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Geologic Investigation of Alternative Flight Testing Sites

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Geologic Investigation of Alternative Flight Testing Sites

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Executive Summary

Sandia National Laboratories is evaluating alternative gravity bomb flight test (GBFT) options that might be more cost effective in the 2025 timeframe than the current Tonopah Test Range (TTR) facility. The alternate ranges being considered are White Sands Missile Range (WSMR) and the Nevada National Security Site (NNSS). One of the factors considered in the decision process is if the geology of the alternative sites is suitable for gravity bomb flight testing.

The study looked at seven specific sites within the three test ranges, including the TTR. Those seven sites are Main Lake and Antelope Lake at TTR, Trinity Lake at WSMR, and Yucca Lake, an area west of Frenchman Flat, Pahute Mesa, and the Pahute Airstrip all at NNSS. The four lakes studied are playas.

In general the findings indicate that the playa lakes (Main, Antelope, Trinity, and Yucca) consist of fine-grained lacustrine sediments with inter-bedded stringers of coarse grains and gravels towards the shorelines. Frenchman Flat and Pahute Airstrip are both located within basins filled with poorly sorted gravel alluviums. Pahute Mesa consists of volcanic tuff.

The seven sites are listed in order from the most favorable location to least favorable based on the suitability of the geology for GBFT. An ideal test site would consist of a succession of soft sediments devoid of hard layers. WSMR Lake Trinity is the most suitable site, exhibiting solely find-grained sediments across the study region. The lakes at TTR follow next with Antelope Lake and Main Lake, Antelope lake being finer grained and more homogeneous than Main Lake. The four NNSS sites are considered the least favorable due the heterogenetic character of Yucca Lake, Pahute Airstrip, and Frenchman Flat. The geology of Pahute Mesa is considered the least favorable consisting of volcanic tuff too hard for current test operations.

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Nomenclature

GBFT	gravity bomb flight test
NNSS	Nevada National Security Site
TEM	time-domain electromagnetic
TTR	Tonopah Test Range
WSMR	White Sands Missile Range

1. Introduction

Sandia is evaluating alternative gravity bomb flight test (GBFT) locations that would be more cost effective and possibly allow for flexibility to load level GBFT operations among several sites. The flight tests are currently being operated at the Tonopah Test Range (TTR). The two alternative test sites being considered are the White Sands Missile Range (WSMR) and the Nevada National Security Site (NNSS). In order to make an informed decision, one of the factors that need to be understood is the geology of each site. Currently, at TTR the target location is a playa lake. This study will assess if similar geologic terrain exists at the other two sites, and if not, will the differences in geology identified impact testing?

This report provides a narrative of the geology of the TTR and of the other two alternative flight test locations. The purpose is to collect, if possible, any past geologic studies and data pertinent to the proposed testing sites, compile the information gathered, and present a compressive geologic understanding of each site within one document. The amount of geologic data available for the sites varies as some sites have been studied in much greater detail than others. The intent was not to perform new work, but to only assess the studies to date.

There are seven specific sites within the three test ranges that were evaluated for their geologic suitability as a GBFT site. A suitable site is defined as a geologic region consisting primarily of soft-grained sediments devoid of hard layers which could potentially damage weapon components. Those seven sites are Main Lake and Antelope Lake at TTR, Trinity Lake at WSMR, and Yucca Lake, an area west of Frenchman Flat, Pahute Mesa, and the Pahute Airstrip at NNSS. In general the findings indicate that the playa lakes (Main, Antelope, Trinity, and Yucca) consist of fine-grained lacustrine sediments with inter-bedded stringers of coarse grains and gravels towards the shorelines. Frenchman Flat and Pahute Airstrip are both located within basins filled with poorly sorted gravel alluviums. Pahute Mesa consists of volcanic tuff. The geology of each site is summarized below by test range.

2. Tonopah Test Range

Tonopah Test Range, located in Nye County, central Nevada is the current test range used for GBFT and has been the host to various other air-delivered weapon systems for decades. Testing occurs at two playa lakes – Main Lake and Antelope Lake - with the majority of testing having been conducted at Main Lake. A comprehensive SAND report was written in 2004 (Rautman, 2004) describing the geology of the two dry lake beds. The report is a product of a geologic drilling and geophysical program to assess the suitability of the playa lakes for subsurface penetrator testing. The TTR is located within the Basin and Range geologic province, specifically the Great Basin section. The province is characterized by a series of fault-block mountains separated by depositional basins. The ranges are volcanic and are generally composed of rhyolitic rocks. The depositional basins contain unconsolidated sediments, which include the playa lakes, accumulated over volcanic rocks located at depth. The playas Main

Lake and Antelope Lake are located within one such basin positioned between the Cactus Range to the west and the Kawitch Range to the east (Figure 1). Both lakes are located closer to Cactus Range than the Kawitch Range.

The 2004 study focused on defining the basic subsurface geology of the two playa lakes, specifically to identify ‘soft’ versus ‘hard’ layers. (The term ‘soft’ indicating fine grained clay and silt sediments, whereas ‘hard’ indicating large grained sediments and clasts). The study consisted of core drilling, rotary drilling, downhole geophysical logging, and time-domain electromagnetic (TEM) profiling. In addition the study also incorporated information gleamed from two previous studies – a 1964 report that examined drive-cores from the entire Main Lake (Woodward-Clyde-Sherrard, 1964) and a 1996 report (Hansen and Patterson, 1996) presenting the results from a cone penetrometer, which hydraulically pushed a probe to depth of refusal at several locations at Main Lake.

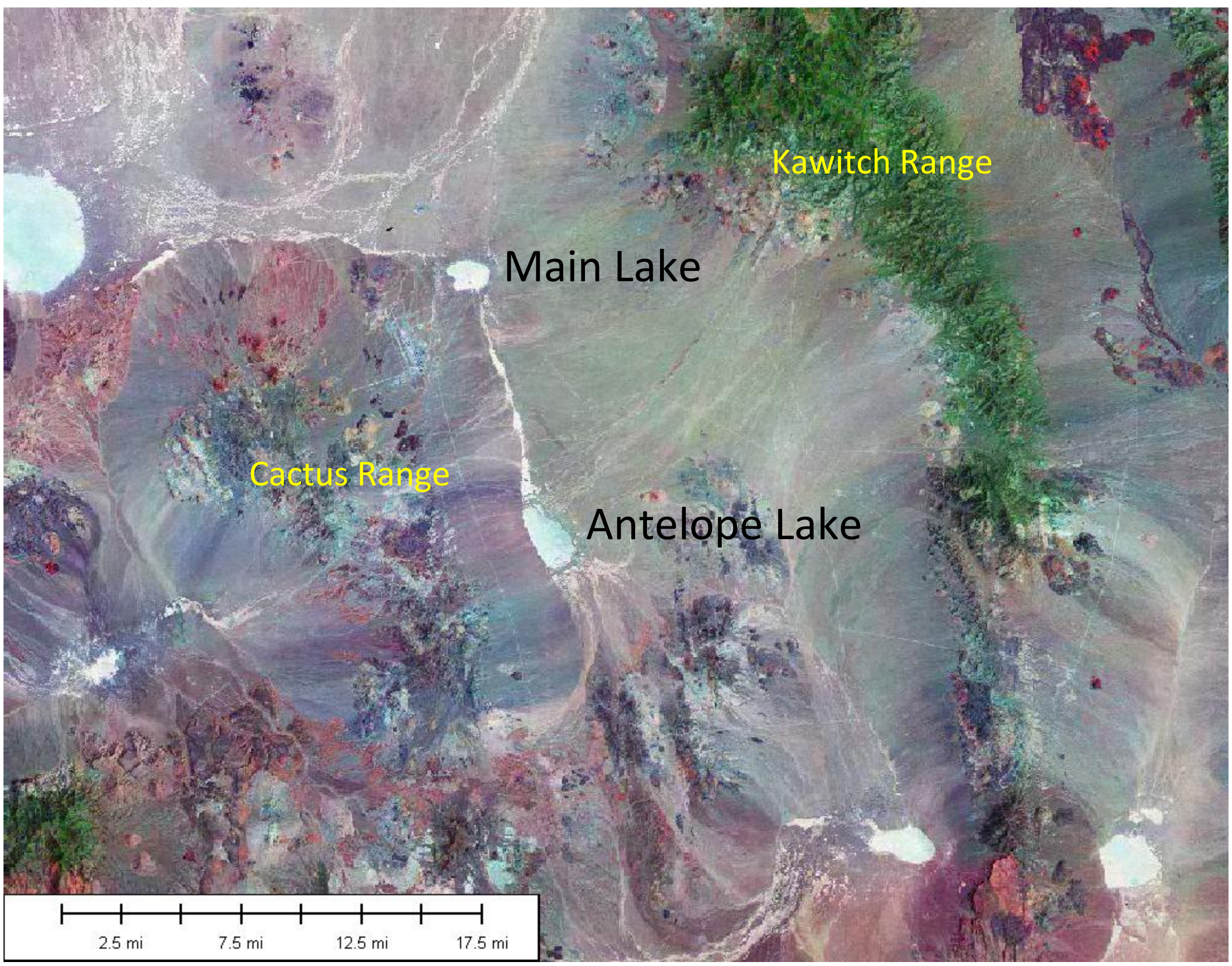

Figure 1. Land sat imagery for part of the Tonopah Test Range and vicinity showing Main Lake, Antelope Lake, the Cactus Range to the west and the Kawitch Range to the east. Figure from Rautman, 2004.

2.1 Main Lake

The study location at Main Lake consisted of the southern half of the dry lake where the most recent testing activities at the time had occurred and was designed to overlap with the cone penetrometer survey conducted in 1996. The geologic evaluation consisted of core drilling, rotary drilling, and downhole geophysical logging to a depth of 40 ft. Figure 2 shows the layout of the drill program as well as the positions of the previous cone penetrometer tests. Nineteen cores were acquired, 71 open holes were drilled and geophysical logs were run in all 90 drill holes.

The main objective of the coring program was to discover the distribution of the coarser grained layers. In general within the 40 feet cored, the top 6 feet consisted of surficial clay. Below the clay the layers alternated between clayey and silty sand among clayey 'gravel' beds. The layers consisting of the coarser grain fraction consisted of granules enclosed by a clay and silt matrix. Within some layers the clasts were in contact with each other, while in other regions the clasts were 'floating' within the matrix.

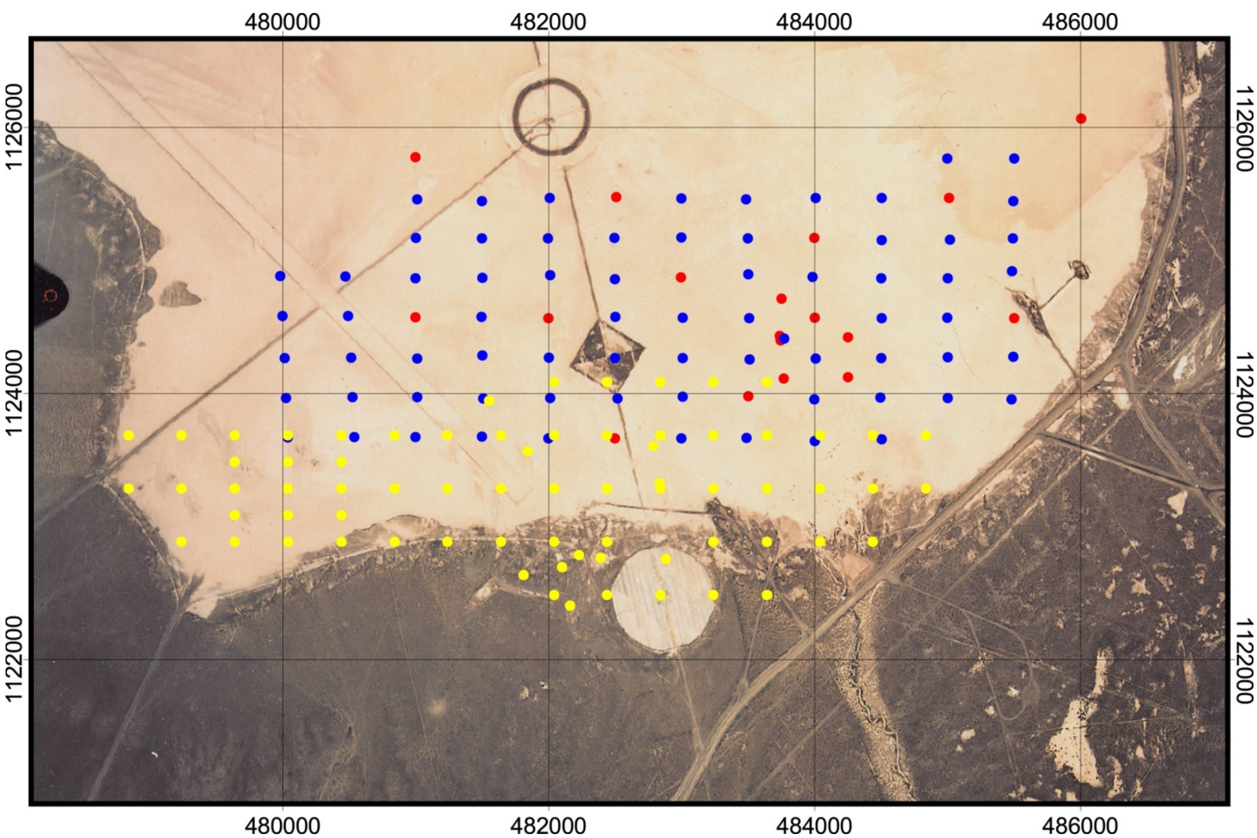

Figure 2. Detail of the southern Main Lake showing several permanently marked targets, as well as the core holes (red) and rotary holes (blue) of this program compared with the positions of cone-penetrometer testing (yellow) reported by Hansen and Pattersen (1996). Grid is Nevada state plane coordinate system, NAD-27, in feet. Figure from Rautman, 2004.

Geophysical logging was conducted in all 90 drill holes. The logging parameter of interest was the density log. Bulk density is inferred from measuring electron density within the formation using a radioactive source. High density measurements indicate dense (i.e. hard) layers. The density values of 2.0 – 2.1 gm/cm^3 measured at Main Lake correlate to sediments containing gravels and coarse sands. Figure 3 groups three core logs to a geophysical log from a hole nearby. The density log correlates fairly well with the core logs. Where the density measures above 2.0 gm/cm^3 the cores generally display coarser grained layers. Figure 4 displays the distribution of density measurements logged across the entire study area. The greatest densities measured are concentrated towards the eastern and southeastern portion of the mapped volume. Those same layers decrease in thickness and number towards the west and slightly to the north.

The geophysical traces were also compared to the 1996 cone penetrator tests. The comparison was not at the same spatial location, but in close proximity. In general the depth where the density increased corresponded to depth where the cone penetrator tip met resistance further supporting that the density measurements can be used as a surrogate to hardness.

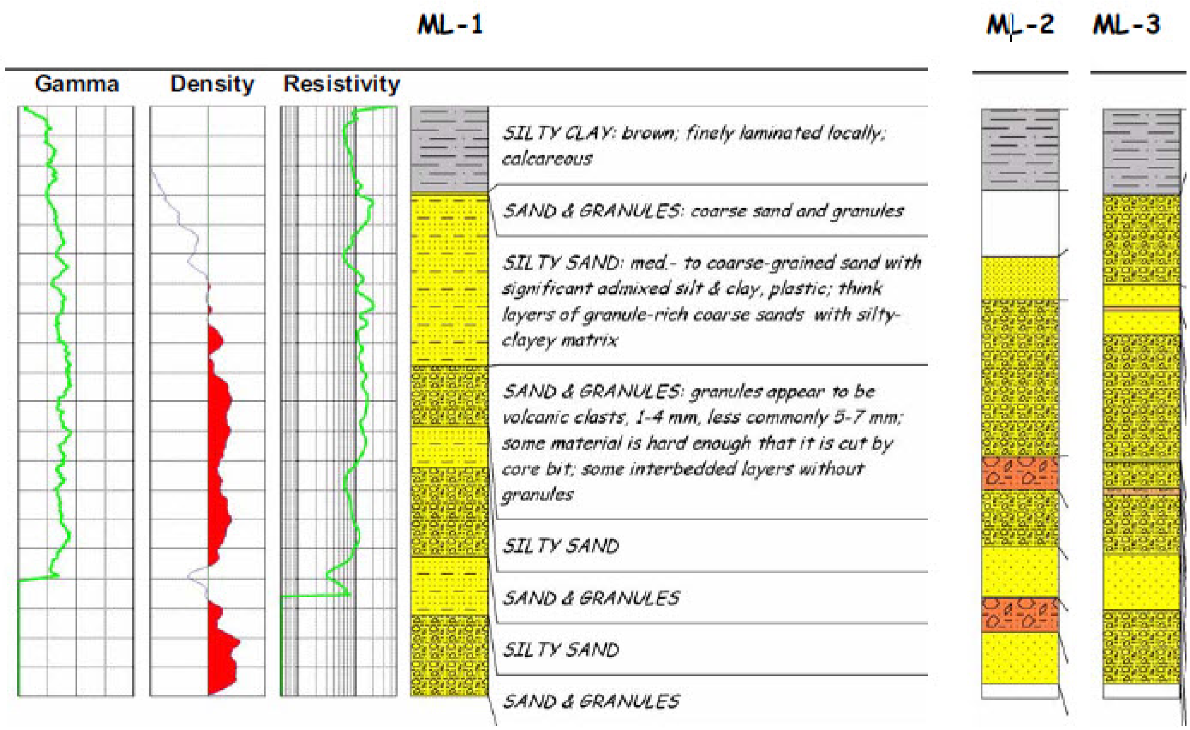

Figure 3. Core logs for drill holes ML-1, ML-2, and MF-3, together with geophysical logs from rotary hole MLR-44. Density values > 2.0 g/cm^3 shaded red. Total depth of each hole is 40 ft. All four holes are located within a radius of less than 20 ft. Figure from Rautman, 2004.

A minimal number of core samples were tested in the laboratory for rock strength. In essence the layers consisting of large volcanic clasts in contact with the surrounding clasts behaved like a mass of parent volcanic rock and hence exhibited great strength, whereas the layers where the volcanic clasts were ‘floating’ in a clay matrix could accommodate early stain by the ability to be displaced within the soft surrounding matrix (Rautman, 2004).

Inference from the compilation of results suggest the Main Lake subsurface geology consists at the near-surface of soft, clay-rich sediments down to a depth between 6 and 10 ft. Below the soft sediments is a complex sequence of inter-fingered fine and coarse grained sediments with the coarse grained materials ranging in size between 1 – 2 cm. These layers cannot be correlated across long distances. With the location of the Main Lake playa in close proximity between the Cactus Range to the west and the Kawtich Range to the east the inter-fingered sections are mostly likely the result of debris flows occurring over time. The lack of grain size sorting is also likely the result of the close proximity to both ranges as sorting typically increases with increasing transport distance. The results show a decrease in ‘hard’ layers towards the west.

The dominance of high density, coarse grained material is widespread across the southeastern and southern portion of the lake below 6 to 10 ft. The debris flow deposits appear to have come to rest near the eastern margin of the lake.

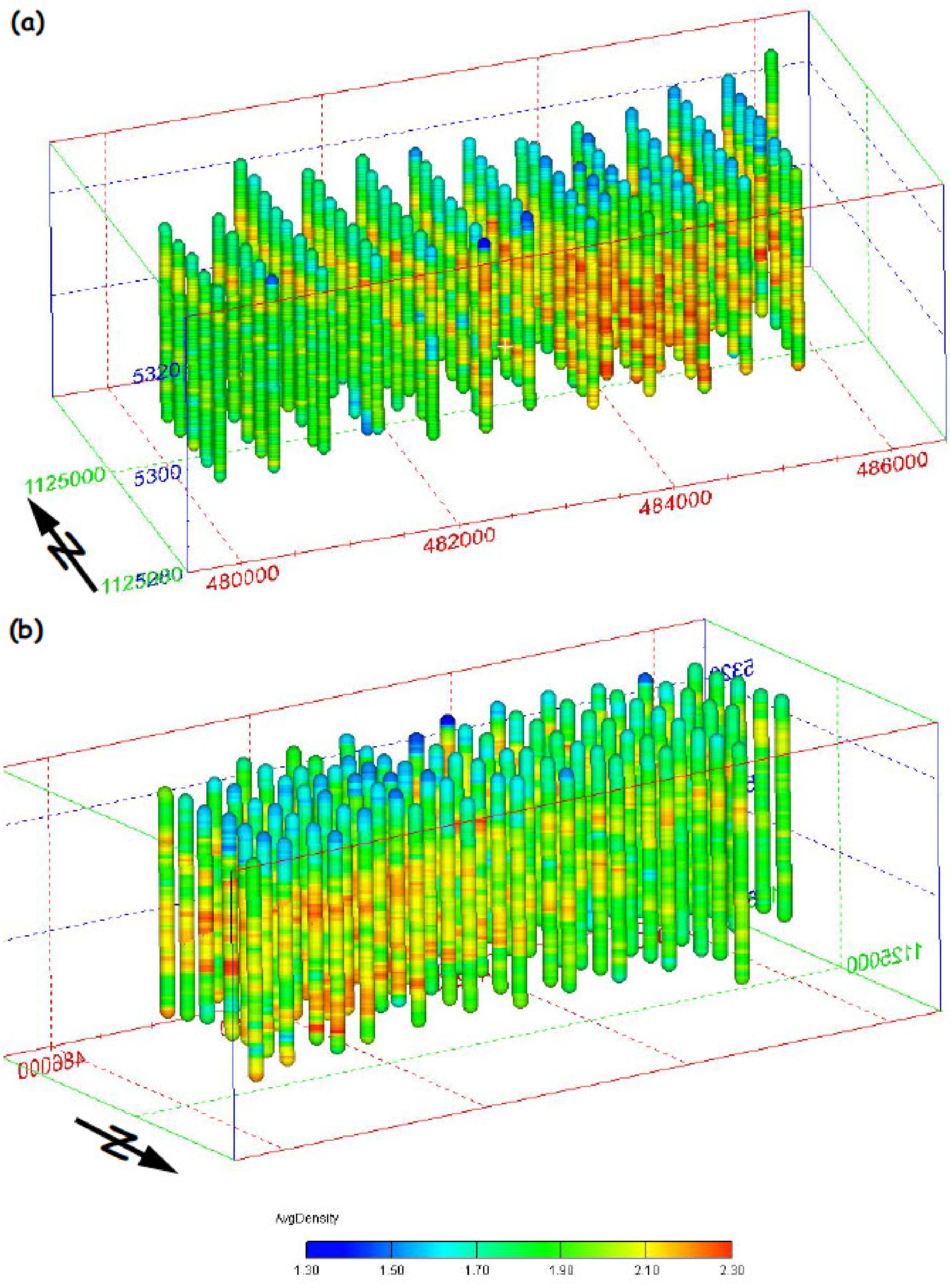

Figure 4. A 3D representation of bulk density at Main Lake, (a) view from the southwest, (b) view from the northeast. One-half-foot averaged densities shown by color scale. Boreholes are all approximately 40 ft. deep. Grid is Nevada state plane coordinate system, NAD-27, in feet. Figure from Rautman, 2004.

2.2 Antelope Lake

Antelope Lake, located 10 miles to the south of Main Lake (Figure 1), had not been previously studied in any detail. Because of the lack of prior characterization the 2004 study was designed to be two-fold to include both a surface-based geophysical investigation as well as a drilling program. The geophysics consisted of a time-domain electromagnetic (TEM) soundings closely spaced coupled with more sparse Schlumberger vertical resistivity soundings. The geophysical survey was over a large areal expanse of the lake, approximately 1.5 X 3 miles (Figure 5). The drilling layout was based on the geophysics results and consisted both of 11 core holes and 20 rotary drilled holes. Drilling was done to a greater depth than Main Lake, to nearly 100 feet, and a larger geophysical log suite was run.

Three different electromagnetic surveys were conducted over the eastern portion of Antelope Lake, TEM resistivity survey, direct –current (Schlumberger-array resistivity), and EM-31 (frequency-domain electromagnetic). All three surveys differ by method, but all three measures the electrical character of the sediments. In general fine-grained sediments have the capability to hold more water due to capillary properties and therefore are more conductive (i.e. less resistive), whereas coarse-grained sediments hold less water and consequently are less conductive (i.e. more resistive). The Rautman (2004) report provides greater detail for each of the three survey methods.

Prior to employing these techniques at Antelope Lake, additional geophysical surveys were conducted over Main Lake in the intent to calibrate the tool over an area with a now well defined subsurface structure. The results validated the original subsurface interpretation. The design for Antelope Lake is displayed in Figure 5 and encompasses the eastern margin of the playa and consists of two north-south profiles and one east-west profile connecting the north-south lines. The Schlumberger soundings were conducted at a select number of TEM locations. The results are displayed in Figures 6-8. The core drilling was designed to check the validity of the geophysics survey and the rotary drilling filled in between the cores in a grid pattern. Results displayed in Figures 9 and 10.

In general the results indicate more conductive materials towards the center of the lake and higher resistivity materials towards the shoreline. The pattern depicted is indicative of a depositional basin with more conductive/finer grained sediments towards the center of the lake and shoreward thickening of the more resistive/coarser-grained sediments. The core holes were strategically located to confirm the geophysics interpretation. Both the core and geophysical logs run within the holes confirmed the interpretation that low resistivity indicates fine sediments and high resistivity corresponds to coarser grained layers. Down to a depth of 40 feet, the sediments are very fine grained. The sediment size, away from the shore line, falls within the silty to sandy clay size. In addition there is evidence of large scaled fractures and faulting at the surface that may originate at depth.

In summary Antelope Lake is much larger than Main Lake and portrays a similar geology. In general the lake is finer grained and more homogeneous than Main Lake.

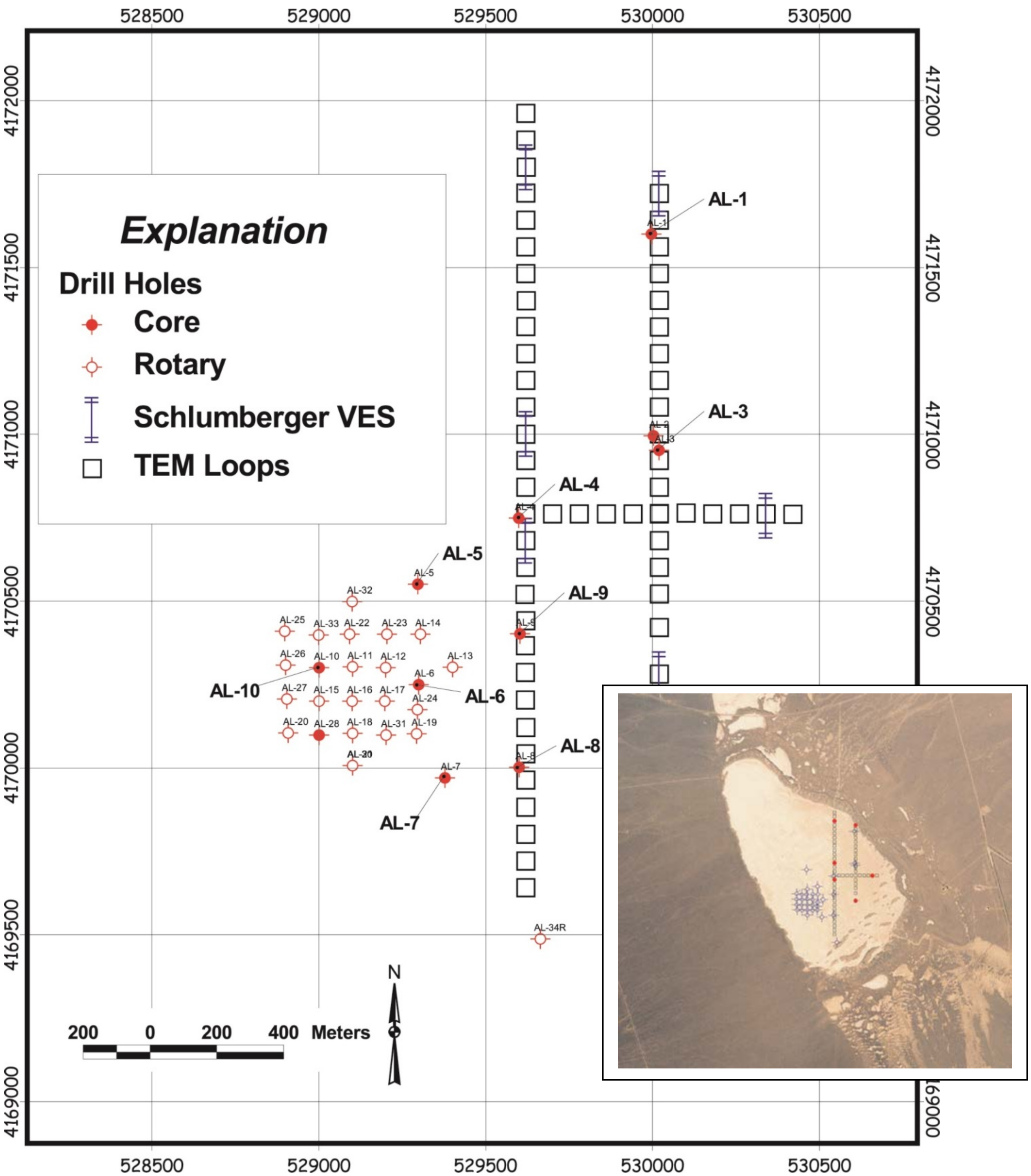

Figure 5. Location of drill holes (open circles), the TEM profiles (open squares), and Schlumberger soundings (red dots) on Antelope Lake. Figure adapted from Rautman, 2004.

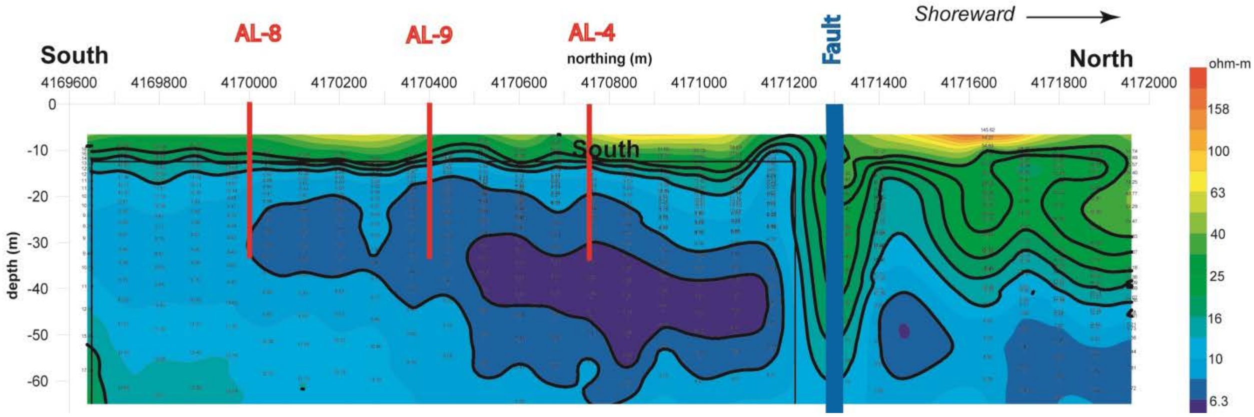

Figure 6. North-south TEM profile number 1 (west), showing modeled electrical resistivity. Drill holes approximately located in red. 10X vertical exaggeration. Figure from Rautman, 2004.

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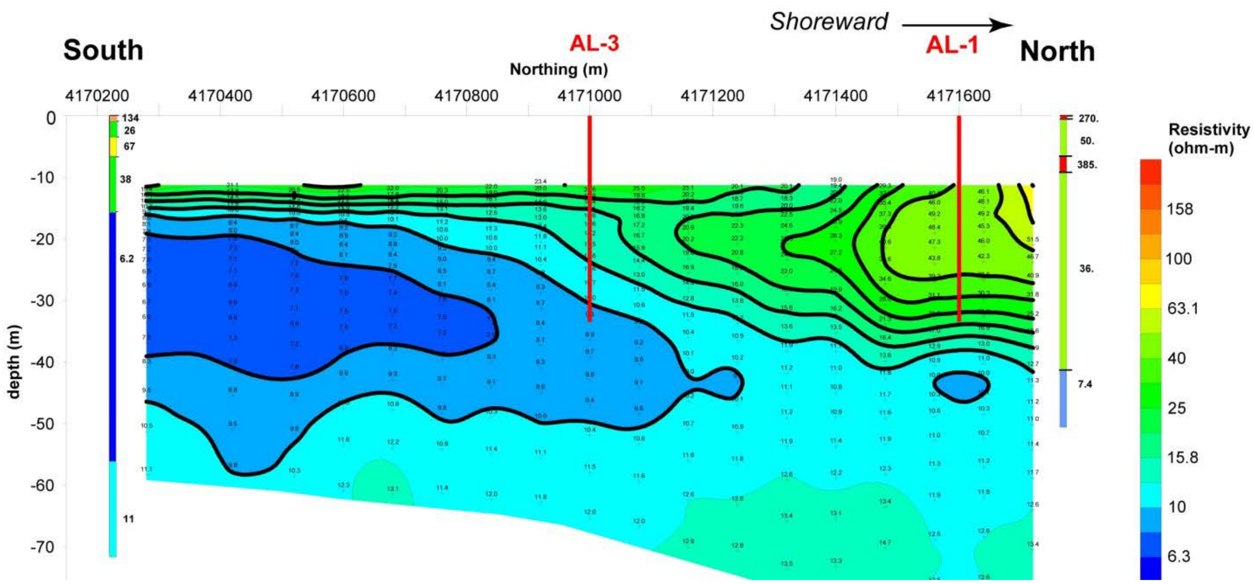

Figure 7. North-south TEM profile number 3 (east), showing modeled electrical resistivity. Drill holes approximately located in red. 10X vertical exaggeration. Figure from Rautman, 2004.

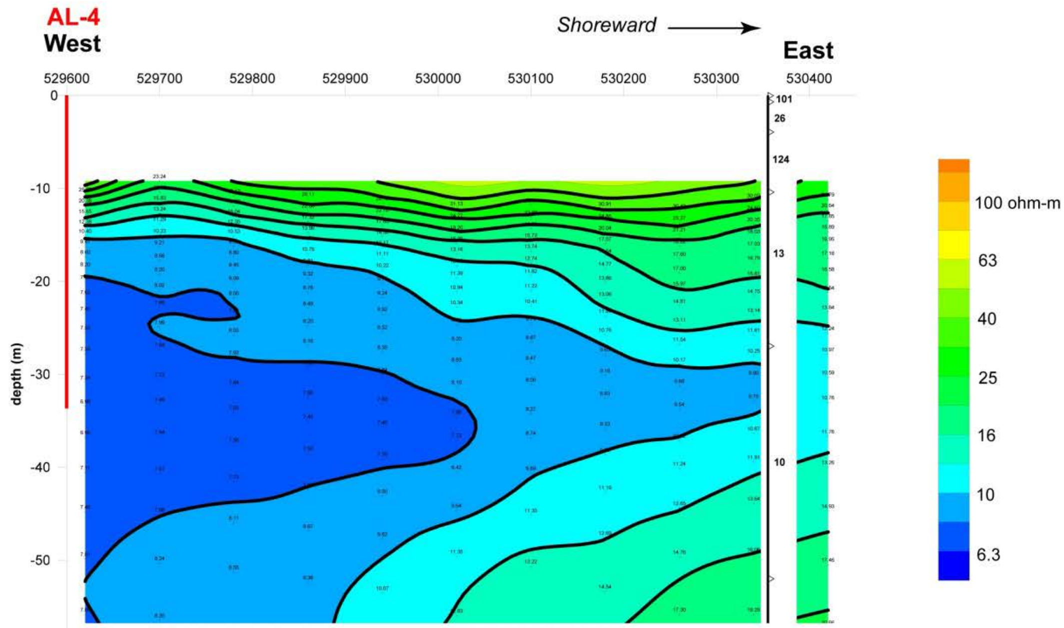

Figure 8. East-west TEM profile number 2, showing modeled electrical resistivity. Drill hole approximately located in red. 10X vertical exaggeration. Figure from Rautman, 2004.

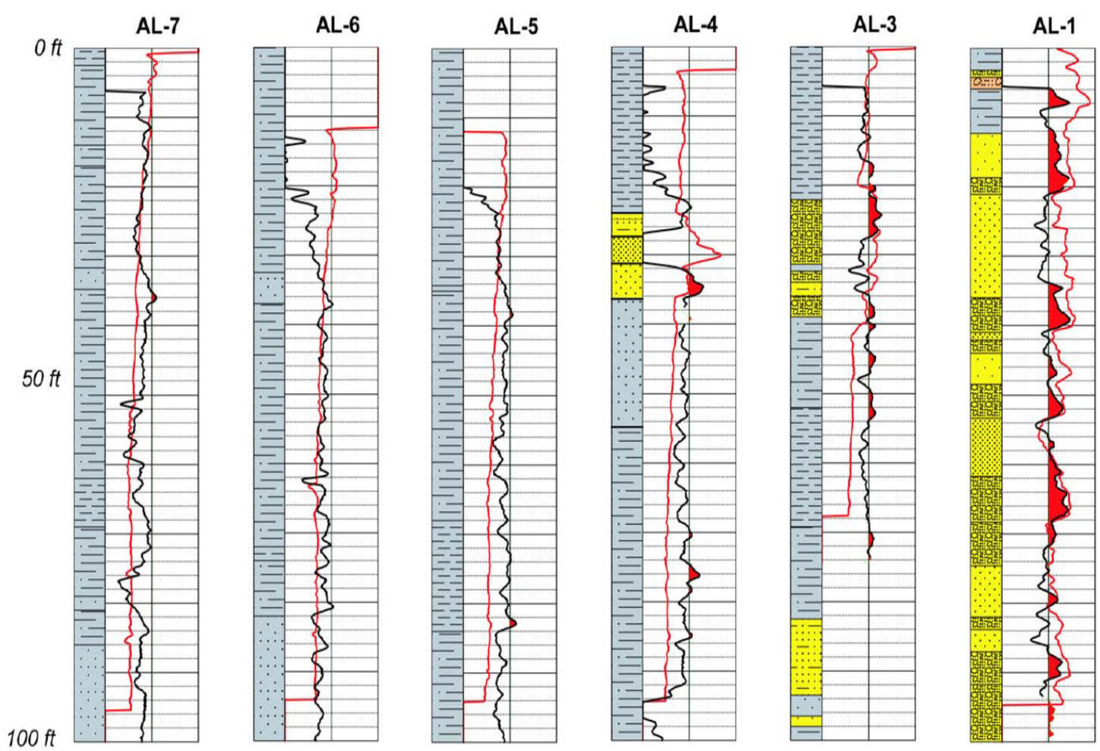

Figure 9. Stratigraphic cross section of initial core hole showing loss of coarse clastic materials ('hard') away from shoreline of Antelope Lake. Left-hand part of each log shows schematic representation of core; right-hand portion shows MG resistivity log in red and density log in black; densities greater than 2.0g /cm3 highlighted in

red. Intervals of dominantly clay shown in grey; intervals of dominantly sand are shown in yellow; particularly coarse gravels shown in orange. Figure from Rautman, 2004.

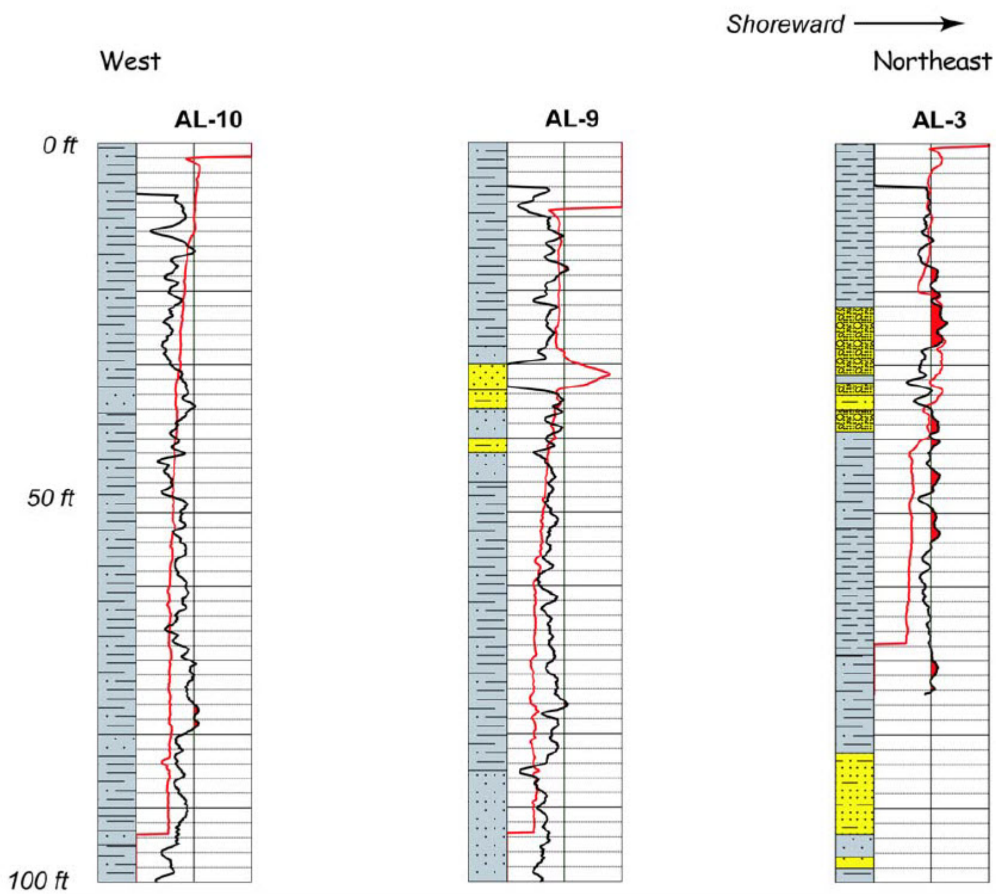

Figure 10. Stratigraphic cross section of initial core hole showing loss of coarse clastic materials ('hard') away from shoreline of Antelope Lake. Left-hand part of each log shows schematic representation of core; right-hand portion shows MG resistivity log in red and density log in black; densities greater than 2.0g /cm3 highlighted in red. Intervals of dominantly clay shown in grey; intervals of dominantly sand are shown in yellow. Figure from Rautman, 2004.

3. White Sands Missile Range

White Sands Missile Range (WSMR) is located in southern New Mexico and encompasses portions of the counties of Socorro, Sierra, Dona Ana, Lincoln, and Otero. The proposed test site is Lake Trinity, a playa lake, located in the northwestern sector of the missile range within Socorro and Sierra counties. WSMR is located within the Mexican Highland section of the Basin and Range geologic province (Weir, 1965). The lake resides within the Jornada del Muerto Valley basin with the Rio Grande to the west and the Oscura and San Andres Mountains to the east (Figure 11). Sandia conducted a comprehensive geologic study across Lake Trinity during the summer of 2006, in order to assess its suitability as GFBT site, similar to the study performed at TTR. However, due to a decision to halt the program in 2007 a final report was never written. Presented her is an interpretation of that data collected back in 2006.

Very little geologic background information exists for the region due to its location on a military installation. A 1983 study (Neal and others, 1983) describes the playa lake as consisting of lacustrine evaporites, primarily gypsum and argillaceous gypsum. Lake Trinity is only partially exposed at surface. The western and northern boundaries are covered by dune deposits. Alluvial fan deposits border the lake from the east. Neal and others (1983) drilled four exploratory holes across the playa (Figure 11) to help define the lake basin shape. The boreholes were drilled to nearly 130 ft. The boreholes on either side of the basin consisted of alternating sequence of sands, silts, clays, and gravels indicative of the alluvial fan deposits derived from the adjacent mountains consisting of limestone and granite. The center of the basin consisted of a massive gypsum sequence engulfing a half meter layer of hexahydrite (magnesium sulphate) at approximately 60 feet (Figure 12).

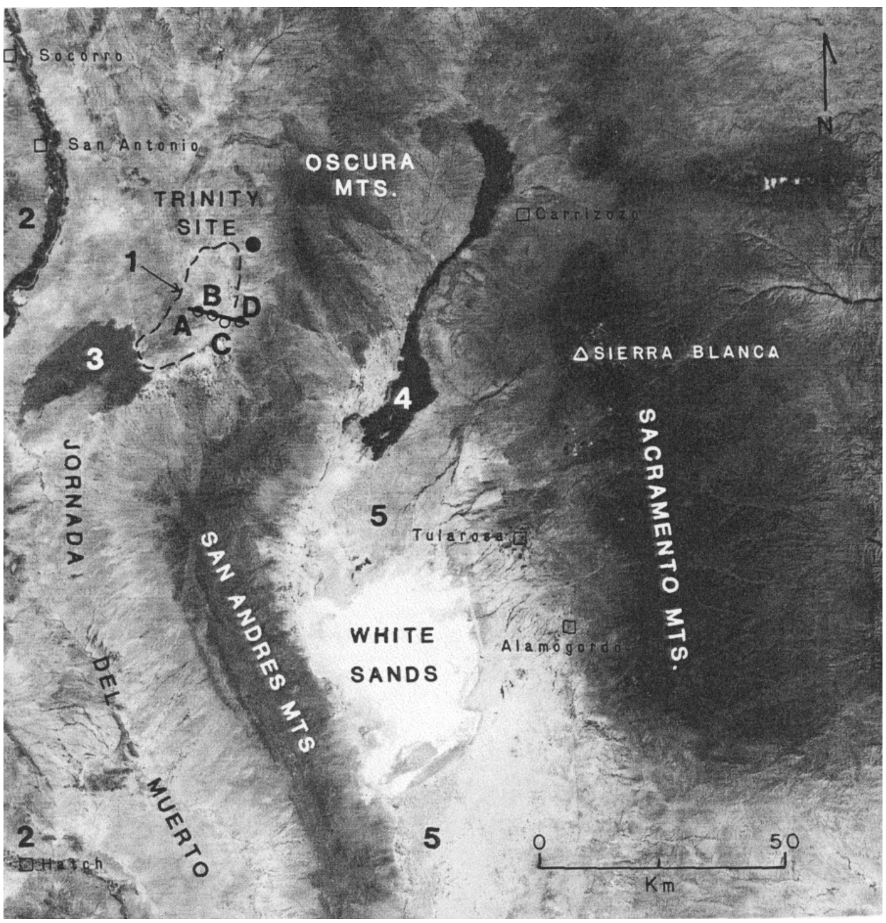

Figure 11. Space imagery of southern New Mexico, including Trinity Lake Basin and adjacent Tularosa basin. Location of 1983 boreholes A, B, C, and D are shown across the central portion of Trinity basin. Figure from Neal and others, 1983.

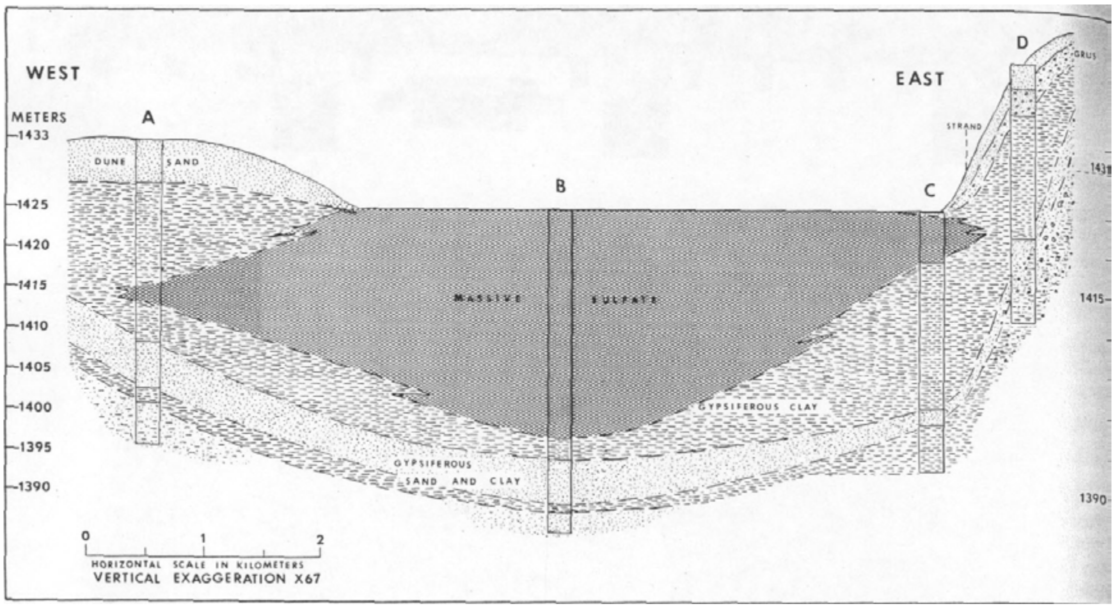

Figure 12. Generalized basin profile based on field logs. Location of transect is shown in Figure 11. Figure from Neal and others, 1983.

The purpose of the geologic evaluation conducted by Sandia was to explore the subsurface to discriminate fine (i.e. soft) materials from coarse (i.e. hard) materials, which could impact gravity bomb flight testing. The program consisted of drilling 20 core holes to a depth of 100 feet and running corresponding geophysical logs within those boreholes. The geophysics consisted of a time-domain electromagnetic (TEM) soundings along with Schlumberger vertical resistivity soundings and EM-31 surveys. Only the TEM surveys are discussed below. Results from the other surveys corroborate the TEM findings. The geophysics surveys were shot over test areas suggested by WSMR (see squares with red diagonal lines in Figure 13) with an additional two TEM surveys shot to better define the basin to shoreline properties. Locations of core holes and geophysics surveys are presented in Figure 13.

TEM measures the electrical character of the sediments. In general fine-grained sediments have the capability to hold more water due to capillary properties and therefore are more conductive, whereas coarse-grained sediments hold less water and consequently are more resistive. The TEM results are displayed in Figures 14-18 depicting formation resistivity. In each figure the surficial materials show high resistivity, which in actuality is a product of the fine–grained materials dried out by the desert environment. In general the basin consists of low resistivity geologic materials, with resistivity decreasing towards the basin center. Resistivity measurements at WSMR are not as low as those measured at TTR. The reason for this may be related to the underlying geology.

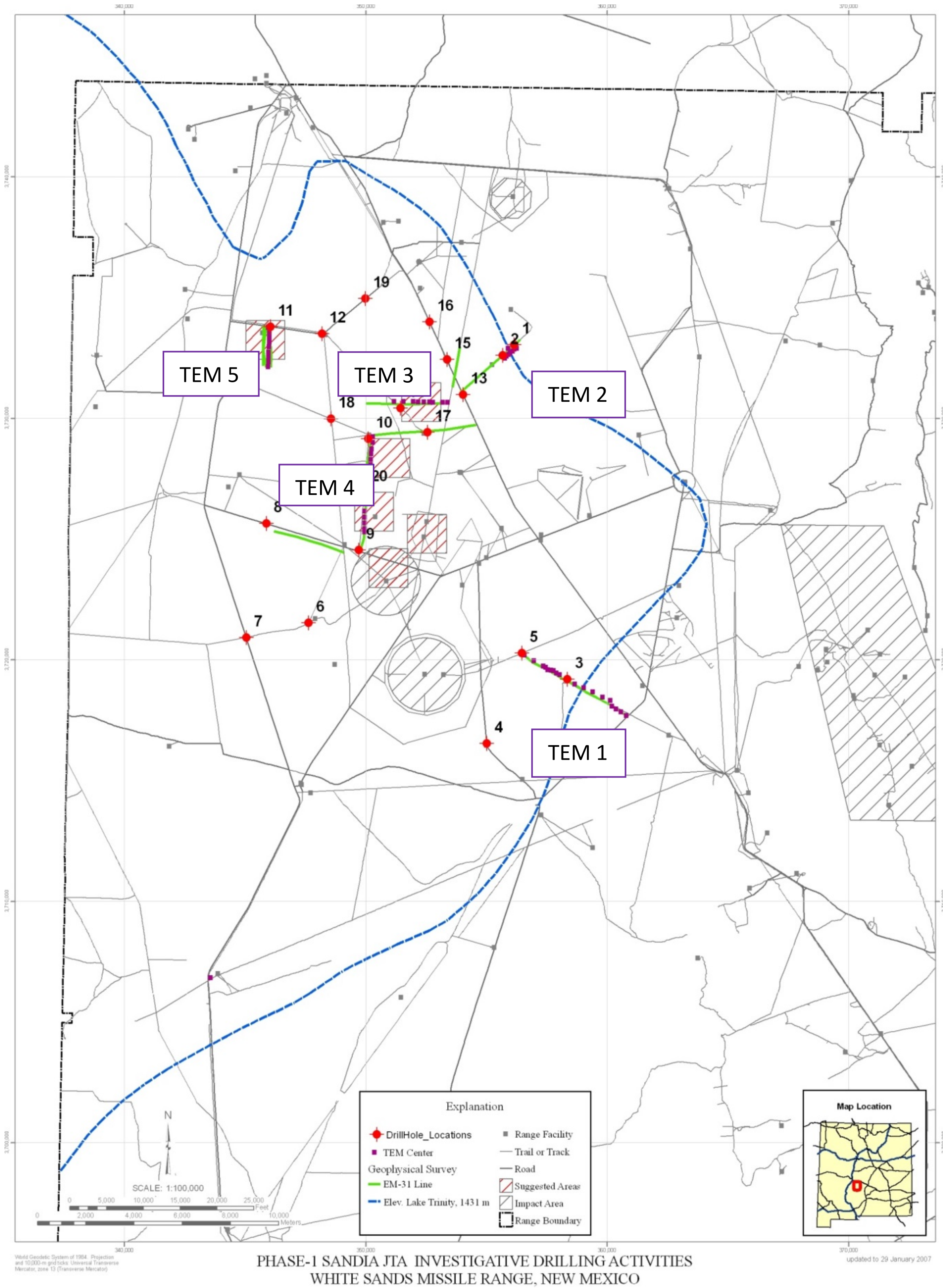

Figure 13. Lake Trinity study area. Locations of TEM surveys are noted by purple squares. Core hole locations are indicated by red circles. Green lines are location of EM-31 Lines.

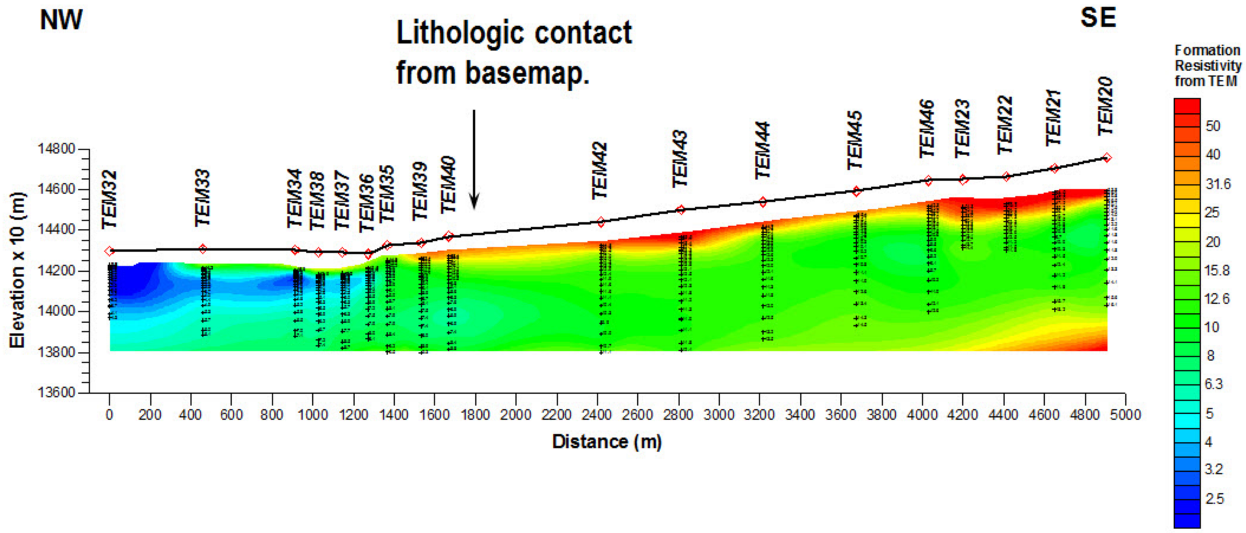

Figure 14. TEM 1 profile, showing modeled electrical resistivity. 10X vertical exaggeration. See Figure 13 for location.

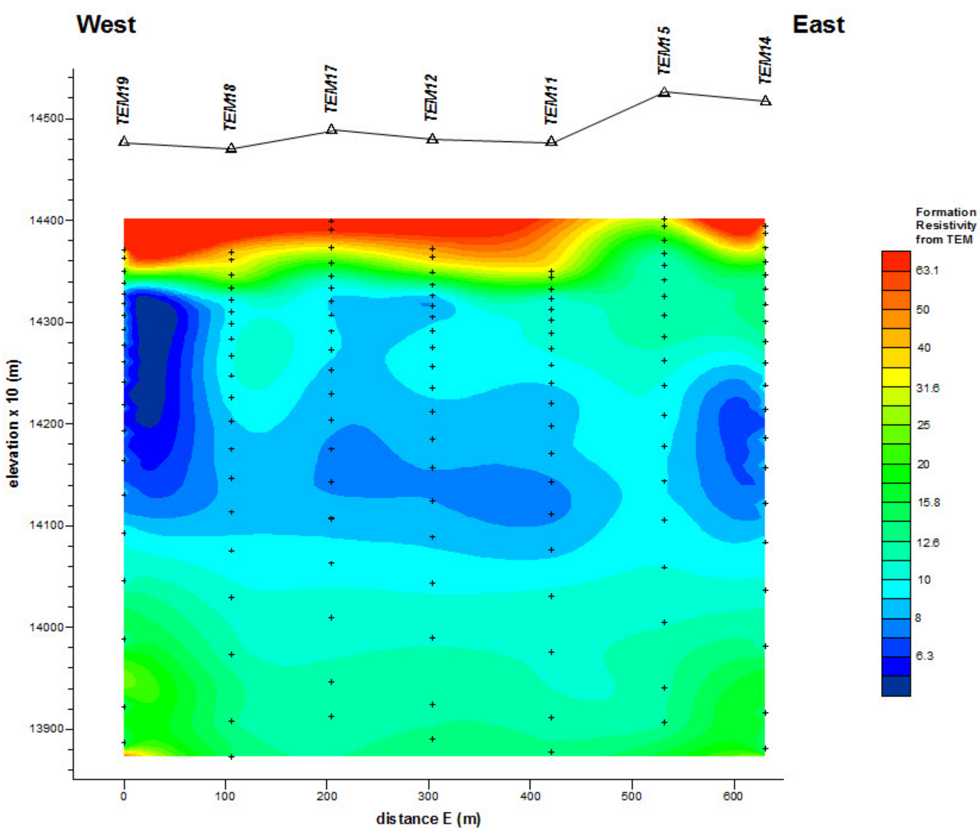

Figure 15. TEM 2 profile, showing modeled electrical resistivity. 10X exaggeration. See Figure 13 for location.

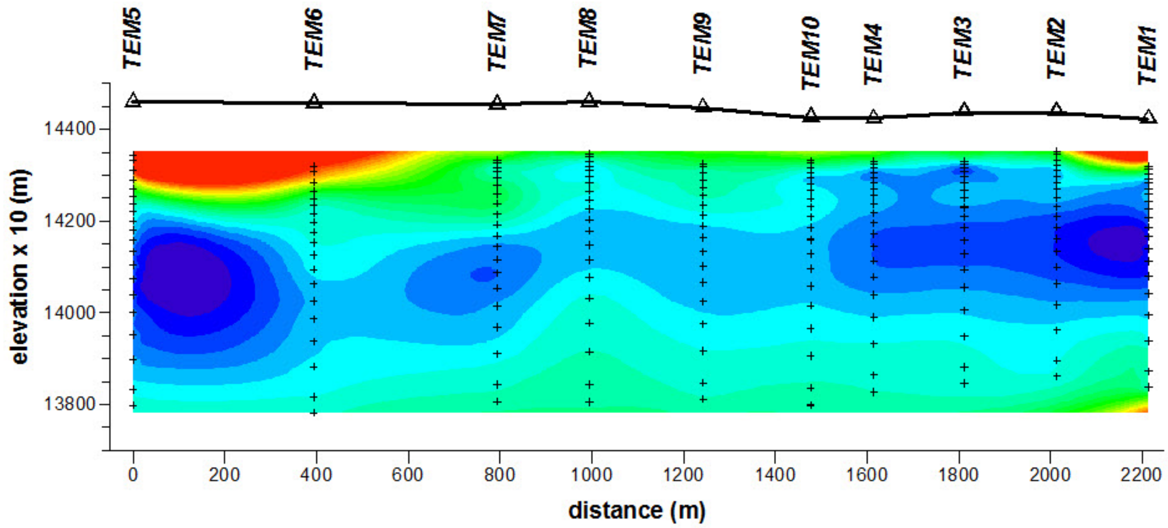

Figure 16. TEM 3 profile, showing modeled electrical resistivity. 10X exaggeration. See Figure 13 for location.

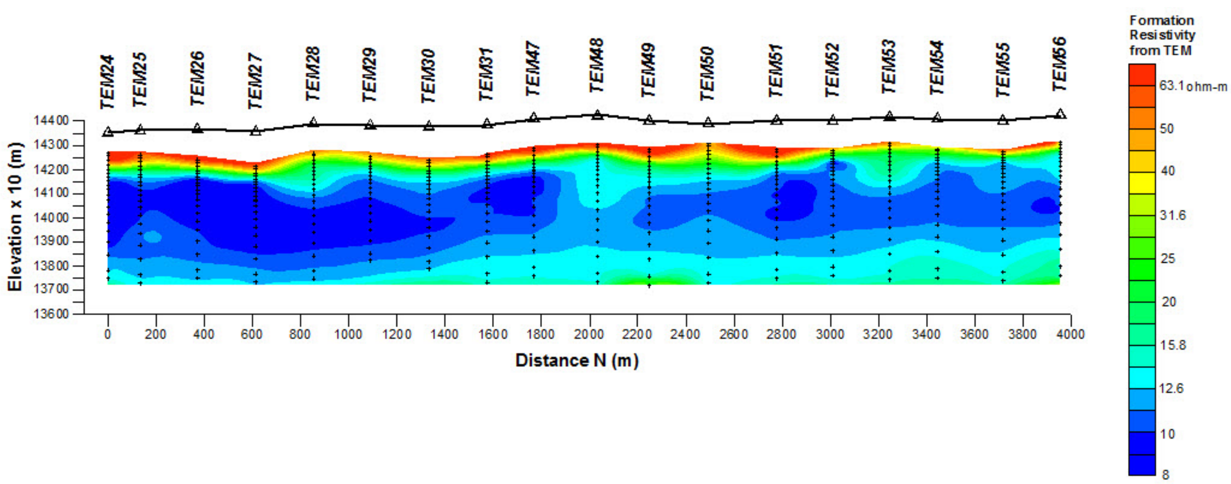

Figure 17. TEM 4 profile, showing modeled electrical resistivity. 10X exaggeration. See Figure 13 for location.

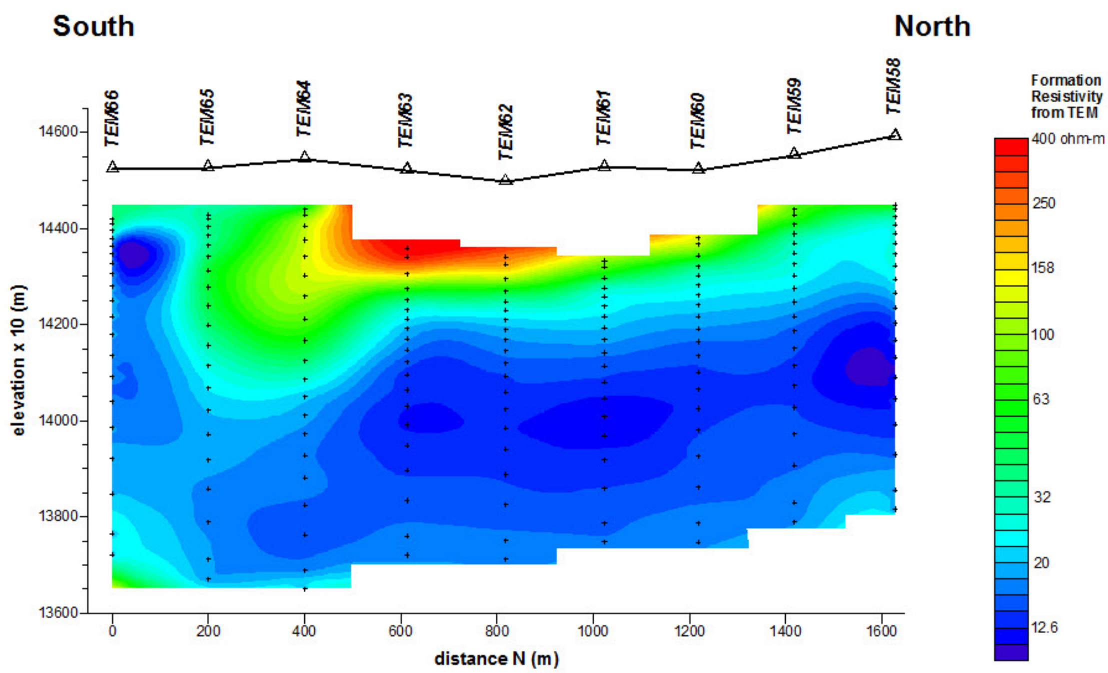

Figure 18. TEM 5 profile, showing modeled electrical resistivity. 10X exaggeration. See Figure 13 for location.

The core holes were strategically located to confirm the geophysics interpretation of the basin character. Core was logged and sampled and the holes logged for density, resistively, natural gamma. Unfortunately, sonic drilling disturbed the retrieval of the sediments, which affected both depth control and the integrity of the borehole. Issues with borehole integrity prevented geophysical logging from being performed in uncased holes. The formation density measurements were therefore 'contaminated' by the density of the surrounding steel pipe, which dominated the response and hence a threshold density pattern was never established. The results of the logged and sampled core confirmed the presence of mainly fine sand, silty clay and gypsum. The majority of the core collected consisted of a mixed lithology of these fine-grained sediments. Minimal coarse-grained deposits were encountered and only along the shoreline. Figure 19 is a geologic map with shaded topographic relief superimposed. The map displays both locations of core holes and select stratigraphic cross-sections.

Figure 20 shows the only two cores collected to contain pebbles and granules, which are located near the western edge of the playa lake under sand dune coverage. This area is probably not the best area for GBFTs due to the presence of hard sediments - pebbles and granules. However, the coarse grained layers encountered do not equal in size what was encountered at TTR. Conversely, the rest of the study area all appears to be suitable for testing. In general the area is composed of fine grained sediments. Thick sequences of gypsum are characteristic of the playa lake itself (see Figure 21). The northern part of the study area is composed of a more mixed lithology, but all fine grained. Figures 22 and 23 depict the stratigraphy of the northern region. The only unknown is the possibility that the near-surface materials may be too soft (i.e. lots of clay sized particles). Sediment size and mineralogy effect shear strength of soils. The WSMR sediments are dominantly clay sized and therefore may exhibit a cohesion affect that alters the soil shear strength.

The Sandia study indicated that the northern region of the study area was thought to be the best area of the site for testing because it is comprised of wide open spaces. South of that region may be encumbered by WSMR infrastructure and regions littered with UXOs (unexploded ordnances).

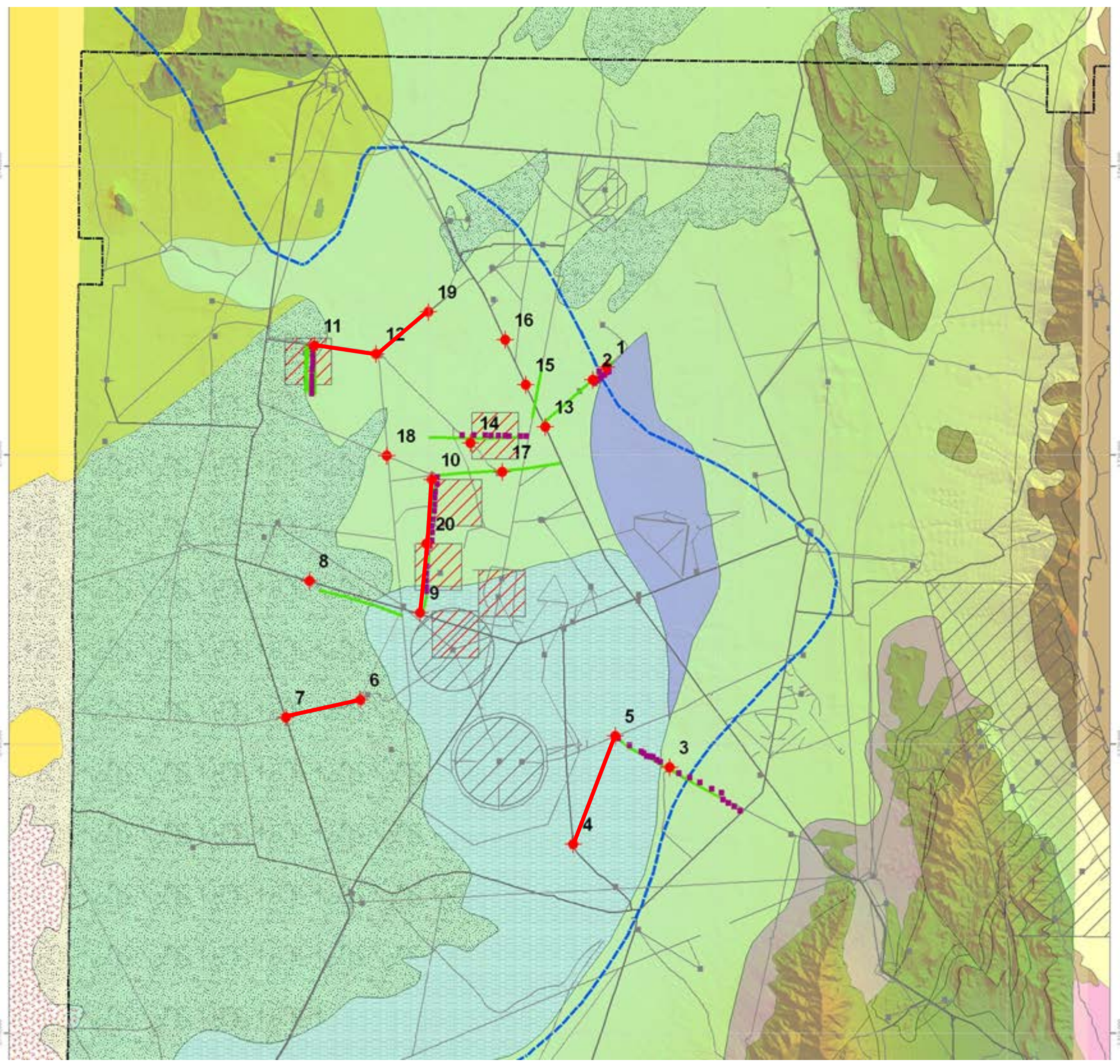

Figure 19. A geologic map of the Lake Trinity area with shaded topographic relief superimposed. Displayed are locations of core holes and select stratigraphic cross-sections.

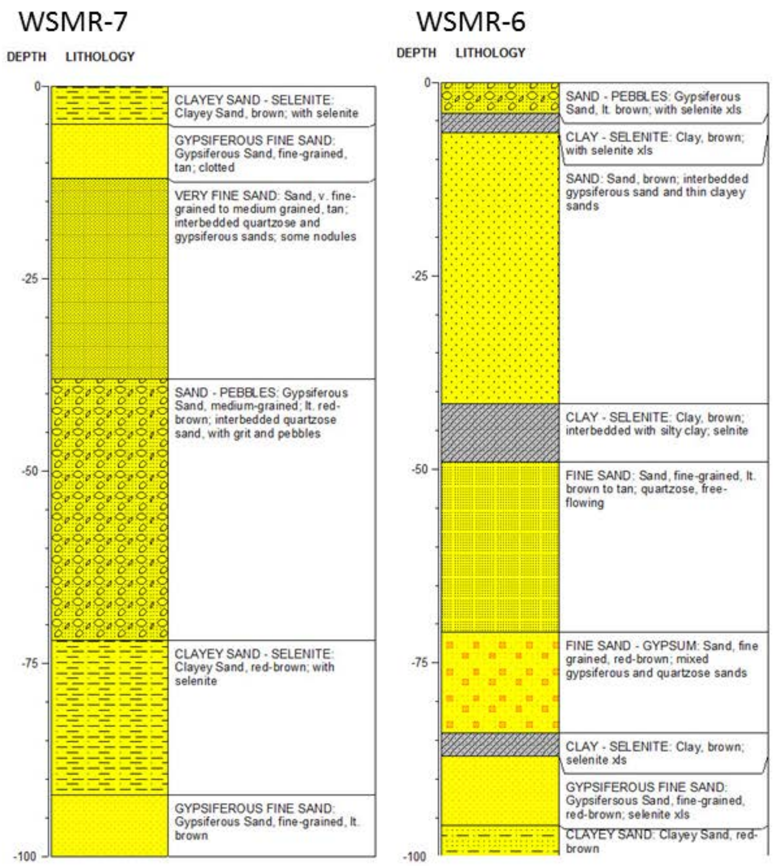

Figure 20. Stratigraphic cross section depicting the core from WSMR-7 and WSMR- 6 both collected from the eastern portion of the study area under sand dune coverage. Note the pebble layers. See Figure 19 for location.

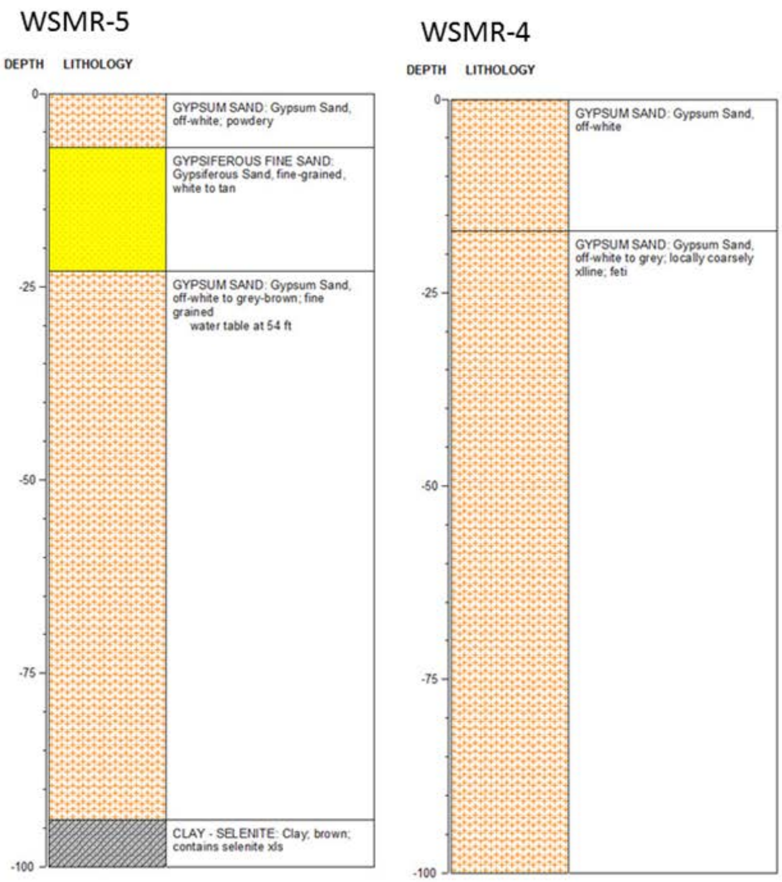

Figure 21. Stratigraphic cross section depicting the core from WSMR-5 and WSMR -4 collected within the uncovered region of the playa lake towards the southeast portion of the study area. This region is characterized by thick deposits of gypsum. See Figure 19 for location.

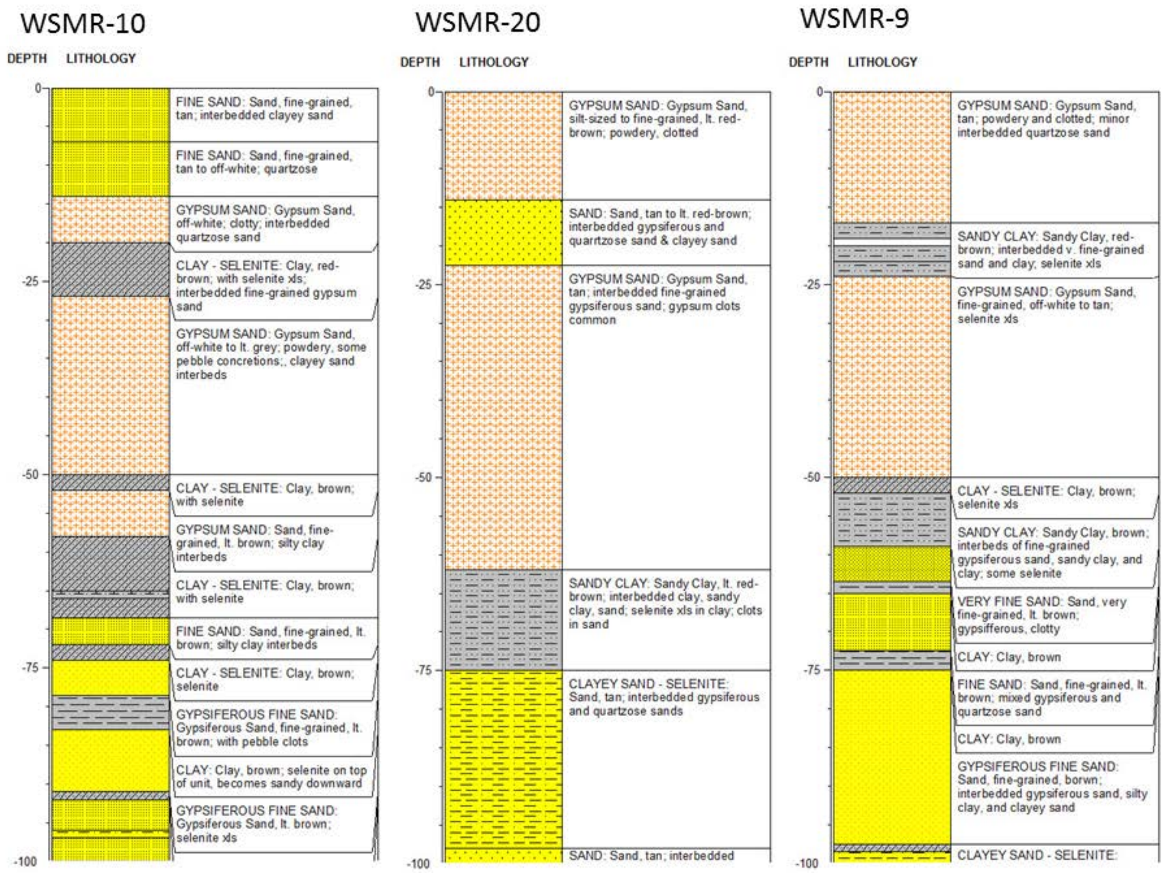

Figure 22. Stratigraphic cross section depicting the core from WSMR-10, WSMR-20 and WSMR-9 collected within the central portion of the study area. This region is characterized by a fine-grained mixed lithology. See Figure 19 for location.

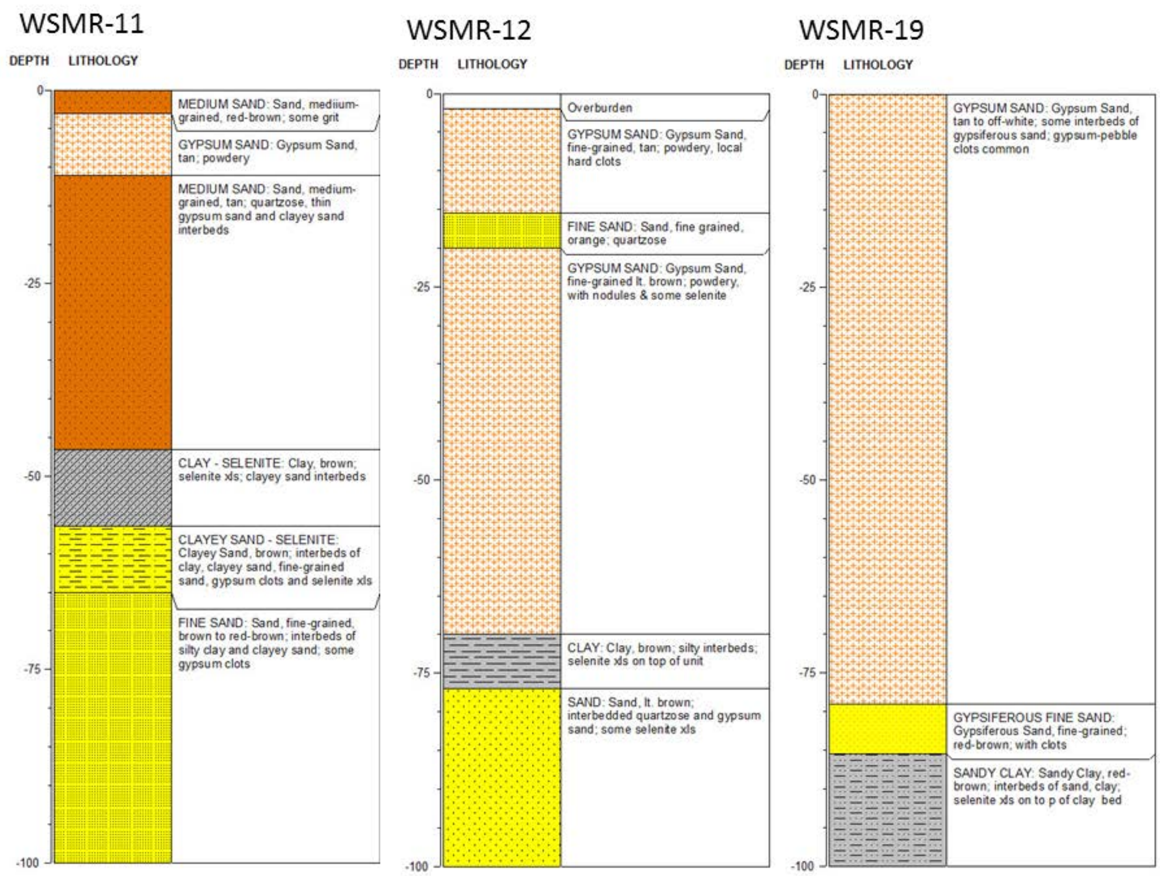

Figure 23. Stratigraphic cross section depicting the core from WSMR-11, WSMR-12 and WSMR-19 collected within the central northern portion of the study area. This region is characterized by a fine-grained mixed lithology. See Figure 19 for location.

4. Nevada National Security Site

The Nevada National Security Site (NNSS), formerly the Nevada Test Site, is the third site under consideration as the flight testing range. NNSS is located south of TTR within Nye County. NNSS has been a nuclear testing site since 1951, with the first above ground test occurring at Frenchman Flat (IGC, 1989). National Security Technologies (NSTec) project personal conducted the geologic evaluation of potential sites within NNSS for Sandia in 2007-2008. The report is an unpublished contractor report to Sandia and is cited as NSTec (2008). The report essentially describes the procedures used to collect the data and tabulates those results in the appendices. Interpretation of the results was not part of the report. We present our interpretation of the data, which was included in the NTSec report appendices, below. Initially, three areas were considered as possible testing locations, Yucca Lake, an area west of Frenchman Flat, and Mid Valley. The first two will be discussed below as Mid Valley is no longer under consideration. In addition to the sites mentioned Sandia also has an interest in investigating both the Pahute Mesa and Pahute Airstrip regions at NNSS, which were not discussed in the NTSec report. Locations of the four areas of interest are presented in Figure 24.

The NNSS is also located within the Basin and Range geologic province. Specifically, NNSS, well as TTR, are within the southern part of the Great Basin section. The eastern and southern portions of the NNSS are characterized by a large basin containing both Yucca Flat and Frenchman Flat. Pahute Mesa, a large volcanic plateau, bounds the site to the northwest and exhibits the largest relief on the range. South of Pahute Mesa is Timber Mountain, an extinct volcano (Sinnock, 1982). The Pahute Airstrip is located within the Timber Mountain caldera.

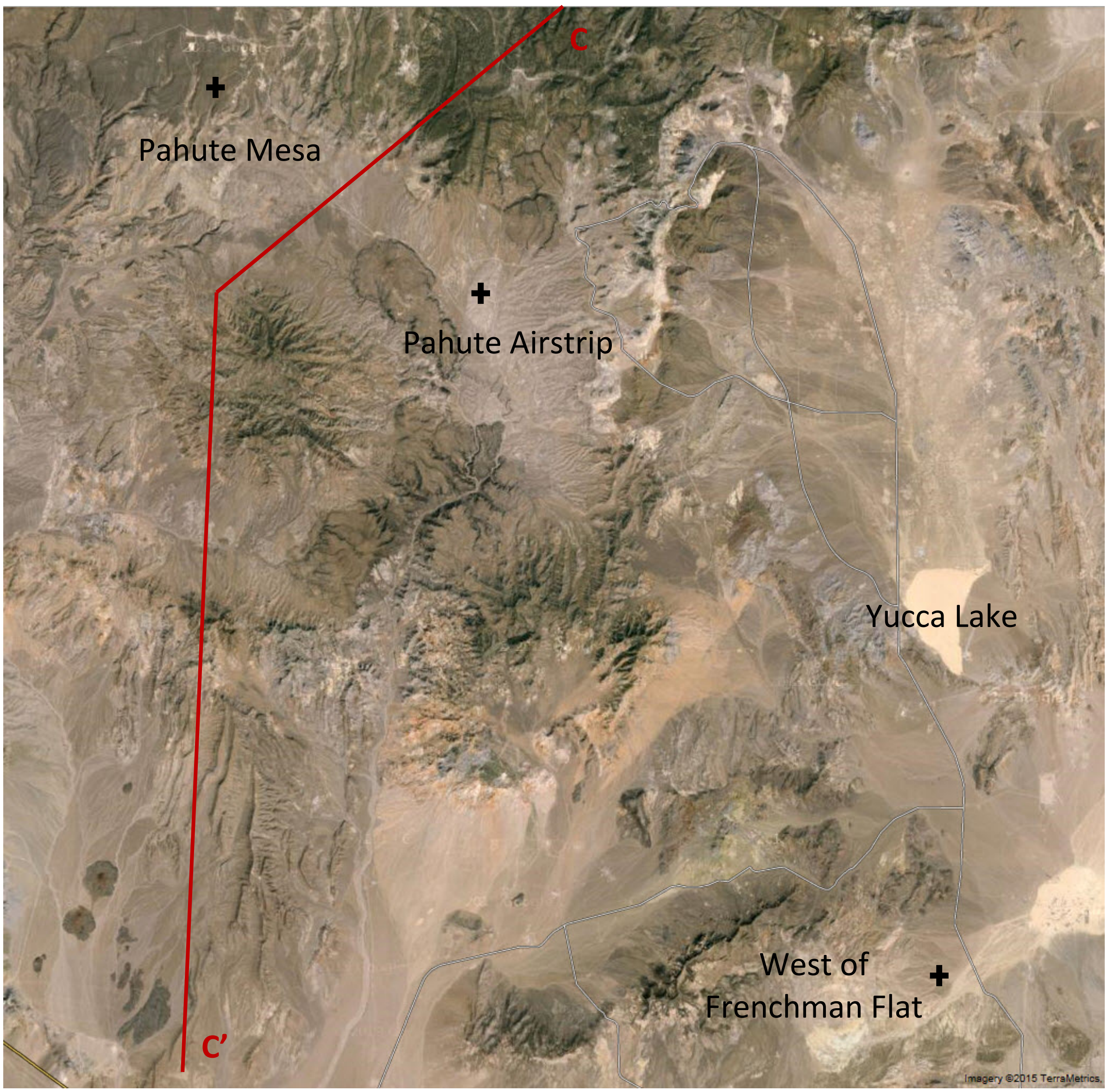

Figure 24. Satellite image of the Nevada Test Site and the four sites of interest. The red line is the approximate location of cross-section C-C'.

4.1 Yucca Lake

Yucca Lake is a playa located towards the southern end of Yucca Flat (Figure 24). Yucca Flat is a depositional basin consisting of up to 2000 feet of unconsolidated alluvium underlain by volcanic tuff and faulted sedimentary rocks. The finer grained and better sorted sediments are within the center of the basin, whereas towards the edge of the basin, near the surrounding ranges, the sediments are less sorted and consist of angular rubble surrounded by silt, sand, and gravels. Playa lakes in general typically consist of several hundred feet of very fine-grained lacustrine deposits (Simcox, 1982; Zohdy and Bisdorf, 1978).

The National Security Technologies (NSTec) geologic evaluation program focused on the northern 1/3 of the playa and consisted of drilling 7 core holes and 5 interval-sampled bore holes (termed Geotech borings) to a depth of 100 ft. Geophysical logging was performed in each core hole (gamma-gamma, density, dual induction, and natural gamma ray). Surface geophysics consisted of three TEM surveys. Location of the surveys and drilled holes are presented in Figure 25. The purpose of the site investigation was to identify the lithology and physical properties of the soils.

Examination of the boring logs, presented in the NSTec report Appendix C, reveals a mixed lithology consisting of clays, silts, sands with lateral and vertical variations in both sand content and grain size. There are stringers of both coarse sand and gravel present across the entire study area. Gravel and/or coarse sand are present in almost every hole examined except SS-4, SS-3, and CH-4. The greatest occurrence of gravel beds are found along the eastern shoreline, seen in holes CH-6, SS-5, and CH-5 (Figure 25). Figures 26 and 27 are stratigraphic cross sections depicting profiles of the lake subsurface from both a north-south direction and a west-east direction. Locations of cross-sections are shown in Figure 25.

Downhole geophysical logging was performed in all seven core holes. The logs were run inside PVC piping that was installed to keep the holes open. NSTec notes that the density log response was less than desirable due to the PVC pipe interference, voids present behind the pipe, and the shallow depth of investigation. In general density data is not available above 50 ft. The densities measured average between 1.5 and 2.0 g/cc, which is below the threshold value designated for the TTR sediments, suggesting fine grained sediments.

Three TEM lines were shot to a depth of 100 meters across the Yucca Lake study area to aid in the identification of high resistivity material indicative of coarse-grained sediments, which hold less water. A lot cultural effects, such as wire and cables, were noted during the collection of data and those regions were edited before data reduction. Figures 28, 29, and 30 display the TEM results. Overall resistivity measurements were low and relatively homogeneous both laterally and at depth. In general the two west-east lines (Figures 29 and 30) both show an increase in resistivity near the shore line, as expected, inferring an increase in occurrence of coarser grained sediments. Cores from holes CH-5 and CH-6 confirm the increase in inter-fingering of coarse sands and gravels derived from the surrounding ranges. In both west-east lines there is also a lens of lower resistivity material occurring between the depth of approximately 10 and 30 m (or 30 and 100 ft) that pinches out towards the east. The north-south TEM line (Figure 28) intersects with both west-east lines and shows an increase in resistivity towards the southern end of the shot line (south of station T22), suggesting the presence of coarser materials. The only core in the vicinity is CH-4 and the core recovered exhibits a continuous column of fine grained sediments, but it should be noted that only 100 ft. of core was collected, whereas the TEM data resistivity increase was recorded below that depth.

In summary Yucca Lake is composed of fine grained sediments, but stringers of gravel and coarse sands are present at various depths across the study area. To the east towards the lake shoreline there is an increase in the concentration of the sand and gravel beds. A lower resistivity region, i.e. an area of finer grained sediments, exists at depth between 30 and 100 feet near the west central region of the study area.

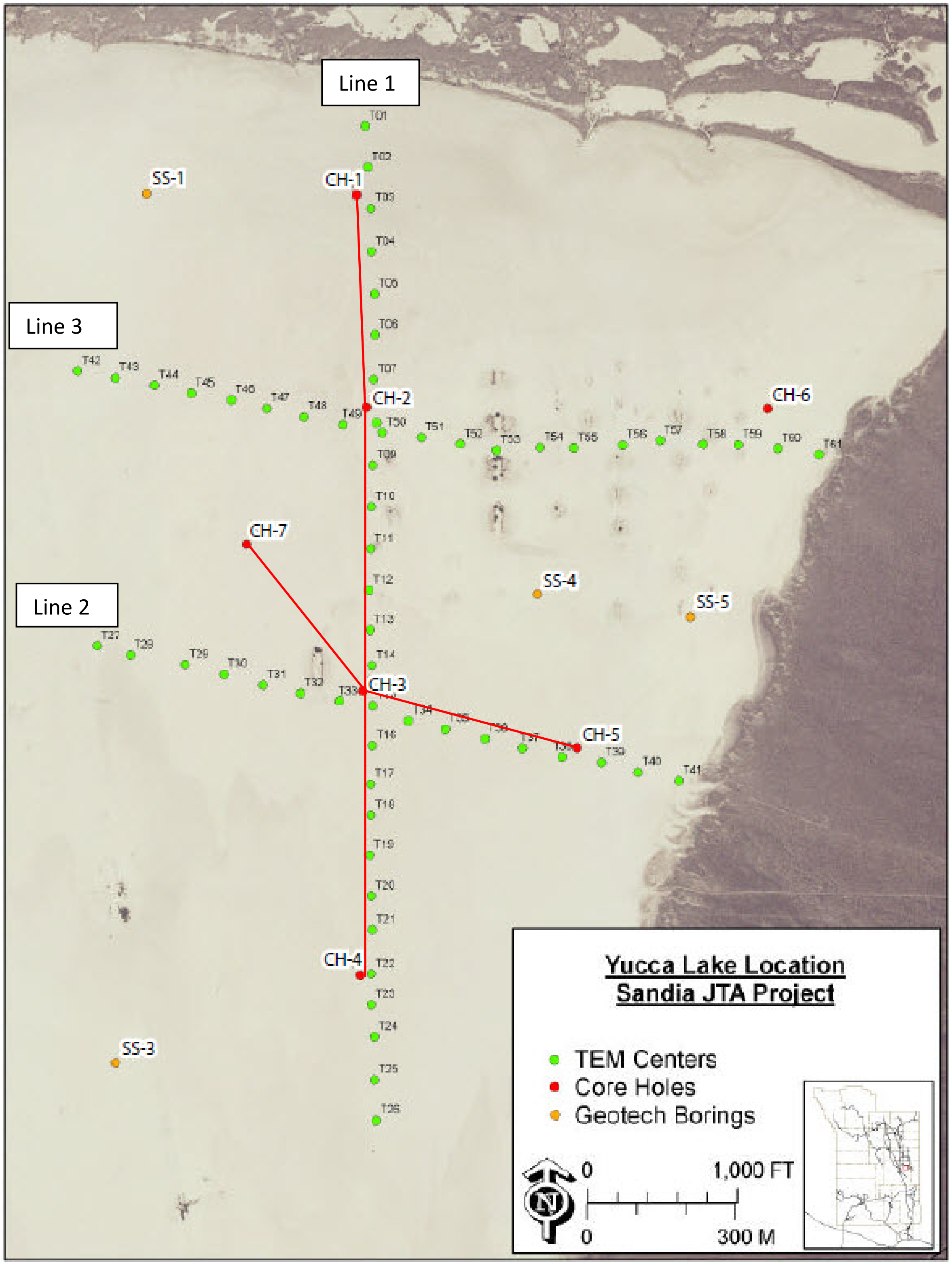

Figure 25. Location of TEM, exploratory holes, and stratigraphic cross-sections (red lines) at Yucca Lake.

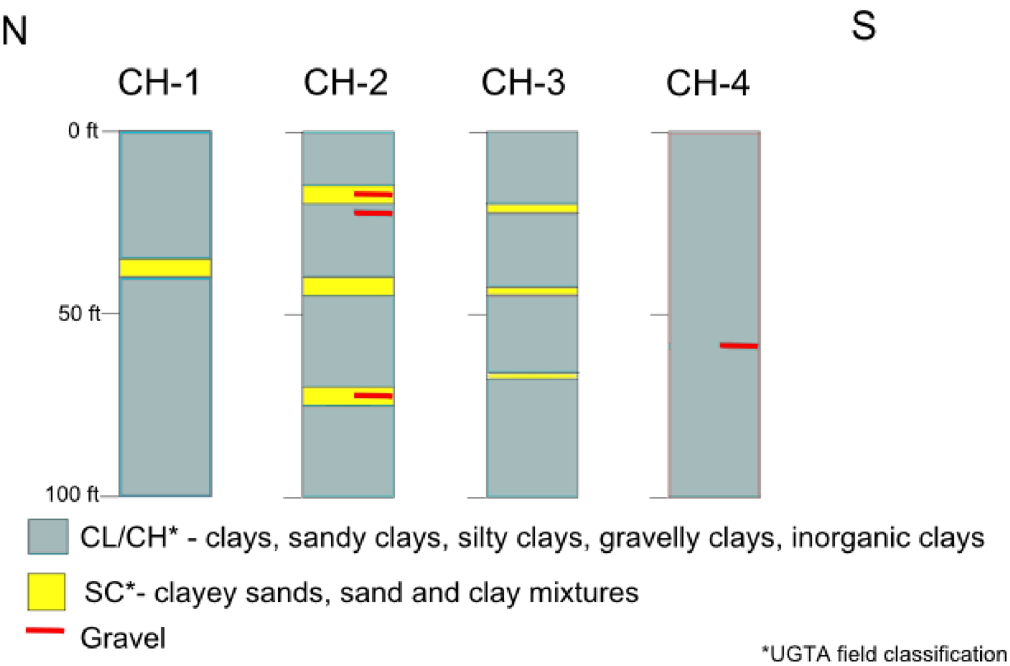

Figure 26. Stratigraphic cross section depicting the Yucca Lake cores CH-1, CH-2, CH-3 and CH-4 from north to south. See Figure 25 for location.

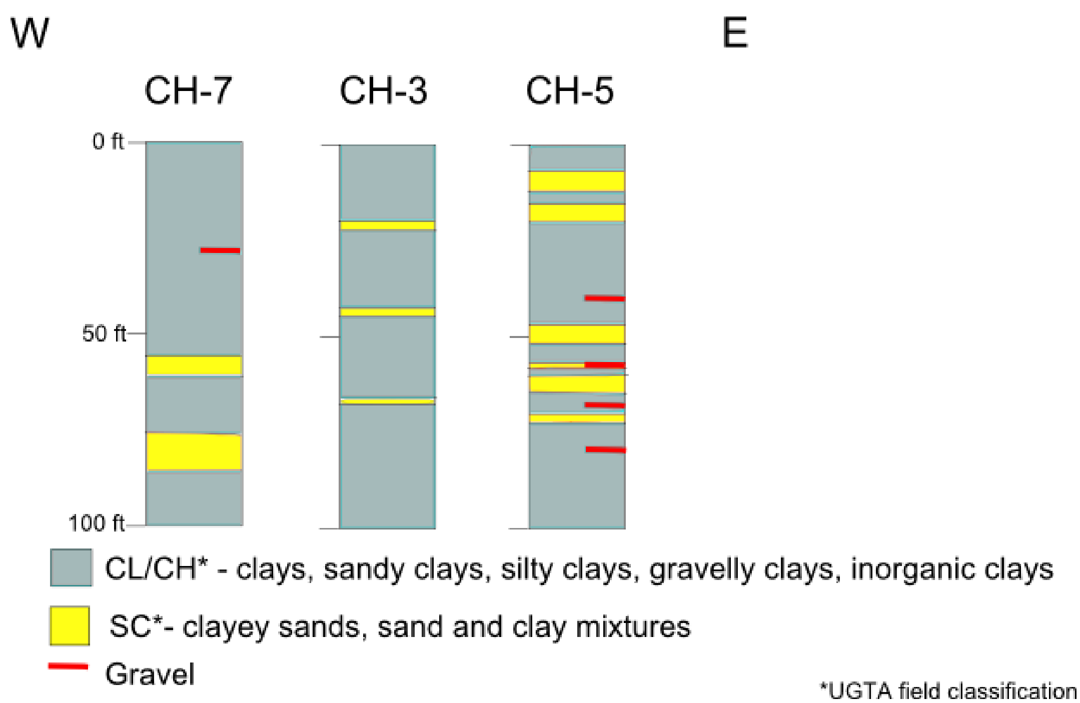

Figure 27. Stratigraphic cross section depicting the Yucca Lake cores CH-7, CH-3 and CH-5 form west to east. See Figure 25 for location.

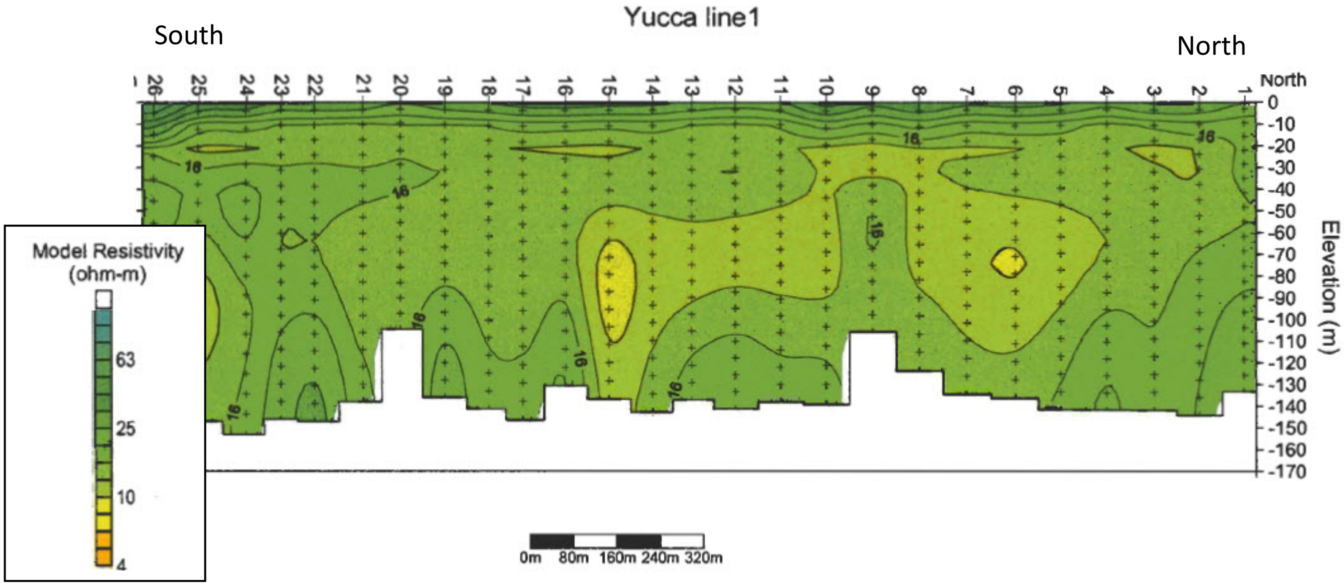

Figure 28. Yucca Lake TEM Line 1 showing modeled electrical resistivity. Depths relative to lake surface. From NSTec, 2008, Appendix G.

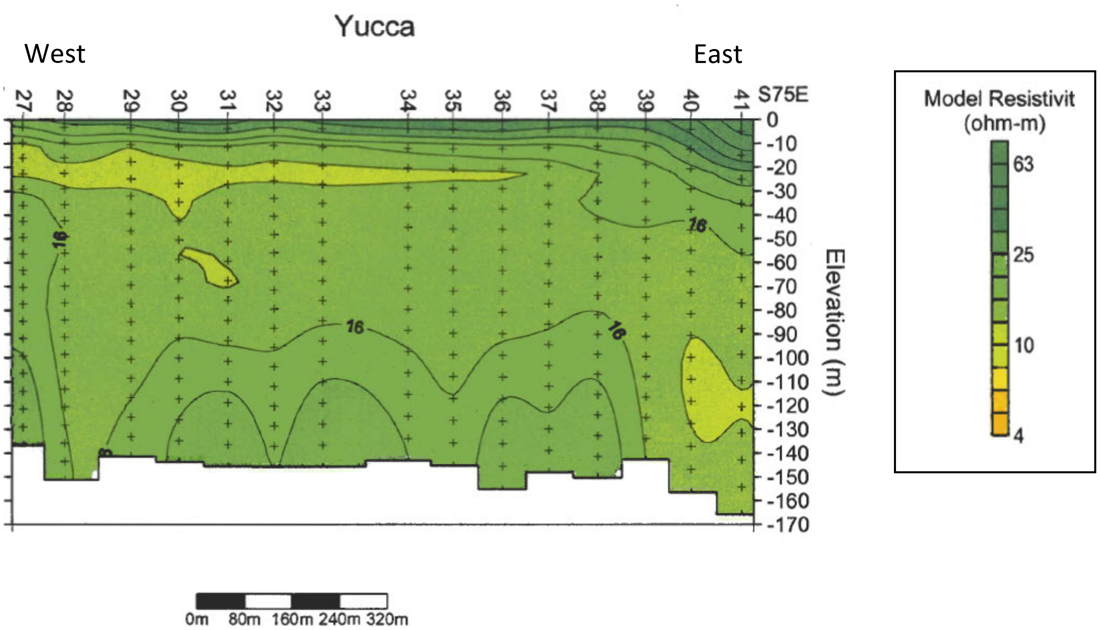

Figure 29. Yucca Lake TEM Line 2 showing modeled electrical resistivity. Depths relative to lake surface. From NSTec, 2008, Appendix G.

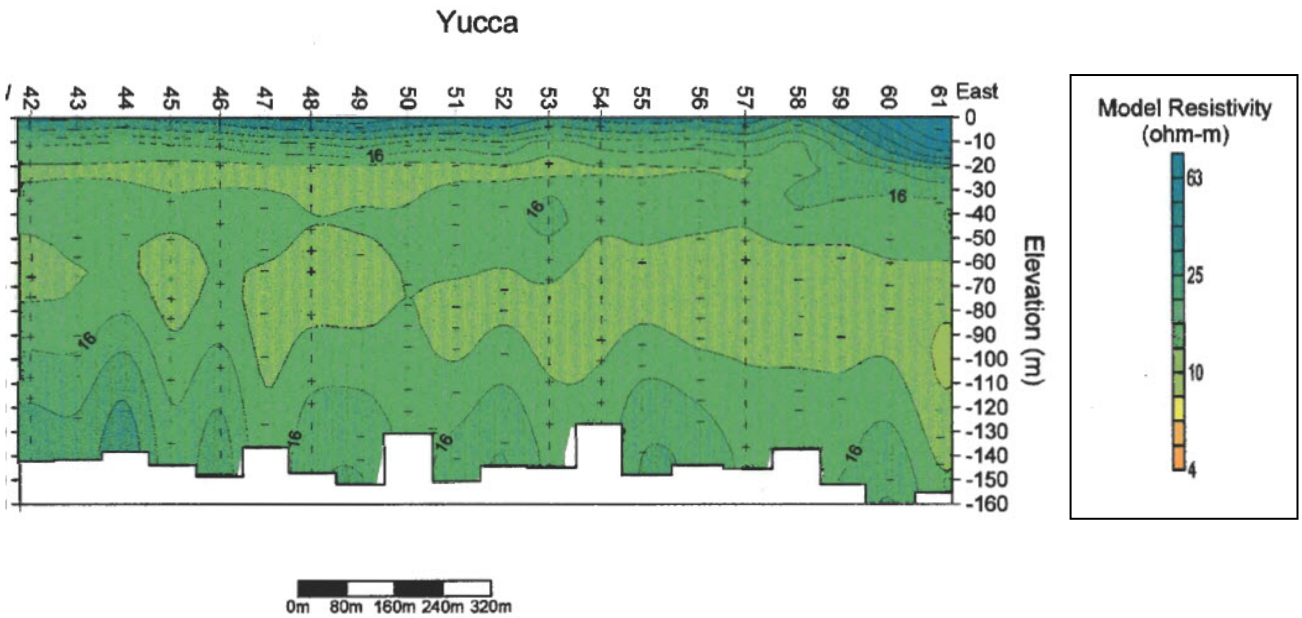

Figure 30. Yucca Lake TEM Line 3 showing modeled electrical resistivity. Depths relative to lake surface. From NSTec, 2008, Appendix G.

4.2 Frenchman Flat

The study area is ***west*** of Frenchman Flat and south of Yucca Lake within the same depositional basin. The location is shown in Figure 24 and is within the alluvium derived from the hills directly to the west and is within a region known as the Wahmonie Salyer area (Simcox, 1928). There is no site specific geologic information that could be found in the literature, but on a field trip taken in September 2005 to the NNSS it was noted by the attendees that the proposed test site is overlain by two distinct alluvial deposits. One deposit containing clasts between 0.5-2 meters in diameter. The other deposit containing pebble-to-cobble sized clasts within a silt matrix.

The National Security Technologies (NSTec) geologic evaluation program, which consisted of drilling 2 core holes and 6 interval-sampled bore holes (i.e. Geotech borings) to a depth of 100 ft. Geophysical logging was performed in the core holes (gamma-gamma, density, dual induction, and natural gamma ray). Surface geophysics consisted of two TEM surveys. Location of the surveys and drilled holes are presented in Figure 31. The purpose of the site investigation was to identify the lithology and physical properties of the unconsolidated surficial materials.

NSTec reported that the sediments sampled and cored consisted of “medium dense to dense, silty to poorly graded sands with frequent inter-bedded layers of dense sandy gravel”. Bedrock or volcanic tuff was encountered at a depth of 72 ft. in borehole SS-1 and at 82 ft. in borehole SS-3 (Figure 31). Examination of the boring logs in detail, located in the NSTec report Appendix C, confirms the greater occurrence of gravel and cobble beds compared to the other sites presented above. Gravels are present in relative abundance in all eight boreholes. There is no apparent depositional pattern. The alternative test sites described above are all within playa lakes, which are characterized by fine grained sediments, while this site is in an alluvial fan depositional environment characterized by episodic erosion and deposition. This leads to a more chaotic stratigraphic sequence.

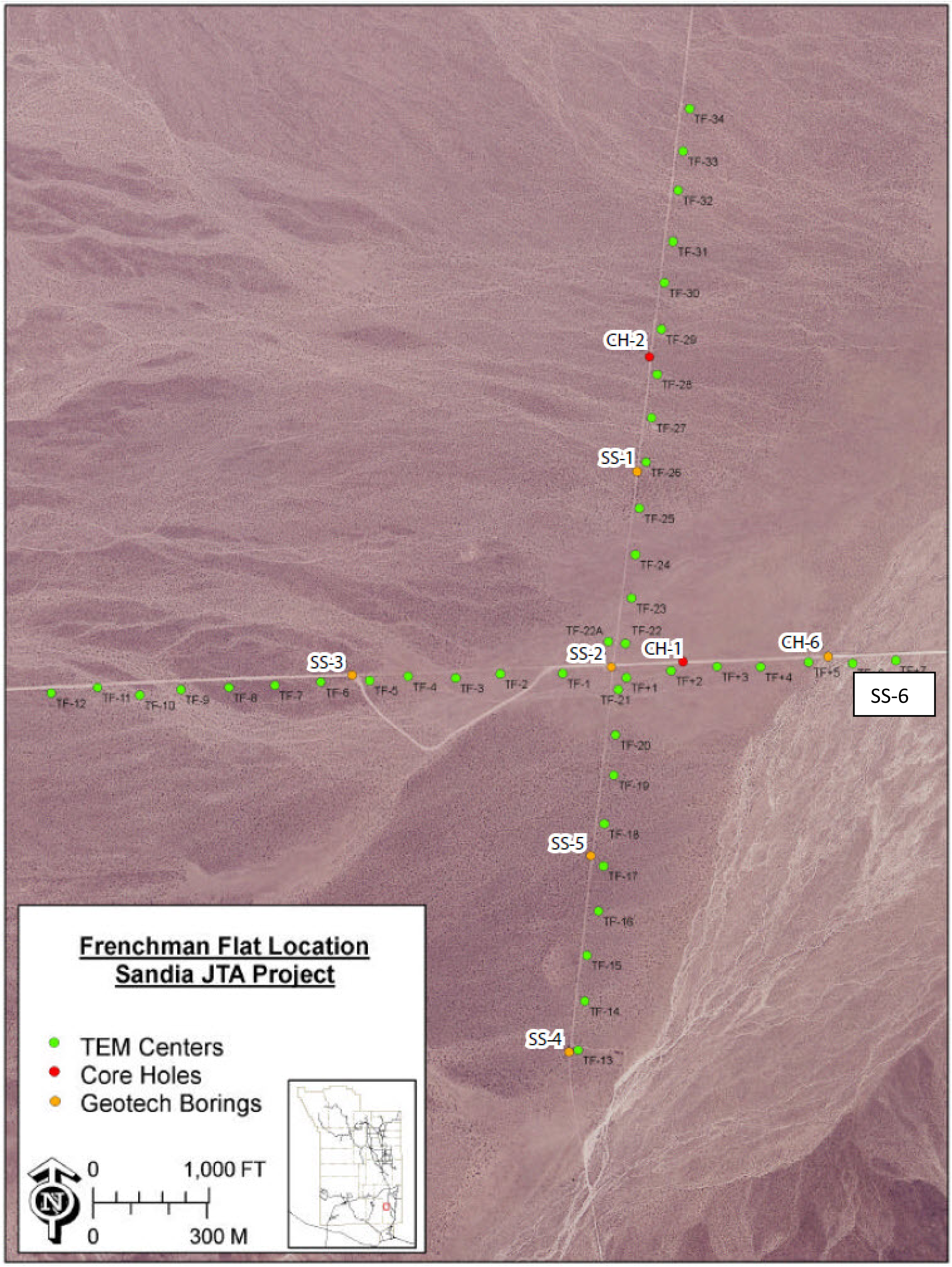

Figure 31. Location of TEM surveys and exploratory holes at the region west of Frenchman Flat.

Downhole geophysical logging was performed in the two core holes drilled. The logs were run inside PVC piping that was installed to keep the holes open. NSTec notes that the density log response was less than desirable due to the PVC pipe interference, voids present behind the pipe, and the shallow depth of investigation. In general density data is available below 15 ft. and the densities measured are greater than those values measured at Yucca Lake, measuring between 2.0 -2.2 g/cc, suggesting the presence of coarse-grained sediments.

Two TEM lines were shot to a depth of 100 meters. The surveys were set up to intersect in a cross pattern, which allowed for both a north-south and east-west subsurface profile covering the Frenchman study area (Figure 31). There were less cultural effects present than at Yucca Lake. Any effects due to wires, cables, and other cultural effects were edited out of the final data set. Compared to Yucca Lake the resistivity measurements at the Frenchman site were significantly higher and more variable spatially which is consistent with the alluvial fan depositional environment. Figures 32 and 33 display the TEM profile results. The NTSec report describes low resistivity regions in relation to the higher resistivity patterns, but it is important to remember the low resistivity measurements the report referred to are equivalent to the high resistivity measurements recorded at the three Nevada playa lakes studied, indicating the Frenchman area is entirely composed of coarse-grained sediments. However, relative to specifically the Frenchman site the northwest and west regions of the study area exhibits the highest resitivities measured with lower resistivities determined within the central and south eastern portions of the site.

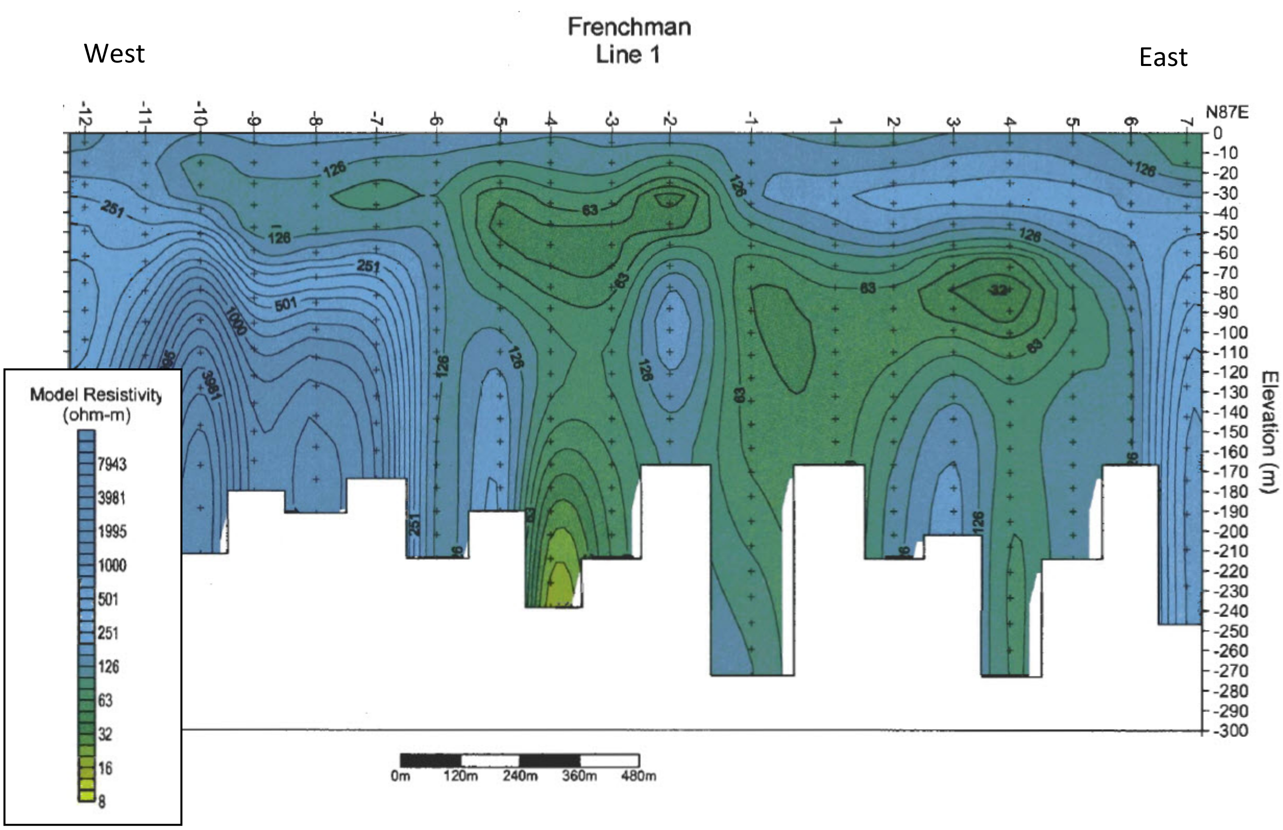

Figure 32. Frenchman TEM profile 1 showing modeled electrical resistivity.

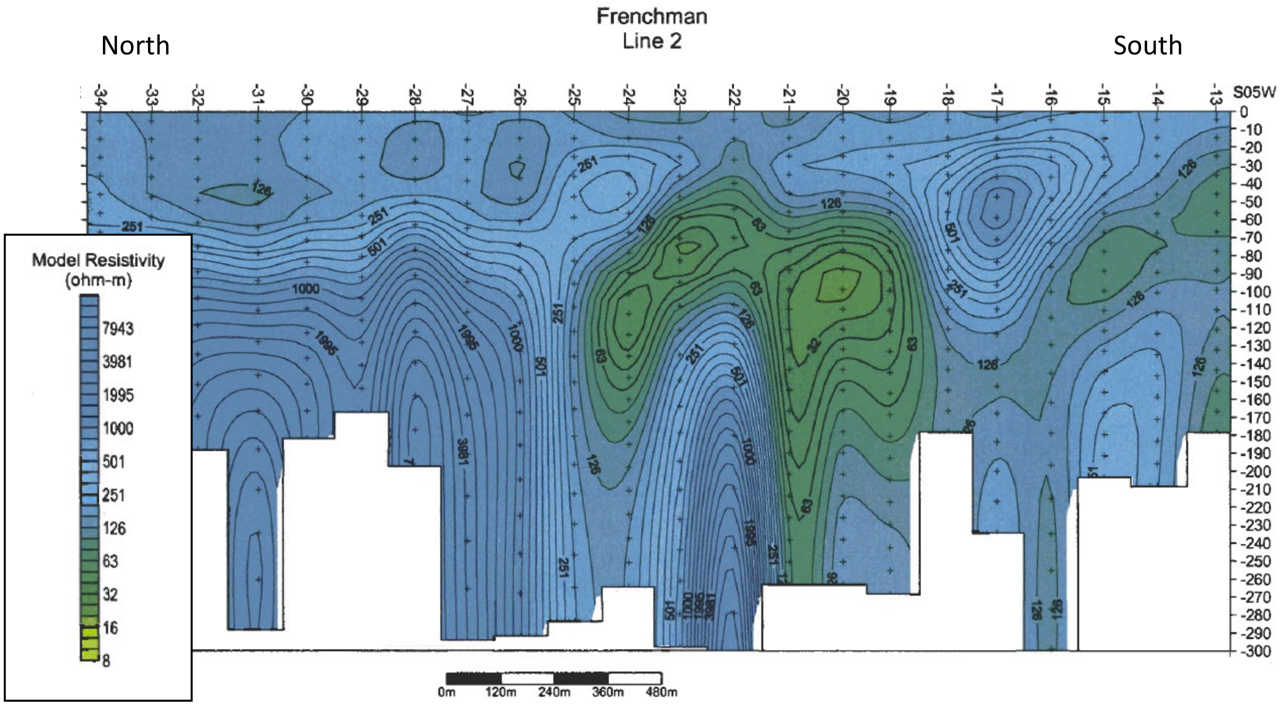

Figure 33. Frenchman TEM profile Line 2 showing modeled electrical resistivity.

In summary, the area west of Frenchman Flat consists of deposits of silts, coarse grained sand, gravels, and cobbles. The sands are poorly sorted with inter-beds of gravel sands. Bedrock was encountered in a few locations near 80 feet below the surface. The proposed test-site is not within a playa lake and represents the accumulation of debris from the surrounding hills.

4.3 Pahute Mesa and Pahute Airstrip

For these two sites there has been no geologic evaluation specific to understanding the shallow subsurface for the purposes of flight tests. Description of the geology presented here is from information gleamed from the literature. These two areas of interest are in close proximity of each other and part of the same volcanic physiographic region and hence will be discussed under the same section. For a comprehensive discussion on the geology of the NNSS refer to Sinnock (1982). The general geology is presented below.

Pahute Mesa is located in the northwest corner of the NNSS site boundary (Figure 24) and is a region defined by ancient volcanic eruptions. The area is characterized by hard igneous rock and there is no fine grained alluvium present. Pahute Mesa is part of the Silent Canyon Caldera, which deposited tuffs known as the Belted Range formation. Over time the caldera was filled with a series of tuffs and rhyolites between 6,000 and 8,000 ft thick. The rock unit capping the series is the Timber Mountain Tuff, extruded from Timber Mountain to the south and forms the surface of Pahute Mesa (Sinnock, 1982; Orkild and others, 1968). Figure 34 depicts a geological cross-section through Pahute Mesa and Timber Mountain.

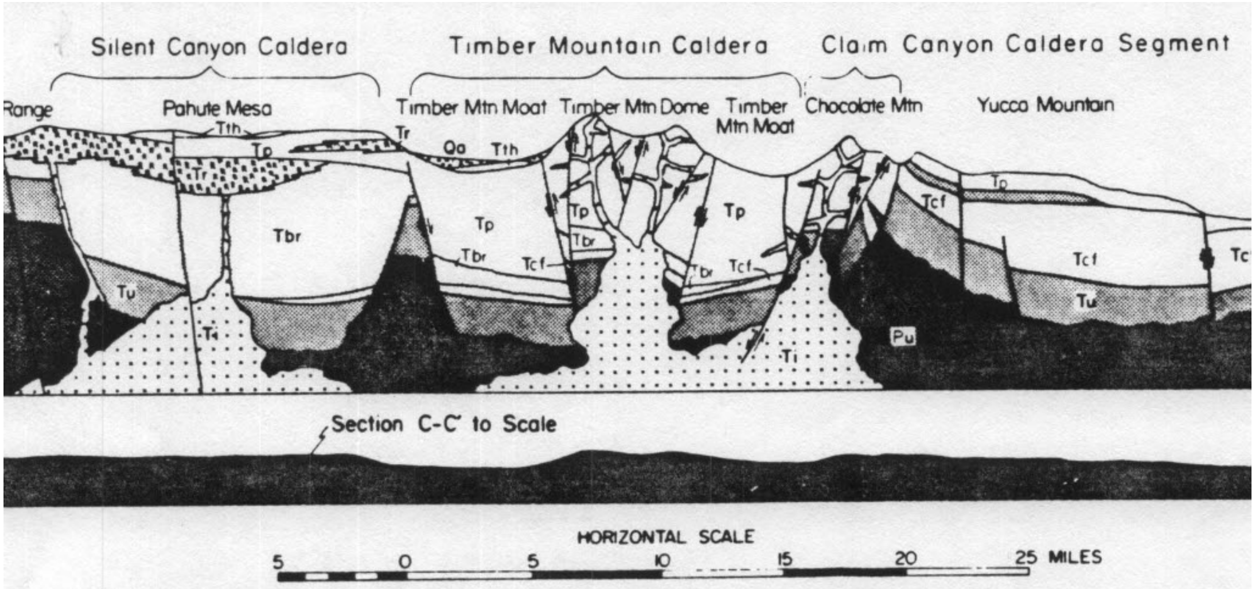

Figure 34. Idealized structure cross-section C-C' depicting Silent Canyon Caldera and Timber Mountain geology. Location of cross-section displayed on Figure 24. Figure from Sinncock, 1982.

The second proposed test site within this volcanic physiographic region is the Pahute airstrip, located southeast of Pahute Mesa (Figure 24) within the Timber Mountain Caldera. The airstrip is within the moat situated off the eastern side of the Timber Mountain Dome (Figure 34). The moat is filled with alluvium and colluvium gravels and the thickness is unknown. Beneath the alluvium and colluvium are layers of tuff from the same formations that form Pahute Mesa. Directly to the west of the airstrip and east of Timber Mountain Dome is Buckboard Mesa, a basalt extrusion within the moat (Sinnock, 1982).

To summarize the region is characterized by a rock series comprised of rhyolites and tuffs. There are no loose soils or alluvium covering Pahute Mesa. The Pahute airstrip is located south of Pahute mesa within the Timber Mountain Moat and is characterized by deposits of gravel overlaying volcanic tuffs.

Geologic Summary

The geology was described for seven alternate gravity bomb flight test sites within three test ranges, including TTR the current test site. It was determined that four of the seven sites identified –Main Lake, Antelope Lake, Trinity Lake and Yucca Lake-are playa lakes and are comprised of mostly fine-grained lacustrine sediments. In general, coarse-grained sediments are concentrated towards the lake shorelines, whereas the dominantly fine-grained lithology is present towards the center of the dry lake beds. Out of the four playas studied Lake Trinity at WSMR consisted of the finest grained sediments with little to no coarse-grained deposits mapped. The lithology at Yucca Lake at NNSS is the least favorable playa studied comprising of fine-grained sediments intermixed with gravel and coarse-grained stringers across the entire area studied. Out of the remaining three sites, both Frenchman Flat and Pahute Airstrip are located within basins characterized by poorly-sorted gravels, sand, and silts. The final site, Pahute Mesa, is a hard volcanic tuff with little or no alluvium present at the surface.

Table 1 lists the seven sites in order from the most favorable location to least favorable based on the suitability of the geology for gravity bomb flight testing. An ideal test site would consist of a homogeneous succession of soft sediments devoid of hard layers, which potentially could damage weapon components. WSMR Lake Trinity is the most suitable site, exhibiting solely find-grained sediments across the study region.   The lakes at TTR follow next with Antelope Lake and Main Lake, Antelope Lake being finer grained and more homogeneous than Main Lake. The four NNSS sites are considered the least favorable due the heterogenetic character of Yucca Lake, Pahute Airstrip, and Frenchman Flat. The geology of Pahute Mesa is considered the least favorable consisting of volcanic tuff too hard for current test operations.

Table 1. Alternate gravity bomb flight test sites listed in order from the most favorable on the left to least favorable on the right based on geologic suitability.

Site Order	Trinity Lake (WSMR)	Antelope Lake (TTR)	Main Lake (TTR)	Yucca Lake (NNSS)	Pahute Airstrip (NNSS)	Frenchman site (NNSS)	Pahute Mesa (NNSS)
Geology Summary	Fine-grained sediments	Fine-grained sediments	Fine-grained sediments towards center of lake and coarse sands/ gravel near shoreline	Fined-grained sediments interbedded with gravel stringers	Gravel colluvium	Poorly-sorted gravels and sediments	Volcanic tuff

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