Case Study Abstract

Tinker Air Force Base
Oklahoma City, OK

Site Name and Location: Tinker Air Force Base	**Geophysical Technologies:** Electromagnetics Seismic reflection Seismic Modeling	**RCRA Permit #** 1571724391
Period of Site Operation: 1942 - present **Operable Unit:** Not applicable		**Current Site Activities:** Portions of the base are undergoing investigation and remediation under the Installation Restoration Program
Point of Contact: Sara Sayler OC-ALC/EMR 7701 Arnold Street, Suite 221 Tinker Air Force Base Tinker, OK 73145-9100 405-734-3058 sara.sayler@tinker.af.mil	**Geological Setting:** Permian-age sedimentary rocks overlain by Quaternary alluvium, sand dunes, and terrace deposits	**Technology Demonstrator:** IT Corporation 312 Directors Drive Knoxville, TN 37923-4799 Phone - 423-690-3211 Fax - 423-690-3626

Purpose of Investigation:
To help identify and map possible conduits for preferential groundwater flow in the shallow subsurface. The site-specific decision being supported was to obtain additional information in planning the optimal placement of the installation of groundwater recovery wells.

Number of Images/Profiles Generated During Investigation:
17,510 linear feet of seismic profiles collected along 8 survey lines. This case study focuses on the modeled and interpreted compressional (p-wave) results from a portion of Line 4 and an intersecting portion of Line 5. These lines were selected to represent typical site data and anomalies. This intersection is also the location of an interpreted sand channel near the intersection of the two lines, making it easier to demonstrate the continuity of the interpreted sand channel.

Results:
Interpretation of the seismic data indicates several places where sand channels cut into the Upper Saturated Zone/Lower Saturated Zone (USZ/LSZ) aquitard. The seismic reflection survey results will be used to recommend the placement of Phase II recovery well drilling locations. The results of Phase I groundwater recovery well yield tests indicated good correlation with several of the seismic anomalies identified in the target zones by the seismic survey. Seismic modeling was conducted to provide support for the interpretation of the seismic results. A EM-31 terrain conductivity survey was conducted along the eight seismic lines to screen for large scale anomalies caused by metallic objects that might interfere with the seismic survey. Most of the anomalies were due to surface metal, such as the chain-link fences, nearby structures, and monitoring well monuments.

EXECUTIVE SUMMARY

Tinker AFB covers 4,277 acres and is located on the southeast edge of the Oklahoma City metropolitan area. The base is situated within the North Canadian River drainage basin and drains into the Crutcho and Soldier Creeks and overlies a complex aquifer system that includes the Garber-Wellington Formation. The Southwest Quadrant Stabilization System (SQSS) Area is the location of two landfills that were used sporadically for disposal over a forty-year span from the 1940s to the late 1960s for disposal of sanitary and industrial wastes, including paints and solvents.

Near-surface geology at Tinker AFB consists of clays and clayey silts that are interbedded with thin, clayey sand layers, reaching a maximum thickness of approximately 60 feet in the western and southwestern parts of the base. The deeper geology is comprised of mostly unconsolidated materials, which are composed of predominantly fine-grained sandstone, with lesser amounts of siltstone and shale. Bedrock formations dip to the southwest by approximately 0.5 degrees, or by 40 to 50 feet per mile. Groundwater occurs at the site in four water-bearing units, but only the surficial unit was the target for this study. Groundwater can occur at depths as shallow as 20 feet, but public water supplies are drawn from depths of greater than 400 feet.

The purpose of the seismic survey was to locate permeable layers in the subsurface that might indicate preferential pathways for groundwater flow. This information is being used to site new extraction wells for the groundwater pump and treat system. Seismic methods were chosen as a cost-effective method for gathering information on the subsurface stratigraphy. The geology of the area is highly complex and other investigative methods, such as soil borings, would have yielded less information at a higher cost.

Two geophysical methods were used during this investigation: electromagnetic (EM) reconnaissance survey, and a seismic survey. The EM survey was conducted to screen for subsurface conditions that might cause interference in the seismic data collection. The seismic survey was conducted to identify conductive layers in the subsurface that might be paths for groundwater migration. Seismic modeling was conducted to provide analytical support for the interpretation of the seismic results.

The seismic survey revealed the presence of sand channels that were incised into the uppermost aquitard and sand lenses located within that aquitard. Seismic modeling significantly improved the investigator's understanding of the seismic anomalies that were found by providing an analytical benchmark against which to compare the seismic results. Strong correlation was found between the location of significant seismic anomalies and known groundwater flow pathways.

The target structures were relatively shallow and groundroll effects were not a significant source of interference. Poor surface conditions and cultural sources did, however, posed difficulties to data collection. Several seismic data processing techniques, such as refraction statics, spectral whitening, and mute analysis, significantly reduced the level of interference in the data and allowed for increased frequency and resolution of the seismic results.

SITE INFORMATION

Identifying Information

Tinker Air Force Base (AFB)
Oklahoma City, OK
RCRA Permit # 1571724391
Southwest Quadrant SMU

Background [1, 2]

Physical Description: Tinker AFB covers 4,277 acres and is located on the southeast edge of the Oklahoma City metropolitan area (see Figure 1). The base is bordered by Sooner Road to the west, Douglas Boulevard to the east, interstate highway I-40 to the north, and SE 79th street to the south The base is situated within the North Canadian River drainage basin and drains into the Crutcho and Soldier Creeks. The base overlies a complex aquifer system that includes the Garber-Wellington Formation .

Figure 1: Site Location

The topology of the seismic study area, located in the southwest portion of the base, is characterized by nearly level plains to gently rolling hills, with surface elevations ranging from 1,240 to 1,270 feet above mean sea level. The surface consists of alluvial soils near streams and flood plains, and residual soils resulting from weathered bedrock [1].

Site Use: The Southwest Quadrant Stabilization System (SQSS) Area is the location of two landfills that were used sporadically for disposal over a forty-year span from the 1940s to the late 1960s. Landfill #2 was used during the 1940s and 1950s for disposal of sanitary and industrial wastes, including paints and solvents. Landfill #4 was used from 1961 to 1968 for the disposal of drummed solvents, and sludges from petroleum and solvent storage tanks.

Release/Investigation History: On-site disposal of industrial wastes occurred from 1942 until 1979 when off-site disposal became the standard disposal practice. Organic solvents, including trichloroethylene (TCE), tetrachloroethylene, and l,2-dichloroethylene, were used for degreasing and aircraft maintenance. In the past, waste oils, solvents, paint sludges, and plating waste generated from maintenance activities were disposed in Industrial Waste Pits Numbers 1 and 2, located about l mile south of Soldier Creek and Building 3001. In 1997, a groundwater treatment system was installed to treat contaminated groundwater.

Regulatory Context: Actions at this site are being undertaken in compliance with Federal and State regulations under the Resource Conservation and Recovery Act (RCRA).

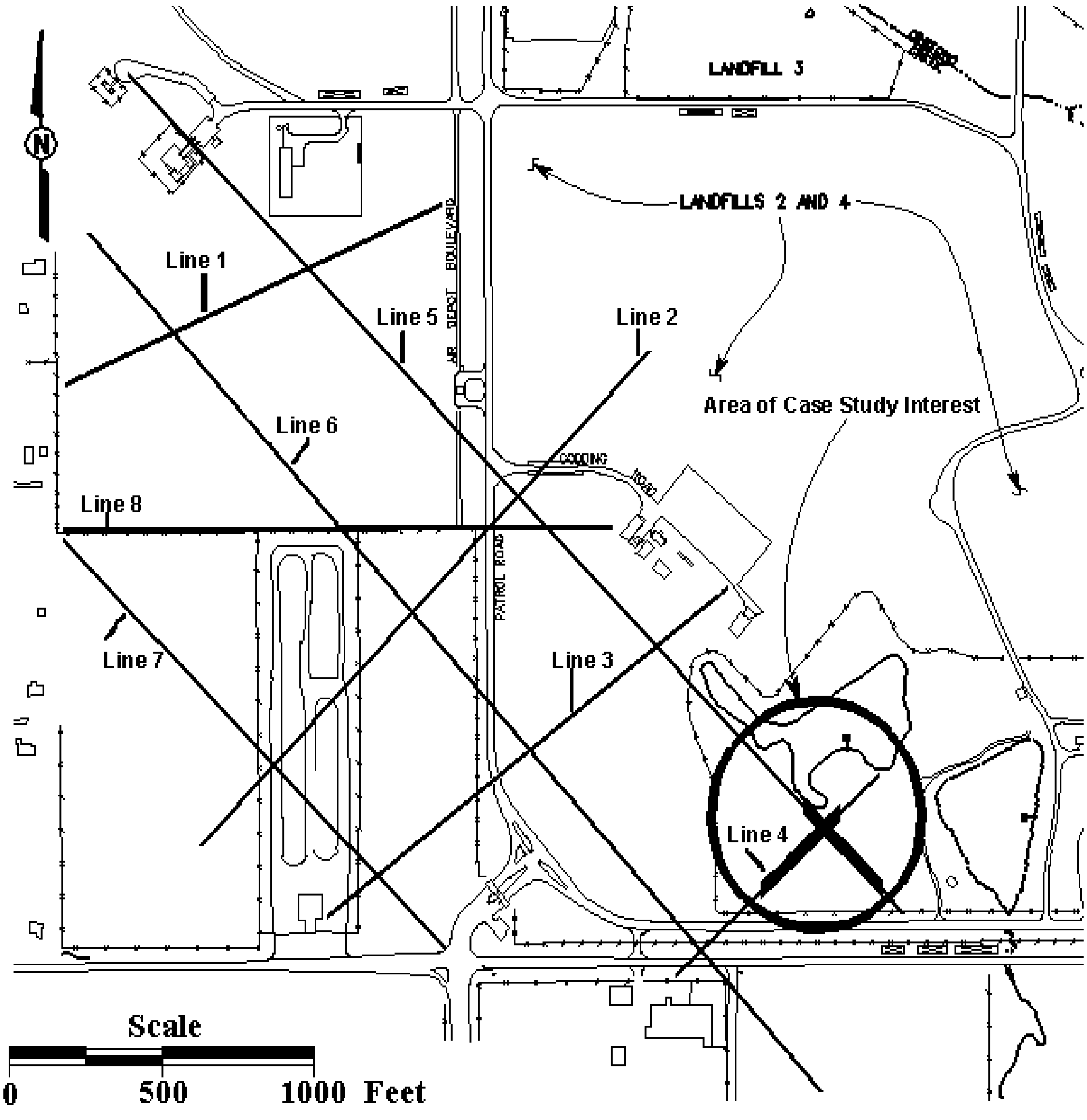

Figure 2: Site location map with seismic survey lines [1].

SITE INFORMATION

Site Logistics/Contacts

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Environmental Protection Agency

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MEDIA AND CONTAMINANTS

Matrix Identification

Type of Matrix Sampled and Analyzed: Subsurface soil/Bedrock

Site Geology/Stratigraphy

Near-surface geology at Tinker AFB consists of the Permian-age Hennessey Group and the Garber-Wellington Formation. The Hennessey Group is composed of clays and clayey silts that are interbedded with thin, clayey sand layers, reaching a maximum thickness of approximately 60 feet in the western and southwestern parts of the base. The Hennessey Group is underlain by the mostly unconsolidated materials of the Garber Formation, which are composed of predominantly fine-grained sandstone, with lesser amounts of siltstone and shale. The deeper Wellington Formation has a similar lithology to the Garber Formation, and together the two comprise the 1,000-foot thick Garber-Wellington Formation. Bedrock formations dip to the southwest by approximately 0.5 degrees, or by 40 to 50 feet per mile.

Groundwater occurs at the site in four water-bearing units, that include the Hennessey Water Bearing Zone (HWBZ), the Upper Saturated Zone (USZ), the Lower Saturated Zone (LSZ), and the Producing Zone (PZ). The HWBZ consists of fine-grained sediments with very low transmissivity and large vertical hydraulic gradients. Beneath the HWBZ, the USZ is the uppermost waterbearing zone of the Garber-Wellington aquifer. The USZ is made up of permeable sand channels and lenses. It is generally believed that the HWBZ and the USZ are not hydraulically connected. The USZ/LSZ aquitard is comprised of overlapping clay layers with interbedded thin sand lenses and is not of uniform thickness. The aquitard ranges in thickness from

MEDIA AND CONTAMINANTS

less than 10 feet to more than 25 feet, with the base of the aquitard occurring at a depth of approximately 110 feet below ground surface (bgs) in the southwest portion of the study area. The LSZ ranges between 140 and 200 feet in thickness, and is separated from the underlying PZ by the 30- to 100-foot-thick LSZ-PZ aquitard. The PZ extends from between 210 and 280 feet bgs to more than 1,000 feet bgs, and is used as the primary source of groundwater on the base and elsewhere in the Oklahoma City area. Groundwater can occur at depths as shallow as 20 feet, but public water supplies are drawn from depths of greater than 400 feet.

Contaminant Characterization

Primary Contaminant Groups: Volatile organics such as TCE.

Matrix Characteristics Affecting Characterization Cost or Performance [1, 2]

Certain subsurface structures, such as utilities and buried metallic objects, can cause interference, or noise, in the seismic data. To screen for such structures, frequency-domain electromagnetic (EM) data were acquired along the seismic lines. No significant sources of subsurface interference were found.

Significant interference with the seismic data collection was caused by muddy surface conditions and standing water along portions of the survey lines, particularly along Line 8. The seismic energy was significantly attenuated as it passed through the saturated soils, resulting in poor seismic data quality along those lines. Other surficial sources of interference included cultural noises, such as pumps, vehicles, wind and aircraft.

Groundroll can cause interference in data collection and interpretation. Groundroll is caused by seismic waves that travel horizontally toward the geophone sometimes obscuring the collection of seismic waves originating from deeper structures. During the investigation at Tinker AFB, the the high velocity surface materials reduced interference from the slow groundroll and the targets of principal interest were shallow and mostly located outside of the groundroll noise cone.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals [2, 3]

To help identify and map permeable materials in the USZ and the USZ/LSZ aquitard that might indicate preferential groundwater flow in the shallow subsurface. This information was used to place extraction wells to optimize the groundwater extraction system. The primary target of interest was near-surface sand channels and lenses within the USZ aquifer and the USZ/LSZ aquitard which may form preferential flow channels in the subsurface [2].

GEOPHYSICAL INVESTIGATION PROCESS

Geophysical Methods [1, 2]

Two geophysical methods were used during this investigation: electromagnetic (EM) reconnaissance survey, and a seismic survey. The EM survey was conducted to screen for subsurface conditions that might cause interference in the seismic data collection. The seismic survey was conducted to identify conductive layers in the subsurface that might be paths for groundwater migration.

The EM survey was performed to detect sources of potential interference to seismic data collection. The EM survey sought to identify variations in the electrical conductivity of subsurface materials that might be caused by buried objects, conductive fluids, or geologic discontinuities. By artificially applying a known electromagnetic field to the ground surface by means of a transmitter, investigators measure the presence of disruptions to the known electromagnetic field with a receiver. These disruptions, termed EM anomalies, can result from either geological changes or the presence of metallic objects, such as pipes, drums, cables, tanks, etc., in the subsurface. The EM survey conducted at Tinker AFB was used to identify buried materials that might interfere with seismic survey by scattering or attenuating seismic waves. A Geonics Limited EM-31 terrain conductivity meter coupled to an Omnidata DL720 digital data logger was used to collect quadrature-phase and in-phase component data along the length of each seismic line in the survey area.

The seismic reflection method was used to collect seismic data in the subsurface with which permeable layers in the subsurface can be identified. These permeable layers may act as groundwater migration pathways, and may be good locations for future extraction wells. In a seismic reflection survey, an artificial seismic source is used to create an acoustic wave that propagates downward through the soil layers. When the wave reaches a soil layer whose seismic conductivity is significantly different from that of the overlying soils, a portion of the wave is re-directed to the surface. A geophone, or electromechanical transducer, is used at the surface to receive the reflected wave energy. Subsurface stratigraphy is then mapped by measuring the travel time necessary for a wave to pass through one layer to another, refract along the interface, and return to the geophones at the surface. Seismic field equipment used to conduct the survey consisted of three 48-channel Geometrics Strataview® seismographs in a master-slave configuration, totaling 144 channels. Single, 40-Hz vertical geophones were used for collection of p-wave data.

Seismic modeling was conducted to provide support for the interpretation of the seismic results. Seismic models were developed to depict the anticipated seismic response of various types of subsurface stratigraphy that might be encountered in the study area, i.e. sand channels cutting into the aquitard or sand lenses embedded in a clay layer. Well lithologies and sonic logs acquired in wells located within the survey area were used to develop estimates of the seismic velocities of the various soil types found within the study area. These estimates were used to construct hypothetical seismic models of subsurface structures of varying thickness and composition. When seismic anomalies were encountered in the survey data, the actual seismic response was compared to the modeled response of different stratigraphic features to help identify the type of subsurface stratigraphy that might create such an anomalous response. The use of seismic models greatly aided investigators in their interpretation of the seismic results by providing a set of benchmarks against which actual results could be compared [4].

Seismic lines were chosen to satisfy three criteria:

- The survey area should include parallel and perpendicular coverage of a known geologic strike. The lines within the area were located so that velocity data could be acquired in at least one well on at least one line of the survey, and each of the lines were to have at least one tie with another line in the survey.

- The survey area should include areas in which known contaminant plumes were present; and

- The survey lines should be placed in areas whose groundwater is under hydraulic control from the groundwater pump and treat system.

Prior to collecting geophysical data, each seismic survey station was geospatially surveyed using a Global Positioning System (GPS). The ability to geospatially reference the seismic profiles allowed investigators to understand the relationships between the individual seismic profiles and the larger site geology. Horizontal and vertical geospatial accuracies were kept within 0.5 feet and 0.1 feet, respectively.

A field test of the seismic parameters was used to evaluate the relative merits of collecting different types of seismic wave during the survey, and to determine the optimal distance between the seismic source and the geophones. Data on two types of seismic waves: compressional (p-wave) and shear(s-wave) wave, were acquired along a short test section of Line 5 to evaluate and compare the results such surveys would produce at the site. While p-wave data, the seismic wave that is projected downward, were less complex to collect and interpret, s-wave data often provide a higher resolution. S-wave data are collected as the seismic energy is transmitted horizontally from the source to the receiver. Along this test section, p-wave data were recorded using vertical source impacts and vertical geophones, and s-wave data were recorded using horizontal impacts and horizontal, s-wave, geophones. Based on the noise tests conducted in the field and the depth of the target, a 5-foot station and l0-foot shotpoint (energy source) spacing were used for the survey. The investigators decided that the p-wave data would provide sufficient resolution to identify the targeted subsurface structures, and, therefore, no additional s-wave data were collected.

GEOPHYSICAL FINDINGS

Technology Calibration [1, 2]

The calibration needed for a successful seismic survey is to establish the relationship between the depth of an anomaly in the subsurface and the time it takes a seismic wave to propagate to that anomaly and return back to the surface. In other words, the seismic time must be "tied" to depth. To establish this link at Tinker AFB, investigators collected vertical seismic profiles (VSPs) and sonic logs. The sonic logs were used to construct synthetic seismograms. A synthetic seismogram is a statistical comparison of seismic velocity, soil density, and depth values used to convert seismic velocity data into depth.

The VSP data were acquired in two monitoring wells with maximum depths of approximately 150 feet in order to better understand the subsurface velocities. For each profile, a geophone is locked in a well at regular depth intervals and used to record the energy from a surface source at each interval. The time lapse recorded between source and receiver is a measure of the time necessary to go from the surface to the geophone in the well is displayed as a time versus depth graphic.

Data from an existing sonic log in a nearby well was also used to link the seismic time data to depth. Together, the sonic log and the VSP data, were used to generate a synthetic seismogram. The seismogram provides a correlated display of seismic velocities, time and known depths to reflectors. These correlations establish the link between the seismic velocity of certain subsurface materials and the depths at which those materials were encountered.

Investigation Results [1, 2]

The EM-31 reconnaissance survey was conducted along the eight seismic lines and revealed large-scale anomalies caused by metallic objects. Most of the anomalies were caused by surface metal, such as the chain-link fences, nearby structures, and monitoring well monuments. Subsurface anomalies were also identified as subsurface pipelines that cross the area, such as a north-to-south trending pipe that exists in the western part of the site.

More than 17,000 linear feet of seismic data were collected along eight survey lines and the resulting profiles identified four reliable locations for future extraction wells. For the purposes of this case study, however, the discussion presented focuses only on the interpreted and modeled results from the intersecting portions of Lines 4 and 5, as shown in Figure 2 on page 3. The seismic results along both lines showed a sand channel near the intersection of the lines, increasing the reliability the interpreted sand channel and its continuity. None of the EM anomalies, discussed above, were located within this area [3].

Muddy surface conditions and standing water along portions of the survey lines caused significant variation in and interference with the quality of the seismic data collected. Two statistical solutions were applied to improve the quality of the data. Refraction statics, proved most effective in minimizing the noise in the data. The adjusted data had less variation and improved resolution.

GEOPHYSICAL FINDINGS

The seismic reflection survey was conducted along each line using a 5-foot interval between geophones and a 10-foot shotpoint interval. Data were acquired using a 0.5-millisecond (msec) sampling rate; the record length was 1,024 msec. As data quality warranted, source impacts per shotpoint were adjusted along each line.

The seismic profile generated along Line 4 at its intersection with Line 5 is shown in Figure 3. In this profile, the top of the USZ/LSZ aquitard was interpreted to be at approximately 70-75 feet bgs (25 msec), and the bottom of the aquitard was interpreted to be at approximately 110-115 feet bgs (35 to 40 msec). Although only the USZ was targeted for this study, other structures can be seen in Figure 3, such as the base of the LSZ, where the LSZ/PZ aquitard occurs, at approximately 295 feet bgs (75 msec). One significant anomaly can be seen in this Figure, centered on Station 295, and is outlined by hash marks. This feature was interpreted to be a large sand channel within the upper portion of the USZ/LSZ aquitard which is laterally continuous and was considered to be part of a larger structure that can be seen nearby on the Line 5 section. The channel was presumed to trend north to northeast, roughly in line with the high-yield B6 and B7 recovery wells. The seismic model data indicate that this anomaly could be caused by the presence of a low conductivity materials (i.e. sand) embedded in higher conductivity materials (i.e. silts and clays). Above this channel, the seismic data indicate the presence of a low velocity medium, likely a sand within the USZ aquifer. This channel was suggested as a good location for a future extraction well.

The seismic profile generated along Line 5 at its intersection with Line 4 is shown in Figure 4. The bottom of the USZ/LSZ aquitard can be seen at a depth of 110-115 feet bgs and a noticeable low in this area (represented by the dashed line) indicated the presence of materials with similar seismic velocity incised into the base of the aquifer, and/or the accumulation of slower velocity materials locally, such as would be expected from a sand channel. Two anomalies appear in the Line 5 data shown in Figure 4. A broad and subtle anomaly extending between stations 680 and 693 at a depth of approximately 75-80 feet bgs was interpreted as a small incised sand lens at the bottom of the USZ aquifer. The feature extending from station 650 to 667 at a depth of 80-90 feet bgs was interpreted to be part of the same large sand channel that occurs along Line 4.

A seismic interpretation map of the entire survey area with the locations of interpreted channels and lenses above and within the upper portion of the USZ/LSZ aquitard is shown in Figure 5A. Several channels were interpreted near the bottom of the USZ/LSZ aquitard, and several deep channel systems were interpreted within the LSZ (not discussed here). There is a substantial concentration of interpreted lower aquitard channels in the southern and southeastern portion of the survey area, and deep channel systems in the central and southeastern portions of the survey area.

GEOPHYSICAL FINDINGS

Results Validation [1]

Seismic data indicating areas of high hydraulic conductivity were compared to well yield test results from the existing Phase I recovery wells which were drilled to an average depth of 80 to 90 feet. All of the Phase I wells were drilled in locations based on engineering factors, plume location, and groundwater flow direction. Wells A8, B3, B6, and B7 were drilled near anomalies identified by the seismic data discussed in this case study. Figures 5A and 5B show the correlation between higher yield zones, as determined with pump tests on the Phase I wells, and the locations of the sand channel identified at the intersection of Lines 4 and 5. On Line 5, anomalies centered on Station 658 correspond to high yields on the B6 and B7 recovery wells. Another anomaly found along Line 5 and interpreted as a sand channel, centered on Station 205, corresponds to the high yield recovery well B3. On Line 6, the anomaly centered near Station 390 corresponds to the high yield A8 recovery well. Several other interpreted sand channels have not been verified at this time. These areas present target locations for possible future Phase II recovery wells.

Further validation was provided by sonic logs taken in five of the extraction wells that were located on or near the seismic survey lines. These helped to confirm reflector identification and also demonstrated good correlation between the seismic findings and well tests [3].

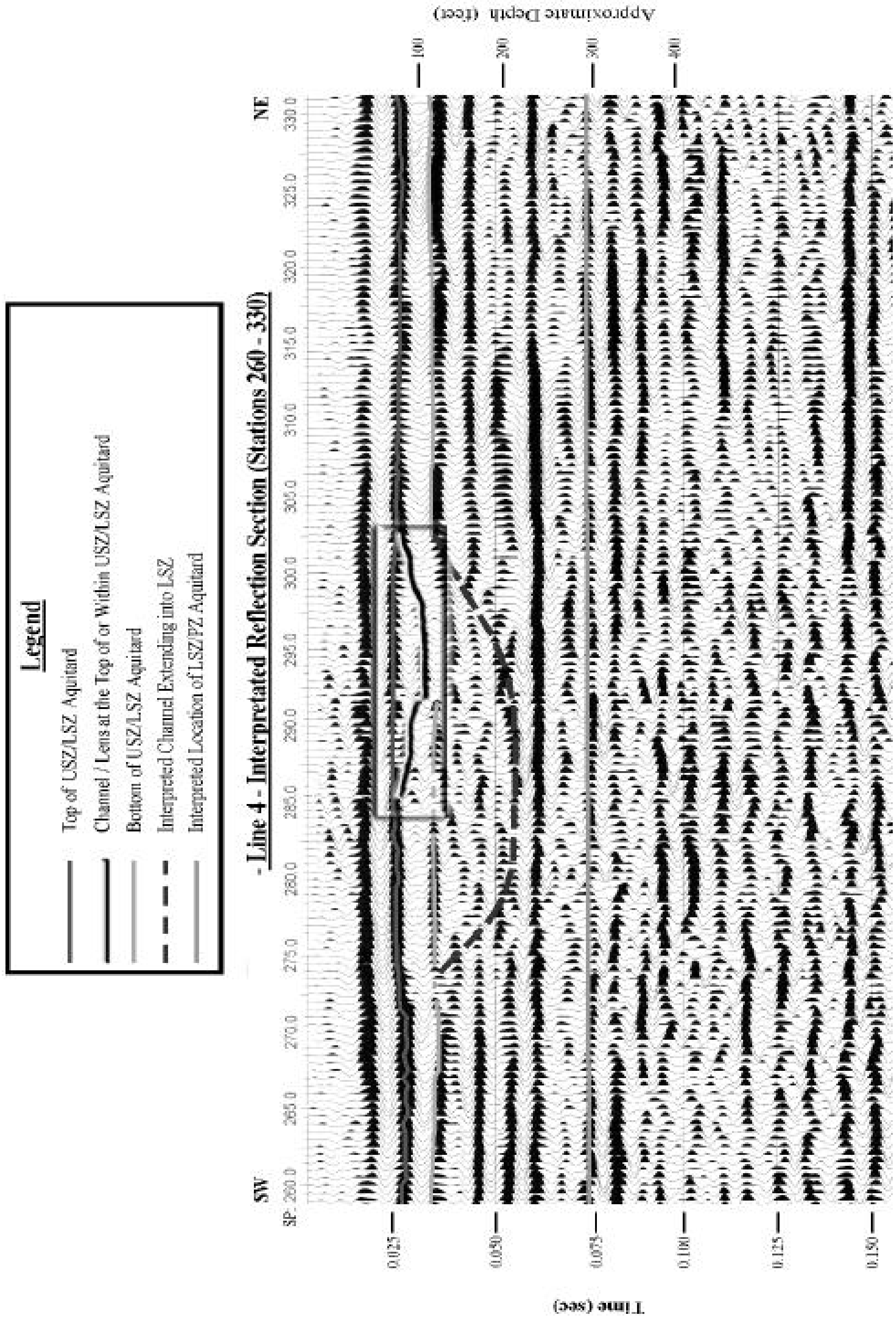

Figure 3: Interpreted Reflection Section on Line 4 [2].

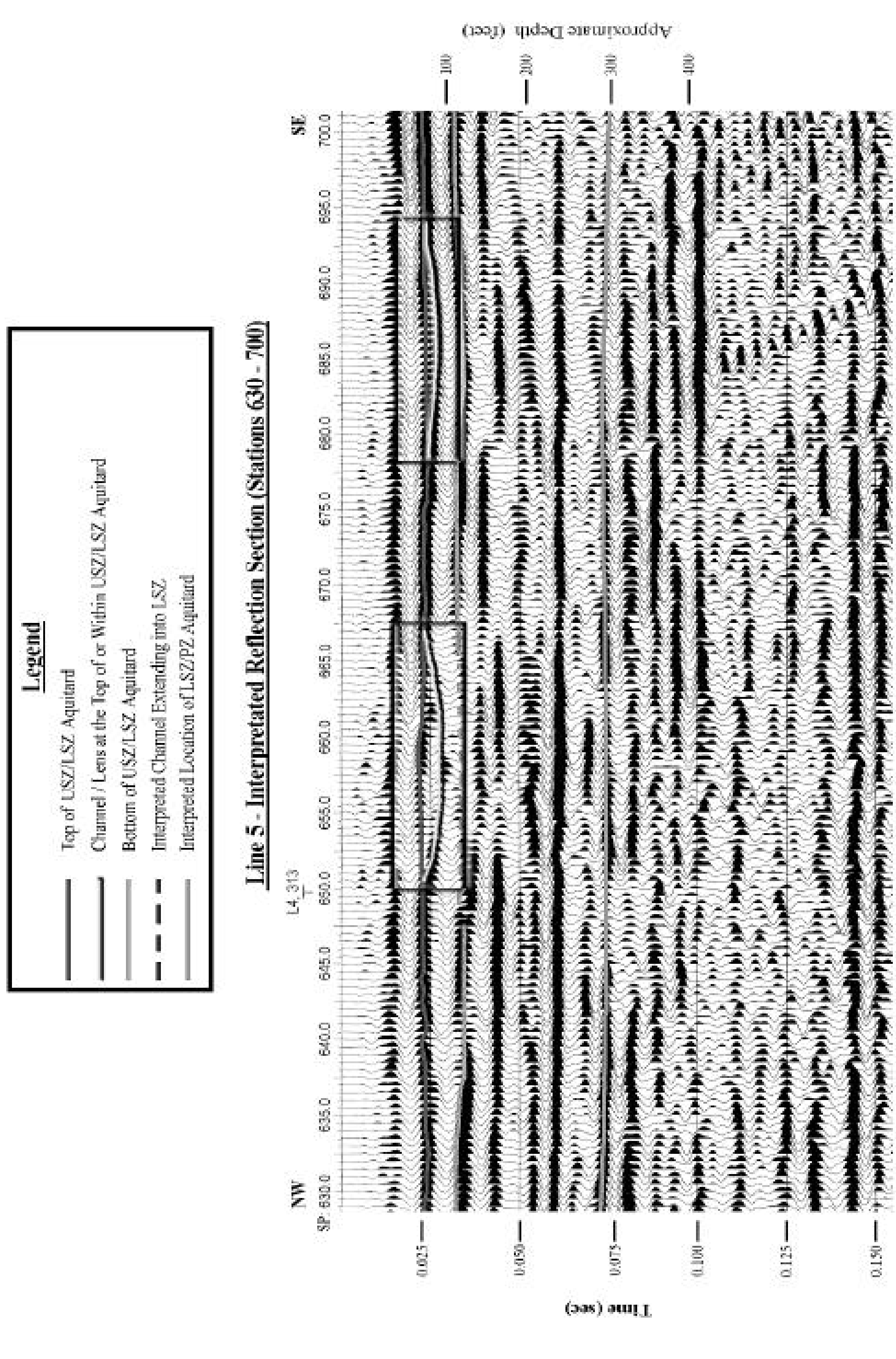

Figure 4: Interpreted Reflection Section on Line 5 [2].

GEOPHYSICAL FINDINGS

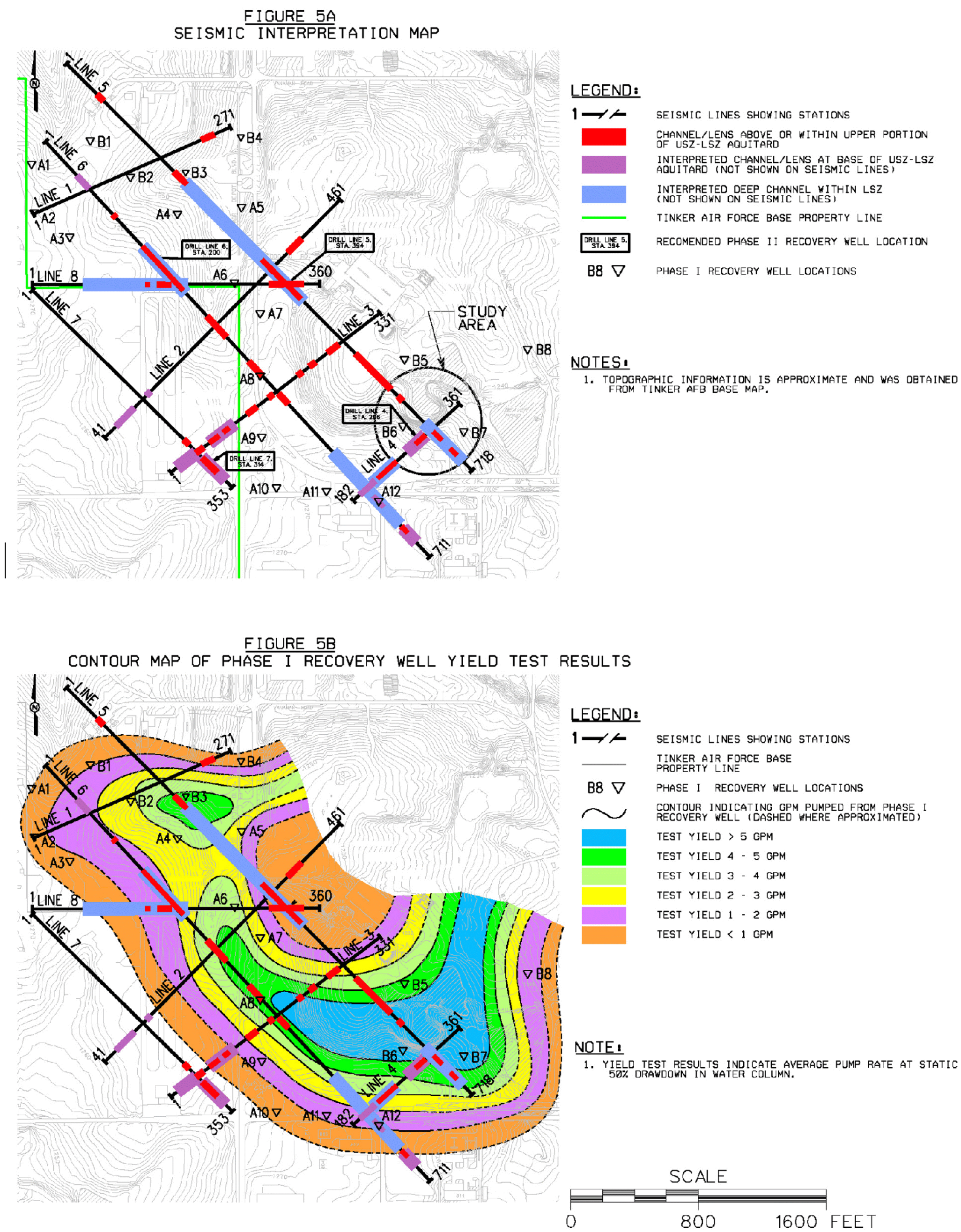

Figure 5: Location of Significant Seismic Anomalies and Correlation with Well Yields[2]

LESSONS LEARNED

Lessons learned at the Tinker AFB study site include the following:

- The seismic survey results identified several areas in which permeable zones in the subsurface are located and which may be favorable locations for future well installation. Four of these sites represent locations where the highest potential for drilling into significant sand channels is thought to exist [1].

- The EM survey successfully identified large scale anomalies caused by metallic objects, such as the chain-link fences, nearby structures, and monitoring well monuments. The EM anomalies found did not present a problem for the seismic data quality.

- Existing well yield data correlates well with several of the anomalies that are interpreted as channels. Incorporation of recently acquired sonic log data and lithologic logs from extraction wells drilled near any of the seismic lines with the seismic data will be particularly useful for refining stratigraphic and depth correlation [1].

- The relatively high seismic velocities in the unconsolidated sediments at this site reduce the spatial resolution that can be attained from the data. S-wave data should increase resolution compared to the p-wave data. However, for this site, the s-wave data proved inferior when compared to p-wave data, especially when the additional cost for acquiring and processing the s-wave data is considered[2].

- The results developed for this site are only valid for two-dimensional cross sections of the subsurface beneath each seismic line. If delineation of the spatial distribution of features between lines is required, the acquisition of three-dimensional data should be considered at this site [2]. Three-dimensional seismic techniques were the preferred method, but due to the large areal extent of the survey area and associated data acquisition and processing costs, the two-dimensional method was used [1].

- The application of seismic data processing algorithms, such as refraction statics and spectral-whitening, reduced the level of interference in the data. This, combined with thorough velocity and mute analysis along the seismic lines, allowed for increased frequency and resolution of the seismic results [1].

- Seismic results often reveal a number of anomalous results attributable to a large variety of conditions, such as poor surface conditions, interference from cultural sources, or variation in seismic wave generation. These anomalies may, on the other hand, represent the target structures. The use of seismic models in this survey aided the investigators by helping them quickly identify whether the anomalous results were due to difficulties in data acquisition or target structures. Moreover, by comparing seismic anomalies to model results, investigators were able to refine their interpretation of the anomalous responses by helping them to distinguish between different lithologic changes, such as a discontinuity in a clay layer and a sand channel incised into the clay layer [4].

REFERENCES

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- Personal communication with Sara Sayler of Tinker Air Force Base. August 25, 1999.

- Personal communication with Sara Sayler of Tinker Air Force Base. December 17, 1999.