was necessary. Therefore, the AMT models were geologically interpreted by SNWA staff in a collaborative effort with Gary Dixon of Southwest Geology, Incorporated. The detailed AMT models were put into a regional context by comparing them with 1:250,000-scale geologic maps of eastern Nevada and adjacent Utah prepared and published by SNWA (Dixon et al., 2007).

The surface geophysical investigations were completed by SNWA, the U.S. Geological Survey (USGS) Geophysical Unit of Menlo Park, and Layne GeoSciences (LGS). The USGS entered into cooperative agreements with SNWA, beginning in 2005 for gravity and AMT work in selected areas. Initially in 2005, SNWA purchased the AMT equipment and provided field assistants for the USGS during the data collection. SNWA contracted LGS from 2008 and 2009 to conduct additional AMT surveys in Spring Valley as part of an aggressive data collection effort. Currently, SNWA is using its own personnel for data collection, modeling, and geologic interpretation of AMT data.

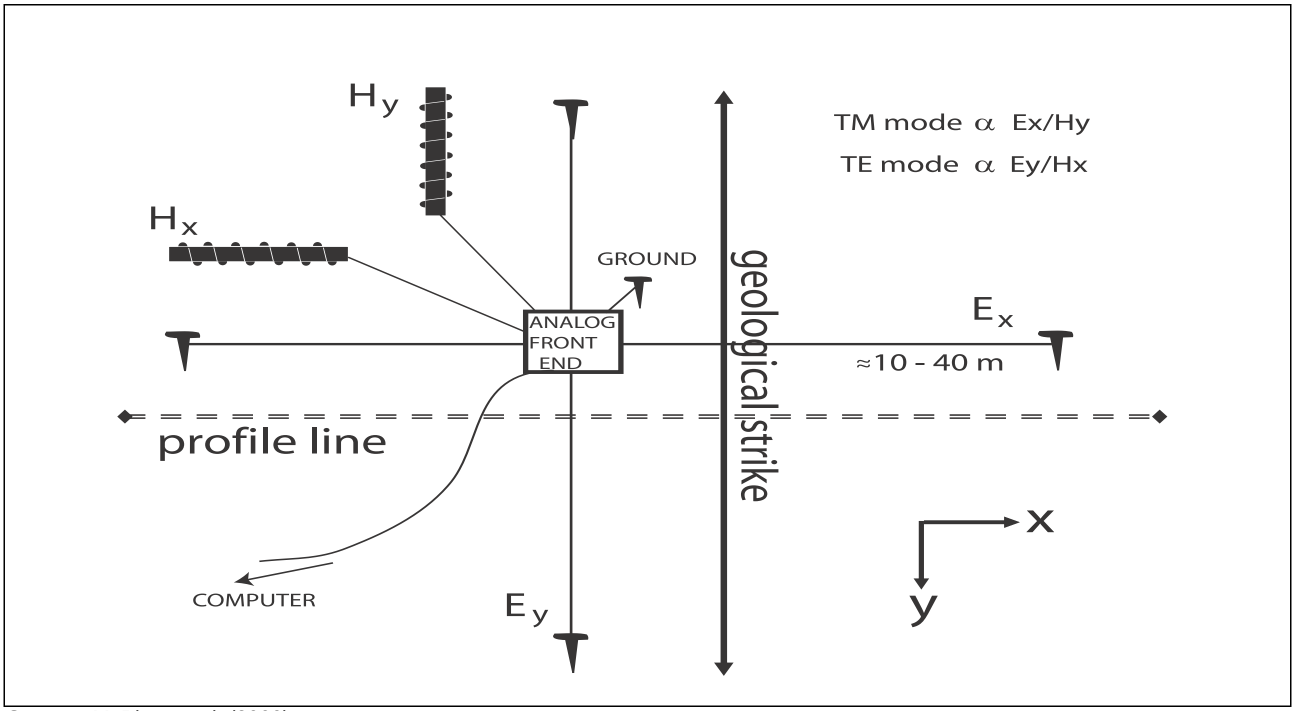
The geology used to evaluate the resistivity data was done at a much less detailed scale than the models produced from the resistivity data. In most cases, the depiction of the faults and surface exposures on the geologic map of Dixon et al. (2007) are at a regional scale (1:250,000), so some spatial inaccuracies are apparent when presented at the detailed scales of the models. The geology depicted on the model figures may have been slightly modified to compensate for the scalar inaccuracies, but follow the broader framework of the map of Dixon et al. (2007).

1.2 Audiomagnetotelluric Method

The AMT surveys use the magnetotelluric (MT) method, a geophysical technique that utilizes the earth's natural electromagnetic (EM) fields as an energy source to investigate the electrical resistivity of the subsurface (Telford et al., 1990; Vozoff, 1991). Within the earth's upper crust, the resistivity of geologic units is largely dependent upon their fluid content, porosity, degree of fracturing, temperature, conductive mineral content, and density (Keller, 1987). Saline fluids within the pore space and fracture openings can reduce bulk resistivity by several orders of magnitude relative to the dry-rock matrix. Resistivity can also be lowered by the presence of conductive clay minerals, graphite, and metallic sulfide mineralization. Marine shale, mudstone, Pleistocene lake beds, and clay-rich alluvium are normally very conductive, having values of a few tens of ohm-m. Fault zones can appear as low-resistivity units of less than 100 ohm-m when they are composed of rocks enough fractured to host fluid transport and consequent mineralogical alteration (Eberhart-Phillips et al., 1995). Unaltered, unfractured igneous rocks normally are highly resistive and have values typically 1,000 ohm-m or greater. Carbonate and clastic rocks are moderately to highly resistive, having values of hundreds to thousands of ohm-m depending on their fluid content, porosity, fracturing and impurities. Unaltered metamorphic and nongraphitic rocks are moderately to highly resistive. Tables of electrical resistivity for a variety of rocks, minerals, and geological environments may be found in Keller (1987) and Palacky (1987).

Using the same principle as the MT method, the AMT method (Zonge and Hughes, 1991; McPhee et al., 2006a) estimates the electrical resistivity of the earth over depth ranges of a few meters to approximately one kilometer, depending upon site conditions, using a high-frequency range (approximately 10 Hz to 100 kHz), whereas MT typically uses a lower frequency range. The resistivity can be estimated with electrical impedance, a tensor quantity defined by the ratio of time-varying electric (E) to magnetic (H) field measured at the earth's surface. The surface impedance is a complex function of frequency; lower frequency data are used to investigate greater depths. In an ideal 2D environment, the surface electrical impedance can be separated into two modes, the transverse electric (TE) and transverse magnetic (TM). When the subsurface geologic structure satisfies this 2D assumption, TE mode data measures the electric fields parallel to the geological strike, while TM mode data measures the electrical fields perpendicular to the geologic strike (Figure 1-1).

The 2D assumption permits significant simplification in the modeling and inversion of MT and AMT data. Three-dimensional (3D) structures make mode determination difficult and consequently can lead to artifacts in the 2D models. Inversion of AMT sounding data provides an estimate of resistivity beneath the receiver site and displays the geoelectric complexity at the measurement site. In areas where the resistivity distribution does not change rapidly from station to station, the resistivity sounding provides a reasonable estimate of the resistivity layering beneath the site.



Source: McPhee et al. (2009)

Figure 1-1
Schematic of Equipment Set-up in the Field

Interference during the collection of the AMT data can be created by natural and man-made sources. These noise sources noted during the data collection included electrical transmission lines, buried pipelines, wind, and nearby lightning. Precautions were taken in the field to avoid these potential noise sources by either conducting the profile at a far enough distance away from the noise source, rotating the equipment set-up to minimize the noise, burying essential components to avoid wind noise, and placing data collection on stand-by to avoid nearby lightning strikes.

The AMT models presented in this report were created with WinGlink (Geosystem, 2008) software using a 2D inversion algorithm. The 2D inverse models are computed from the TE, TM, and TE+TM mode data using the conjugate gradient, finite-difference method of Rodi and Mackie (2001). The criteria for choosing the final models include goodness of fit of the model response to the data as reported by the root mean square (RMS), the lack of artifacts in the model not supporting the data, and the geological rationality of the model. The RMS value is commonly used to express the misfit between field data and the model response. Data points affected by noise during the data collection were removed as part of the data processing. The resistivity scale and depth resolution shown on each model may vary.

2.0 DELAMAR VALLEY

Delamar Valley is a north-trending valley about 40 km long and 10 km wide, between the South Pahroc Range on the west and the Delamar Mountains on the east. The southern end of the valley is bounded by the Pahranagat Shear Zone (PSZ). Three AMT profiles were compiled in the southern portion of Delamar Valley to delineate concealed faults of the PSZ (Figure 2-1). All three profile models illustrate resistivity contrasts that are associated with faults within the PSZ. Sources of potential noise identified in the vicinity of the profiles include a north-to-south-trending electrical transmission line, 3D artifacts from subsidiary subparallel faults, and wind. These sources were avoided as much as possible during collection of data.

2.1 AMT Profile DELA5

Profile 5 (DELA5) was completed in southern Delamar Valley, south of the Delamar dry lake bed. The profile and is perpendicular to the buried Delamar Lake fault of the PSZ. The profile trends northwest, is 700 m long, and consists of 11 stations with a 50 to 100 m station spacing. The profile was conducted in two phases, first with 50 m station spacing, then with 100 m station spacing as testing of the equipment was being conducted to determine if the closer station spacing would provide better data resolution. It was determined through the modeling process that the station spacing provided sufficient model resolution along this profile. The data in profile DELA5 were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography. At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for DELA5 illustrates prominent resistivity contrasts near station S3, buried beneath basin-fill deposits mapped at the surface (Figure 2-2). The resistivity contrasts are interpreted to be a large, steeply-dipping, left-lateral fault. The high-conductivity anomaly probably represents altered volcanic tuffs due to the lateral movement along a fault associated with the PSZ.

2.2 AMT Profile DELA2

Profile 2 (DELA2) was completed in southwestern Delamar Valley, about 2 km east of DELA1. The profile was sited to get a second look at the Maynard Lake fault of the PSZ. Profile DELA2 trends northwest, is 950 m long, and consists of six stations with a 100 to 200 m station spacing. The data in profile DELA2 were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography. At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for DELA2 illustrates buried resistivity contrasts at station S5 (Figure 2-3), interpreted to be the Maynard Lake fault that here appears to be dipping steeply to the north. The resistivity

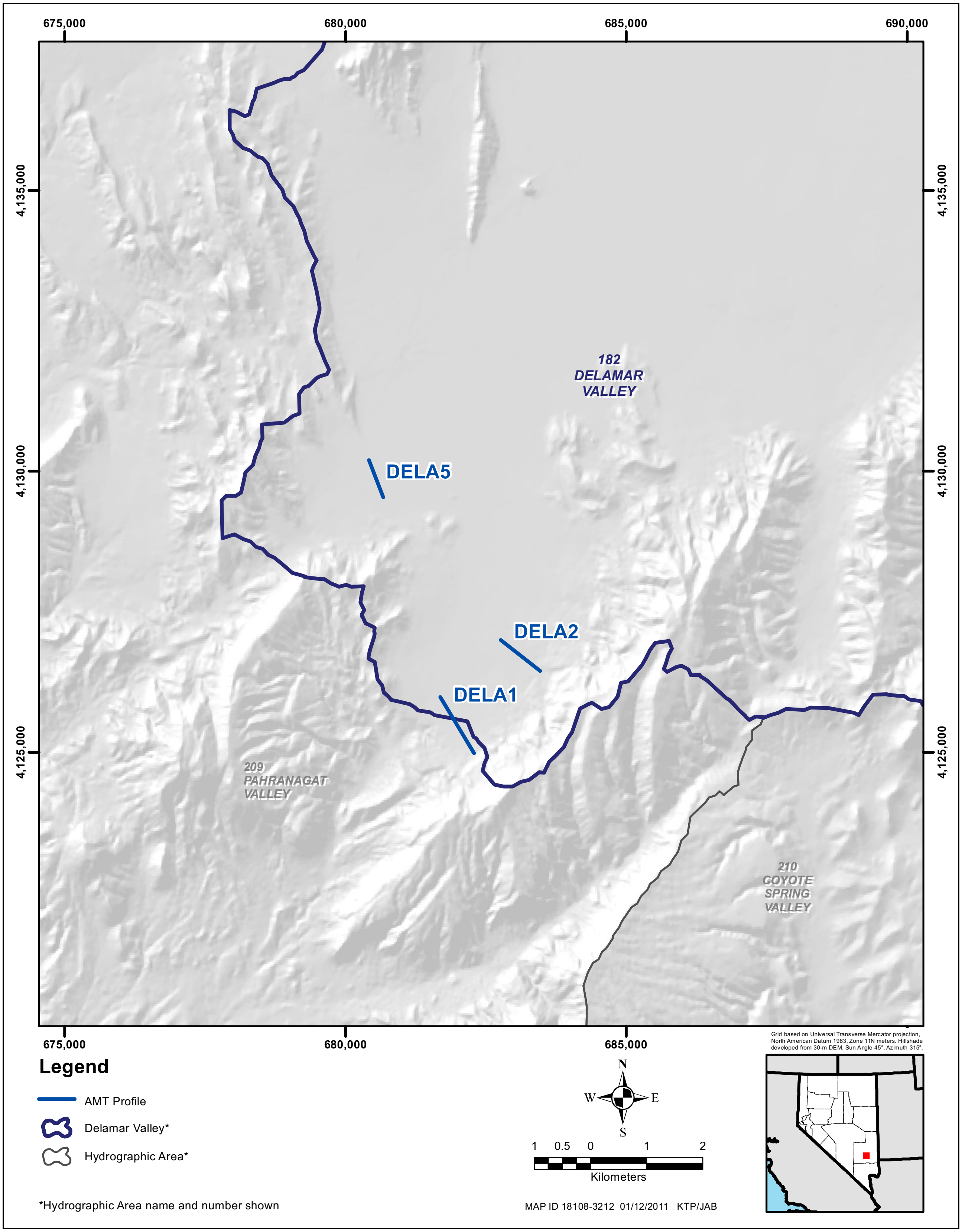


Figure 2-1
Delamar Valley AMT Profiles

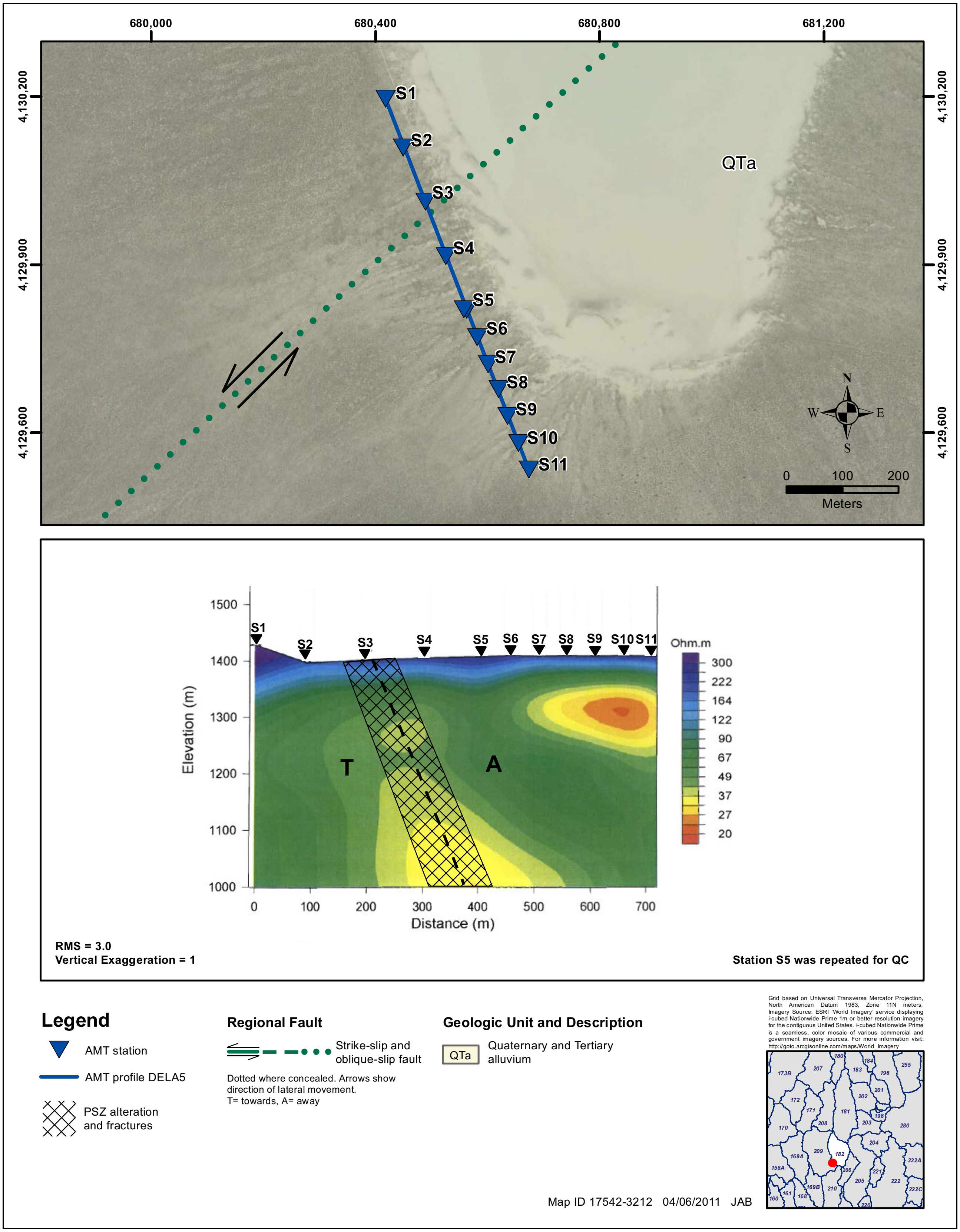


Figure 2-2
Map and 2D Model of DELA5

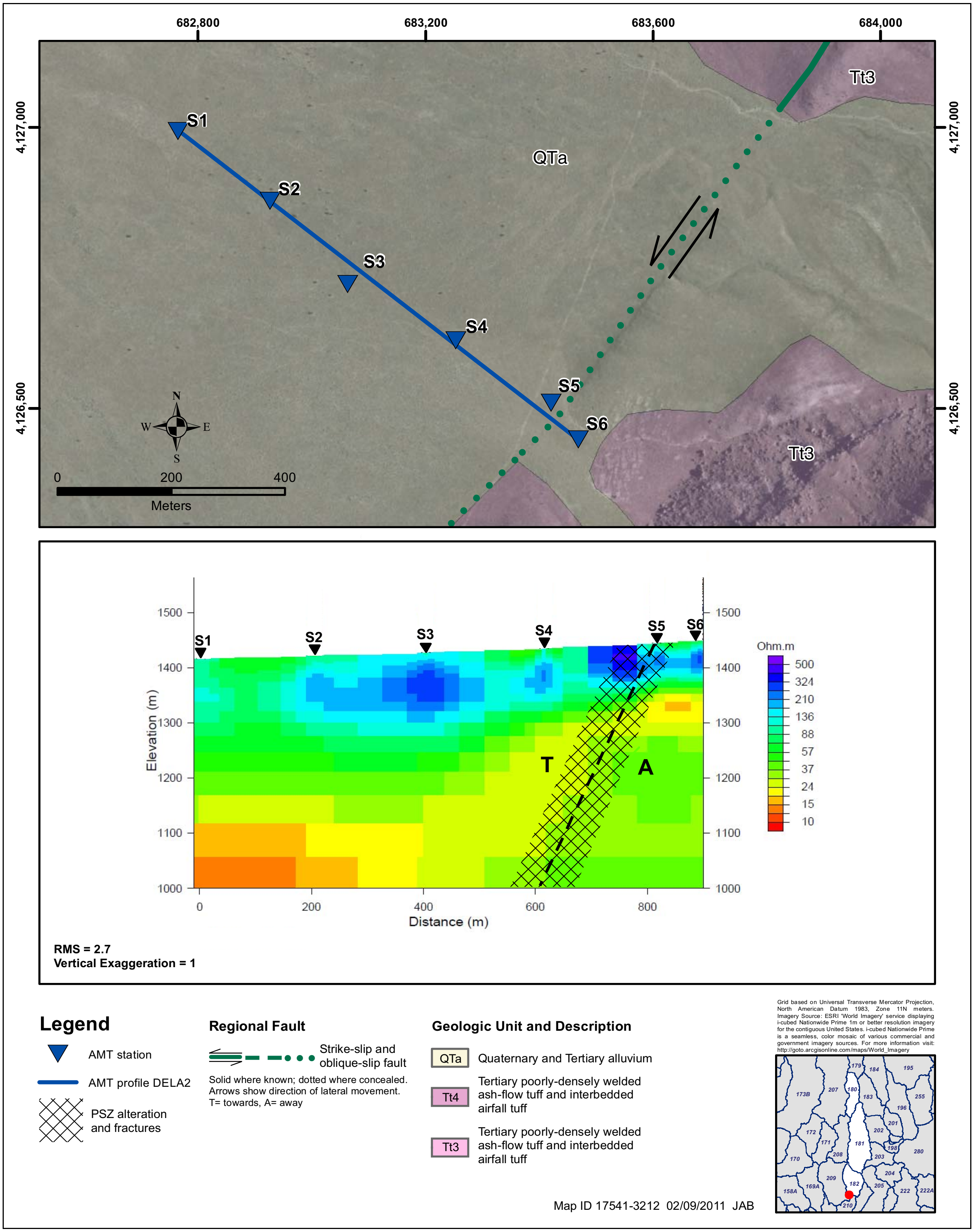


Figure 2-3
Map and 2D Model of DELA2

contrasts are interpreted to represent volcanic tuffs altered due to the lateral movement along the fault. The interpreted fault correlates to a concealed strike-slip fault of the PSZ and shown on the location map (Figure 2-3).

2.3 AMT Profile DELA1

Profile 1 (DELA1) was completed in southwestern Delamar Valley, near the southern end of the Delamar Mountains. The profile was sited to portray the Maynard Lake fault, the largest left-lateral fault within the PSZ. Profile DELA1 trends northwest, is 1,215 m long, and consists of seven stations with a 200 m station spacing. Station S1 was not used in the modeling process due to poor data quality, likely caused by interference from the electrical transmission lines located northwest of the profile. The data in profile DELA1 were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography. At a later time, SNWA geologically interpreted the final model provided by the USGS.

The DELA1 model illustrates buried resistivity contrasts between stations S5 and S6 (Figure 2-4), interpreted to be a buried, wide vertical fault zone, as expected for a major strike-slip fault. The resistivity contrast probably represents volcanic tuffs altered due to the lateral movement along the fault. The greater conductivity on either side of the fault may reflect greater groundwater traveling in the fractures in the outer damage zone on either side of the central core zone, which is generally closed to high water flow by the fault gouge.

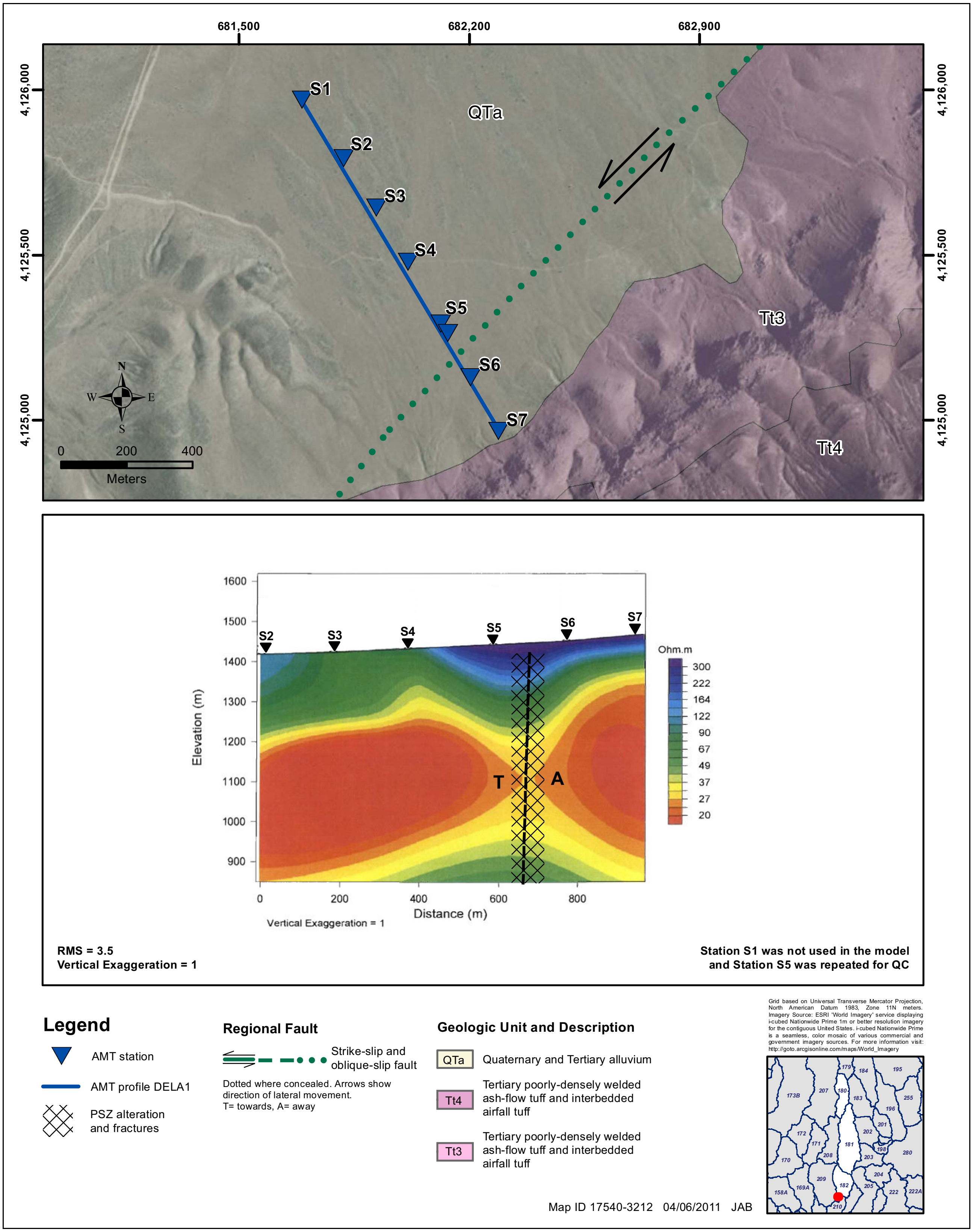


Figure 2-4
Map and 2D Model of DELA1

3.0 DRY LAKE VALLEY

Dry Lake Valley is a north-trending valley approximately 90 km long and 10 km wide. Northern Dry Lake Valley, also called Muleshoe Valley, is west of the Fairview Range, while the remainder of Dry Lake Valley is west of the Ely Springs, West, Black Canyon, and Burnt Spring ranges, and east of the North Pahroc Range. Muleshoe Valley is separated from the rest of Dry Lake Valley by the Blue Ribbon transverse zone; the southern portion of Dry Lake Valley is separated from Delamar Valley by the Timpahute transverse zone (Dixon et al., 2007).

A total of nine AMT profiles were completed in Dry Lake Valley to identify concealed portions of range-front faults, interbasin faults, and the thickness of the basin-fill deposits (Figure 3-1). Noise sources identified in the vicinity of the profiles include a north to south-trending electrical transmission line, 3D artifacts from subsidiary subparallel faults, wind, and lightning.

3.1 AMT Profile DLV18

Profile DLV18 was completed at the western base of the Fairview Range, in Muleshoe Valley (northern Dry Lake Valley). The profile was sited to identify faults concealed by basin fill, and define resistivity contrasts between the basin fill and the carbonate rocks of the Fairview Range. Profile DLV18 trends west, is 1,200 m long, and consists of seven stations with a 100 to 200 m station spacing. The data from profile DLV18 were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008). The model provided by the USGS was modeled again by SNWA because the east to west orientation reversed. The final model was completed using the TM mode and incorporated topography (Figure 3-2). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile DLV18 illustrated a buried resistivity contrast between stations S5 and S6, interpreted to be a concealed basin-range fault, as shown on the geologic map of Best et al. (1998). A subtle resistivity change may be present between stations S1 and S2, where a buried fault may be projected from where it was mapped to the north (Best et al., 1998). The highly conductive rocks at depth in the western half of the profile may be the Chainman Shale.

3.2 AMT Profile DLV2

Profile 2 (DLV2) was completed in northeastern Dry Lake Valley, near the northern portion of the West Range. The profile was sited to identify the location of a regional fault that is concealed by the basin fill. Profile DLV2 trends southwest, is 980 m long, and consists of eight stations with a 50 to 400 m station spacing. Station S3 was not used for the model due to poor quality of the high frequency data, likely due to lack of the transmitters source signal that is noted in McPhee et al. (2008). The data from profile DLV2 were processed and modeled, but not geologically interpreted by

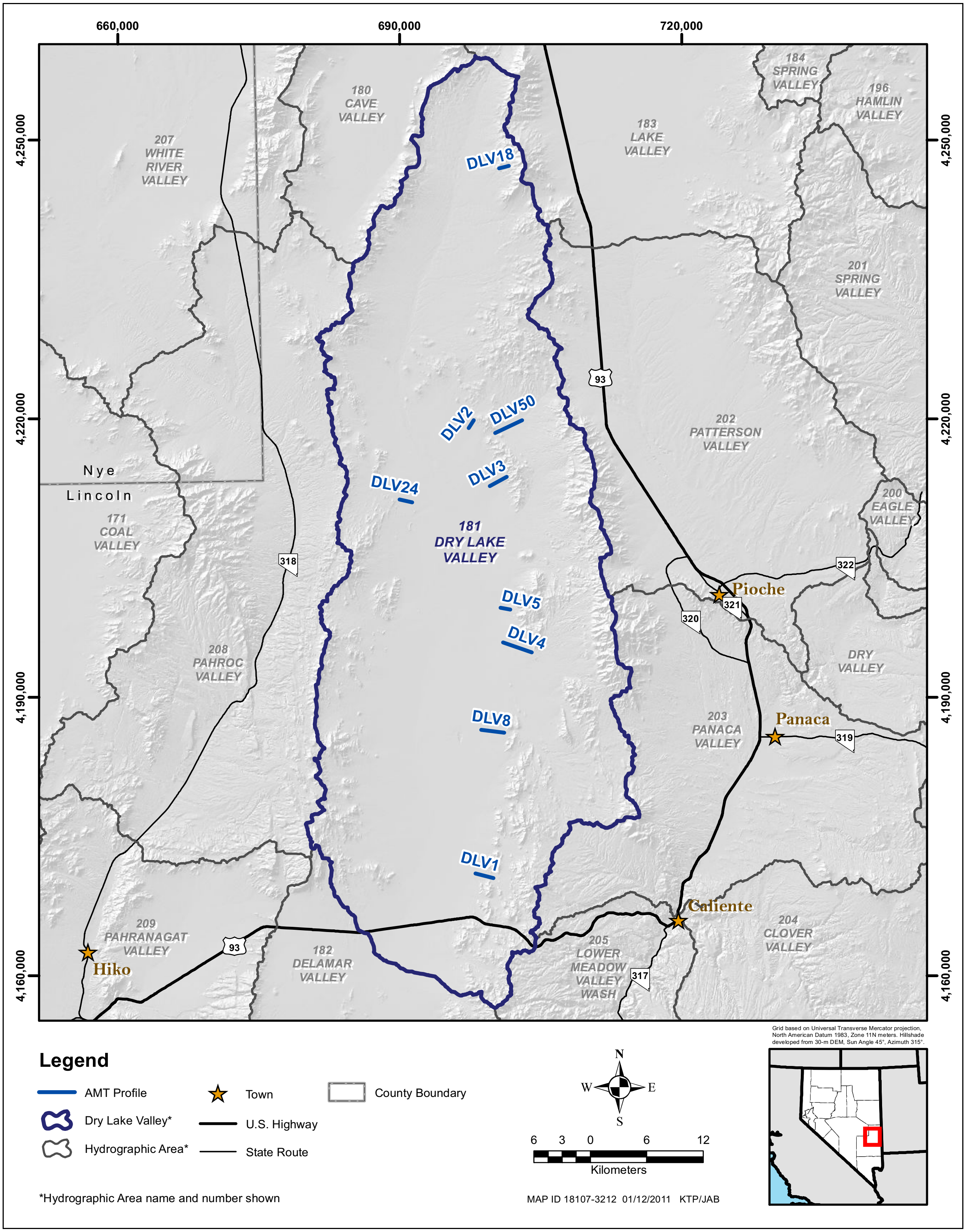


Figure 3-1
Dry Lake Valley AMT Profiles

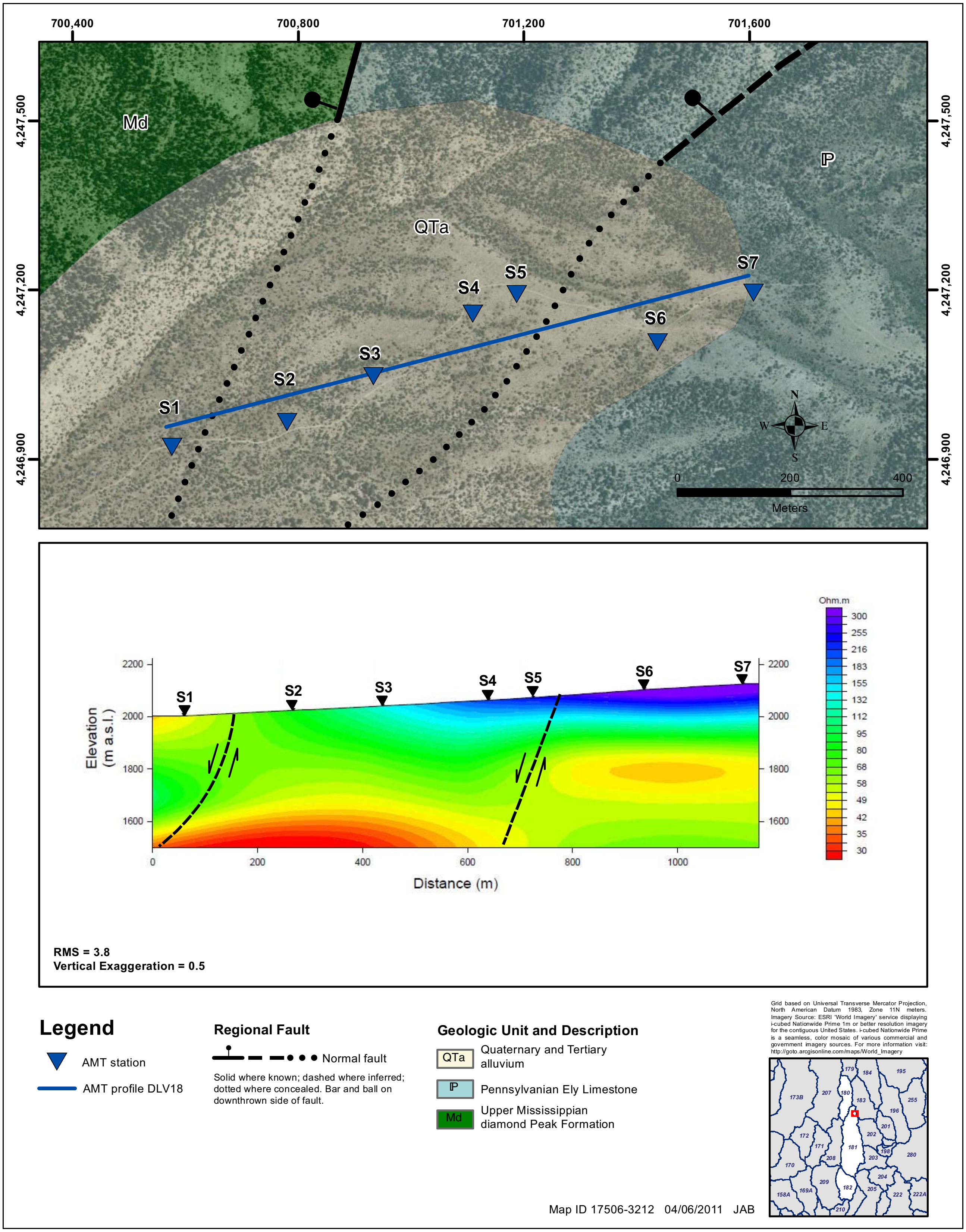


Figure 3-2
Map and 2D Model of DLV18

the USGS (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography (Figure 3-3). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for profile DLV2 illustrates one or two resistivity zones near stations S4 (approximately 140 ohm-m), and between S2 and S4 (approximately 25 to 60 ohm-m). The resistivity contrasts are inferred to be the result of a broad range-front fault zone that defines the interface between the carbonates of the West Range and the basin fill to the west. Due to the lack of data resolution between stations S2 and S4, the inferred fault is based on surficial evidence and geologic mapping. The fault interpretated at station S2 is shown as a concealed normal fault in Dixon et al. 2007 and illustrated in Cross Section T—T'.

3.3 AMT Profile DLV50

Profile DLV50 was completed in northeastern Dry Lake Valley, just east of the West Range. The profile was sited to identify concealed structures, and in order to conduct testing of the equipment to determine if the AMT technique could illustrate the geologically mapped carbonate rocks masked by volcanic tuff in the vicinity of the profile. Volcanic tuff is a conductive material that may influence the depth investigation of the technique. Profile DLV50 trends southwest, is 3,200 m long, and consists of 15 stations with a 200 to 400 m station spacing. The data from profile DLV50 were processed and modeled by SNWA, including geologic interpretation. The final model was completed using the TM mode and incorporated topography (Figure 3-4); stations S1 through S3 were omitted from the final model due to poor data quality, likely due to subsurface faults that are subparallel to the profile.

The model illustrates three resistivity zones between stations S7 and S8, S4 and S5, and S13 and S14. The resistivity zones between S13 and S14, and between S4 and S5 correlate to right lateral-faults shown on the geologic map of Dixon et al. (2007). In between the two faults, between stations S7 and S8, the profile clearly shows a still larger buried vertical right-lateral fault. Although not mapped by Dixon et al. (2007) because of the 1:250,000 scale that the geology was presented at, this strike-slip fault was mapped at a scale of 1:24,000 by Page and Ekren (1995). It is clearly a major structure that contains highly conductive hydrothermal clay, fault gouge, and groundwater. The model also was able to show resistive (190 to 1,000 ohm-m) carbonate rocks at depth (approximately 900 m) between stations S10 through S15.

3.4 AMT Profile DLV3

Profile 3 (DLV3) was completed in the northeastern portion of Dry Lake Valley and near the west-central West Range. The profile was sited to identify the regional fault and subsidiary faults that are concealed by basin fill, and to measure the resistivity contrasts of the basin fill and the carbonates of the West Range. Profile DLV3 trends southwest, is 2,050 m long, and consists of 11 stations with a 200 m station spacing. The data from profile DLV3 were processed and modeled by the USGS (McPhee et al., 2008), but not geologically interpreted with the final model completed using the TM mode and incorporating topography (Figure 3-5). At a later time, SNWA geologically interpreted the final model provided by the USGS.

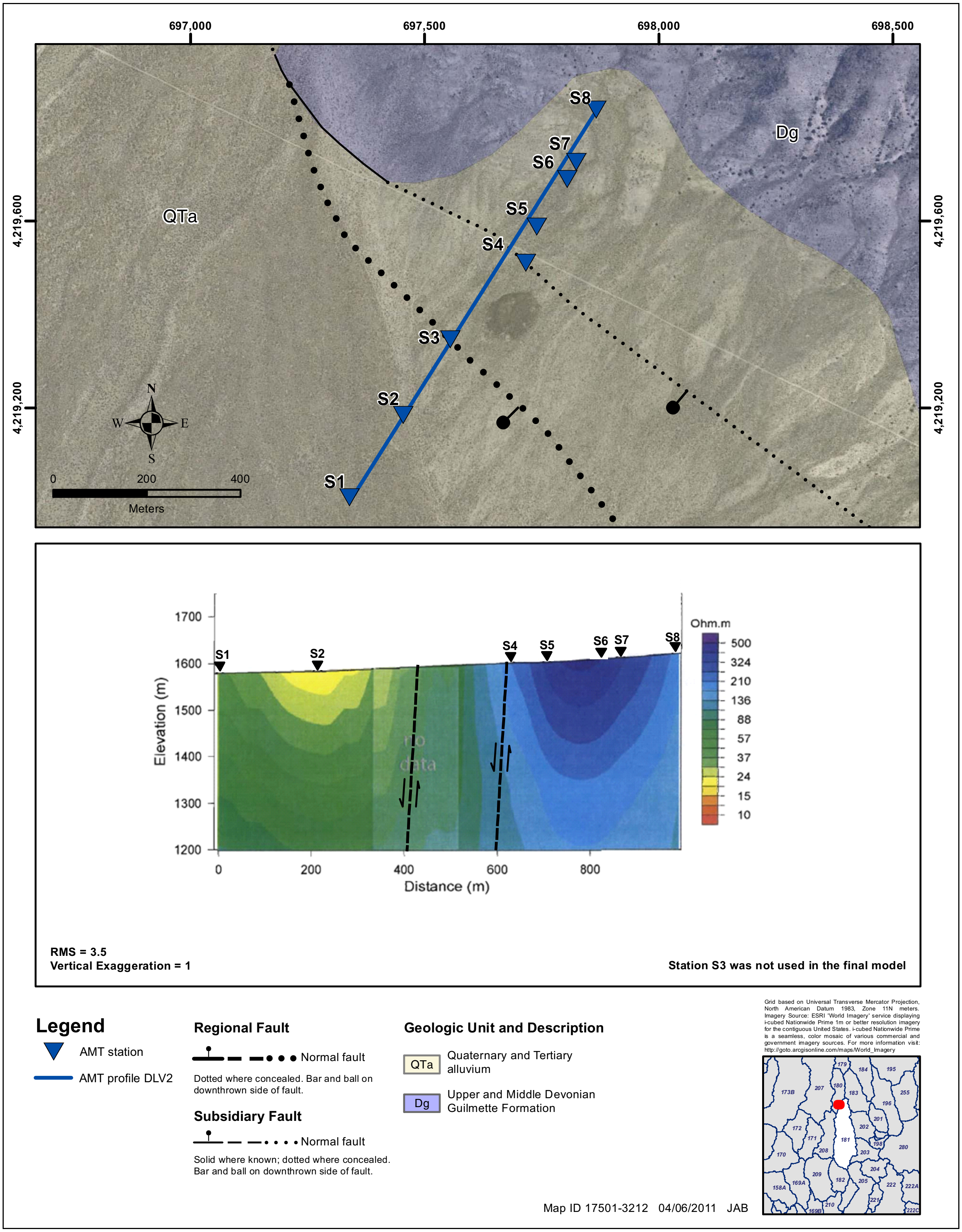


Figure 3-3
Map and 2D Model of DLV2

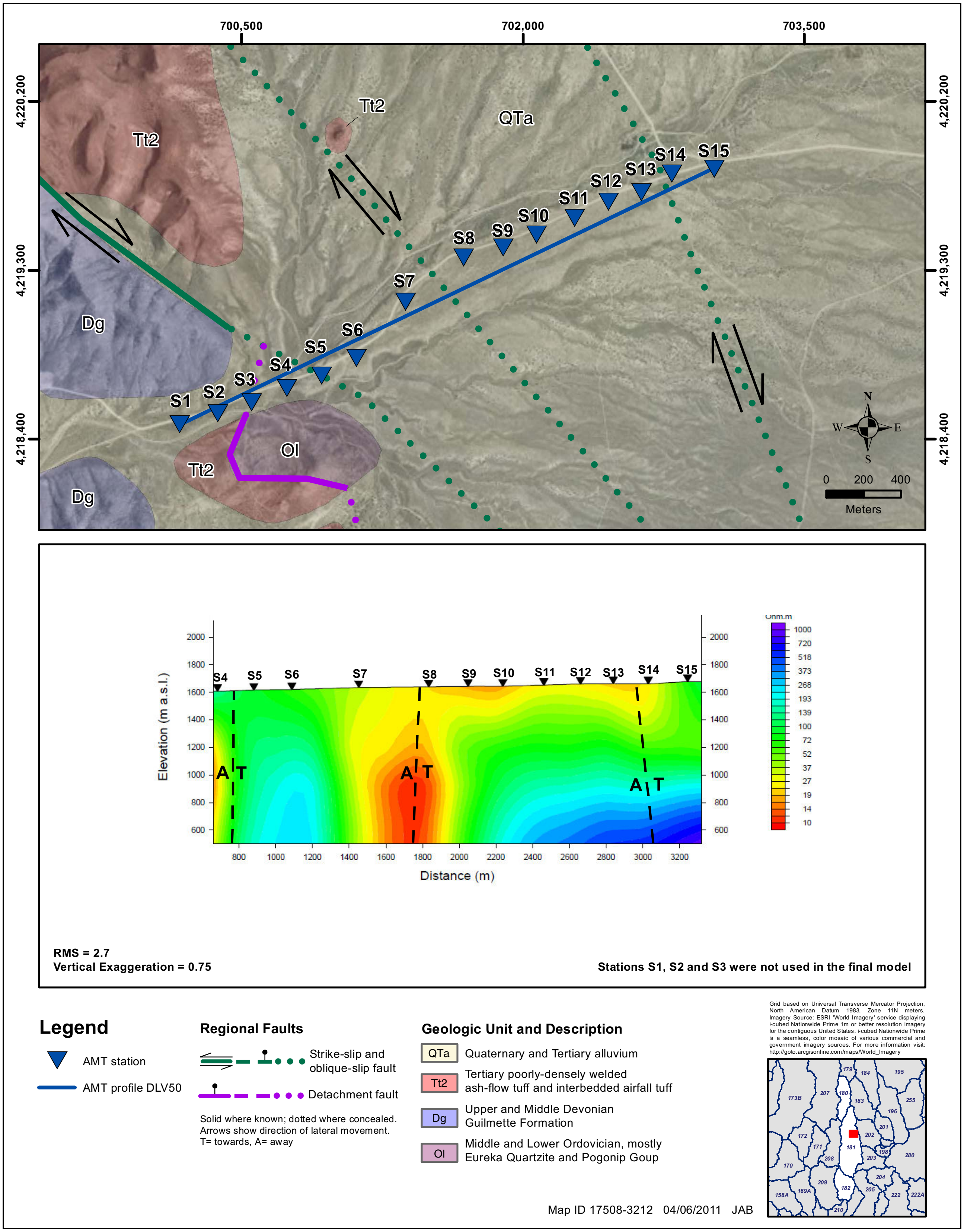


Figure 3-4
Map and 2D Model of DLV50

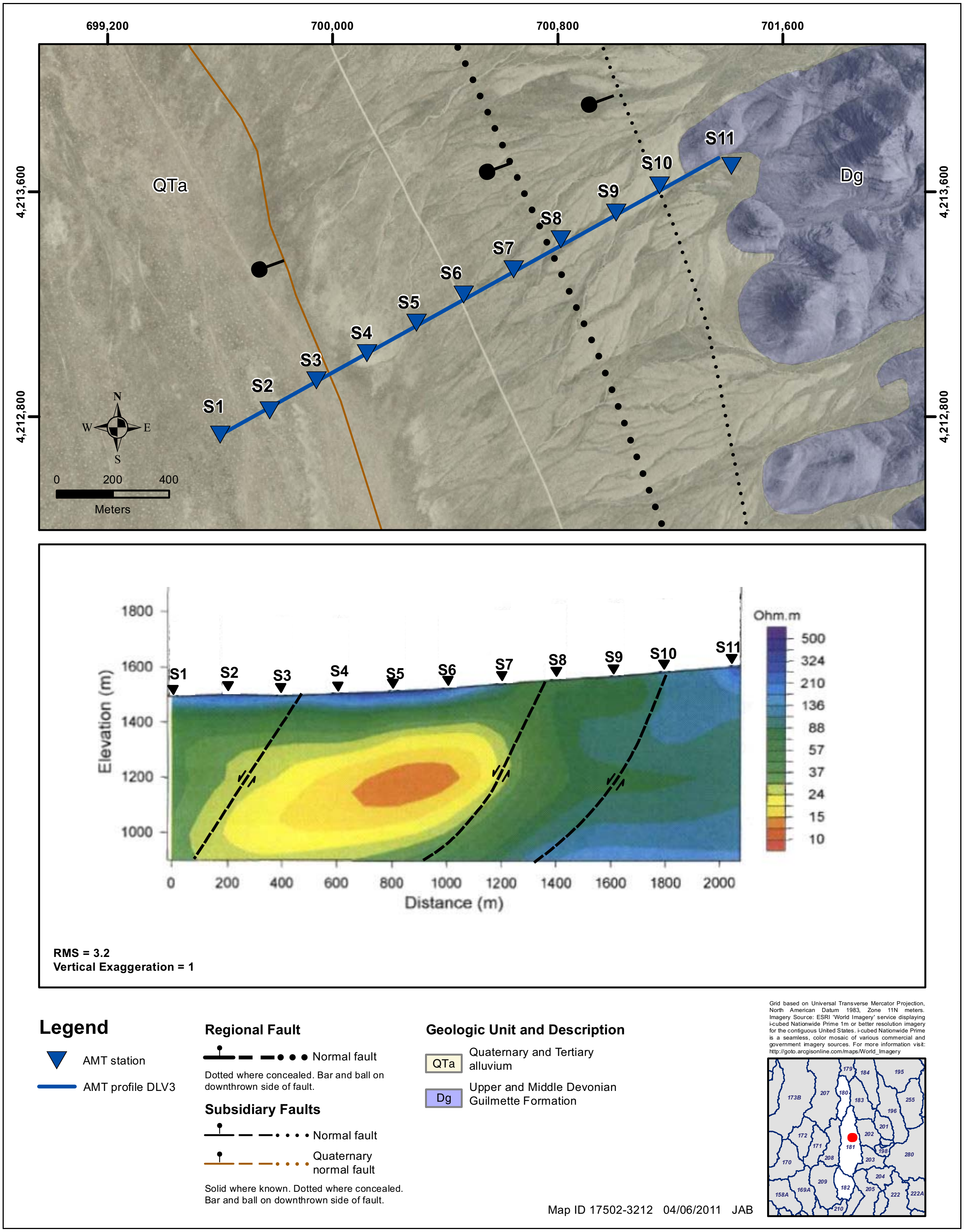


Figure 3-5
Map and 2D Model of DLV3

The model for Profile DLV3 illustrates resistivity contrasts between stations S3 and S4, near stations S8, and S10. These resistivity contrasts are interpreted to be down-to-the-west normal faults, the eastern of which separates resistive (>200 ohm-m) carbonate bedrock on the east from more conductive (approximately 50 ohm-m) alluvial-fan deposits at station S10. The main range-front fault is beneath station S8, separating alluvial-fan deposits on the east from alluvial fan deposits underlain by very conductive (<20 ohm-m) buried lake-bed sediments to the west. The western fault (at S3) is mapped as a subsidiary fault by Dixon et al. (2007) with some Quaternary displacement but, judging by the large resistivity contrast beneath it, may be a significant interbasin fault.

3.5 AMT Profile DLV24

Profile DLV24 was completed in northwestern Dry Lake Valley, near the northern portion of the North Pahroc Range. The profile was sited to identify faults concealed by basin fill. Profile DLV24 trends west, is 1,400 m long, and consists of eight stations with a 200 m station spacing. The data from profile DLV24 were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography (Figure 3-6). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile DLV24 illustrates resistivity contrasts near stations S2, between S4 and S5, and near S8. The resistivity contrasts are interpreted as a concealed west-dipping normal fault at station S8, a concealed east-dipping normal fault between stations S4 and S5, and a concealed right-lateral fault zone near station S2. The highly resistive rock in the graben between stations S5 and S8 may be lake beds within the basin-fill sediments.

3.6 AMT Profile DLV5

Profile 5 (DLV5) was completed on the eastern side of Dry Lake Valley, just west of the central Ely Springs Range. The profile was sited to identify faults associated with fissures present west of the Ely Springs Range. Profile DLV5 trends west, is 1,000 m long, and consists of 10 stations with a 100 to 200 m station spacing. The data from profile DLV5 were processed and modeled, but not geologically interpretated by the USGS (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography (Figure 3-7). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile DLV5 illustrates a broad resistivity contrast between stations S7 and S9. This contrast is interpreted to be a large range-front, basin-range normal fault that has Quaternary movement and is shown as shown on Plate 1 in Dixon et al. (2007). Historic and active fissures were discovered by Swadley (1995) about 0.4 km west of, parallel to, and probably resulted from the movement on the fault containing Quaternary movement. A second resistivity contrast, which is at depth at station S3; this is interpreted to be a secondary interbasin down-to-the-west basin-range fault. A third resistivity contrast is suggested just west of the profile, where Dixon et al. (2007), mapped a major interbasin basin-range fault.

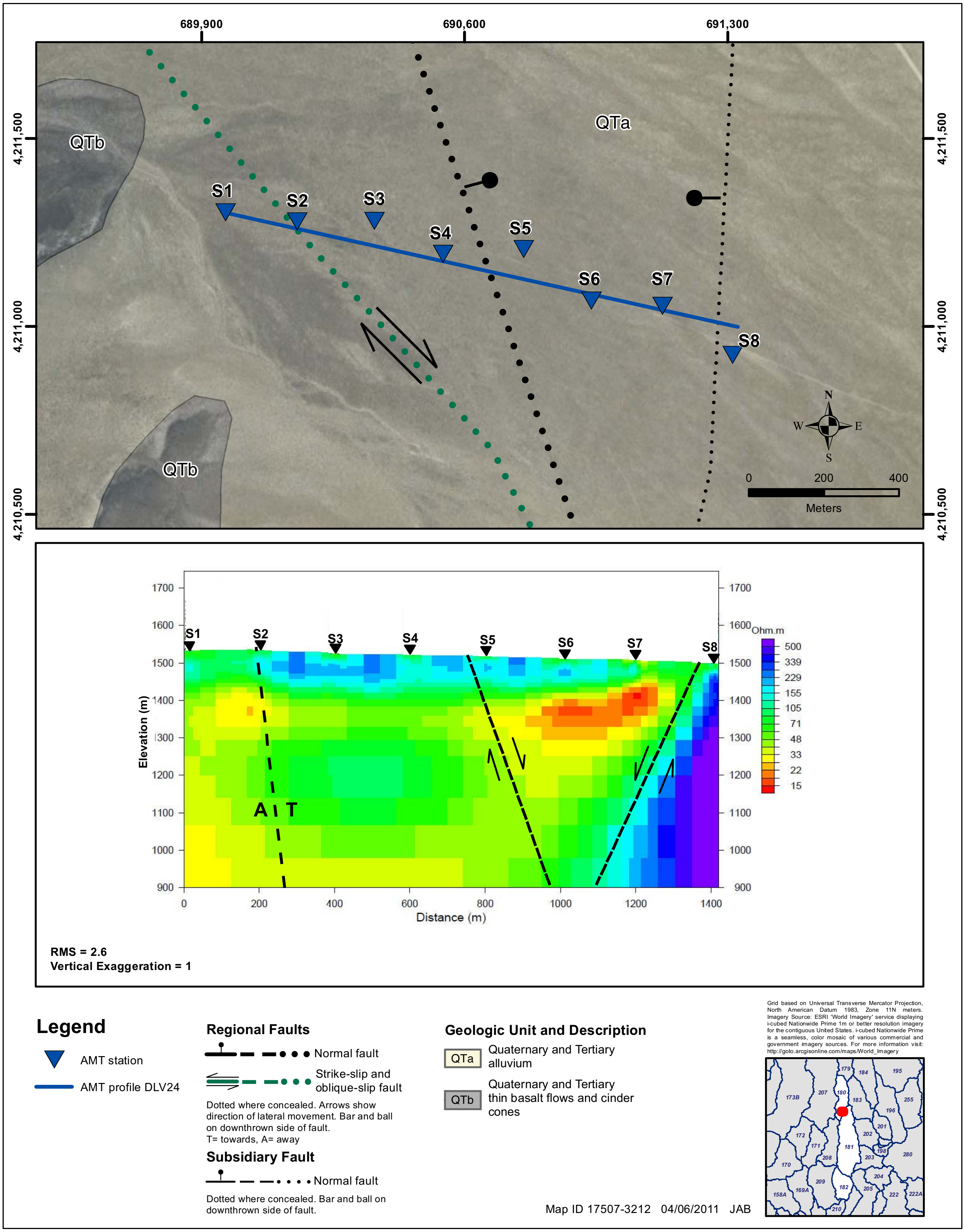


Figure 3-6
Map and 2D Model of DLV24

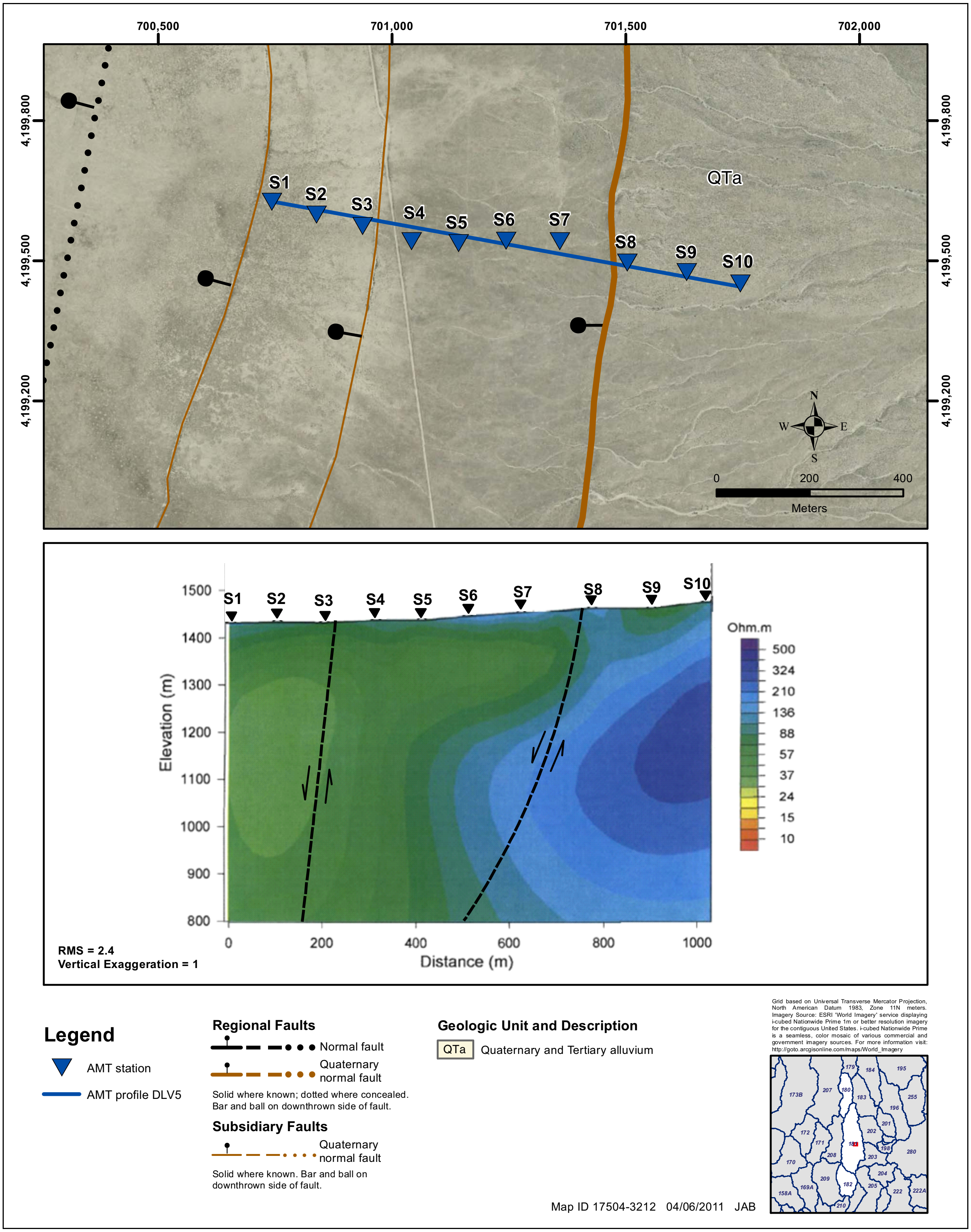


Figure 3-7
Map and 2D Model of DLV5

3.7 AMT Profile DLV4

Profile 4 (DLV4) was completed in on the eastern side of Dry Lake Valley, near the southern portion of the Ely Springs Range. The profile was sited to identify faults concealed by the basin fill and to identify resistivity contrasts within the basin fill. Profile DLV4 trends west, is 3,240 m long, and consists of 14 stations with a 200 to 400 m station spacing. The data from profile DLV4 were processed and modeled by the USGS (McPhee et al., 2008), but not geologically interpreted with the final model completed with the TM mode and incorporating topography. At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile DLV4 indicates that the eastern side of Dry Lake Valley is extensively faulted. At least five resistivity contrasts (stations S4, S5, S8, S10, and S13) are interpreted to represent five buried basin-range faults, as shown by Figure 3-8. From east to west, the resistivity changes from resistive (>500 ohm-m) carbonate rocks into alluvial fan deposits (approximately 30 to 90 ohm-m) at station S13, alluvial-fan deposits to very conductive buried lake-bed sediments at station S10, buried lake-bed sediments to basin fill at station S8, an antithetical (opposite dipping) fault at station S5, buried resistive carbonate bedrock to basin fill between stations S4 and S5, and a down-to-the-west dipping fault at station S4. A Quaternary fault is mapped near station S1, but the fault dips west and the profile was not extended far enough to the west to show the fault.

3.8 AMT Profile DLV8

Profile 8 (DLV8) was completed in eastern Dry Lake Valley, along the northern Burnt Springs Range. The profile was sited to identify faults that are concealed by basin fill. Profile DLV8 trends west, is 2,500 m long, and consists of 14 stations with a 100 to 400 m station spacing. The data from profile DLV8 were processed and modeled, but not geologically interpretated by the USGS (McPhee et al., 2008), with the final model completed using the TE and TM modes and incorporating topography (Figure 3-9). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile DLV8 illustrates resistivity contrasts at stations between S3 and S2, near S4, S5, and S11. The most prominent of these are at stations S5 and S11, which represent two mapped splays (Dixon et al., 2007) of the range-front faults that define the eastern edge of Dry Lake Valley. The western of these has Quaternary displacement, including historic but inactive, fissures at and west of it (Swadley, 1995). An associated antithetical fault at station S4, and a secondary interbasin fault is seen between stations S2 and S3. The highly conductive rocks between stations S1 and S8 may represent lake sediments and groundwater.

3.9 AMT Profile DLV1

Profile 1 (DLV1) was completed in the southeastern portion of Dry Lake Valley, just west of the central Burnt Springs Range. The profile was sited to identify faults that are concealed by the basin fill. Profile DLV1 trends west, is 1,850 m long, and consists of 13 stations with a 100 to 200 m station spacing. The data in profile DLV1 were processed and modeled by the USGS (McPhee et al., 2008), but not geologically interpreted with the final model completed using the TM mode and incorporating

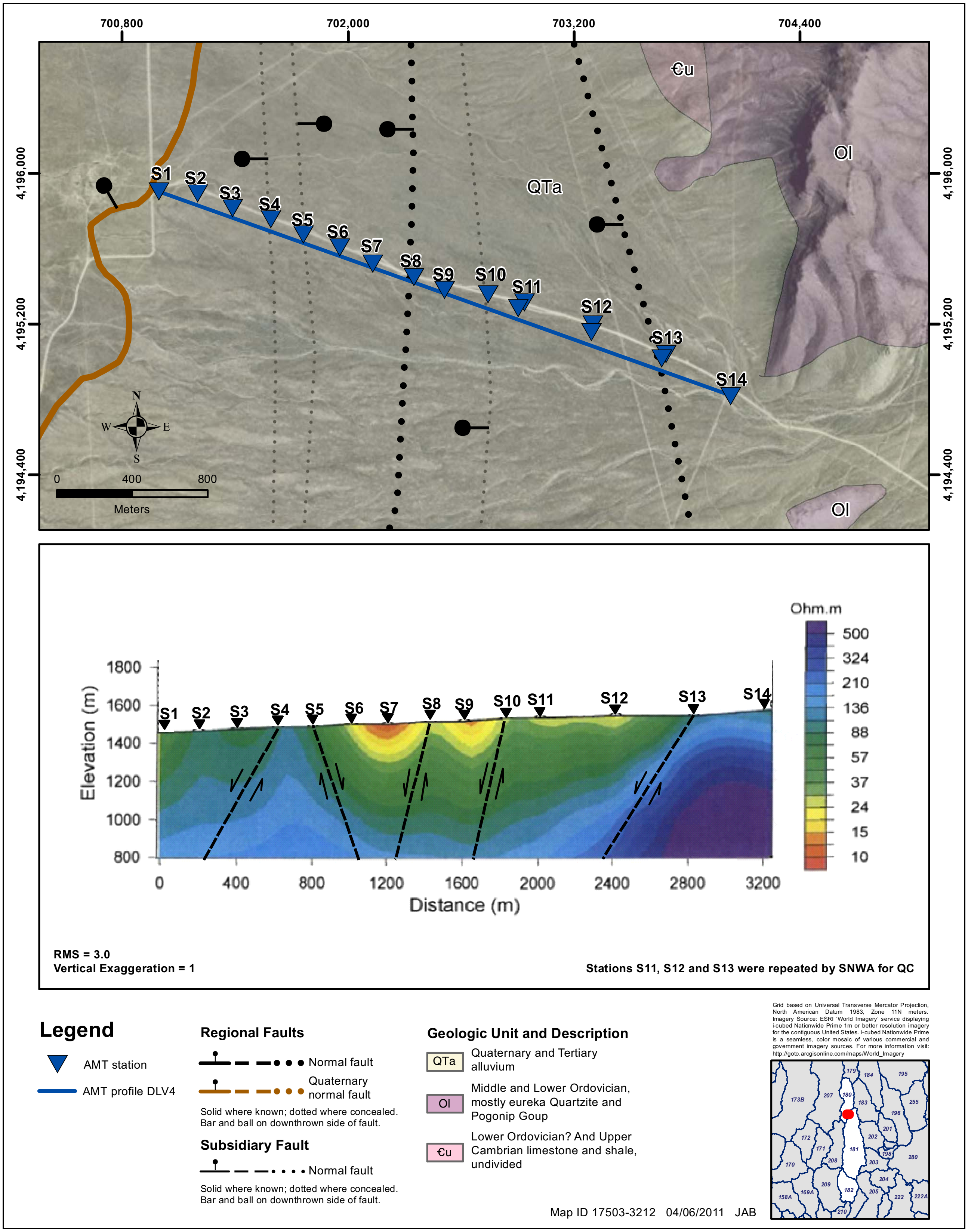


Figure 3-8
Map and 2D Model of DLV4

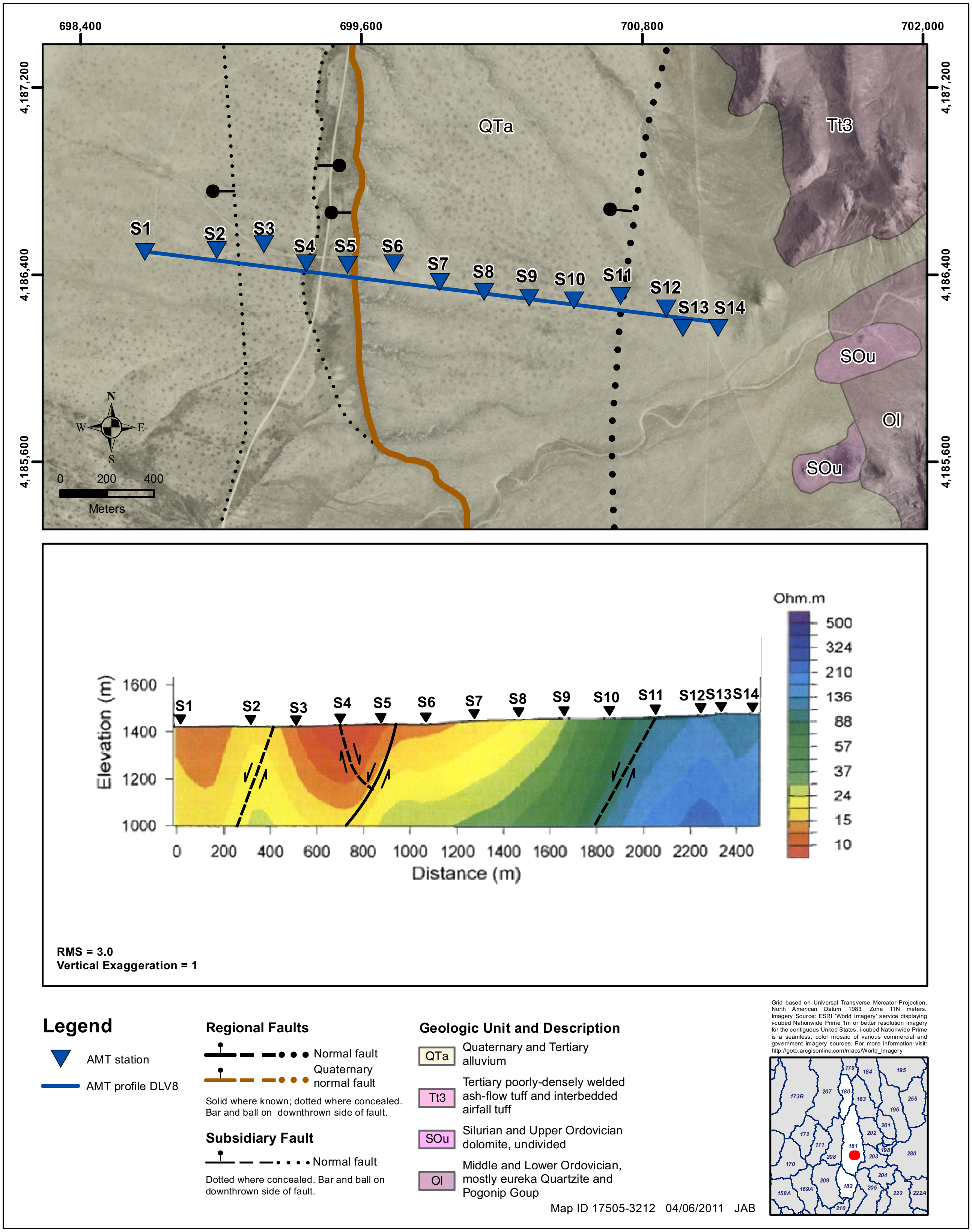


Figure 3-9
Map and 2D Model of DLV8

topography (Figure 3-10). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile DLV1 illustrates major resistivity contrasts near stations S3, and three small contrasts in the surface of the underlying high-resistivity rock (limestone) at stations S8, S9, and S10. Although difficult to resolve the resistivity model, these faults are mostly interpreted based on evidence from geologic mapping. The resistivity contrasts at stations S8 and S9 are inferred to be subsidiary normal faults that are dipping to the west. The resistivity contrast at station S10 is an inferred fault dipping to the northeast. The large resistivity zone near station S3 is interpreted to be due to the main range-front fault which has a Quaternary component of displacement because it offsets the basin-fill sediments at the surface. At depth the fault separates Cambrian carbonate rocks on the east from Quaternary basin-fill deposits on the west. This fault is geologically mapped on Plate 1 and illustrated in Cross Section S—S' in Dixon et al. (2007).

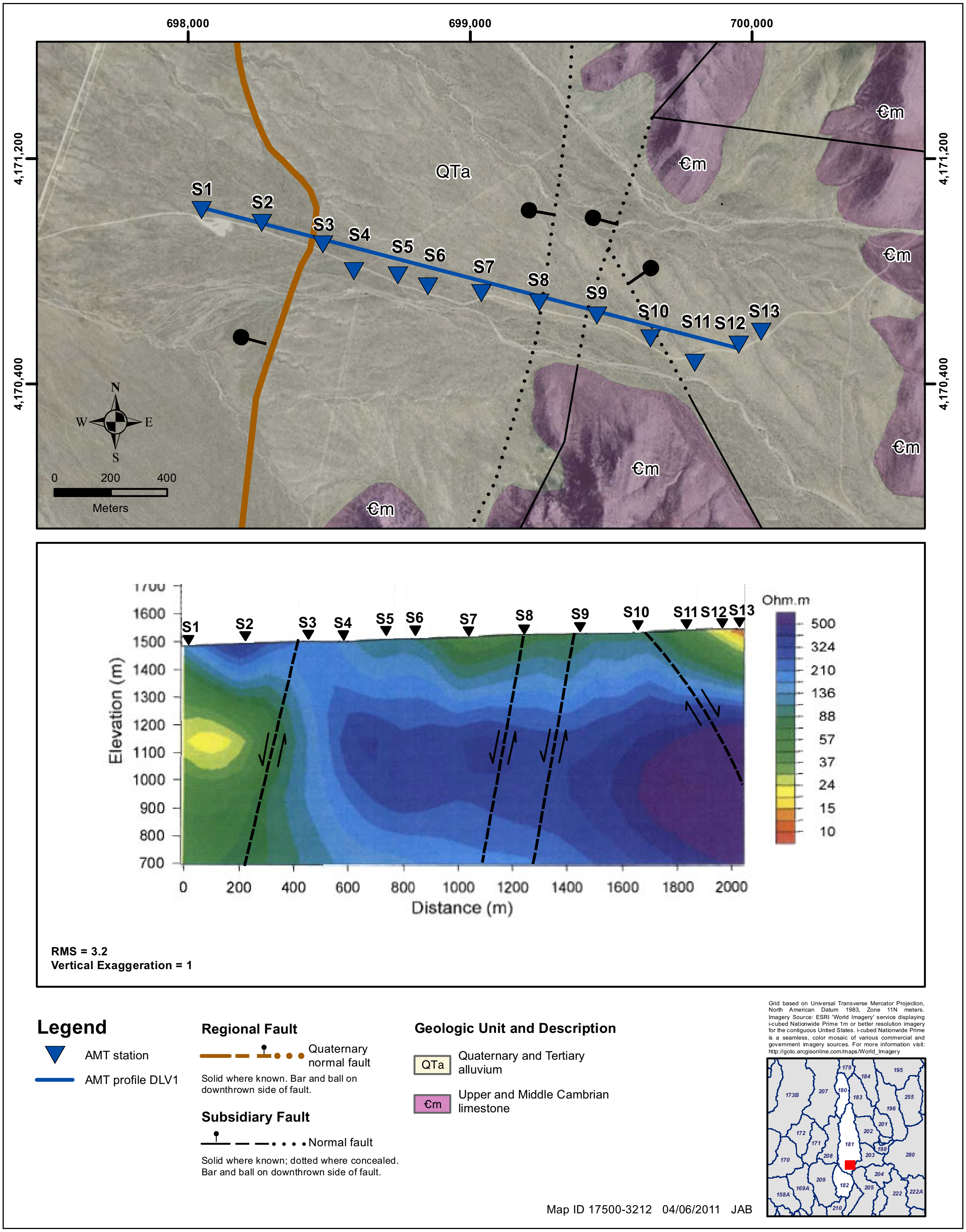


Figure 3-10
Map and 2D Model of DLV1

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4.0 CAVE VALLEY

Cave Valley is a north-trending valley approximately 65 km long and 10 km wide, between the Egan Range on the west and the Schell Creek Range on the east. Both ranges are horsts, bounded on both sides by range-front basin-range faults of large magnitude. The Egan and Schell Creek ranges merge at the southern end of Cave Valley. A single AMT profile was done in Cave Valley to delineate concealed portions of range-front faults along the Schell Creek Range (Figure 4-1). A potential noise source identified in the area was wind.

4.1 AMT Profile CVE

Profile E (CVE) was completed in southeastern Cave Valley, just west of Sidehill Pass. The profile was sited to identify range-front faults that are concealed by basin fill. Profile CVE trends west, is 3,390 m long, and consists of 16 stations with a 200 to 400 m station spacing. The data from profile CVE were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2006b), with the final model completed using the TM mode and incorporated topography (Figure 4-2). The model did not include stations S15 and S16 due to poor data quality. At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for profile CVE shows a large resistivity contrast near station S11, between resistive carbonate bedrock on the east and conductive basin fill on the west. The resistivity contrast is interpreted to mark the concealed range-front normal fault of the Schell Creek Range (Figure 4-2).

Wells were drilled in southern Cave Valley, to the south and north of AMT profile CVE. Each of the wells encountered about 130 m of partially cemented gravel (up to cobble to bolder size) with some silty clay, underlain by carbonate bedrock. The resistivities that AMT profile CVE shows between stations S12 through S14 is within the range (70–1,000 ohm-m) of the typical values of the lithology encountered in the wells. One of the wells, SNWA 180902M drilled south of profile CVE and east of the main range-front fault, had a total depth of approximately 280 m (Figure 4-1). Oil test well Sidehill Pass Federal No. 18-13, drilled just north of the map area of Figure 4-1 and west of the main range-front fault, penetrated about 1,550 m of basin-fill sediments before passing onto the Mississippian Joana Limestone, which continued to a total depth of about 2,070 m (Hess, 2004). Profile CVE compared favorably with an adjacent industry seismic profile (Scheirer, 2005).

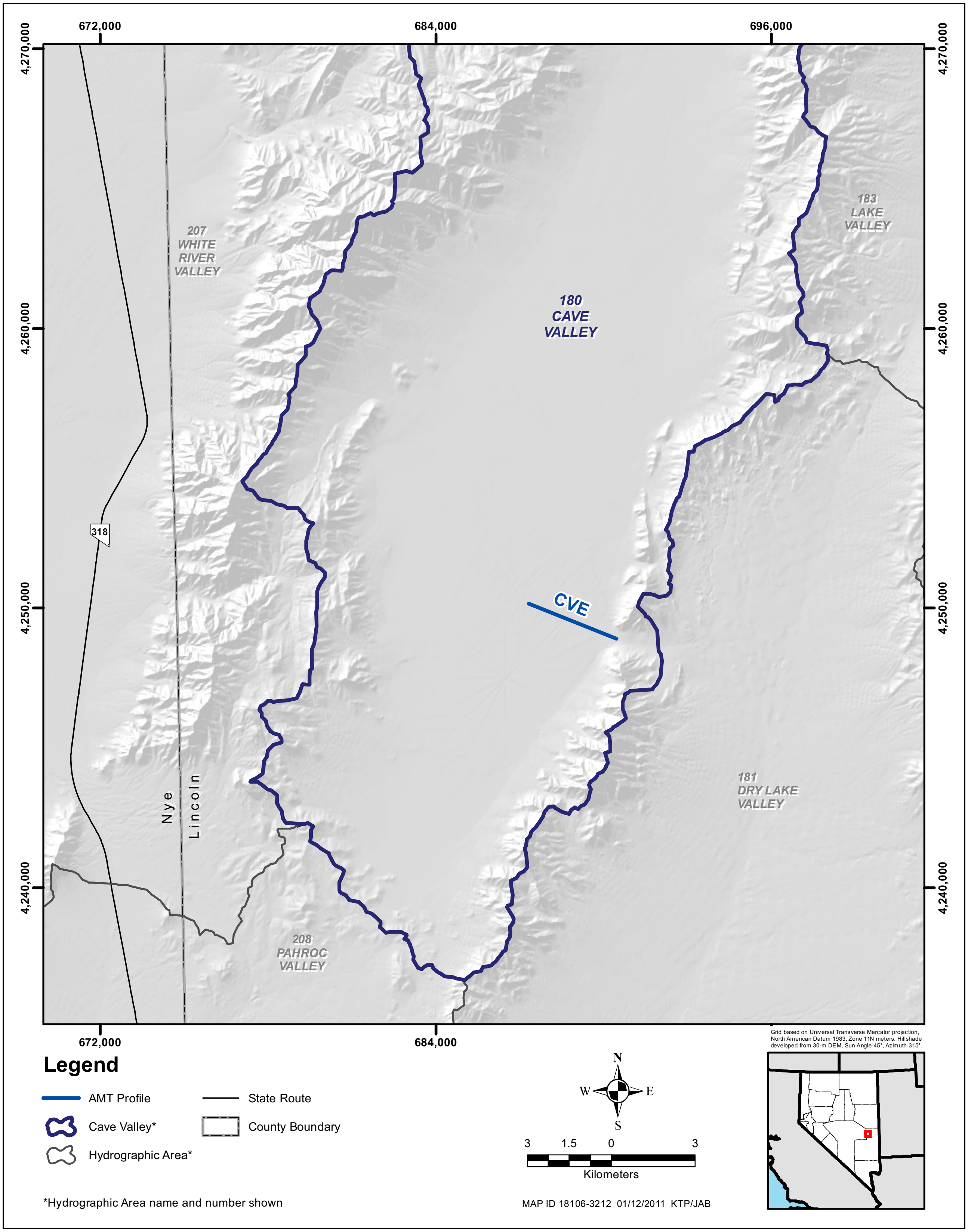

Figure 4-1
Cave Valley AMT Profile

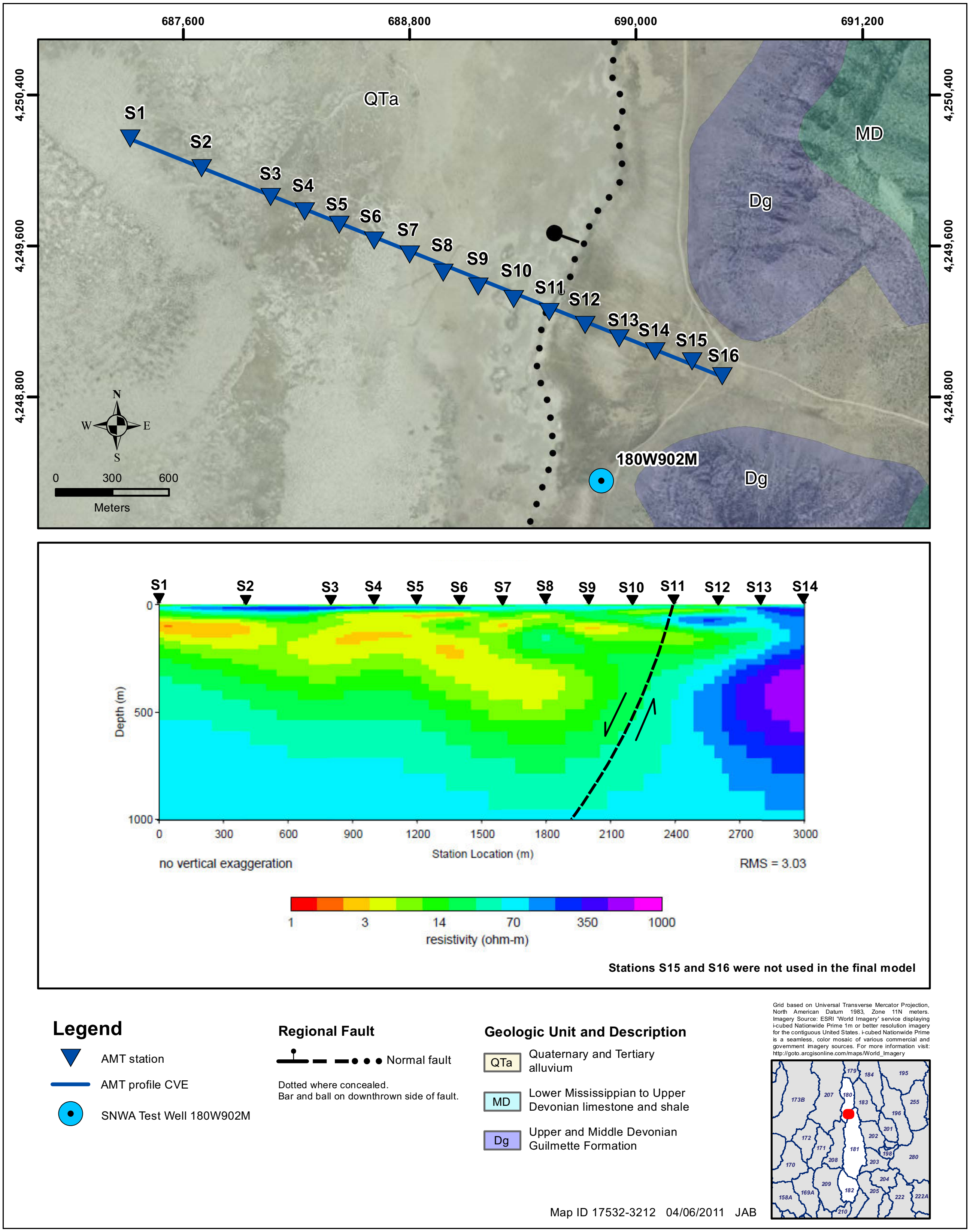

Figure 4-2
Map and 2D Model of CVE

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5.0 SPRING VALLEY

Spring Valley is a north-trending valley approximately 185 km long and generally 10 to 15 km wide. Most of the valley is between the Schell Creek Range on the west and the Snake Range on the east, but the Fortification Range is on the southwestern margin and the Antelope Range the northeastern margin. A total of twenty AMT profiles were done in Spring Valley to delineate concealed portions of range-front faults, interbasin faults, thickness of the basin-fill deposits, resistivity contrasts within the basin fill, and subsurface features at SNWA points of diversion (POD) applications (Figure 5-1). Sources of potential noise identified in the vicinity of the profiles included electrical transmission lines, buried pipe (aqueducts), irrigation lines, 3D effects from subsidiary subparallel faults, wind, and lightning.

5.1 AMT Profile SVNF

Profile F (SVNF) was completed in western Spring Valley, 20 km north of the intersection of U.S. Highway 93 (US 93) and U.S. Highway 6/50 (US 6/50). The profile was sited to identify subsurface faults that have been concealed by basin fill, to define the resistivity contrasts within the basin fill of the Cleve Creek alluvial fan, and to characterize the subsurface at POD 54021. Profile SVNF trends west, is 3,240 m long, and consists of 12 stations with a 200 to 400 m spacing. The data from profile SVNF were processed, modeled, and geologically interpreted (slightly modified by SNWA) by the USGS (McPhee et al., 2006b), with the final model completed using TM mode and incorporating topography (Figure 5-2). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile SVNF illustrates resistivity contrasts at stations S2, between S4 and S5, near S6, and near S7. The contrasts in resistivity are interpreted to be east-dipping normal faults except near station S6, where the fault is interpreted to dip west and be antithetical to the fault between stations S4 and S5.

5.2 AMT Profile SVNH

Profile H (SVNH) was completed in northwestern Spring Valley, near Cooper Canyon. The profile was sited to identify concealed range-front faults. Profile SVNH trends west, is 2,600 m long, and consists of 14 stations with a 100 to 200 m station spacing. The data from profile SVNH were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2007), with the final model completed using the TM mode and incorporating topography (Figure 5-3). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile SVNH illustrates a profound resistivity contrast at station S6, which is interpreted as the main range-front normal fault on the eastern side of the Schell Creek Range. This

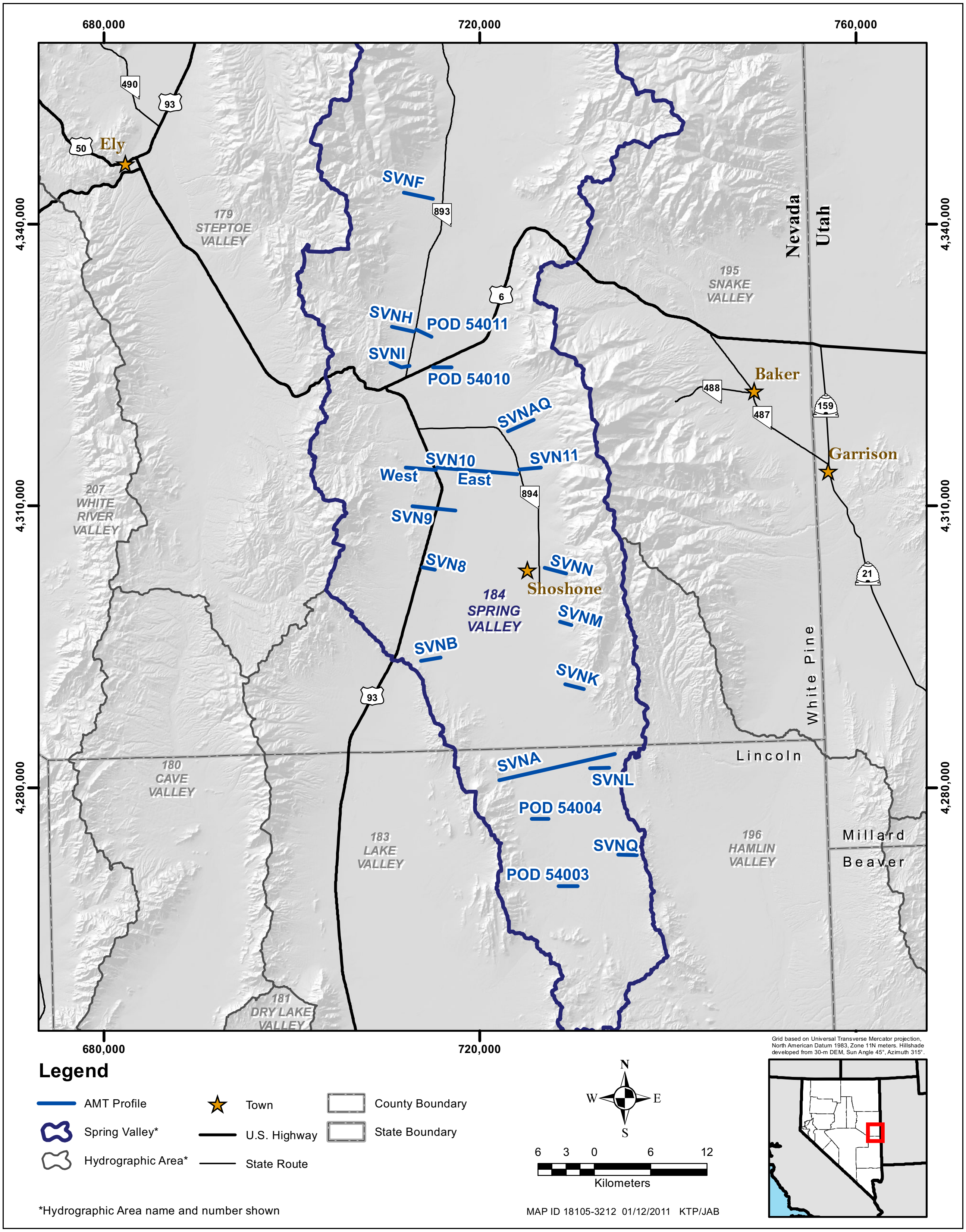


Figure 5-1
Spring Valley AMT Profiles

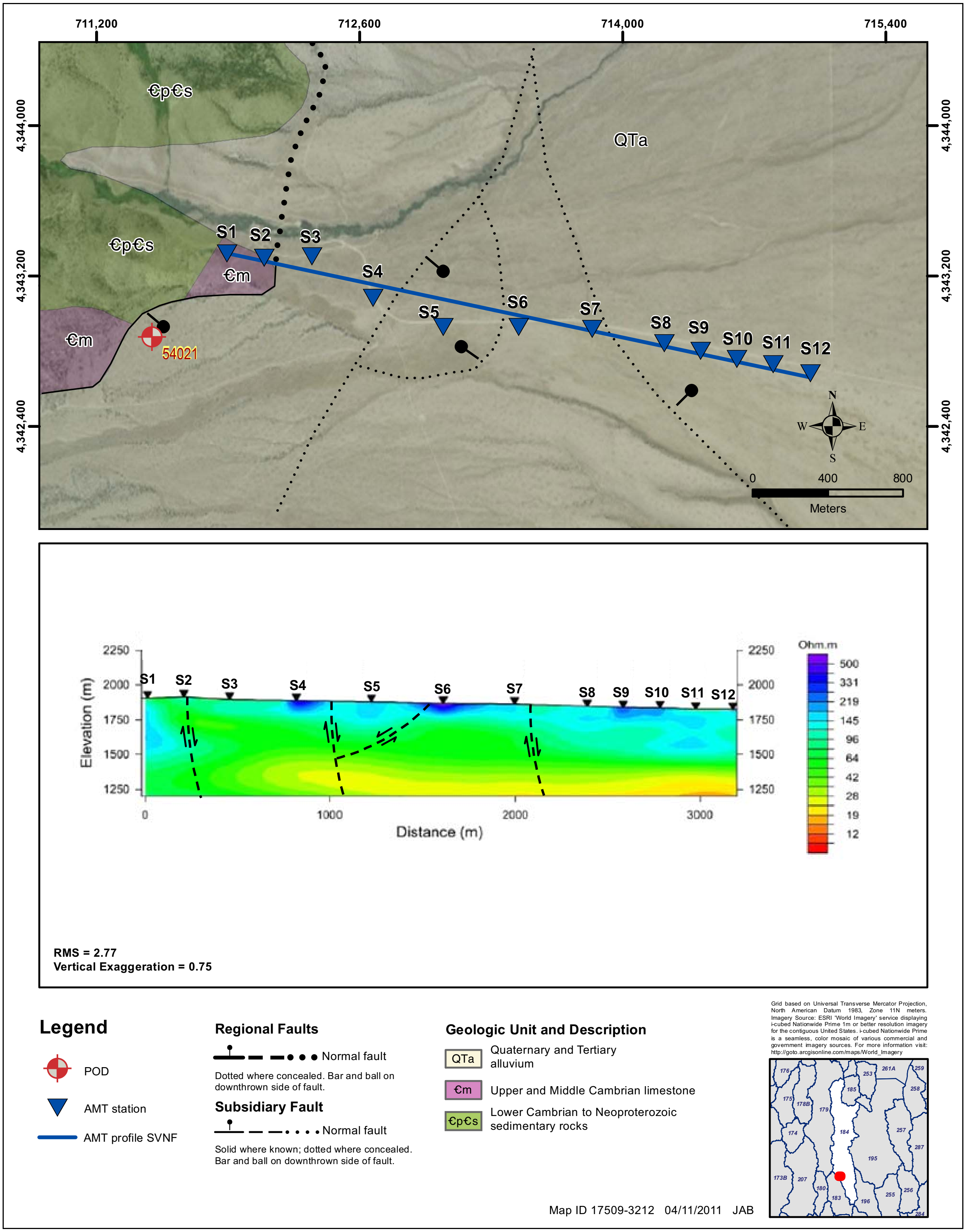


Figure 5-2
Map and 2D Model of SVNF

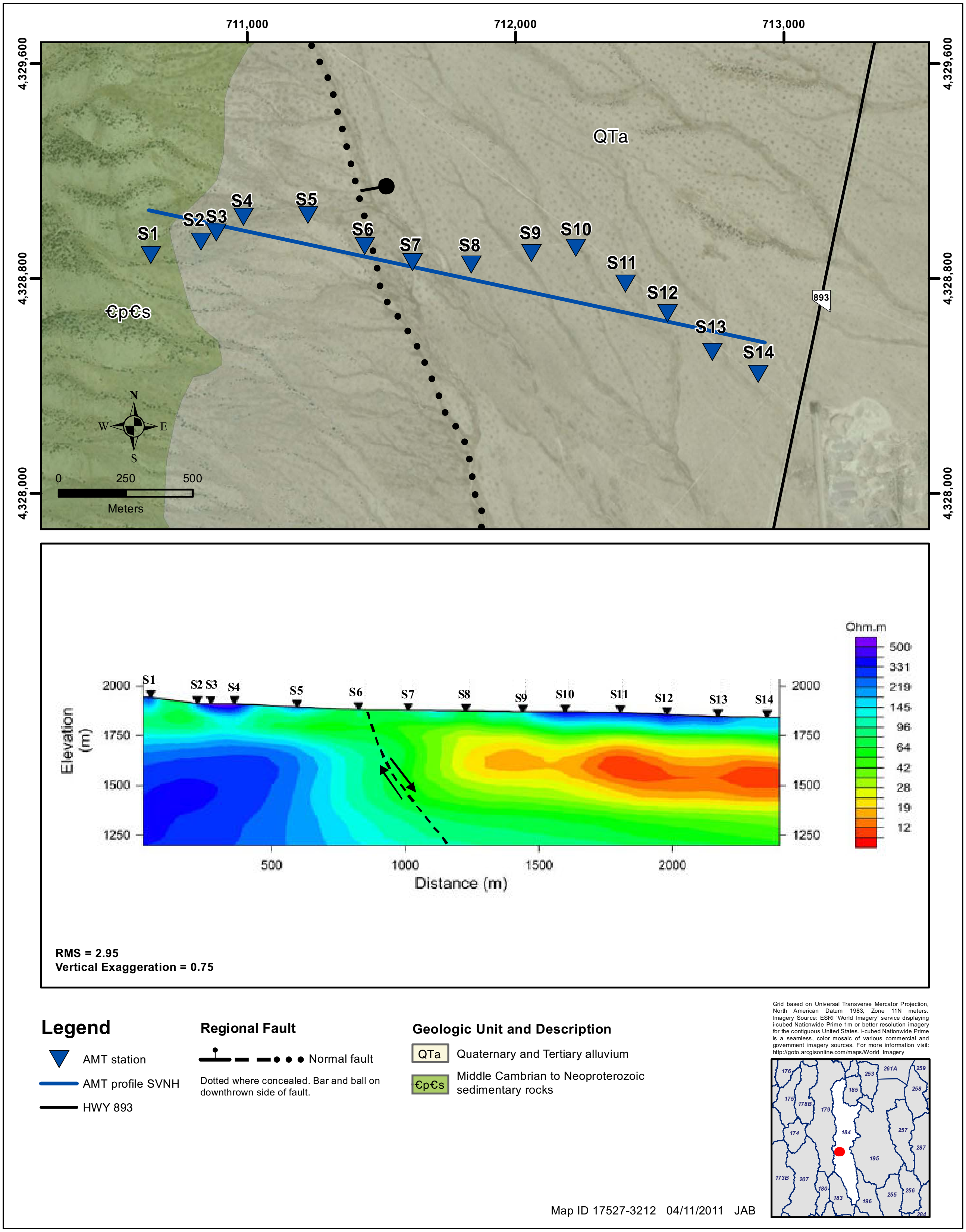


Figure 5-3
Map and 2D Model of SVNH

inferred fault creates a boundary from resistive carbonate bedrock to the west to more conductive basin fill to the east.

5.3 AMT Profile POD 54011

Profile POD 54011 was completed in western Spring Valley, about 4 km north of US 6/50. The profile was sited to characterize the subsurface at POD application 54011, and to evaluate resistivity within the basin fill. Profile POD 54011 trends northwest, is 1,600 m long, and consists of 10 stations with a 200 m spacing. The data from profile POD 54011 were originally processed, modeled, but not geologically interpreted by LGS (Layne GeoSciences, 2009) and later re-processed, modeled, and geologically interpreted by SNWA, with the final model completed using the TM mode and incorporating topography (Figure 5-4).

The model for POD 54011 illustrates prominent shallow and deep resistivity contrasts beneath stations S3 and S7. These contrasts are interpreted to be east-dipping normal faults. The high-conductivity rocks imaged over most of the profile may represent playa and pluvial-lake sediments.

5.4 AMT Profile SVNI

Profile I (SVNI) was completed in western Spring Valley, north of the intersection of US 93 and US 6/50. The profile was sited to identify faults in the area that are concealed by the basin fill. Profile SVNI trends northwest, is 1,650 m long, and consists of 10 stations with a 100 to 200 m station spacing. The data from profile SVNI were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2007), with the final model completed using the TM mode and incorporating topography (Figure 5-5). At a later time, SNWA geologically interpreted the final model provided by the USGS.

Differences in shallow and deep resistivity data at stations S2 and S5, are interpreted as buried normal faults. The fault near station S2 is interpreted to be the main range-front fault on the eastern side of the Schell Creek Range.

5.5 AMT Profile POD 54010

Profile POD 54010 was completed in central Spring Valley, just south of US 6/50 and north and east of Rattlesnake Knoll, a small hill of volcanic bedrock that protrudes from the basin fill. The profile was sited to characterize the subsurface in the vicinity of Rattlesnake Knoll and POD application 54010. The profile trends west to east, is approximately 2,000 m long, and consists of 11 stations with a 200 m station spacing. The data from profile POD 54010, originally processed and modeled, but not geologically interpreted by LGS (Layne GeoSciences, 2009), was later re-processed, modeled, and geologically interpreted by SNWA, with the model completed using the TM mode and incorporating topography (Figure 5-6). Station S5 was not used in the modeling process due to poor data quality from an unknown noise source.

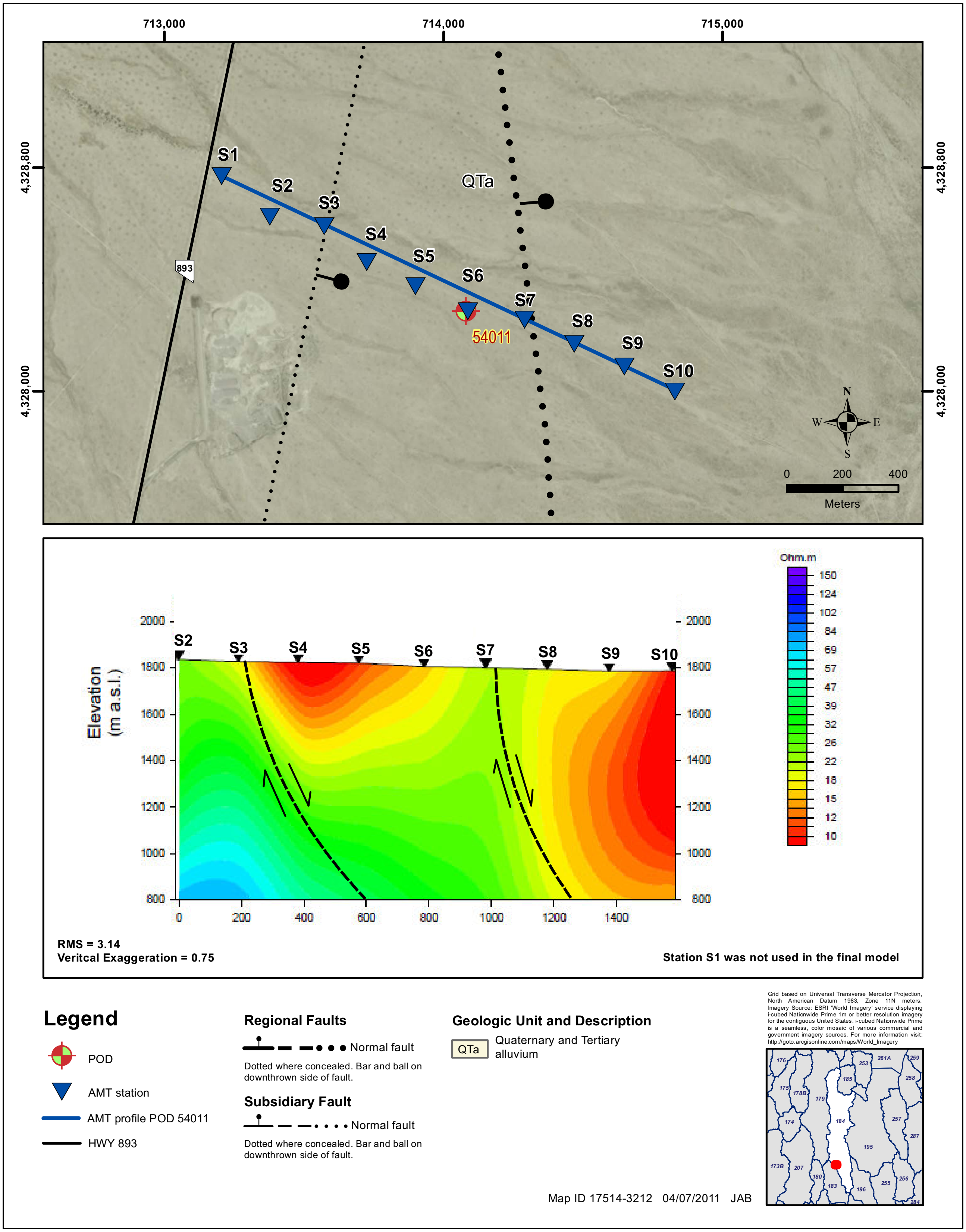


Figure 5-4
Map and 2D Model of POD 54011

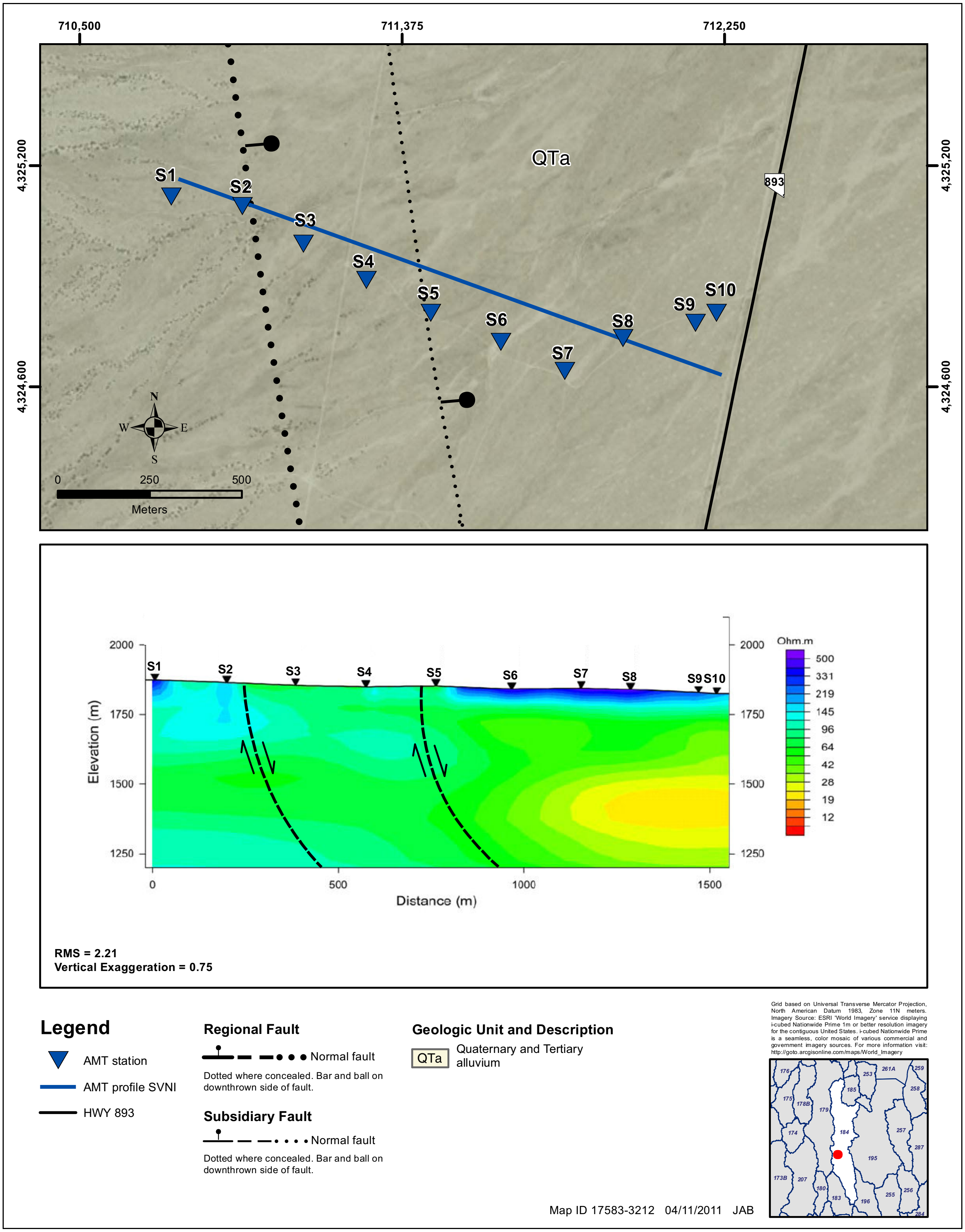
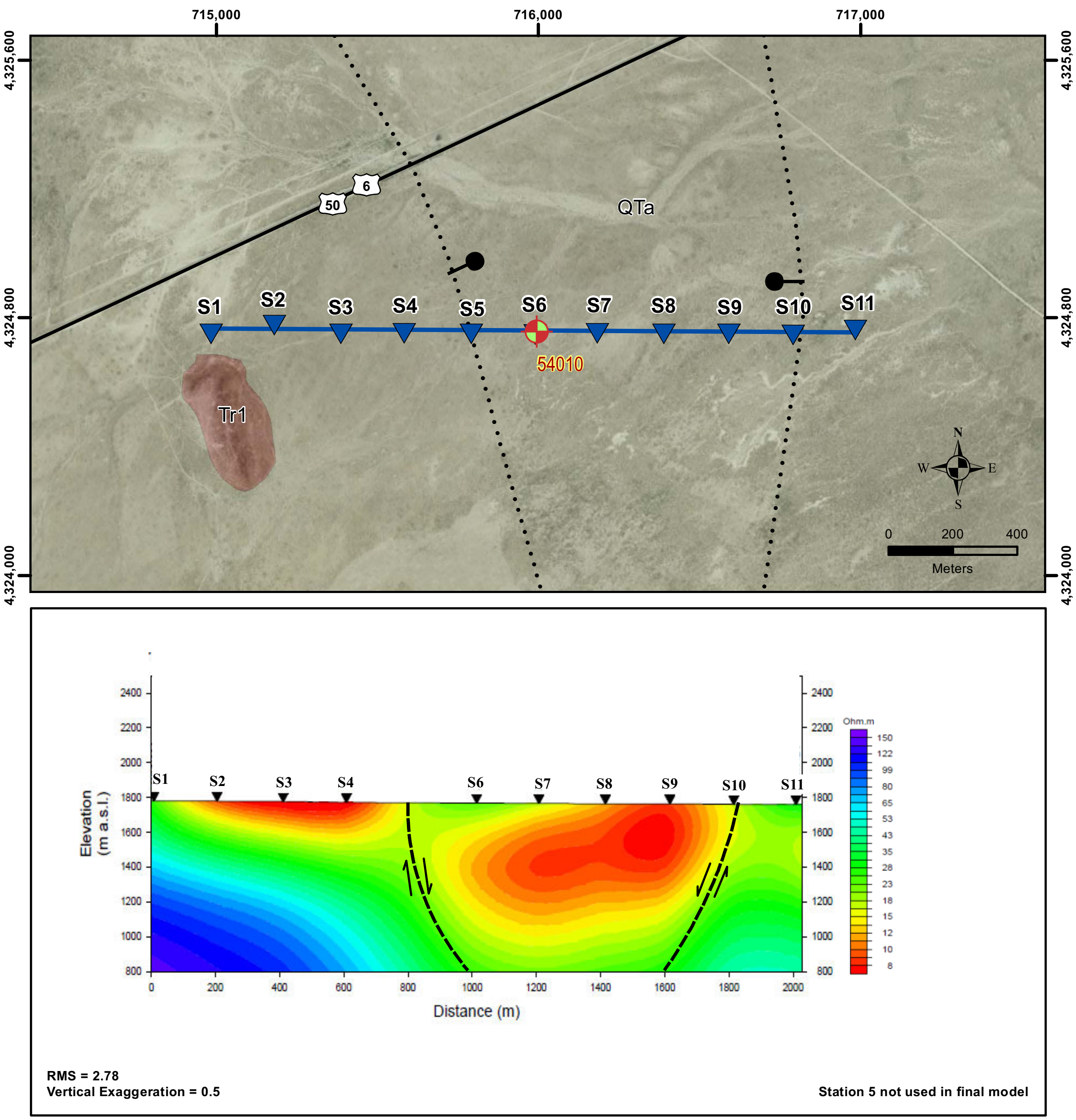


Figure 5-5
Map and 2D Model of SVNI



Legend

POD

AMT station

AMT profile POD 54010

HWY 6/50

Subsidiary Fault

Normal fault

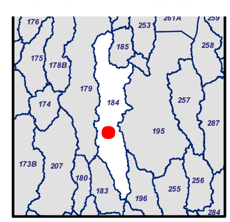
Dotted where concealed. Bar and ball on downthrown side of fault.

Geologic Unit and Description

QTa — Quaternary and Tertiary alluvium

Tr1 — Tertiary low-silica rhyolite lava flows and vocanic domes

Grid based on Universal Transverse Mercator Projection, North American Datum 1983, Zone 11N meters. Imagery Source: ESRI "World Imagery" service displaying i-cubed Nationwide Prime 1m or better resolution imagery for the contiguous United States. i-cubed Nationwide Prime is a seamless, color mosaic of various commercial and government imagery sources. For more information visit: http://goto.arcgisonline.com/maps/World_Imagery



Map ID 17513-3212 04/11/2011 JAB

Figure 5-6
Map and 2D Model of POD 54010

The model for Profile POD 54010 illustrates shallow and deep resistivity contrasts beneath stations S5, and S10. These contrasts are interpreted to be buried interbasin normal faults that dip in opposite directions so as to create a narrow graben. Rattlesnake Knoll is made up of bedded volcanic breccia, the site of a former flourspar mine (Mankinen et al., 2006). The model appears to have imaged Rattlesnake Butte at depth below stations S1 through S4. The high-conductivity rocks in and west of the graben are interpreted to be playa and pluvial-lake sediments in the axis of Spring Valley.

5.6 AMT Profile SVNAQ

Profile AQ (SVNAQ) was completed in eastern Spring Valley, 1 km east of SNWA Harbecke Ranch, and parallel to and 200 to 400 m south of the Harbecke Ranch aqueduct. The profile was sited to provide subsurface data to assist with siting irrigation well SPR7023I. Profile SVNAQ trends northeast, is 3,065 m long, and consists of 15 stations with a 200 m station spacing. The data from profile SVNAQ were processed and modeled by the USGS, but not geologically interpreted (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography (Figure 5-7). At a later time, SNWA geologically interpreted the final model provided by the USGS.

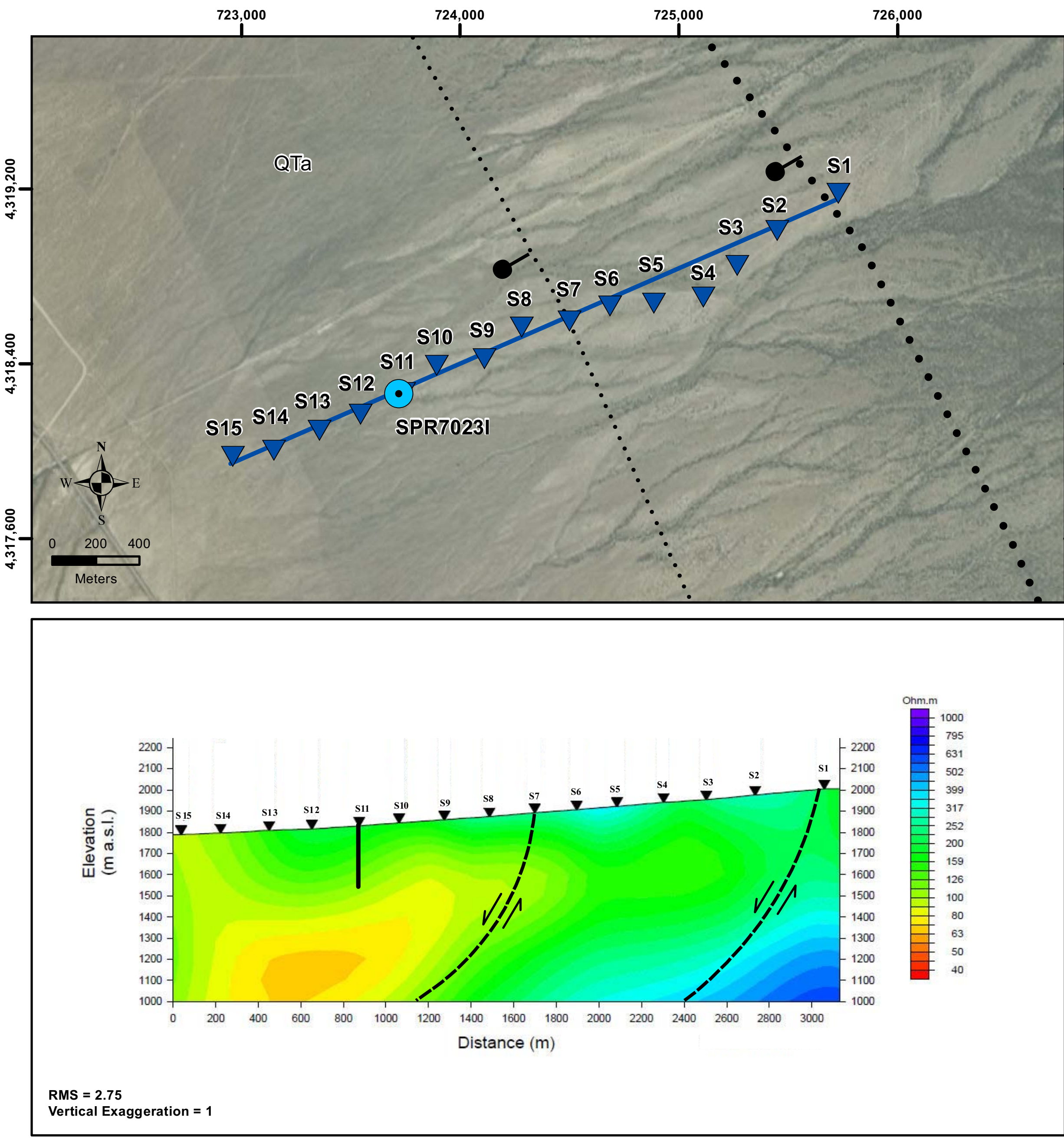
The model for Profile SVNAQ illustrates resistivity contrasts at stations S1 and S7, interpreted to be normal faults. The eastern most is the main range-front fault on the western side of the Snake Range.

SNWA drilled irrigation well SPR7023I near station S11 of the profile. The well was drilled to approximately 372 m bgs and encountered Quaternary alluvium and Quaternary and Tertiary basin-fill deposits for the entire borehole. The lithology encountered consisted of quartzite sand and gravel derived from the Snake Range consistent with the resistivity values shown at the well location (approximately 100–250 ohm-m). The high-conductivity rocks near the bottom of the well may be lake deposits, likely to transmit less groundwater.

5.7 AMT Profile SVN10 West

Profile 10 West (SVN10 West) was completed in western Spring Valley, about 10 km south of US 6/50 on the northern side of a bedrock horst block protruding from the basin fill. The profile was sited to identify faults that have been concealed by basin fill. Profile SVN10 West trends west, is 3,200 m long, and consists of 16 stations with a 200 m station spacing. The data from profile SVN10 West were originally processed and modeled by LGS (Layne GeoSciences, 2009), but later re-processed, modeled, and geologically interpreted by SNWA with the final model completed using the TE and TM modes and incorporating topography (Figure 5-8).

The model illustrates shallow and deep resistivity contrasts at stations S2, S6, S8, S12, and S16. The resistivity data are interpreted as normal faults that bound three sides of the horst (at stations S2, S12, and S16) and that are internal to the horst (at stations S6 and S8). Of these, the eastern faults (at stations S12 and S16) are interpreted to be the main splays of the main range-front fault of the eastern Schell Creek Range, and the high-conductivity rocks between them may be lake beds within the basin fill.



Legend

Irrigation Well SPR7023I

AMT station

AMT profile SVNAQ

Irrigation Well SPR7023I
Total depth = 372 m

Regional Fault

Normal fault

Dotted where concealed. Bar and ball on downthrown side of fault.

Subsidiary Fault

Normal fault

Dotted where concealed. Bar and ball on downthrown side of fault.

Geologic Unit and Description

QTa Quaternary and Tertiary alluvium

Grid based on Universal Transverse Mercator Projection, North American Datum 1983, Zone 11N meters. Imagery Source: ESRI "World Imagery" service displaying i-cubed Nationwide Prime 1m or better resolution imagery for the contiguous United States. i-cubed Nationwide Prime is a seamless, color mosaic of various commercial and government imagery sources. For more information visit: http://goto.arcgisonline.com/maps/World_Imagery

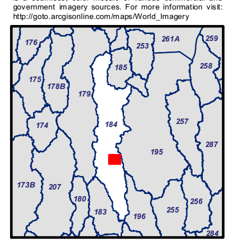


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Figure 5-7
Map and 2D Model of SVNAQ

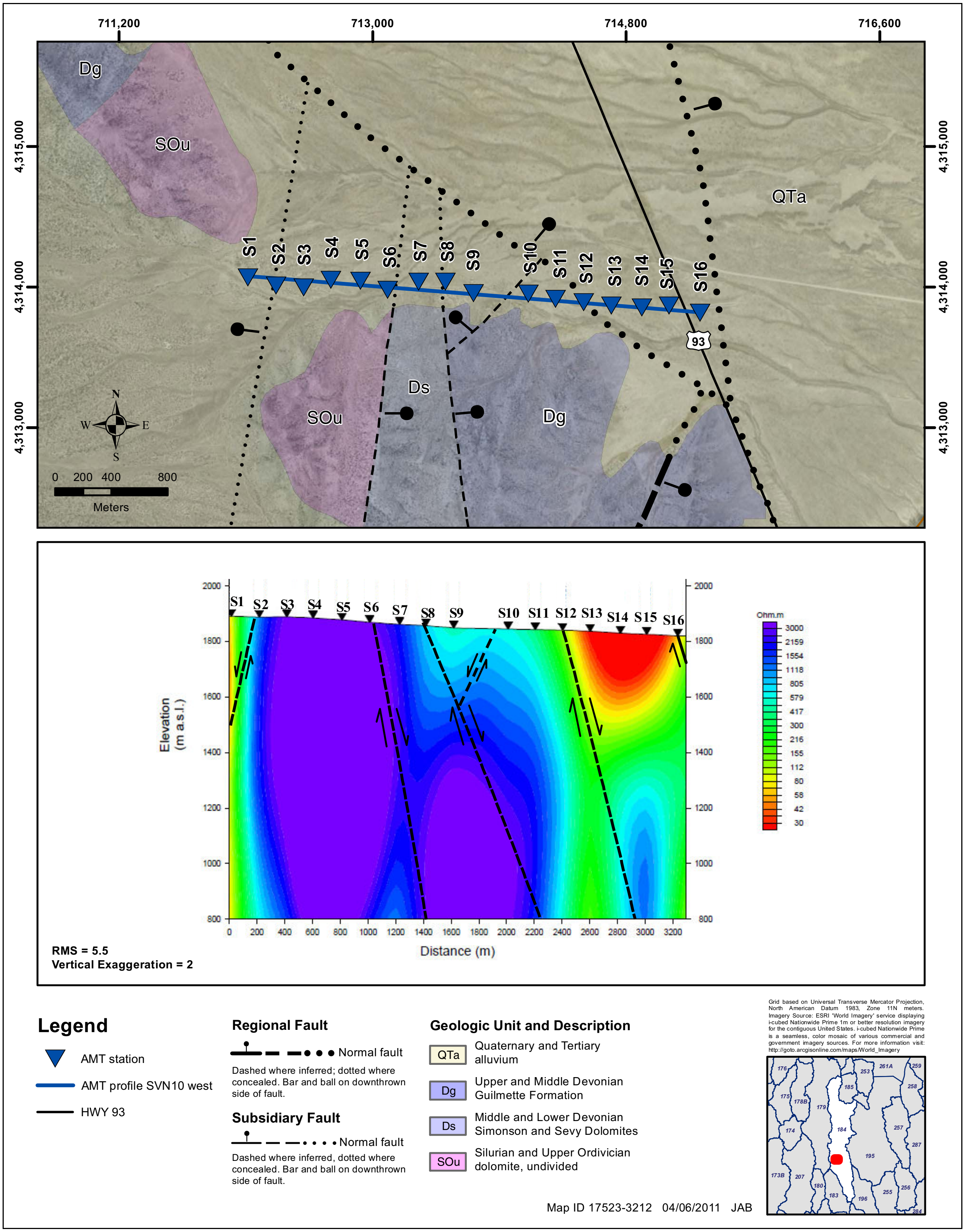


Figure 5-8
Map and 2D Model of SVN10 West

5.8 AMT Profile SVN10 East

Profile 10 East (SVN10 East) was completed in western Spring Valley, east and across US 93 from profile SVN10 West. The profile was sited to identify subsurface faults that have been concealed by basin fill, to further refine the resistivity values of the basin fill across Spring Valley, and to characterize the subsurface at POD application 54009. Profile SVN10 East trends west, is 8,500 m long, and consists of 25 stations with a 200 to 400 m station spacing. The data from profile SVN10 East were originally processed and modeled by LGS (Layne Geosciences, 2009), but later re-processed, modeled, and geologically interpreted by SNWA with the final model completed using the TM mode and incorporating topography (Figure 5-9). Stations S5, S6, S13, and S15 through S19 were not used in the modeling process due to poor data quality from an unknown noise source.

The model for Profile SVN10 East illustrates profound shallow and deep resistivity contrasts at stations S1, S8, S10, and S25. The resistivity changes are interpreted to be major normal faults except the fault near station S8, which is a fault that contains some Quaternary displacement and is of somewhat lesser overall overset. This fault and adjacent faults here control several springs. The fault at station S25 also controls several springs. The high-conductivity rocks between stations S10 and S25 are probably playa-lake deposits, as now being deposited at the surface.

5.9 AMT Profile SVN11

Profile 11 (SVN11) was completed in eastern Spring Valley, along the west Snake Range across from State Route (SR) 894. The profile was sited to identify subsurface faults that have been concealed by basin fill, and reveal any resistivity transitions within the basin fill. Profile SVN11 trends west, is 1,600 m long, and consists of 11 stations with a 200 m station spacing. The data from profile SVN11 were processed, modeled, and geologically interpreted by SNWA, with the final model completed using the TM mode and incorporating topography (Figure 5-10).

The model for Profile SVN11 indicates no evidence of subsurface faults and no major horizontal resistivity contrasts. The model is considered mostly one dimensional with the resistivity range shown being consistent with coarser grained sediments in the basin fill.

5.10 AMT Profile SVN9

Profile 9 (SVN9) was completed in western Spring Valley, across the eastern side of a horst block of Devonian carbonate rocks poking out of the basin fill. The profile was sited to identify faults that have been concealed by basin fill. Profile SVN9 trends west, is 4,800 m long, and consists of 24 stations with a 200 m station spacing. The data from profile SVN9 were originally processed and modeled by LGS (Layne Geosciences, 2009), then later re-processed, modeled, and geologically interpreted by SNWA (Figure 5-11). The final model was completed using the TM mode and does not incorporate topography. Stations S19, S21, and S24 were not included in the model due to poor data quality caused by an unknown noise source.

The model for Profile SVN9 illustrates profound shallow and deep resistivity contrasts along the profile near stations S6, between S13 and S14, and at S22 and S23. The resistivity contrasts are

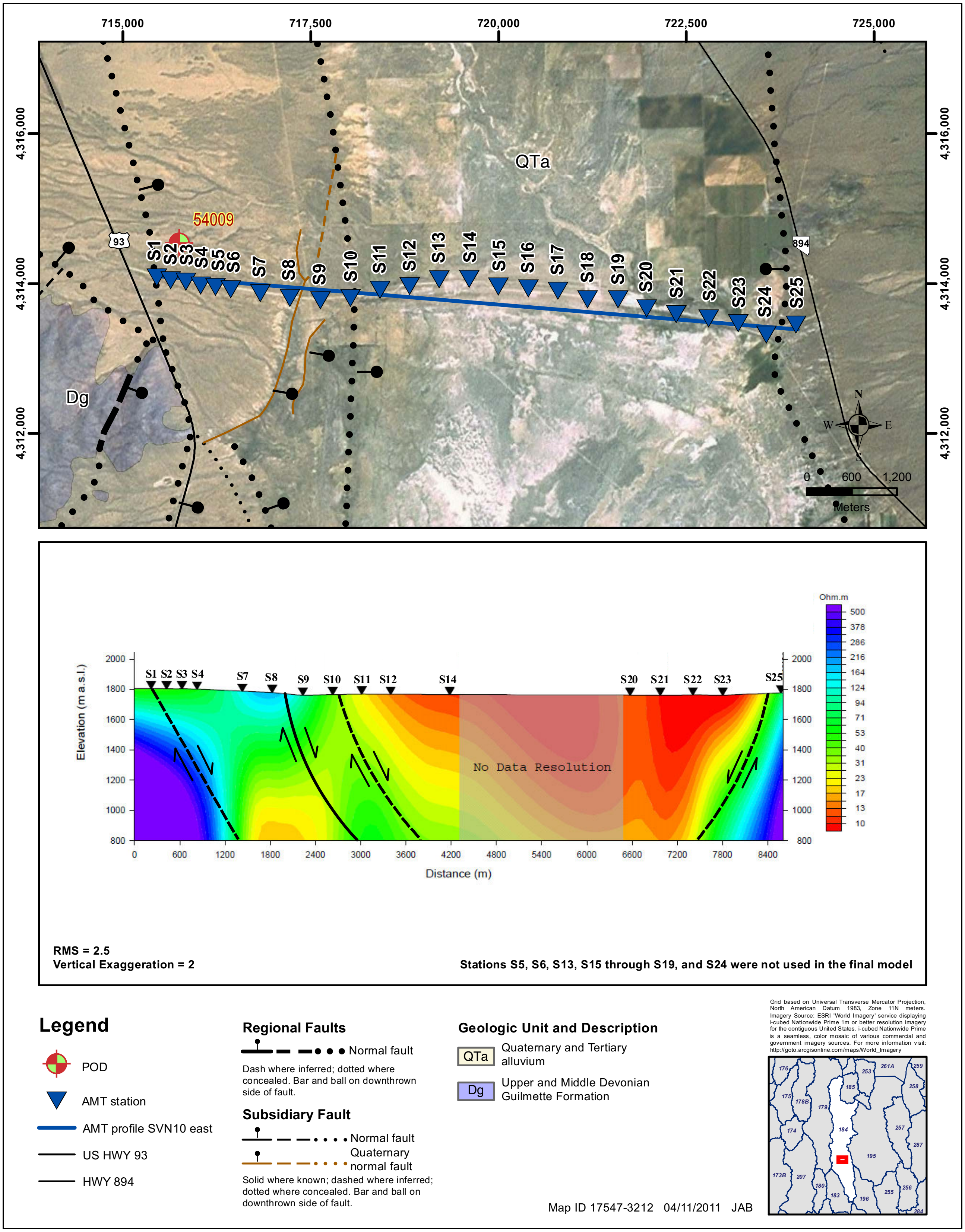
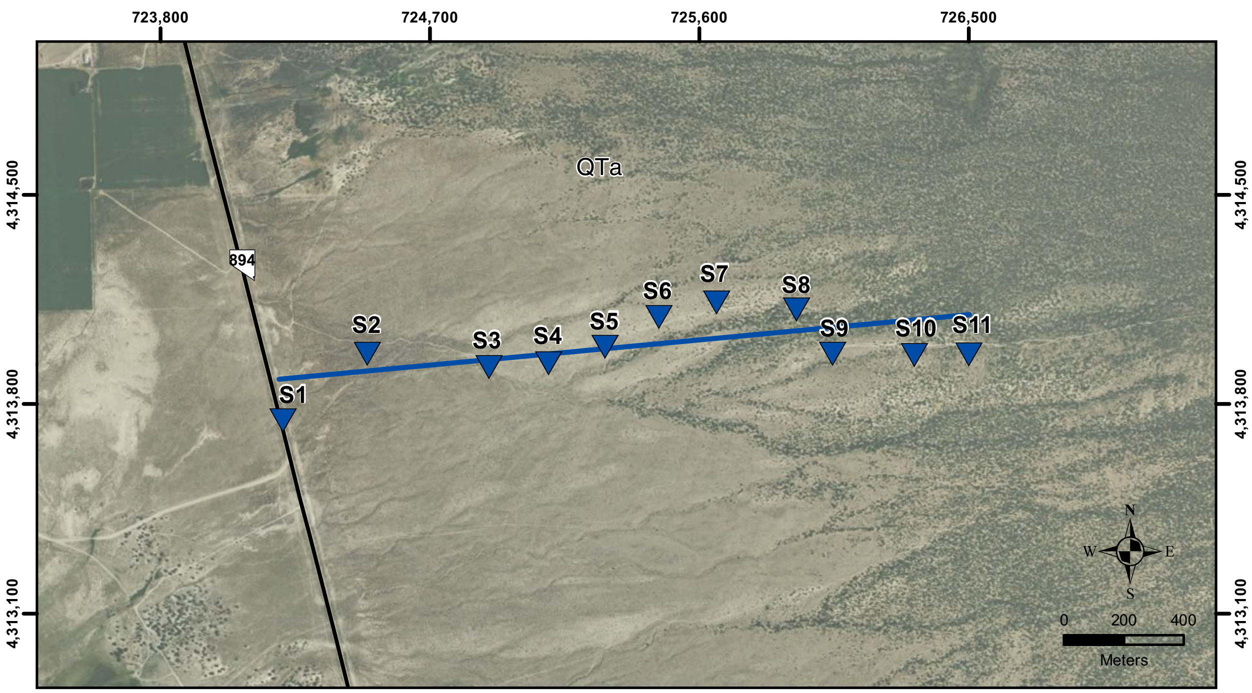
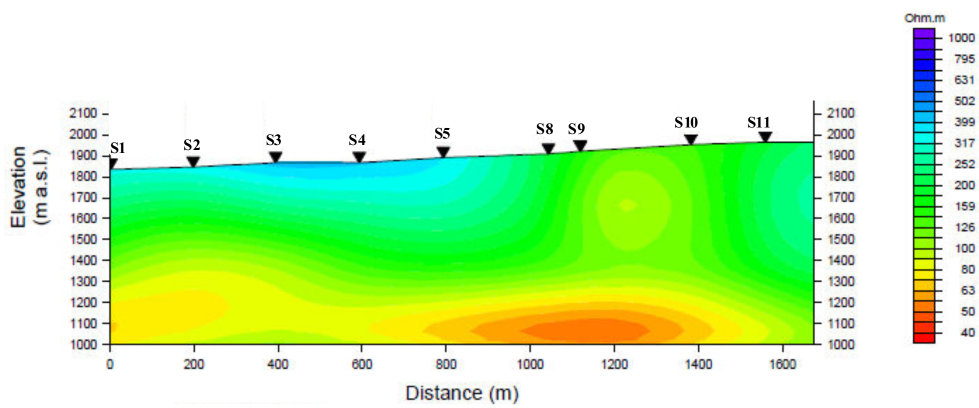


Figure 5-9
Map and 2D Model of SVN10 East





RMS = 4.0
Vertical Exaggeration = 0.5

Stations S6 and S7 were not used for final model

Legend

AMT station

AMT profile SVN11

HWY 894

Geologic Unit and Description

QTa Quaternary and Tertiary alluvium

Grid based on Universal Transverse Mercator Projection, North American Datum 1983, Zone 11N meters. Imagery Source: ESRI 'World Imagery' service displaying i-cubed Nationwide Prime 1m or better resolution imagery for the contiguous United States. i-cubed Nationwide Prime is a seamless, color mosaic of various commercial and government imagery sources. For more information visit: http://goto.arcgisonline.com/maps/World_Imagery

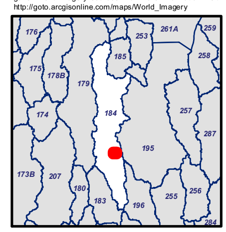


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Figure 5-10
Map and 2D Model of SVN11

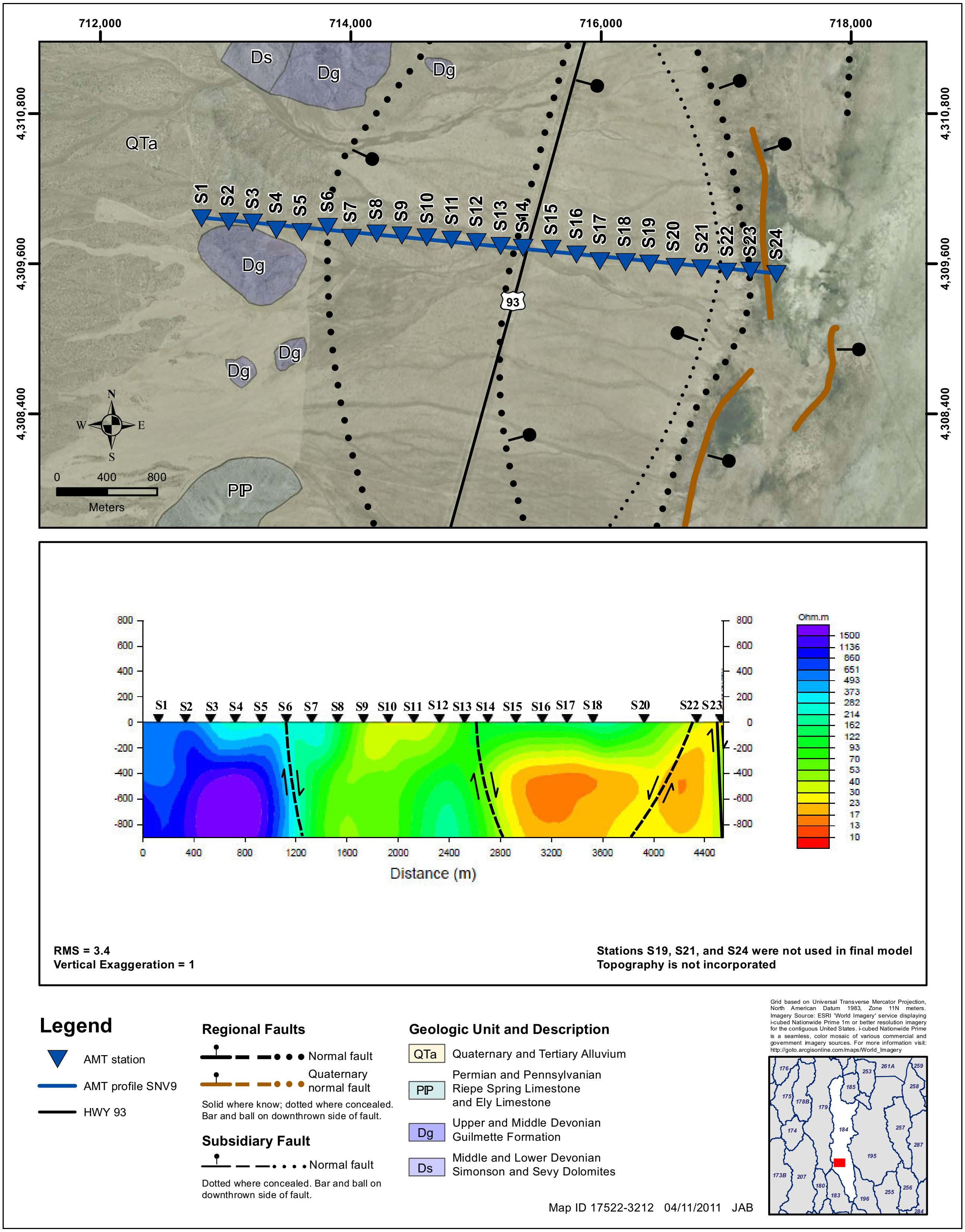


Figure 5-11
Map and 2D Model of SVN9

interpreted to be buried down-to-the-east normal faults and, at station S22, a subsidiary buried down-to-the-west antithetical normal fault. Just east of station S23, several small Quaternary faults are present, part of a major fault zone that controls springs in the area.

5.11 AMT Profile SVN8

Profile 8 (SVN8) was completed in southwestern Spring Valley, 1.2 km north of SNWA POD application 54008 (just south of the map area). The profile was sited to identify faults that are concealed by basin fill and to characterize the subsurface at POD application 54008. Profile SVN8 trends west, is 1,400 m long, and consists of eight stations with a 200 m station spacing. The data from profile SVN8 were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography (Figure 5-12). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile SVN8 has no significant resistivity contrasts, therefore no evidence of buried faults. The model is one dimensional with low resistivity values indicating fine-grained sediments, likely lake-bed deposits, are present below the surface.

5.12 AMT Profile SVNB

Profile B (SVNB) was completed in western Spring Valley, approximately 3.3 km east of US. 93 crossing the Atlanta dirt road. The profile was sited to identify faults to assist with the sighting of SNWA Test Well 184W103. The profile trends west, is 2,300 m long, and consists of nine stations with a 200 to 400 m station spacing. The data from profile SVNB were processed and modeled by the USGS (McPhee et al., 2006b), then remodeled by SNWA for training purposes of SNWA staff to show repeatability with the USGS model, with the final model completed using the TM mode and incorporating topography (Figure 5-13). Station S6 was not included in the model due to lesser data quality from an unknown source.

The model for Profile SVNB illustrates resistivity contrasts near station S4 and between S1 and S2. These different resistivity values are interpreted to be due to range-front normal faults. The fault at station S4 is a major range-front that to the west swings northward to define the eastern side of the Schell Creek Range.

SNWA drilled Test Well 184W103 just north of station S1. The well was completed to a depth of approximately 310 m bgs and encountered carbonate rocks for the majority of the borehole, with the exception of the upper 12 m, which was alluvium. This lithology correlates well with the resistivity values of profile SVNB (approximately 400–2,000 ohm-m).

5.13 AMT Profile SVNN

Profile N (SVNN) was completed in eastern Spring Valley, near the south end of SR 894 at the eastern Snake Range. The profile was sited to characterize the subsurface geometry to identify range-front faults, to interpret the adjacent SNWA well, and perhaps provide additional information to explain the

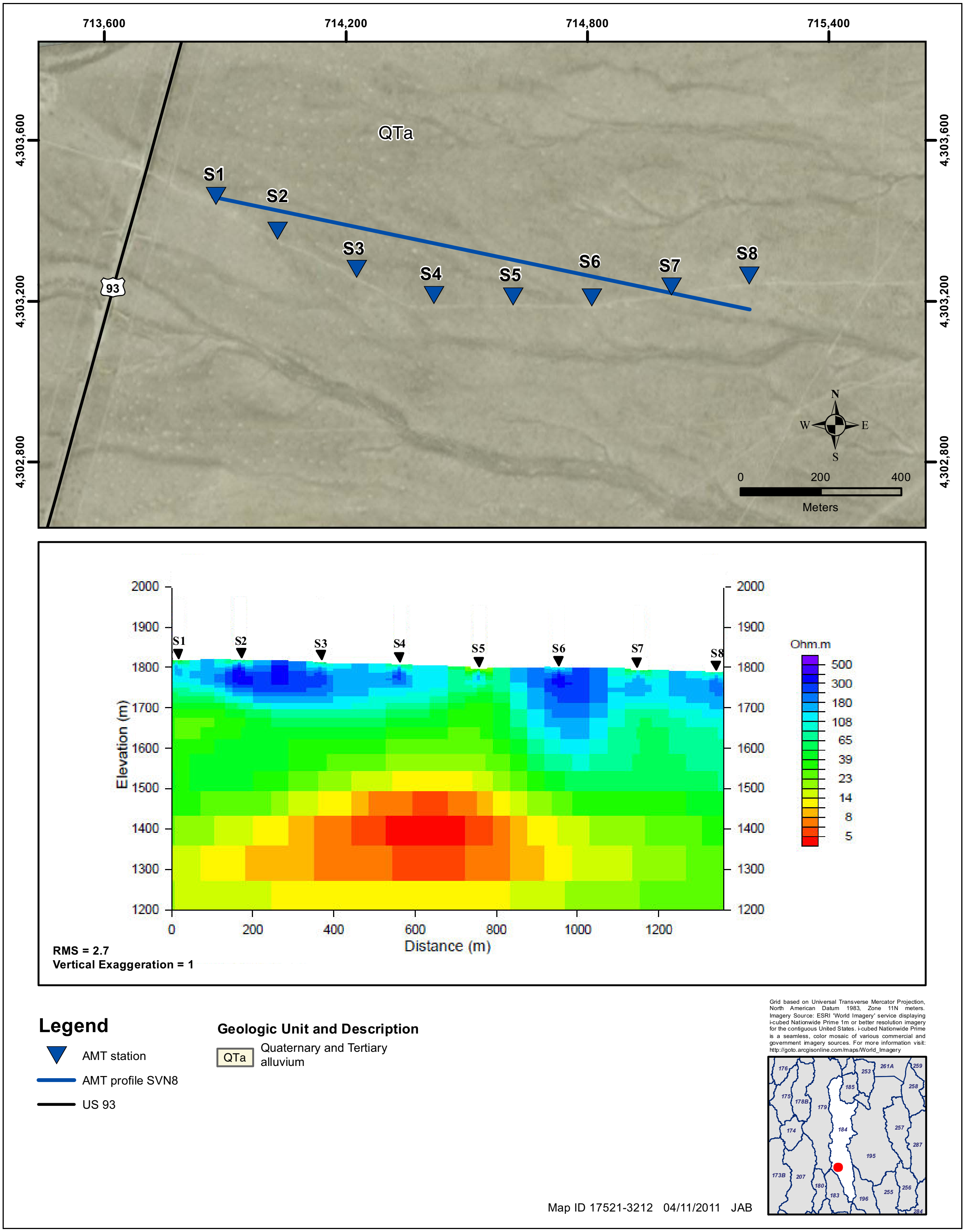


Figure 5-12
Map and 2D Model of SVN8

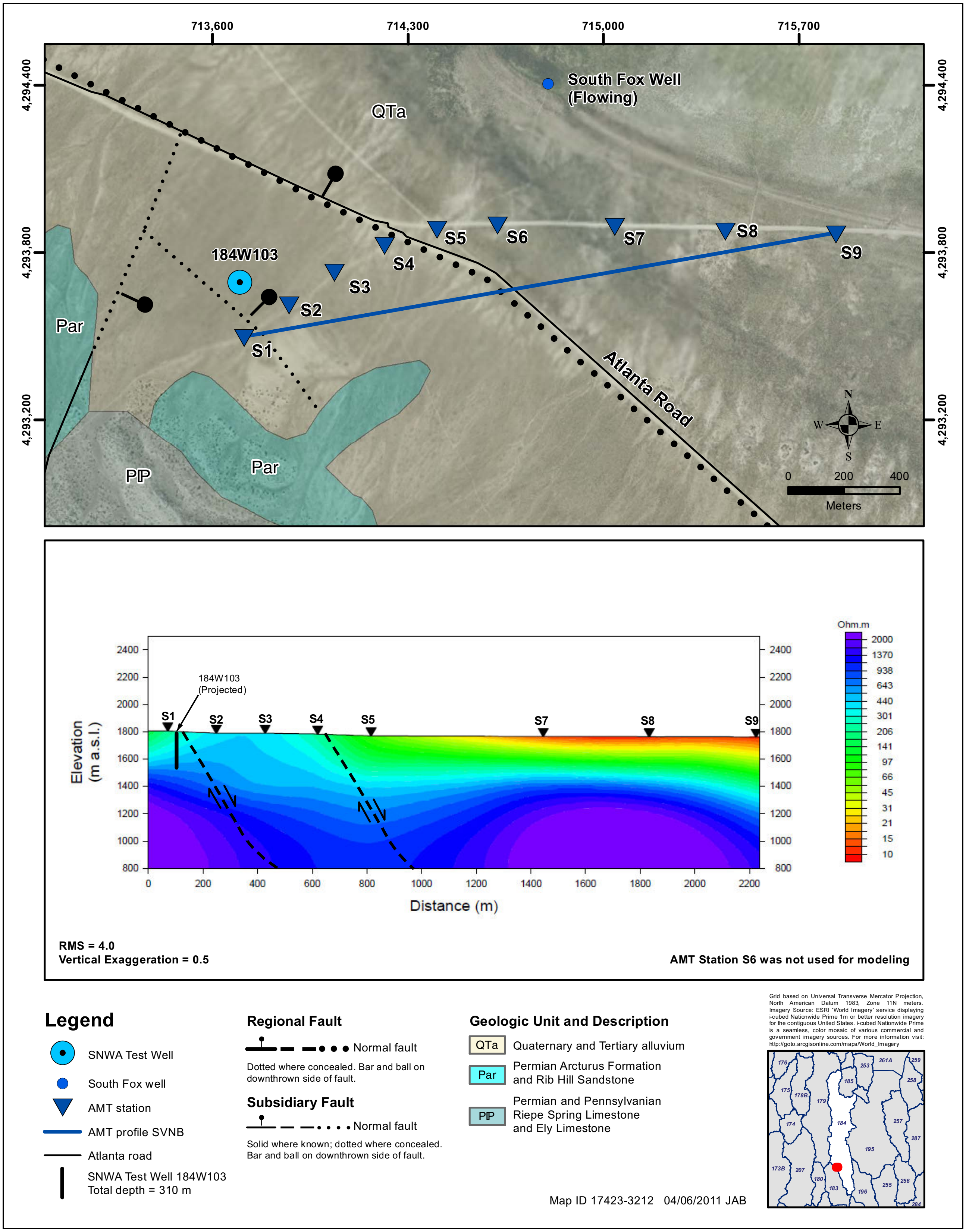


Figure 5-13
Map and 2D Model of SVNB

origin of Swallow Spring. Profile SVNN trends west, is 2,510 m long, and consists of thirteen stations with a 200 m station spacing. The data from profile SVNN were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008), with the model completed using the TM mode and incorporating topography (Figure 5-14). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile SVNN illustrates areas of relatively minor deep resistivity contrasts at station S3, and another area of profound shallow and deep resistivity change at station S12. The former is interpreted as a relatively small displacement interbasin normal fault, and the latter is the main regional range-front fault. Swallow Spring, near station S10, is in a more conductive zone (<15 ohm-m) within the basin-fill sediments, perhaps controlled by a fracture or small fault related to the regional fault at station S12.

SNWA drilled test well SPR7007X near station S6 of the profile. The well was drilled to approximately 317 m bgs and encountered Quaternary alluvium and Quaternary and Tertiary basin-fill deposits for the entire borehole. The lithology is a quartzite sand and gravel derived from the Snake Range to the east of the profile. This lithology correlates well with the resistivity values of the profile (approximately 60–100 ohm-m).

5.14 AMT Profile SVNM

Profile M (SVNM) was completed in southeastern Spring Valley, just west of the southwestern Snake Range. The profile was sited to identify range-front faults that are concealed by basin fill. Profile SVNM trends west, is 1,280 m long, and consists of seven stations with a 200 m station spacing. The data from profile SVNM were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2007), with the final model completed using the TM mode and incorporating topography (Figure 5-15). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile SVNM illustrates a large difference in shallow and deep resistivity between stations S5 through S7. This difference is interpreted as the large buried range-front normal fault zone of the western Snake Range, as mapped by Dixon et al. (2007).

5.15 AMT Profile SVNK

Profile K (SVNK) was completed in southeastern Spring Valley. The profile was sited to identify faults concealed by the basin fill. Profile SVNK trends northwest, is 2,000 m long, and consists of 11 stations with a 200 m station spacing. The data from profile SVNK were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2007), with the final model completed using the TM mode and incorporating topography (Figure 5-16). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile SVNK illustrates differences in resistivity near stations S8 and S10, and apparently also between stations S3 and S4, and are interpreted to represent three buried splays of the western range-front fault of the Snake Range.

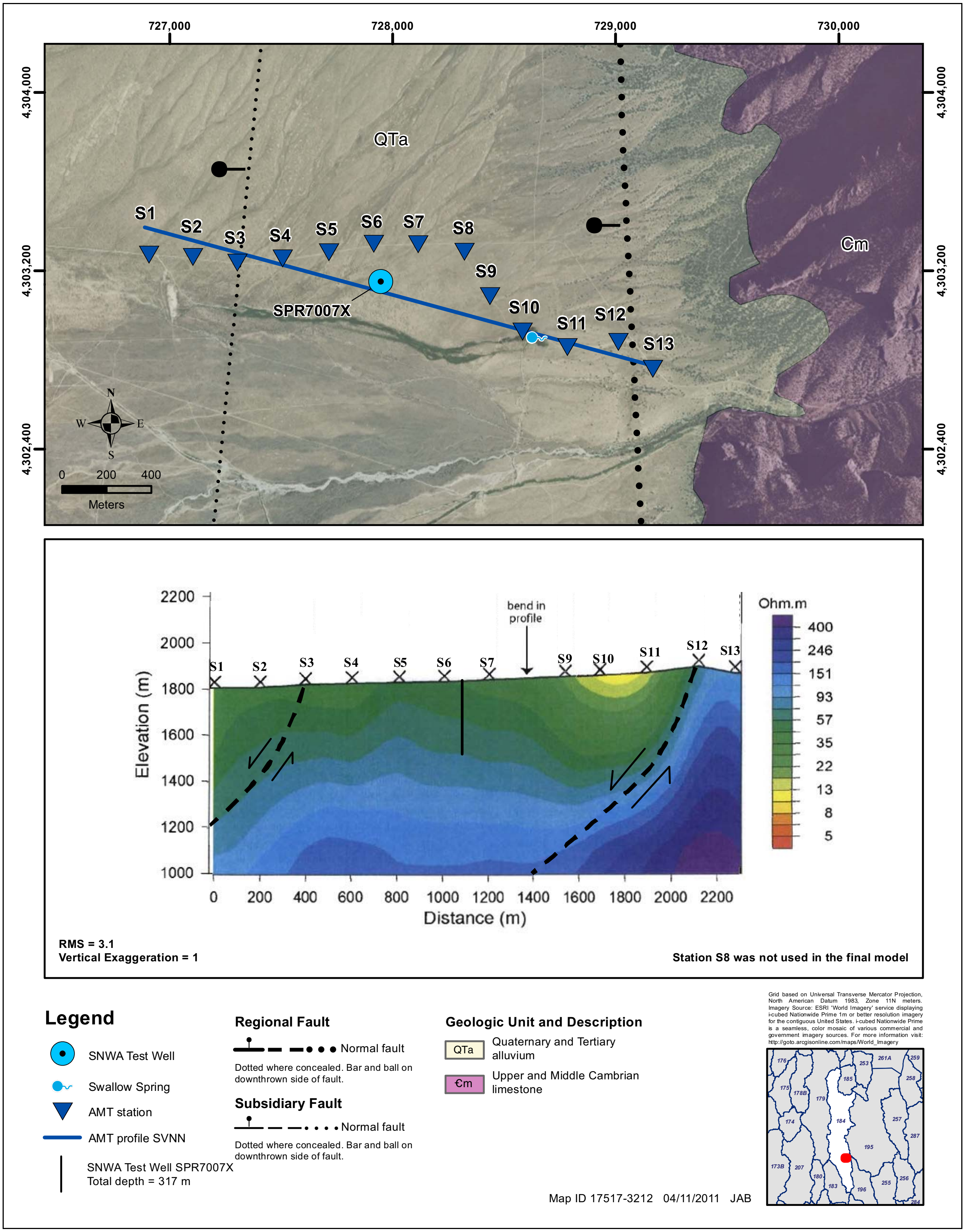


Figure 5-14
Map and 2D Model of SVNN

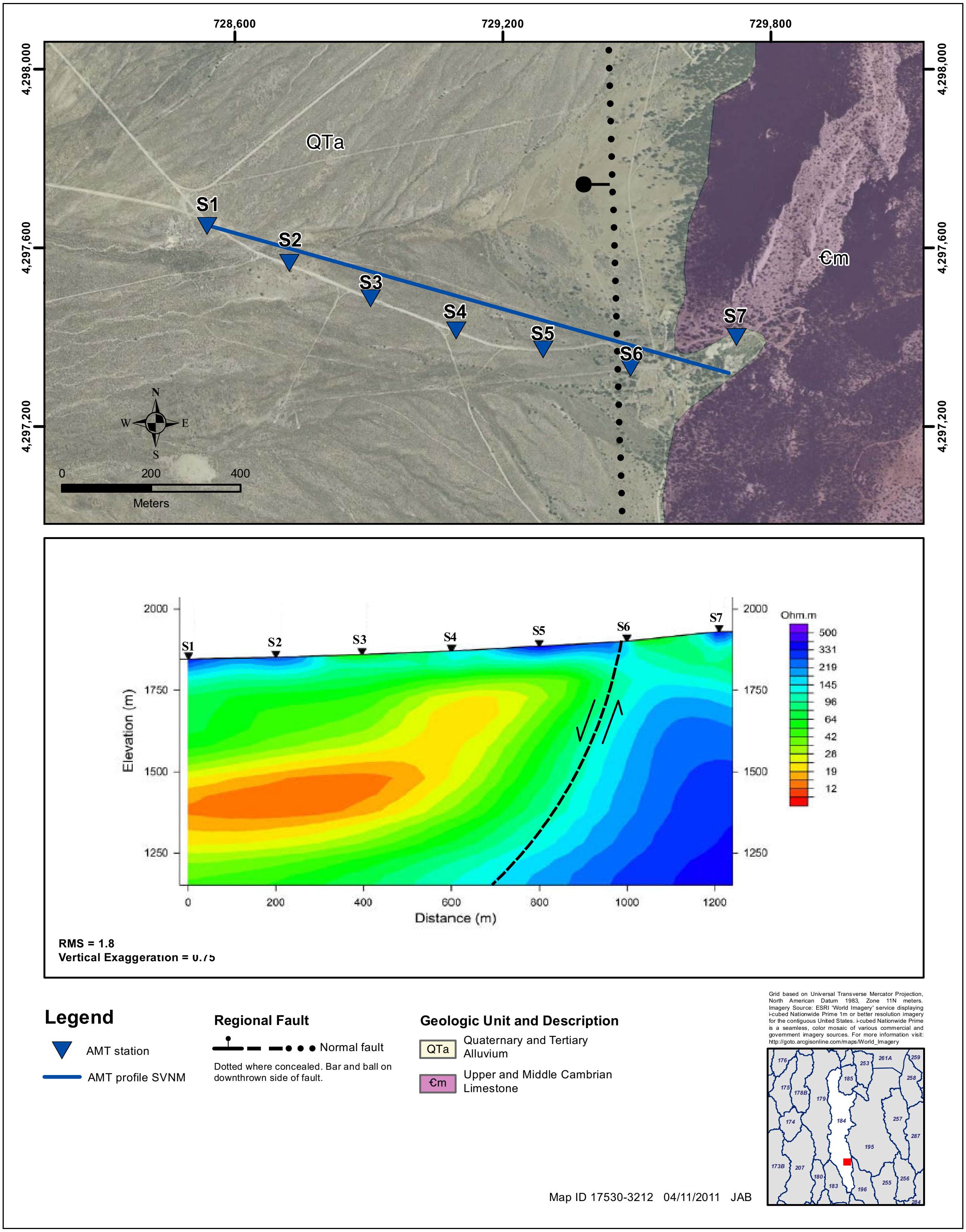


Figure 5-15
Map and 2D Model of SVNM

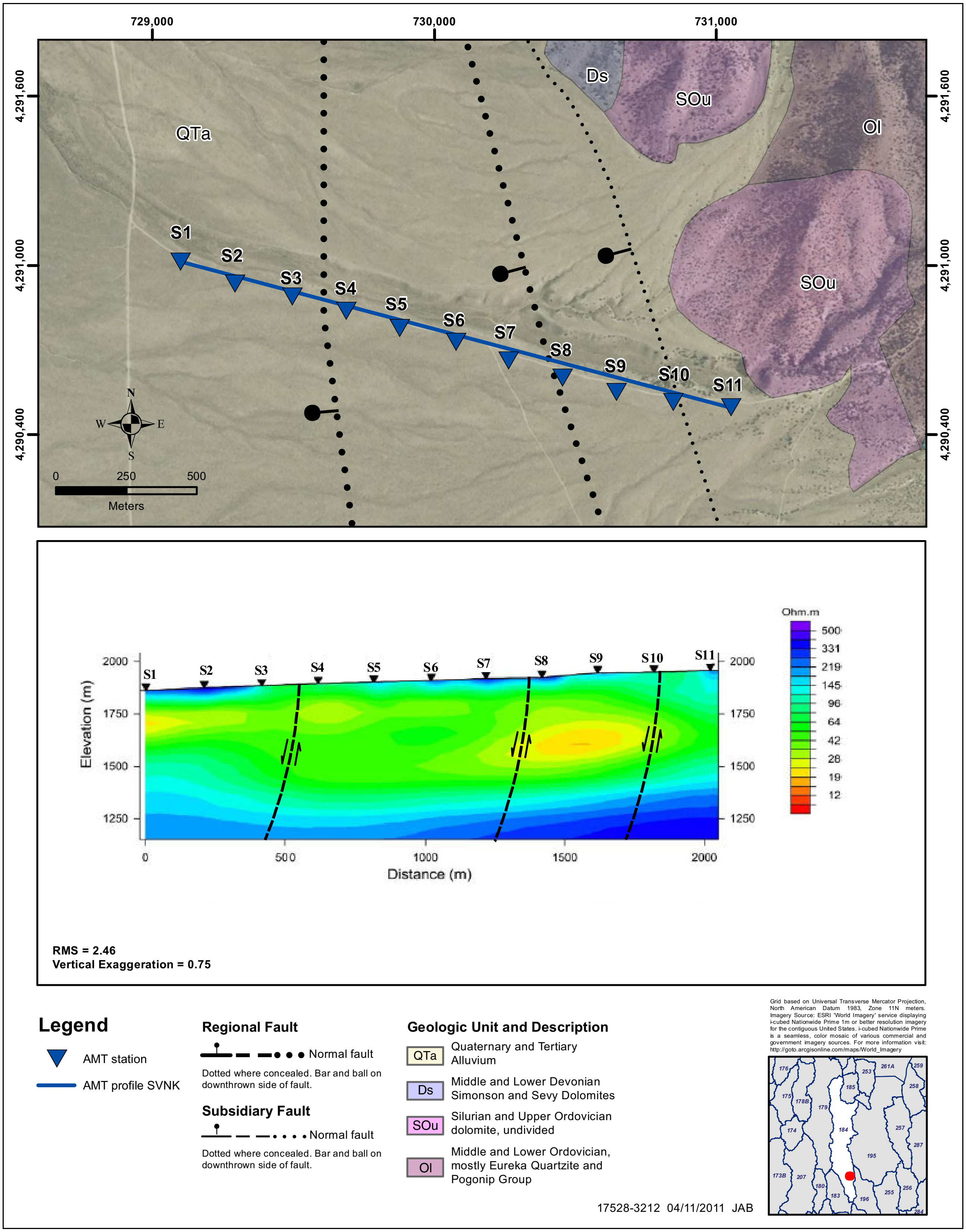


Figure 5-16
Map and 2D Model of SVNK

5.16 AMT Profile SVNA

Profile A (SVNA) was completed across southern Spring Valley, from volcanic tuff outcrops at the base of the southern Fortification Range to carbonate outcrops near the northern portion of Limestone Hills. The profile was sited to identify concealed faults at depth, and possibly to delineate the northern margin of the Indian Peak caldera complex. Profile SVNA trends west, is 12,720 m long, and consists of 63 stations with a 200 m station spacing. The data from profile SVNA were processed, modeled, and geologically interpreted by the USGS (McPhee et al., 2005, 2006a and b), with the final model completed using the TM mode and incorporating topography. The geologic interpretation was completed prior to SNWA drilling and completing Monitor Well 184W508M. Because of this, the lithology was interpreted based on the resistivity values shown on the model and not verified by borehole data. Due to overlaps in resistivity values (Palacky, 1987), lithologies such as volcanic tuffs and basin-fill alluvium would exhibit similar resistivity values. SNWA has reinterpreted some aspect of the profile (Figure 5-17).

The model for Profile SVNA illustrates 14 faults that are interpreted based on resistivity zones and correlated with large mapped faults (large dots). Conclusions about rock types based on their resistivities are given on the profile.

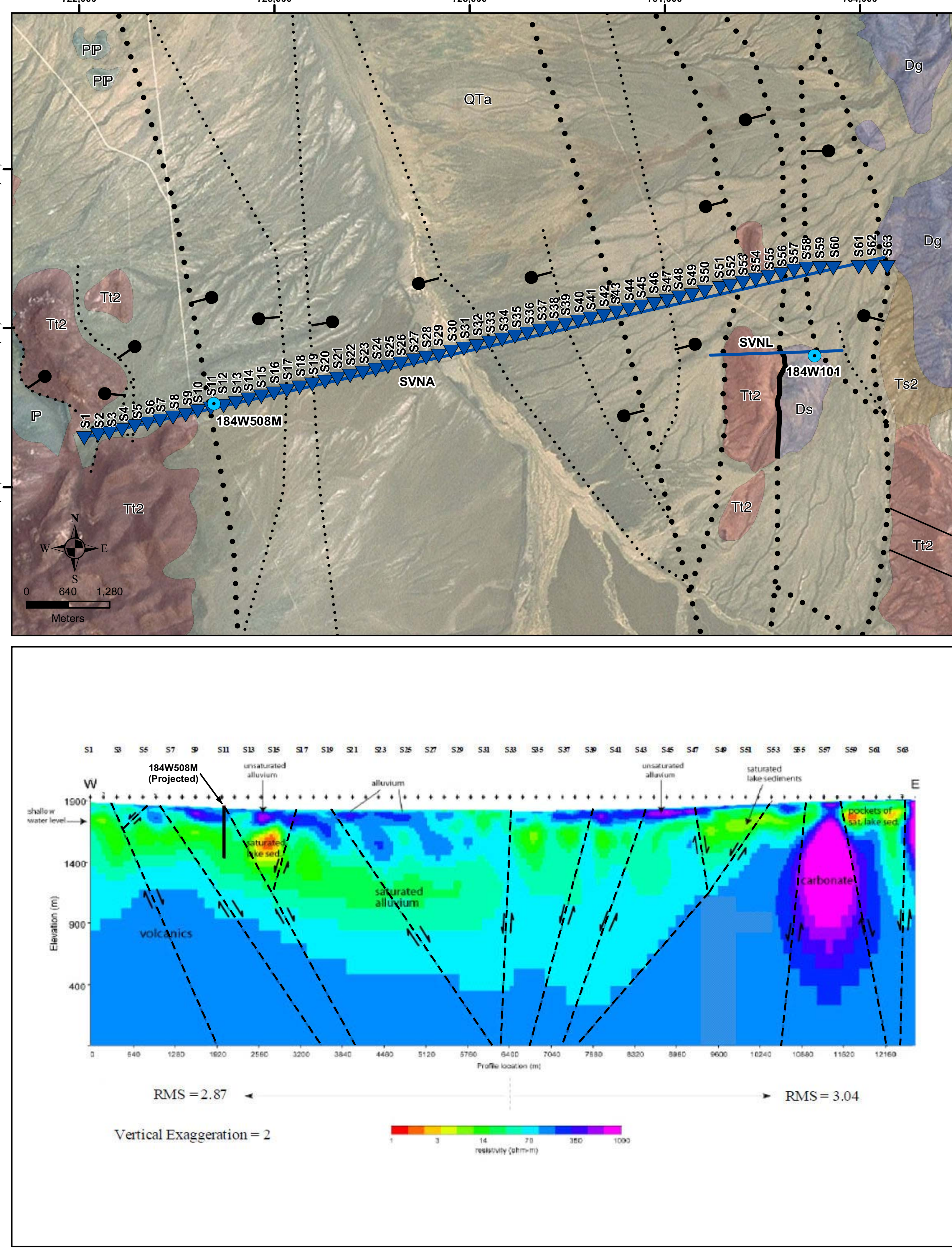
SNWA drilled Monitor Well 184W508M near station S11 of the profile. The well was completed to approximately 360 m bgs and encountered approximately 27 m of basin-fill alluvium, and approximately 332 m of nonwelded to moderately welded volcanic tuffs within the borehole. This lithology correlates well with the resistivity values of profile SVNA (approximately 14–70 ohm-m) near station S11. The location of SNWA Test Well 184W101 and Profile SVNL are shown on Figure 5-1 and will be discussed with Profile SVNL.

5.17 AMT Profile SVNL

Profile L (SVNL) was completed in southeastern Spring Valley, 1.2 km south of the eastern portion of profile SVNA. The profile was sited to identify faults between carbonate and volcanic rocks (Dixon et al., 2007), and to interpret SNWA Test Well 184W101. Profile SVNL trends west, is 2,040 m long, and consists of 12 stations with a 50 to 200 m station spacing. The data from profile SVNL were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2007), with the final model completed using the TM mode and incorporating topography (Figure 5-18). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile SVNL illustrates significant differences in deep, and to the east, shallow resistivity contrasts at stations S2, and near stations S6, S10, and S12. These resistivity differences are interpreted as west-dipping normal faults except at station S10, where a east-dipping antithetical normal fault is apparent. The west-dipping faults are regional normal faults noted by Dixon et al. (2007), probably all splays of the main range-front fault of the western Snake Range.

SNWA drilled Test Well 184W101 near station S9 of the profile. The well was completed to 536 m bgs and encountered carbonate rock for the entire borehole length. This lithology correlates well with the resistivity values of this part of the profile SVNL (approximately 100–500 ohm-m).



Legend

- AMT station
- AMT profile SVNA
- SNWA well
- SNWA Monitor Well 184W508M

Regional Fault

Normal fault

Solid where known; dotted where concealed. Bar and ball on downthrown side of fault.

Subsidiary Fault

Normal fault

Solid where known; dotted where concealed. Bar and ball on downthrown side of fault.

Geologic Unit and Description

QTa	Quaternary and Tertiary alluvium
Ts2	Tertiary, mostly tuffaceous sandstone and bedded airfall tuff
Tt2	Tertiary, poorly-densly welded ash-flow tuff and interbedded airfall tuff
IP	Pennsylvanian Ely Limestone
PIP	Permian and Pennsylvanian Riepe Spring Limestone and Ely Limestone
Dg	Upper and Middle Devonian Guilmette Formation
Ds	Middle and Lower Devonian Simonson and Sevy Dolomites

Grid based on Universal Transverse Mercator Projection, North American Datum 1983, Zone 11N meters. Imagery Source: ESRI 'World Imagery' service displaying i-cubed Nationwide Prime 1m or better resolution imagery for the contiguous United States. i-cubed Nationwide Prime is a seamless, color mosaic of various commercial and government imagery sources. For more information visit: http://goto.arcgisonline.com/maps/World_Imagery

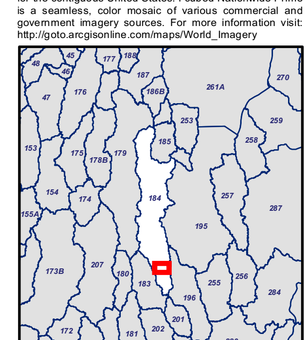


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Figure 5-17
Map and 2D Model of SVNA

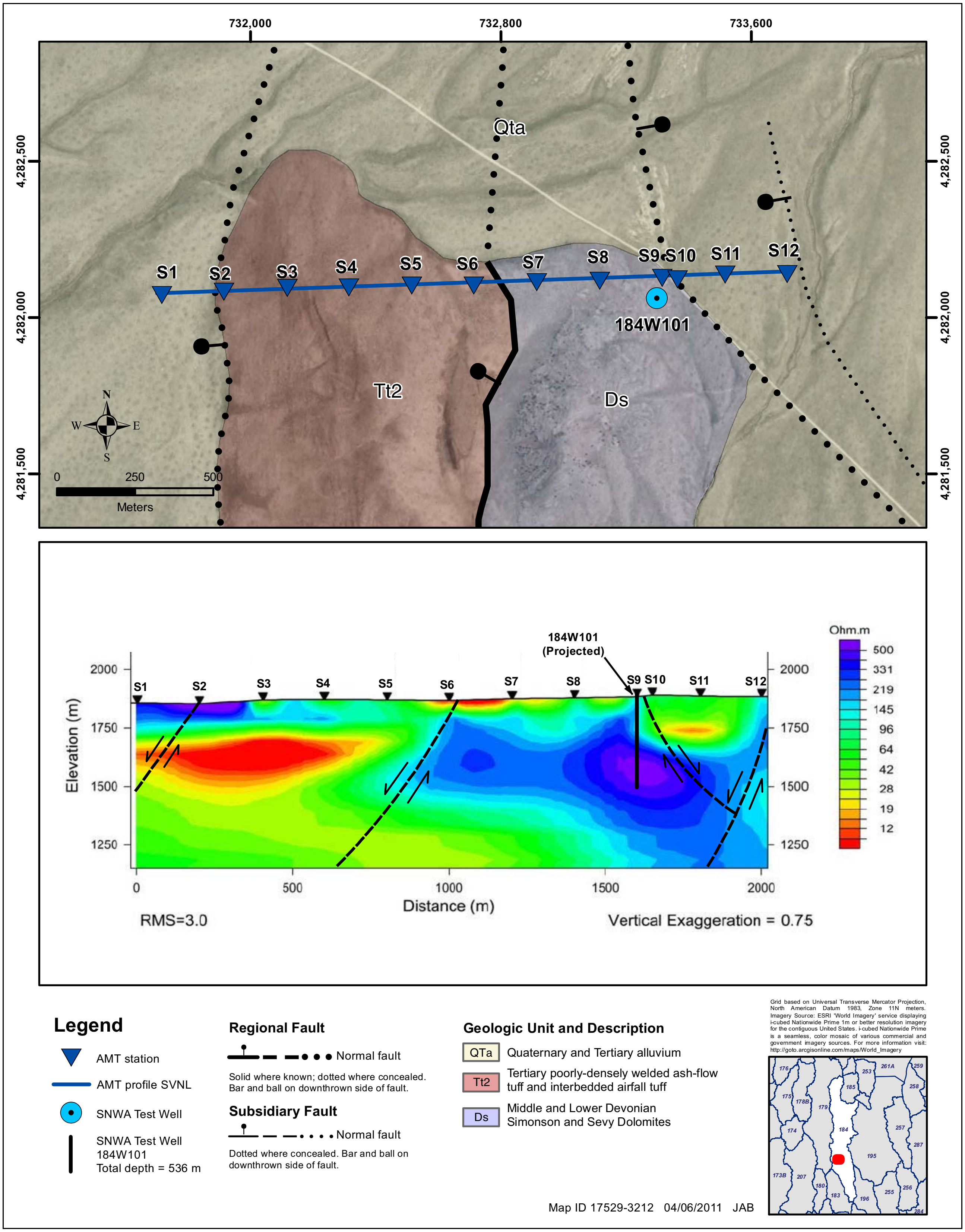

Figure 5-18
Map and 2D Model of SVNL

5.18 AMT Profile POD 54004

Profile POD 54004 was completed by LGS in southwestern Spring Valley, near SNWA POD application 54004. The profile was located to characterize the subsurface at POD application 54004, and evaluate the resistivity variation within the basin fill. The profile trends west to east, is approximately 2,000 m long, and consists of 11 stations with a 200 m station spacing. The data from profile POD 54004 were processed and modeled by LGS (Layne GeoSciences, 2009), then later re-processed, modeled, and geologically interpreted by SNWA, with the final model incorporating topography (Figure 5-19); the final model did not include station S7 due to poor data quality from an unknown source.

The model for Profile POD 54004 illustrates two shallow and deep resistivity contrasts along profile near stations S6 and between stations S8 and S9. The resistivity contrast at station S6 is interpreted as the approximate caldera margin of the Indian Springs Caldera complex mapped by Dixon et al. (2007). The contrast between stations S8 and S9 is interpreted as a down-to-the-west normal fault, likely the same antithetical structure that is illustrated at station S17 of Profile SVNA that is 6 km to the north.

5.19 AMT Profile POD 54003

Profile POD 54003 was completed in southwestern Spring Valley, east of the Fortification Range and near SNWA POD application 54003. The profile was sited to characterize the subsurface at POD application 54003, and to evaluate resistivity variations within the basin fill. Profile POD 54003 trends west, is 2,000 m long, and consists of 11 stations with a 200 m station spacing. The data from profile POD 54003 were processed, modeled, but not geologically interpreted by LGS (Layne GeoSciences, 2009), with the model completed using the TE and TM modes and incorporated topography (Figure 5-20). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile POD 54003 has no significant resistivity contrasts, therefore no evidence of buried faults. The model is one dimensional with low resistivity values indicating fine-grained sediments are present below the surface.

5.20 AMT Profile SVNQ

Profile Q (SVNQ) was completed in southeastern Spring Valley, just west of the central Limestone Hills. The profile was sited to locate buried faults. Profile SVNQ trends west, is 1,970 m long, and consists of 12 stations with a 100 to 200 m station spacing (Figure 5-21). The data from profile SVNQ were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008), with the final model completed using the TE and TM modes and incorporating topography. At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile SVNQ illustrates profound shallow and deep resistivity contrasts at stations S8 and S11. These changes are interpreted to represent the main concealed range-front fault at station S11, with a small concealed antithetical fault at station S8.

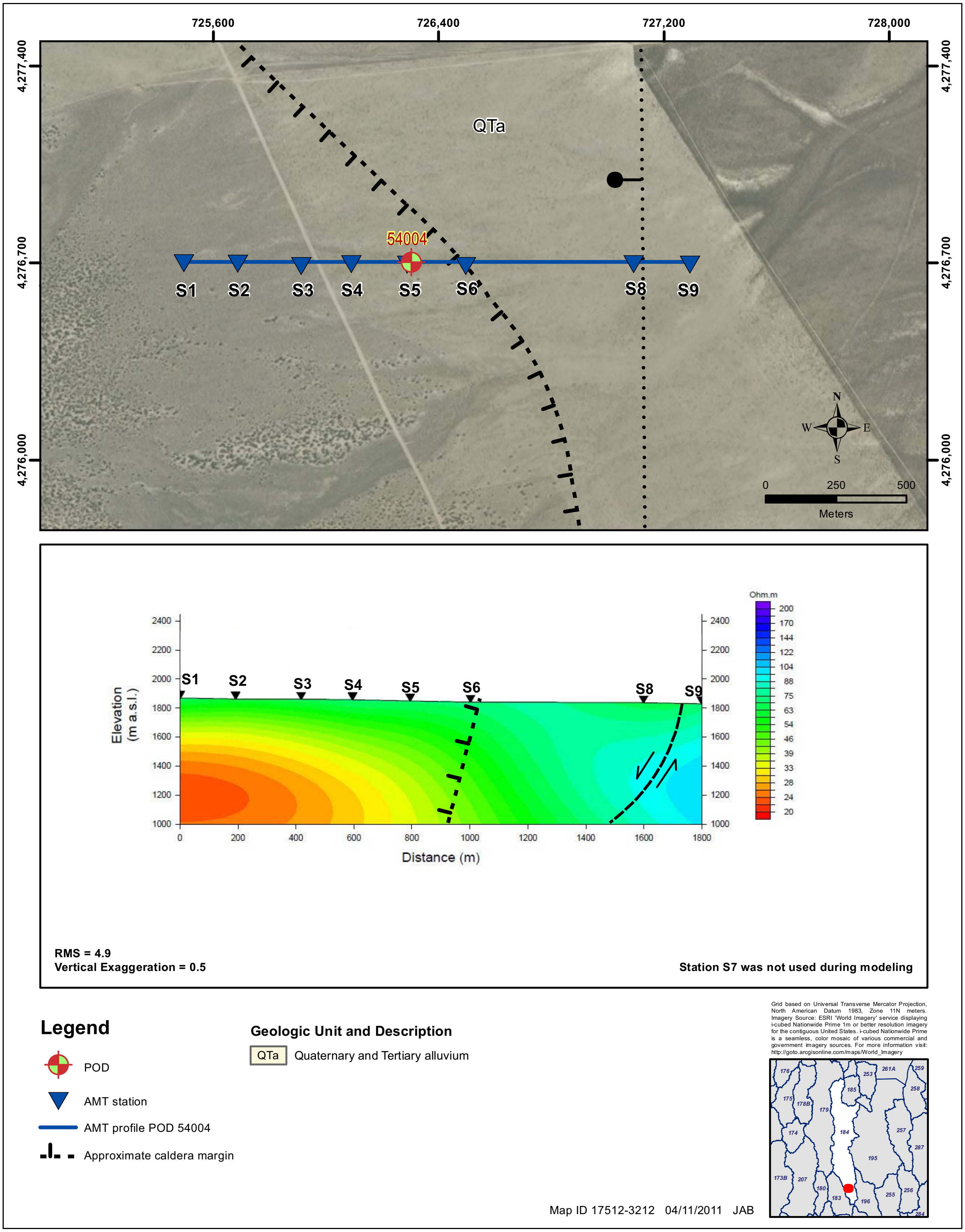

Figure 5-19
Map and 2D Model of POD 54004

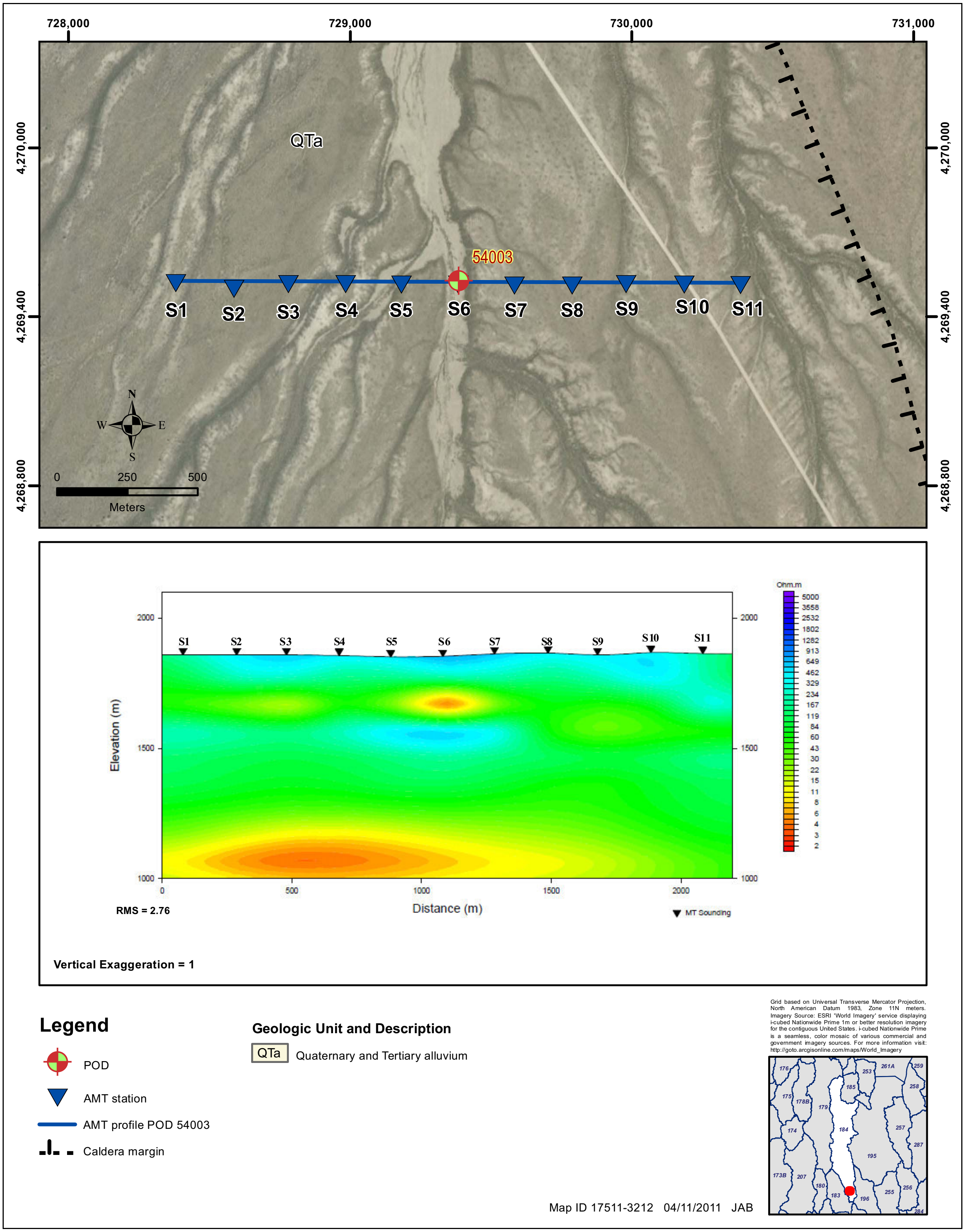

Figure 5-20
Map and 2D Model of POD 54003

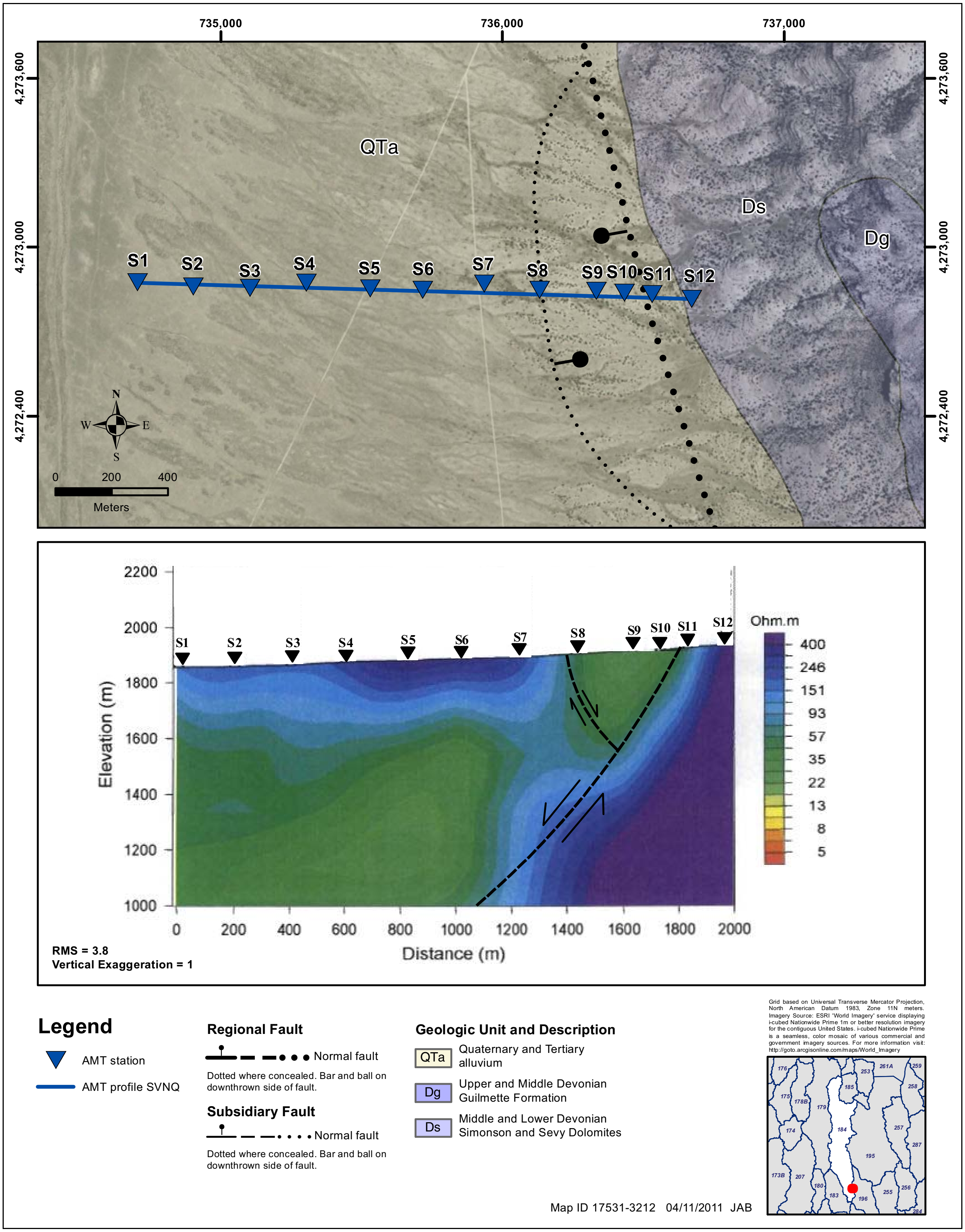

Figure 5-21
Map and 2D Model of SVNQ

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6.0 The Limestone Hills

The Troughs is a pass at the topographic divide between the southern Snake Range and the northern Limestone Hills that separates Spring Valley with Hamlin Valley. Limestone Hills is a low, north-trending range that is 21 km long and south of the Snake Range. Two AMT profiles were done in the vicinity of the Troughs to delineate concealed faults, to determine resistivity values of the basin-fill deposits, and to refine the subsurface geometry of this topographic divide (Figure 6-1). Sources of potential noise identified in the vicinity of the profiles included buried pipes, subsidiary subparallel faults, and wind.

6.1 AMT Profile SVNO

Profile O (SVNO) was completed near the Troughs. The profile was sited to identify concealed faults covered by the basin fill. Profile SVNO trends northeast, is 1,100 m long, and consists of seven stations with a 200 to 400 m station spacing. The data from profile SVNO were processed and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography (Figure 6-2). Station S2 was not used in the model due to poor data quality, likely due to faults trending at an oblique orientation to the profile. At a later time, SNWA geologically interpreted the final model provided by the USGS.

Model SVNO does not image a fault because it did not go far enough to the east, where a fault (Figure 6-2) dips east and drops down volcanic rocks to the east with respect to a buried Paleozoic carbonate rocks to the west. The model shows a gradual transition downward from conductive (10 to 15 ohm-m) saturated basin-fill deposits above and resistive (150 to 500 ohm-m) carbonate rocks below. The basin-fill deposits become gradually thicker to the east because the throw of the fault east of the profile drags the rocks vertically down adjacent the fault.

6.2 AMT Profile SVNP

Profile P (SVNP) was completed near the Troughs. The profile was sited to identify concealed faults covered by the basin fill. Profile SVNP trends east, is 2,800 m long, and consists of 15 stations with a 200 m station spacing. The data from profile SVNP was edited and modeled, but not geologically interpreted by the USGS (McPhee et al., 2008), with the final model completed using the TM mode and incorporating topography (Figure 6-3). At a later time, SNWA geologically interpreted the final model provided by the USGS.

The model for Profile SVNP shows shallow and deep resistivity contrasts that are interpreted as faults; near station S10, between stations S10 and S11, and at station S15. Although the resistivities of the rocks near the surface west of station S10 are similar to those of the surface east of station S10, the former are surficial and basin-fill sediments, whereas the latter represents a graben filled with

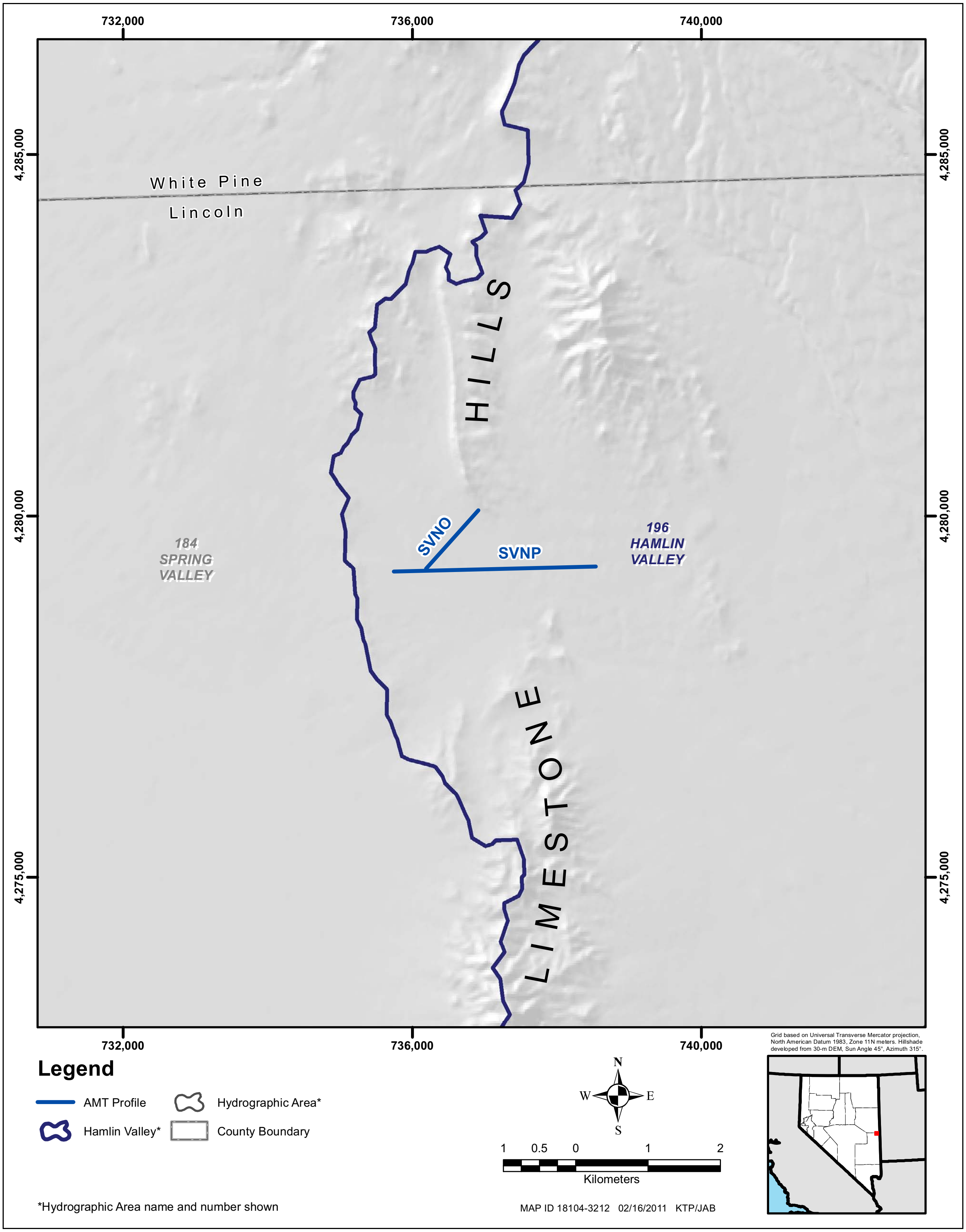
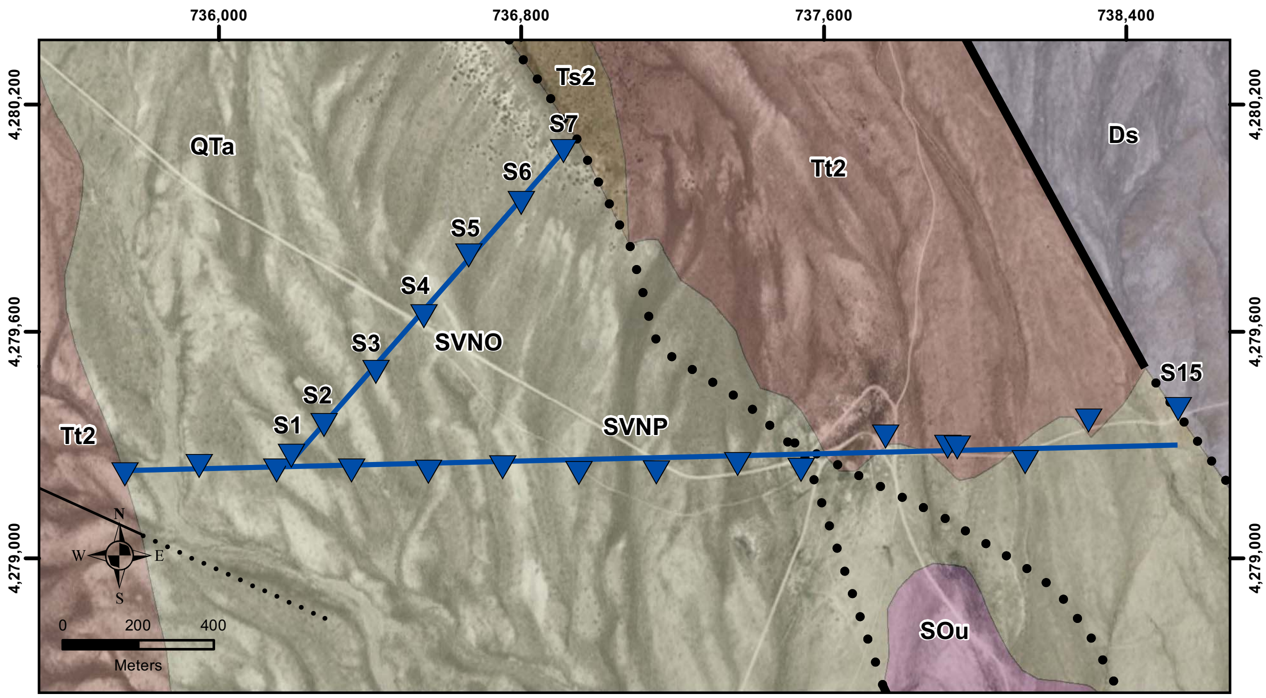
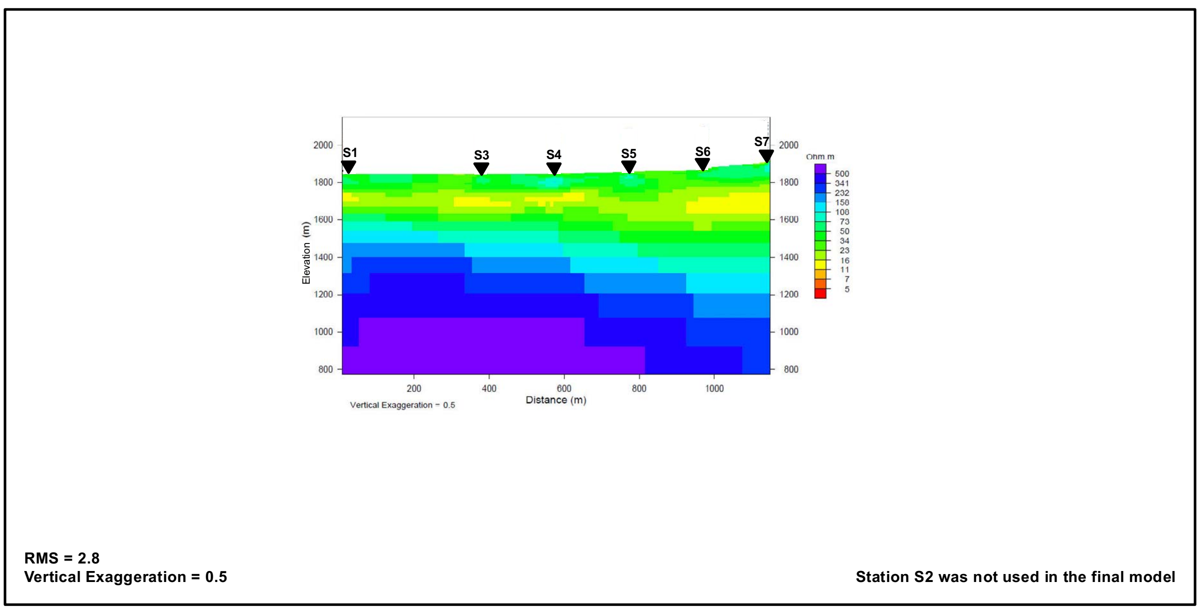


Figure 6-1
The Limestone Hills AMT Profiles





Legend

AMT station

AMT profile

Regional Fault

Normal fault

Solid where known; dotted where concealed. Bar and ball on downthrown side of fault.

Subsidiary Fault

Normal fault

Solid where known; dotted where concealed. Bar and ball on downthrown side of fault.

Geologic Unit and Description

- QTa — Quaternary and Tertiary alluvium
- Ts2 — Tertiary, mostly fluvial tuffaceous sandstone and bedded airfall tuffs
- Tt2 — Tertiary poorly-densely welded ash-flow tuff and interbedded airfall tuff
- Ds — Ds Middle and Lower Devonian Simonson and Sevy Dolomites
- SOu — Silurian and Upper Ordovician dolomite, undivided

Grid based on Universal Transverse Mercator Projection, North American Datum 1983, Zone 11N meters. Imagery Source: ESRI "World Imagery" service displaying i-cubed Nationwide Prime 1m or better resolution imagery for the contiguous United States. i-cubed Nationwide Prime is a seamless, color mosaic of various commercial and government imagery sources. For more information visit: http://goto.arcgisonline.com/maps/World_Imagery

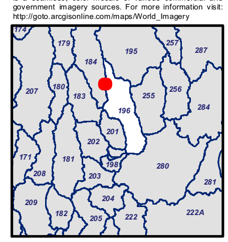


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Figure 6-2
Map and 2D Model of SVNO

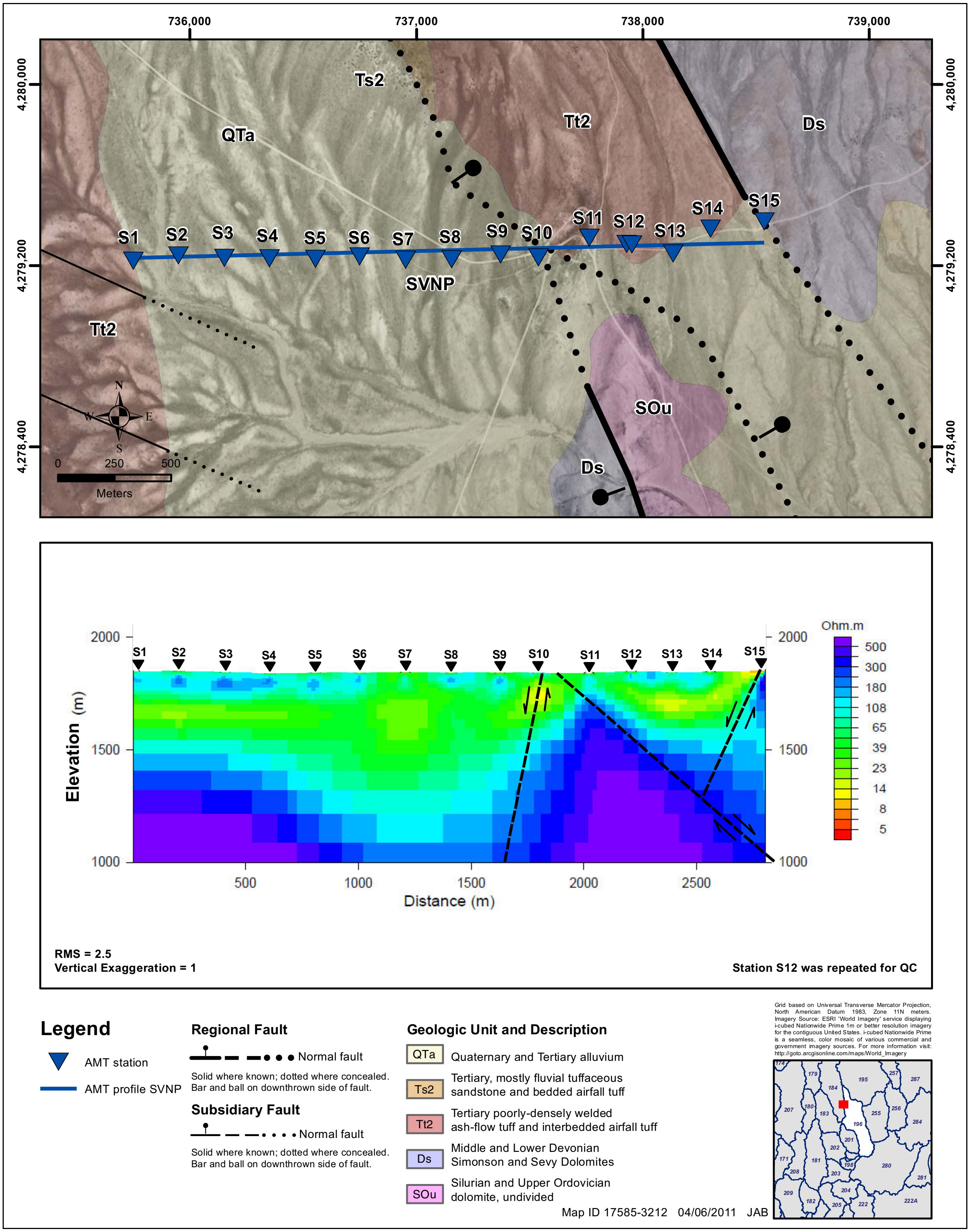

Figure 6-3
Map and 2D Model of SVNP

volcanic rocks. The high-resistivity rocks, beneath the basin-fill and volcanic rocks, represent Paleozoic carbonate rocks.

6.3 The Limestone Hills Summary

Profiles SNVNO and SVNP were collected in the topographic divide between Spring Valley and Hamlin Valley in an effort to appraise whether interbasin groundwater flow was possible beneath the divide separating Spring and Hamlin Valleys. Profile SVNP was able to delineate faults that correlate with the mapped faults discussed in Dixon et al. (2007). One of these faults, the down-to-the-east fault separating volcanic rock on the east from Silurian and Ordovician carbonate rocks on the west, may allow some groundwater to pass at depth across the basin divide.

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7.0 SUMMARY

Thirty-five AMT profiles were compiled by SNWA to assist in analyzing and characterizing the subsurface of four groundwater basins and one basin margin. The AMT method was effective in characterizing the subsurface faults along the majority of the models, and in determining the resistivity transitions in the basin-fill material and bedrock. In other words, normal faults, strike-slip faults, and geologic material types could be inferred from the resistivity values and contrasts between these values. Additionally, information was gathered to characterize current and potential production well locations. Resistivity contrasts and values from the profiles generally correlated with mapped features noted by Dixon et al. (2007) and well logs from nearby wells. The AMT geophysical method is a valuable resource for identifying subsurface features. The method is even more valuable when combined with regional gravity, ground magnetics, aeromagnetics, and seismic geophysics. In combination, the techniques can successfully determine basin geometry, fault locations, and general dip angles of beds and structures.

By conducting geophysical investigations in the four basins, SNWA was able to develop an understanding of the subsurface in a non-invasive manner. These data sets will continue to assist SNWA in siting well locations, determine interbasin groundwater flow, and delineate the geometry of project basins.

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