SEISMIC-REFRACTION STUDY OF SUSPECTED DRIFT-FILLED BEDROCK VALLEYS IN RAMSEY COUNTY, MINNESOTA

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CONTENTS

ILLUSTRATIONS

CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply Inch-Pound Unit	By	To Obtain Metric Unit
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)

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ABSTRACT

Seismic-refraction surveys were made across suspected buried, drift-filled bedrock valleys believed to underlie two sites of known ground-water contamination--the Twin Cities Army Ammunition Plant (TCAAP) near New Brighton and the former Koppers Coke Plant in St. Paul, Ramsey County, Minnesota. Refraction data were collected along two lines at each site; each line traversed the axis of a suspected valley.

Drift-filled bedrock valleys were thought to incise the Prairie du Chien-Jordan aquifer to an altitude between 500 and 560 feet above sea level at the TCAAP site. The interpretation of one seismic profile indicates that a valley probably does not exist under the area surveyed; the modeled depth profile shows the bedrock surface ranging between altitudes of about 700 to 780 feet. Interpretation of a second seismic profile just south of the TCAAP indicates that a shallow valley may exist under the northern half of the line; the modeled depth profile shows that the bedrock surface declines from an altitude of about 780 feet to about 690 feet over a horizontal distance of 400 feet.

A drift-filled bedrock valley was thought to incise the St. Peter aquifer to an altitude between 770 and 800 feet above sea level at the Koppers site. The interpretation of a seismic profile just east of the Koppers site is not conclusive, but suggests that a bedrock valley may be present near the middle of the line. The interpretation of a second seismic profile across the westward extension of the same suspected valley also is not conclusive, but suggests that a bedrock valley may be present at the north end of the line. The optimal field layout for each line at the site (longer shot offsets) could not be obtained because of limited space available in the densely developed residential neighborhoods.

INTRODUCTION

Background

Toxic organic substances have been found by the Minnesota Pollution Control Agency (MPCA) in ground water collected near the Twin Cities Army Ammunition Plant (TCAAP) and the site of the former Koppers Coke Plant, each located in Ramsey County in the Twin Cities area, Minnesota (fig. 1). The U.S. Environmental Protection Agency (USEPA), in cooperation with the MPCA, is studying the ground water in those areas to determine the level and extent of the contamination.

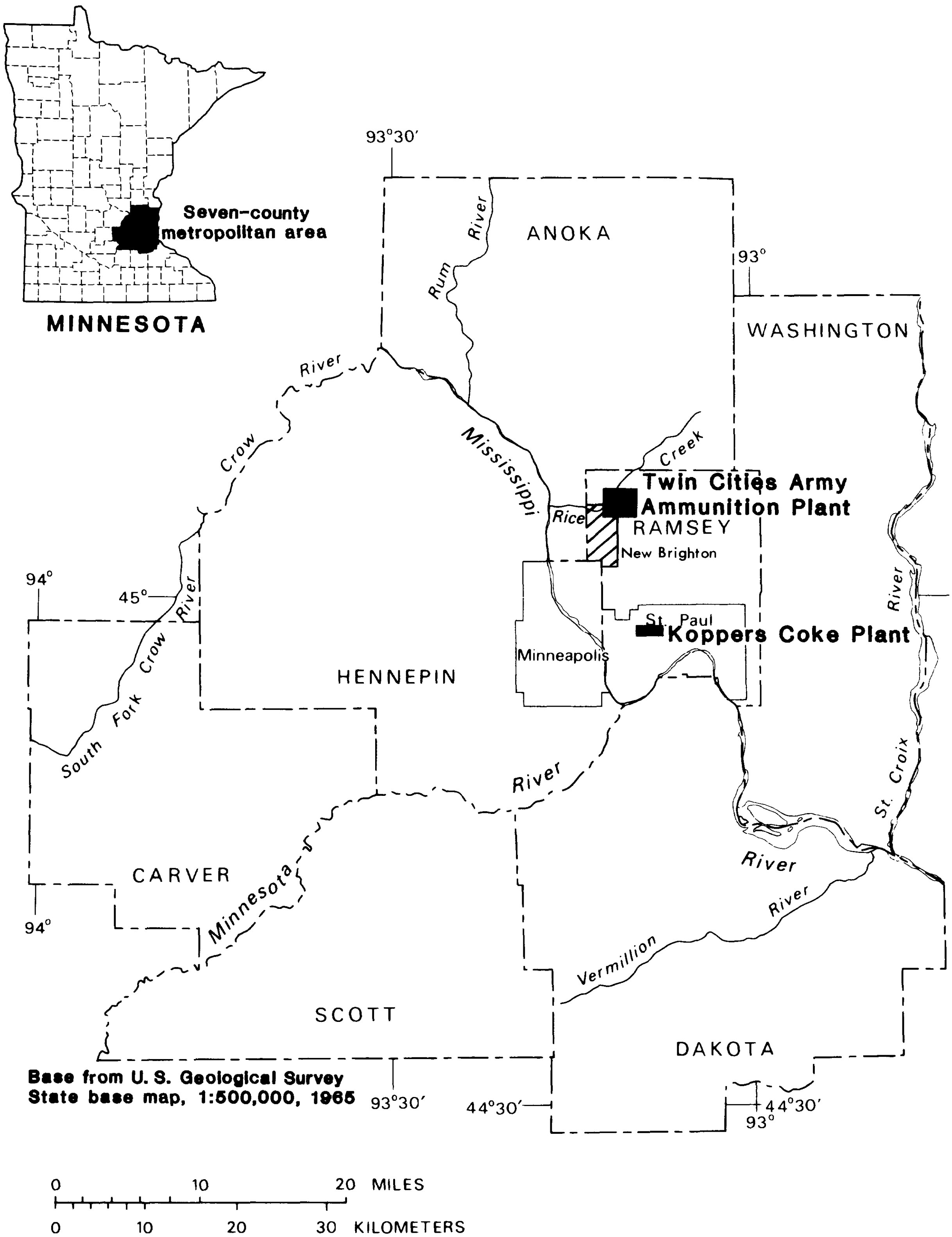

Figure 1.--Location of Twin Cities Army Ammunition Plant (TCAAP) and the site of former Koppers Coke Plant, Ramsey County, Minnesota

Numerous maps, including unpublished geologic maps prepared by the Minnesota Geological Survey in 1982, show the presence of drift-filled bedrock valleys underlying the areas of suspected contamination (Stone, 1966, pl. 2; Norvitch and Walton, 1979, pl. 3; Mossler, 1983). The valleys, as mapped, dissect two major bedrock aquifers in the Twin Cities area -- the Prairie du Chien-Jordan aquifer composed of the Ordovician Prairie du Chien Group and Cambrian Jordan Sandstone at the TCAAP site and the St. Peter aquifer in the overlying Ordovician St. Peter Sandstone at the Koppers site. In a hydrogeologic study of a drift-filled bedrock valley located 6 miles northeast of the TCAAP site, Winter and Pfannkuch (1976) concluded that buried valleys could be preferred avenues for the transport of contaminants from the land surface to bedrock aquifers because they cut through a number of bedrock aquifers in the region.

In order to evaluate the influence of bedrock valleys on the transport of contaminants near the TCAAP and Koppers sites, the USEPA proposed a test-drilling program to define the geometry and lithology of the drift-filled bedrock valleys. The U.S. Geological Survey was asked by the USEPA to conduct a series of seismic-refraction surveys to (1) determine the feasibility of using the surveys to better define the location and depth of the buried-bedrock valleys and, if feasible, (2) use the interpreted refraction profiles to guide the test-drilling program.

Purpose and Scope

This report describes the field collection, interpretation techniques, and interpreted results of seismic surveys conducted at the TCAAP and Koppers sites in Ramsey County. Two seismic-refraction lines were shot at each site in order to gain subsurface geologic information regarding suspected drift-filled bedrock valleys. Because the sites are located in an urban setting, optimal field arrays and equipment could not be used. The project was designed to provide reconnaissance-type information to use as a guide for further test drilling.

SEISMIC-REFRACTION METHODS

Seismic-refraction methods are based on the principle that differences in the elastic properties of rocks result in changes in the velocity of wave propagation and changes in the geometry of the propagation path (Hobson, 1970). The refraction method of seismic geophysics requires that two conditions be met in the subsurface horizons before depth to the various interfaces can be calculated accurately:

1. The seismic velocity of successive layers must increase with depth, and,

2. The various layers through which the refracted wave travels horizontally must have a thickness that permits transmission of the refracted wave. The thickness is a function of the depth of burial and the velocity contrast between the adjacent layers.

Seismic-refraction data are collected in the field by recording the time for pulses of elastic energy to propagate through the subsurface from the initiation point (the shot point) to the detectors (geophones). A Nimbus Model ES-1210F 12-channel seismograph[1] was used in this project; NIPAK two-component explosives detonated by a Seiscap blasting cap were used to generate the seismic energy. The explosives were placed at the bottom of boreholes augered either to the water table or to about a 15-foot depth. The boreholes were back-filled with cuttings and were tamped before the explosives were detonated. In the present study, the optimal field layout for determining the bedrock topography was one in which the shot point was offset at such a distance from the geophone spread so that the first 2 geophones detect refractions from the water table and the remaining 10 geophones detect refractions from the bedrock surface. Each geophone spread recorded seismic data generated from at least two shot points. A shot point was offset, in-line, from each end of the geophone spread, thereby establishing a "forward" and a "reverse" shot point. By analyzing the combined data from the forward and reverse shots, the effects of a dipping subsurface layer can be documented.

The interpretation of shallow seismic-refraction data seldom is simple and straightforward. The travel-time plot of first-break arrivals is the basis for interpreting refraction data, and different combinations of subsurface structure or layering can result in the same travel-time plot.

The seismic-refraction data were analyzed with a computer program originally developed for the U.S. Bureau of Mines by Scott and others (1972), and modified by Scott (1977). The computer technique involves a two-dimensional modeling process in which the delay-time method is used to obtain a first approximation of model layers, after which iterative ray-tracing methods are used to refine the model. The criterion for adjusting and refining the model is that the discrepancies between travel times obtained from field measurements and those obtained by computer ray tracing are minimized (Scott and others, 1972, p. 2). The following basic assumptions apply to the modeling procedure used in the model program:

1. Layers are continuous and extend from one end of the refraction line to the other.

2. Layer velocity increases with layer depth.

3. Horizontal velocity is equal to or greater than vertical velocity for any given layer.

4. Both horizontal and vertical velocities are constant within each layer from one end of the spread to the other.

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[1]The use of model or name brands in this report is for identification purposes only, and does not constitute endorsement by the U.S. Geological Survey.

The results of the model analysis for this study are depicted as depth profiles that show the land surface and the interpreted water table and bedrock surface. Because the purpose of these investigations was to provide reconnaissance-level information on bedrock topography, preliminary, rather than detailed, interpretations were made. Interpretations are termed "not conclusive" if (1) the discrepancy between the depth approximations of a refraction interface as determined by ray tracing from two or more shot points was too great, or (2) the number of data points used to define a refraction interface was too small. These shortcomings possibly could have been corrected by using more shot points on each profile. Again, this was not done because of the limited scope of the study.

SEISMIC-REFRACTION STUDIES

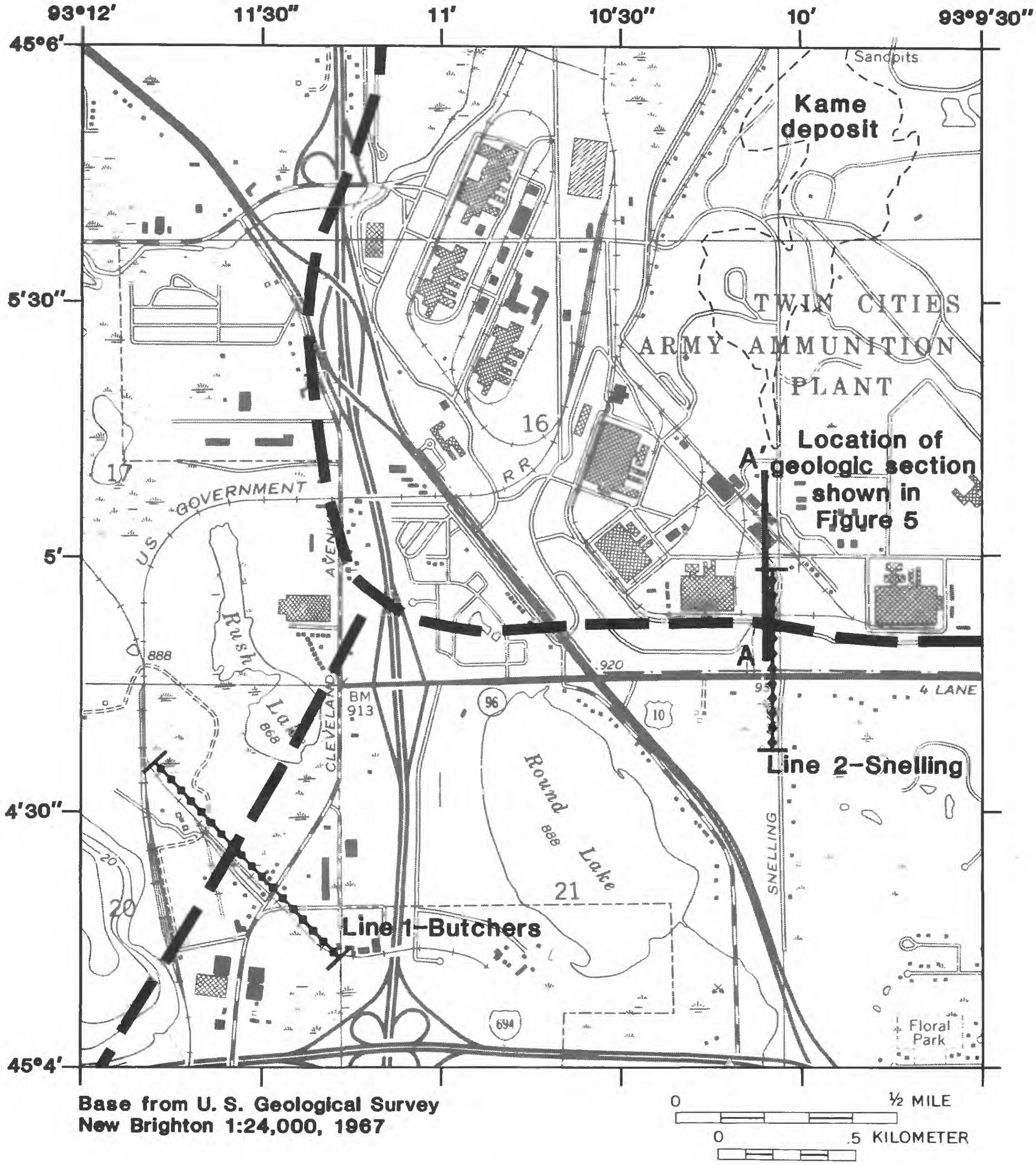
Twin Cities Army Ammunition Plant Site

The Twin Cities Army Ammunition Plant (TCAAP) in New Brighton, Minnesota, was constructed in 1941 and 1942, with the production, inspection, and storage of ammunition occurring through approximately 1957 and again from 1966 through 1974. The plant site and adjacent area are located on various deposits of glacial drift that range in thickness from about 100 to 400 feet. Dolomite of the Prairie du Chien Group underlies the drift in this area and is the upper unit of the Prairie du Chien-Jordan aquifer. Suspected drift-filled bedrock valleys were believed to trend close to the western and southern boundaries of the TCAAP, with a tributary valley believed to trend southwest from the TCAAP (fig. 2). The valleys were thought to range from one-half to one mile in width and to incise the Prairie du Chien-Jordan aquifer to altitudes from 500 to 560 feet above sea level.

Data Collection

Two refraction profiles were made at the TCAAP site (fig. 2) during May 3-5, 1982. Line 1-Butchers was shot across the axis of a suspected drift-filled bedrock valley believed to trend southwest from the TCAAP. The field layout for Line 1 is shown on figure 3. As indicated on figure 3, Line 1 consisted of three overlapping geophone spreads.

Existing hydrogeologic control for Line 1-Butchers was obtained from an abandoned refinery well (constructed in the 1920's) located about 150 feet west of the line, and a piezometer (constructed in 1981) also located about 150 feet west of the line (fig. 3). A television downhole-camera inspection of the "Old Northwest Refinery" well by the Minnesota Department of Health on February 1982 disclosed that the well casing extended 178 feet below land surface where it terminated in dolomite of the Prairie du Chien Group (Jim Nye, Minnesota Department of Health, written commun., 1982). Because it is common practice for drillers in the area to set well casing at least 10 feet into bedrock, it can be assumed that the refinery well encountered bedrock at a depth of about 168 feet (an altitude of about 720 feet above sea level). The water table was measured in piezometer P-3C-81 at 10.5 feet below land surface (about 885 feet above sea level) on July 8, 1981 (Soil Exploration Co., written commun., 1981).



EXPLANATION

Location of refraction line

Location of suspected drift-filled bedrock valley

Figure 2.--Location of refraction lines and suspected bedrock valleys in the vicinity of the Twin Cities Army Ammunition Plant

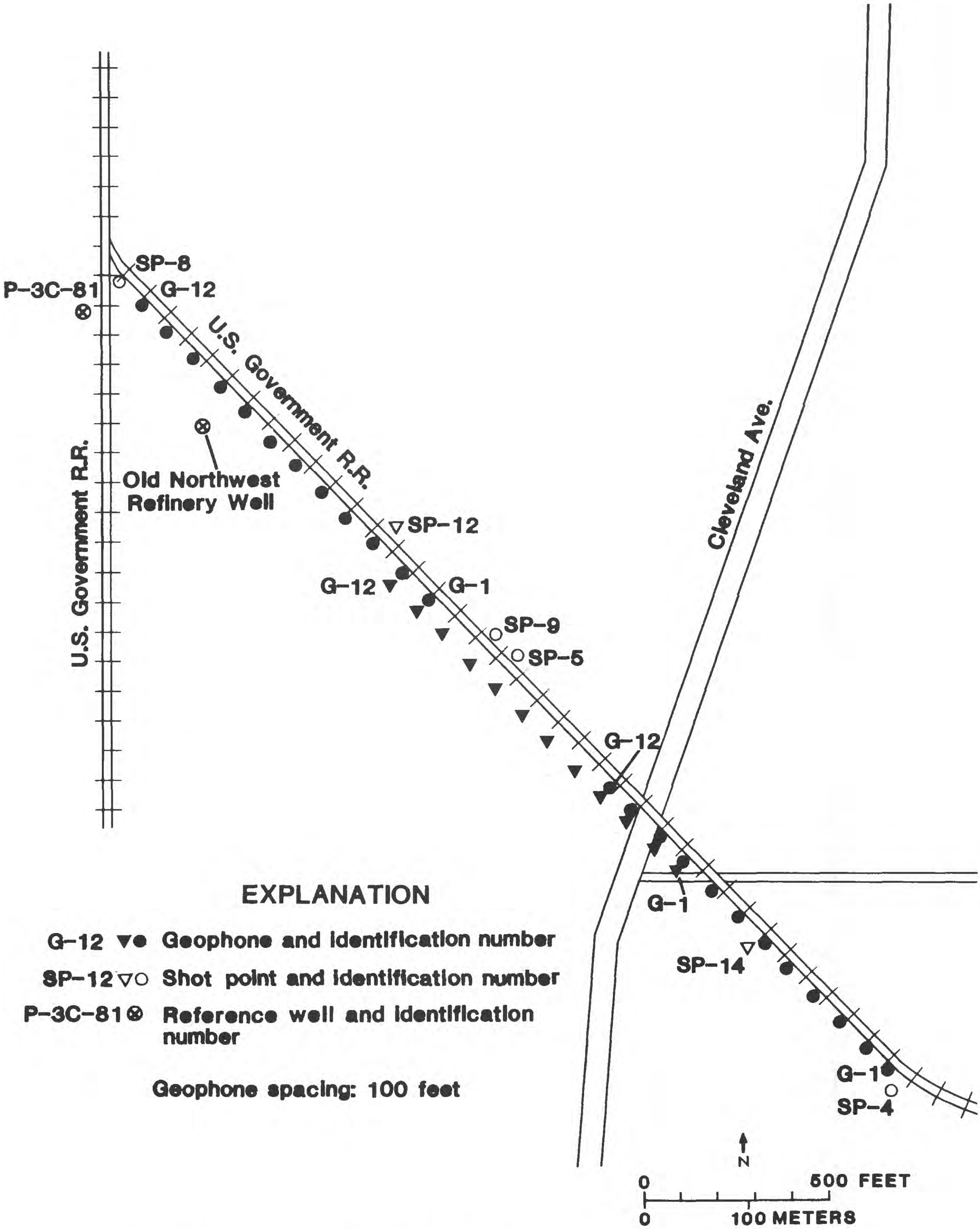


Figure 3.--Field layout for Line 1-Butchers, Twin Cities Army Ammunition Plant site

Line 2-Snelling was shot across the axis of a suspected drift-filled bedrock valley believed to trend east-west just south of the TCAAP (fig. 2). The field layout for Line 2 is shown on figure 4, and consisted of two in-line geophone spreads that did not overlap.

Existing hydrogeologic control for Line 2-Snelling was obtained from the driller's log of test hole PSB-4, which is located on the TCAAP grounds approximately 70 feet west of the line, from piezometer ST-4-U3 located next to test hole PSB-4, and from the driller's log of a domestic water well (Minnesota unique well number 206763) drilled in 1970 approximately 600 feet west of the line (fig. 4). The log of test hole PSB-4 is characterized as follows:

Depth below land surface, in feet	Hydrogeologic description
0-15.5	Fill. Organic and inorganic silt and inorganic clay.
15.5-55.0	Twin Cities Formation of stone, 1966. Complex mixture of pale brown, reddish brown,and light gray clay till; confining bed.
55.0-100.0	Arsenal Sand of stone, 1966. Gravelly, fine to coarse sand found in a kame deposit located in the TCAAP.
100.0-219.8	Hillside Sand of stone. Poorly graded, medium to coarse sand believed to be proglacial outwash.
219.8-221.7	Dolomite of the Prairie du Chien Group.

Thus, the bedrock was encountered about 220 feet below land surface (an altitude of 730 feet above sea level). The water table was measured in piezometer ST-4-U3 at 99.8 feet below land surface (an altitude of about 850 feet) on September 23, 1982 (STS Consultants Ltd., 1983); and the water table was measured in the domestic well at 92 feet below land surface (848 feet above sea level) in November 1970.

A glacial kame composed of sand and gravel creates a distinctive topographic high in the central part of the TCAAP site (fig. 2). The geologic interpretation of recent test-hole drilling in the TCAAP site (STS Consultants, Ltd., 1983) shows that the clay till of the Twin Cities Formation thins as it approaches the kame from the south and eventually pinches out against the kame (fig. 5).

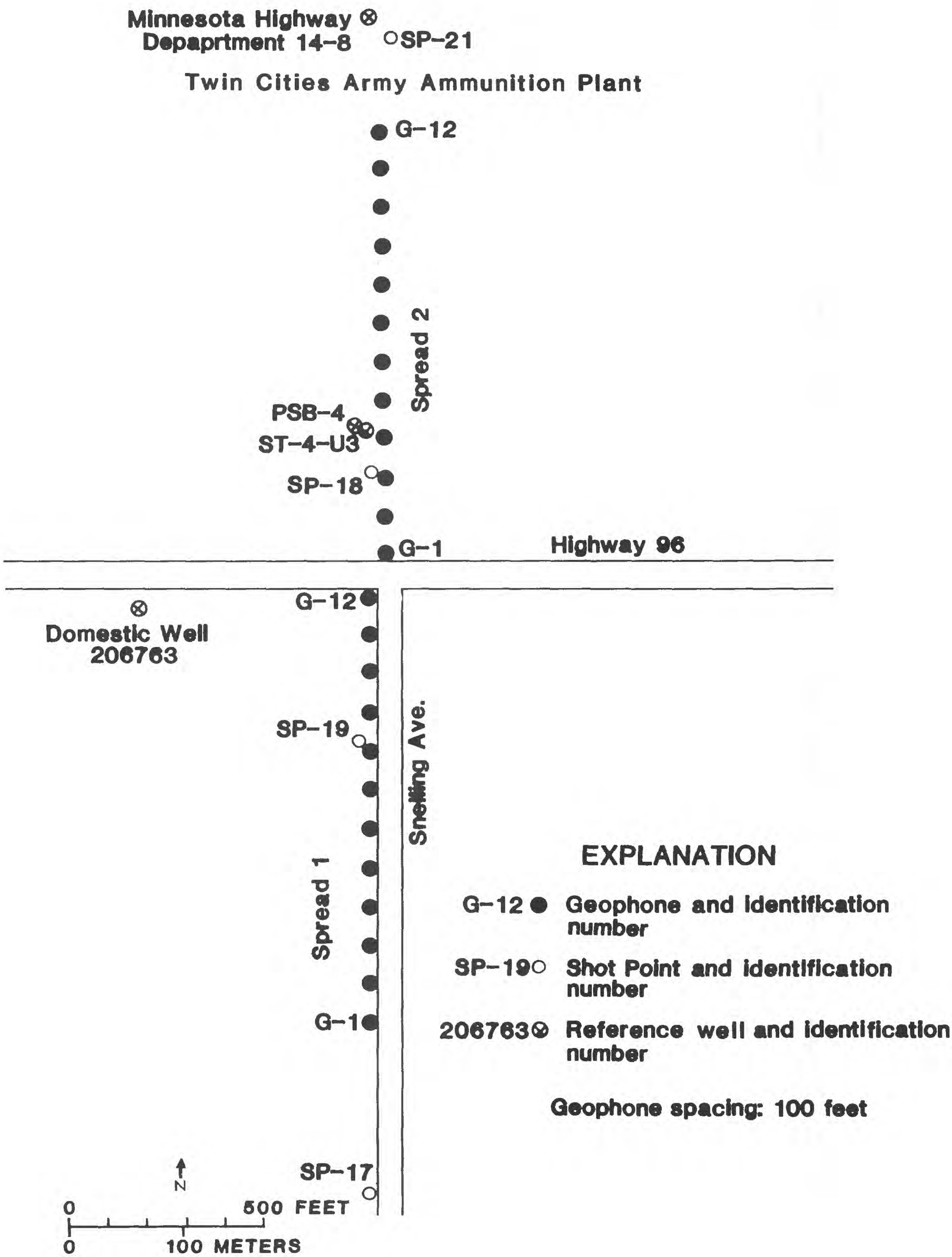


Figure 4.--Field layout for Line 2-Snelling, Twin Cities Army Ammunition Plant site

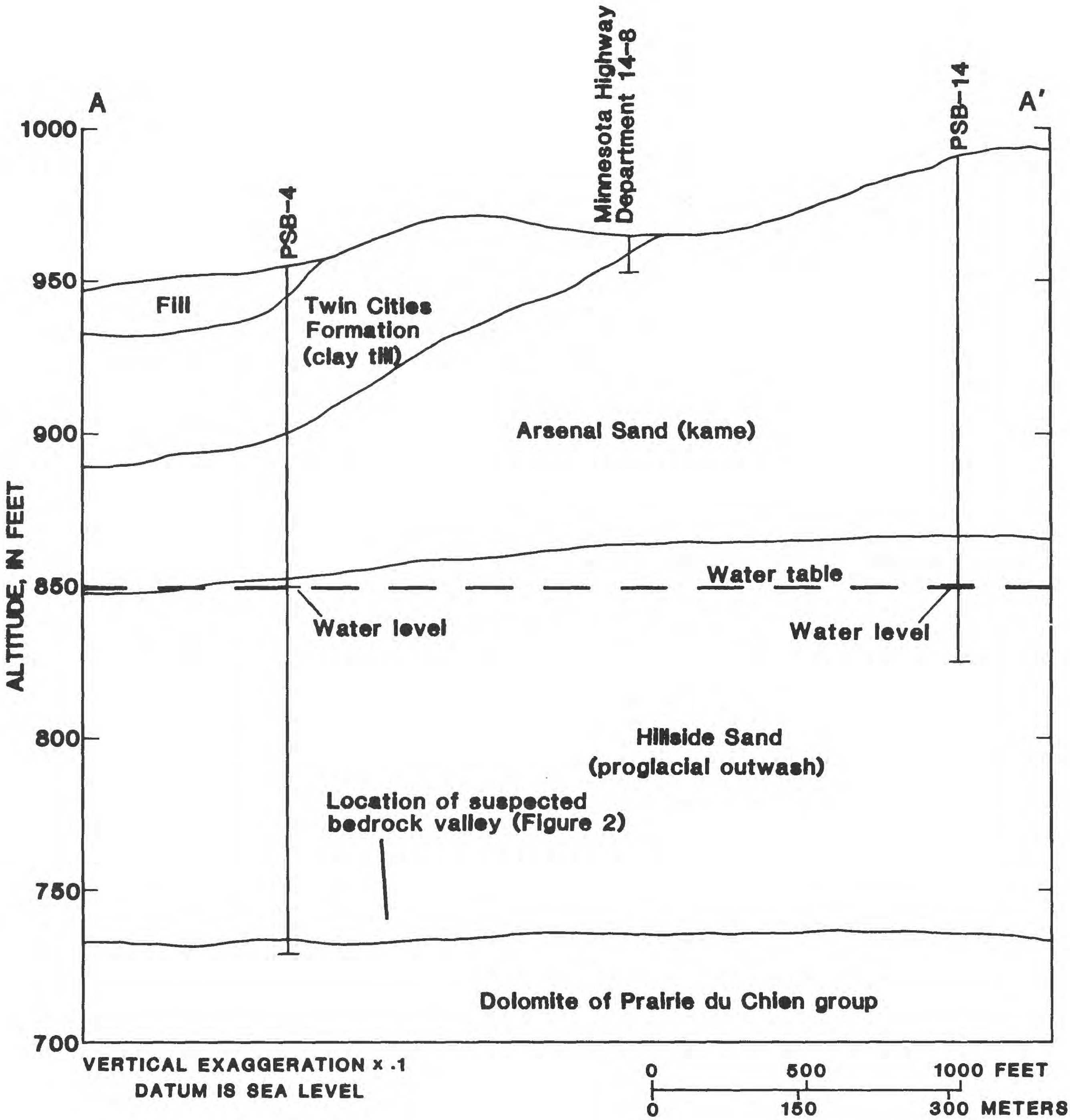


Figure 5.--Geologic section of northern part of Line 2-Snelling, Twin Cities Army Ammunition Plant site (Modified from STS Consultants, LTD, 1983)

Interpretation

The travel-time plot of first-break arrivals from Line 1-Butchers agrees with geologic evidence that a three-layer earth model should be assumed for the seismic interpretation. Layer 1 has a velocity averaging about 900 ft/s and corresponds to the unsaturated drift. Layer 2 has a velocity averaging about 5,700 ft/s and corresponds to saturated drift. Layer 3 has a velocity averaging about 15,900 ft/s and corresponds to dolomite in the Prairie du Chien Group. The interfaces between Layers 1 and 2 and between Layers 2 and 3 represent the water table and the bedrock surface, respectively.

Interpretation of Line 1-Butchers indicates that a bedrock valley probably does not exist under the area surveyed. The suspected bedrock valley was believed to incise the Prairie du Chien-Jordan aquifer to an altitude of about 560 feet, and the interpreted depth profile of Line 1-Butchers (fig. 6) shows the bedrock surface ranging between altitudes of about 700 to 800 feet. The assumed bedrock depth in the "Old Northwest Refinery" well agrees favorably with the interpreted depth profile, and the depth to the water table measured in piezometer P-3C-81 closely matches the interpreted water-table depth (fig. 6).

The travel-time plot of first-break arrivals from Line 2-Snelling generally agrees with the geologic evidence that a three-layer earth model should be assumed for the seismic interpretation. Layer 1 has a velocity ranging from about 2,250 ft/s for the northern part of the line to about 3,600 ft/s for the southern part, and corresponds to the unsaturated drift. The unsaturated drift changes in thickness and lithology along Line 2-Snelling. Along the southern half of the line (spread 1, fig. 4), Layer 1 is about 90 feet thick and is considered to be composed of about 50 feet of clay till (Twin Cities Formation) over about 40 feet of coarse sand and gravel (Arsenal Sand); whereas, along the northern half of the line (spread 2, fig. 4), Layer 1 is about 110 feet thick and is composed of coarse sand and gravel (fig. 5). The 50-foot layer of clay till thins and eventually pinches out to the north. The representative seismic velocity of clay is between 3,000 and 5,000 ft/s and that for dry sand or gravel is between 1,500 and 3,000 ft/s (Jakosky, 1950). Thus, the seismic velocity for Layer 1 along Line 2-Snelling should be expected to be higher in the southern part where the clay till is present and lower in the northern part where the clay till pinches out. Layer 2 has a seismic velocity averaging about 4,700 ft/s and corresponds to saturated drift. Layer 3 has a velocity averaging about 12,000 ft/s and corresponds to dolomite in the Prairie du Chien Group.

The interpretation of Line 2-Snelling, presented in figure 6, indicates that a bedrock valley may be present under the northern half of the line. The suspected bedrock valley was believed to incise the Prairie du Chien-Jordan aquifer to an altitude of about 500 feet. The interpreted depth profile of Line 2-Snelling shows the bedrock surface at an altitude of about 780 feet throughout the southern half of the line, whereas the bedrock surface drops to about 690 feet over a horizontal distance of 400 feet in the northern half of the line (fig. 6). The bedrock depth in test hole PSB-4 agrees favorably with

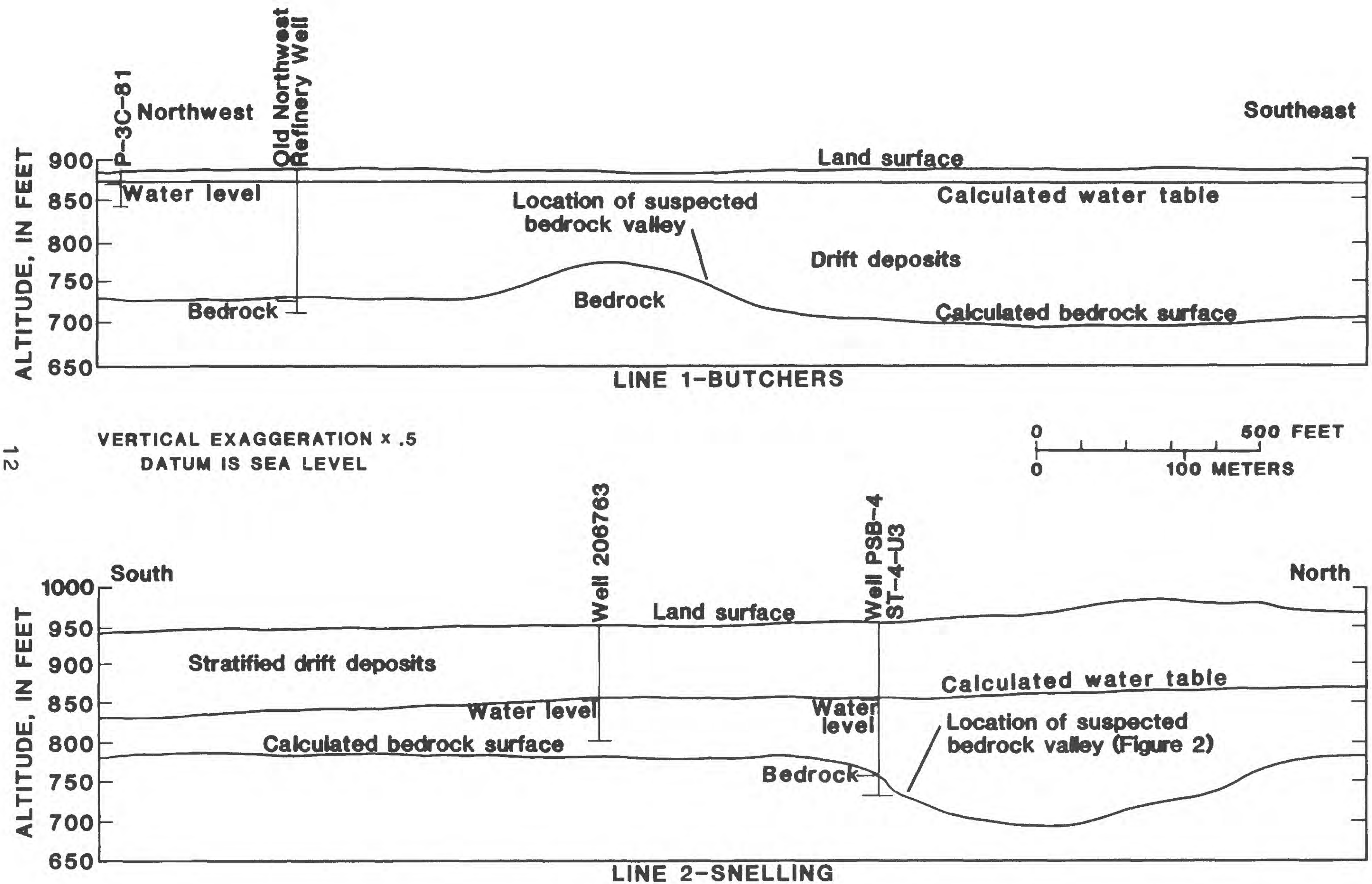


Figure 6.--Hydrogeologic sections showing depth profile for Line 1-Butchers and Line 2-Snelling, Twin Cities Army Ammunition Plant site

the interpreted depth profile, and depths to the water table measured in piezometer ST-4-U3 and the domestic well closely match the interpreted depth to the water table.

Koppers Coke Plant Site

The Koppers Coke Plant was located in the formerly industrialized area of northern St. Paul (fig. 1). The plant was built in 1917 and was in continuous operation until May 1979. The plant site covers a 38-acre triangular tract (fig. 7) and is located on fill and drift deposits that range in total thickness from 60 to 125 feet. These unconsolidated deposits overlie bedrock consisting of either the Decorah Shale or the Platteville Limestone. Both of these formations are part of a confining bed that overlies the St. Peter aquifer. A bedrock valley was believed to trend east-west just south of the Koppers Coke Plant (fig. 7). The valley was thought to range from about 500 to 1,200 feet in width, and to incise the St. Peter aquifer to an altitude from about 770 to 800 feet above sea level.

Data Collection

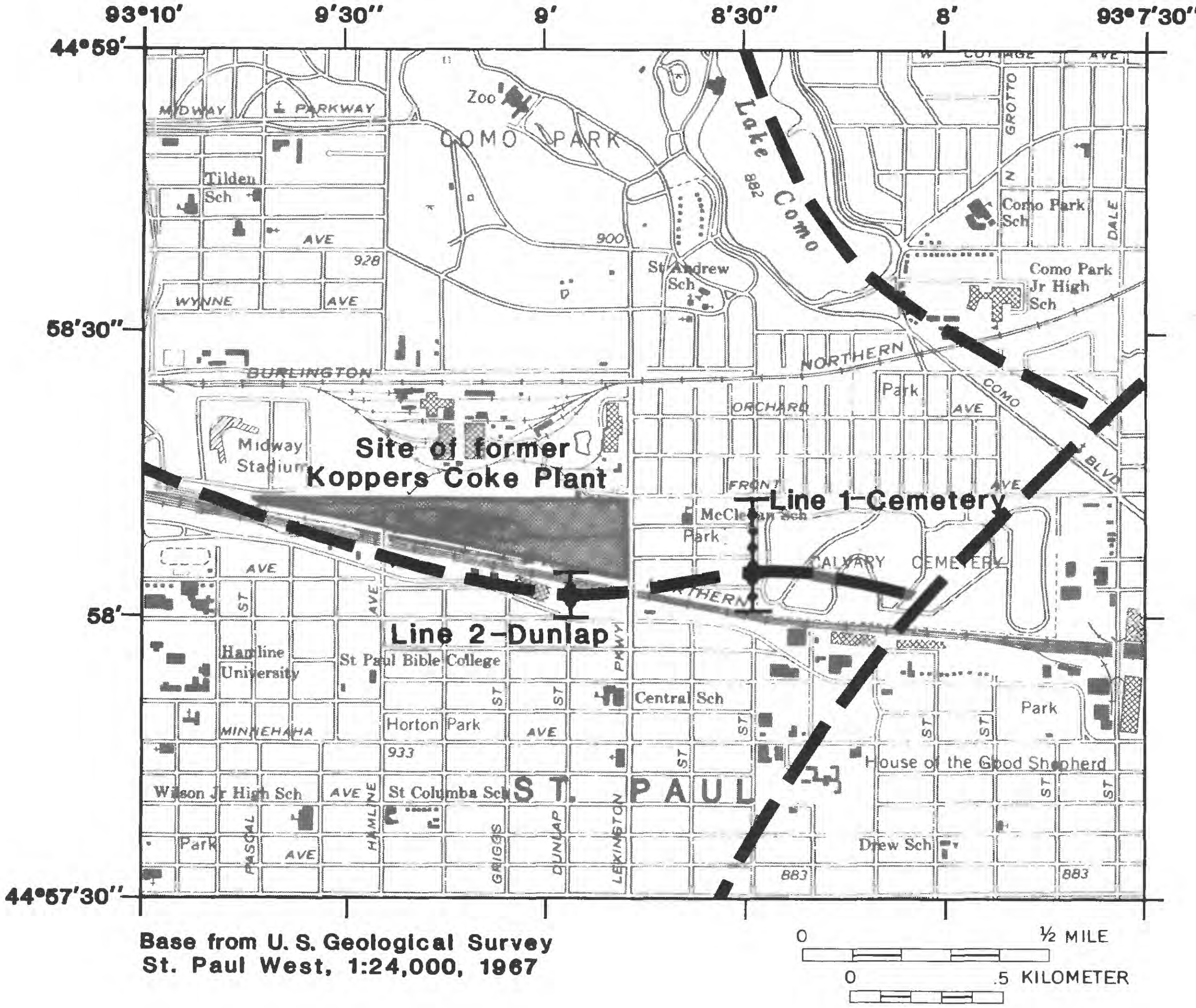
Two refraction profiles were made at the Koppers site (fig. 7) during May 11-12, 1982. Line 1-Cemetery was shot across the axis of a suspected drift-filled bedrock valley believed to trend east-west just south of the site. The field layout of Line 1, shown on figure 8, consisted of one geophone spread with three shot points. The optimal field layout for this line (the use of longer shot offsets) was not possible because of limited space available in a densely developed residential neighborhood.

Line 2-Dunlap was shot across the axis of the westward extension of the same suspected bedrock valley believed to trend just south of the plant site. The field layout of Line 2, shown on figure 9, consisted of one geophone spread. The optimal field layout for this line (the use of a longer shot offset at the north end of the spread) was not possible due to the presence of a large mound of unconsolidated material on the plant site.

Existing hydrogeologic control for Line 2-Dunlap was obtained from driller's logs and water-level measurements in observation wells drilled on the Koppers site (fig. 9). Well G22, drilled in August 1980, is located about 70 feet west of the line and encountered bedrock (Ordovician Decorah Shale) at an altitude of 817 feet. Well G2, drilled in July 1980, is located next to well G22; the water table was measured in well G2 at an altitude of 873.2 feet on October 28, 1980 (Geraghty and Miller, 1981). Well OW9, drilled in 1979, is located about 100 feet west of the line; the well was completed in drift at an elevation of 804 feet and did not encounter bedrock.

Interpretation

The travel-time plot of first-break arrivals from Line 1-Cemetery agrees with geologic evidence that a three-layer earth model should be assumed for the seismic interpretation. Layer 1 has a velocity averaging about 1,700 ft/s and



EXPLANATION

Location of refraction line

Location of suspected drift-filled bedrock valley

Figure 7.--Location of refraction lines and suspected bedrock valleys in the vicinity of the former Koppers Coke Plant

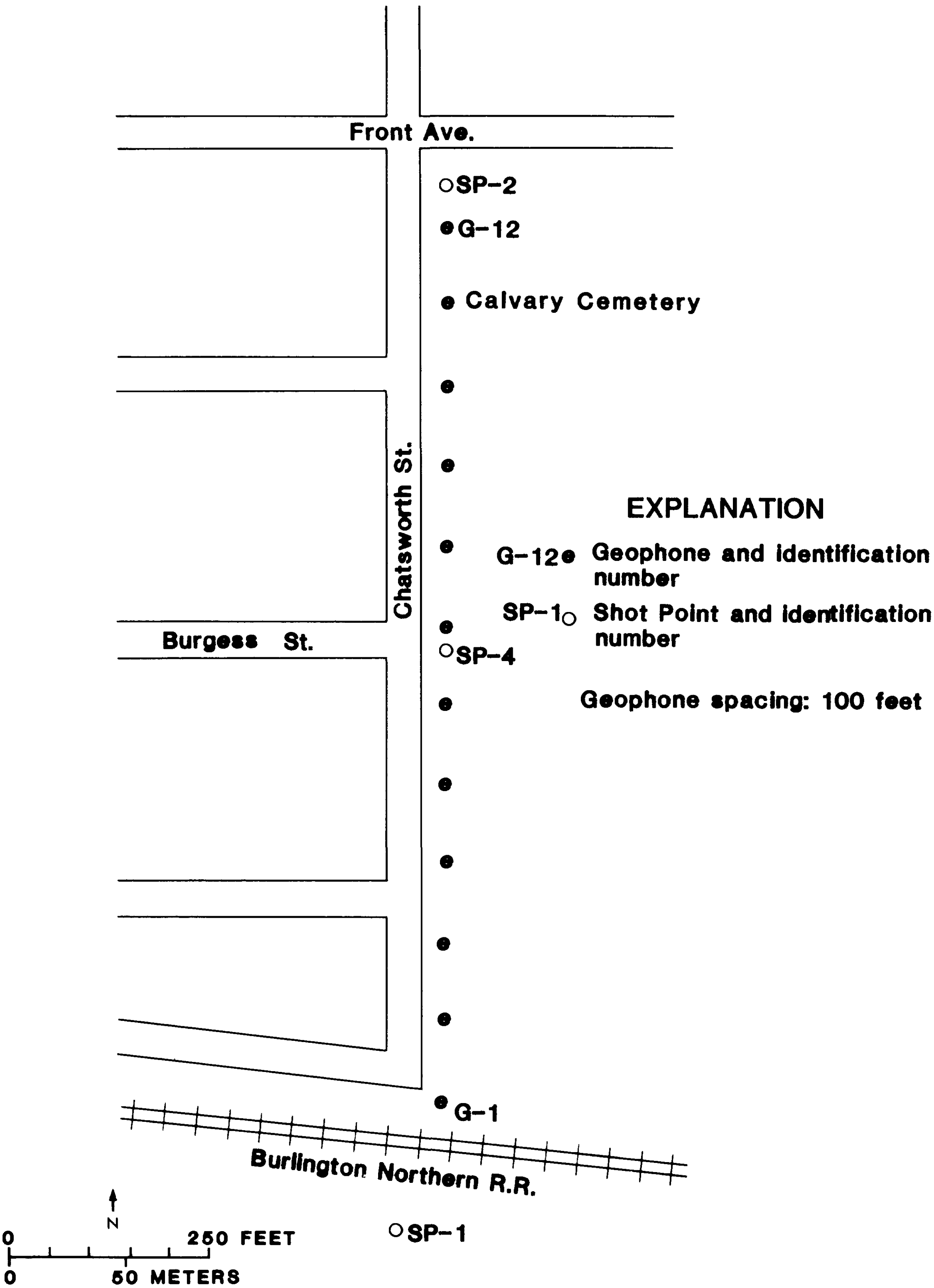


Figure 8.--Field layout for Line 1-Cemetery, Koppers site

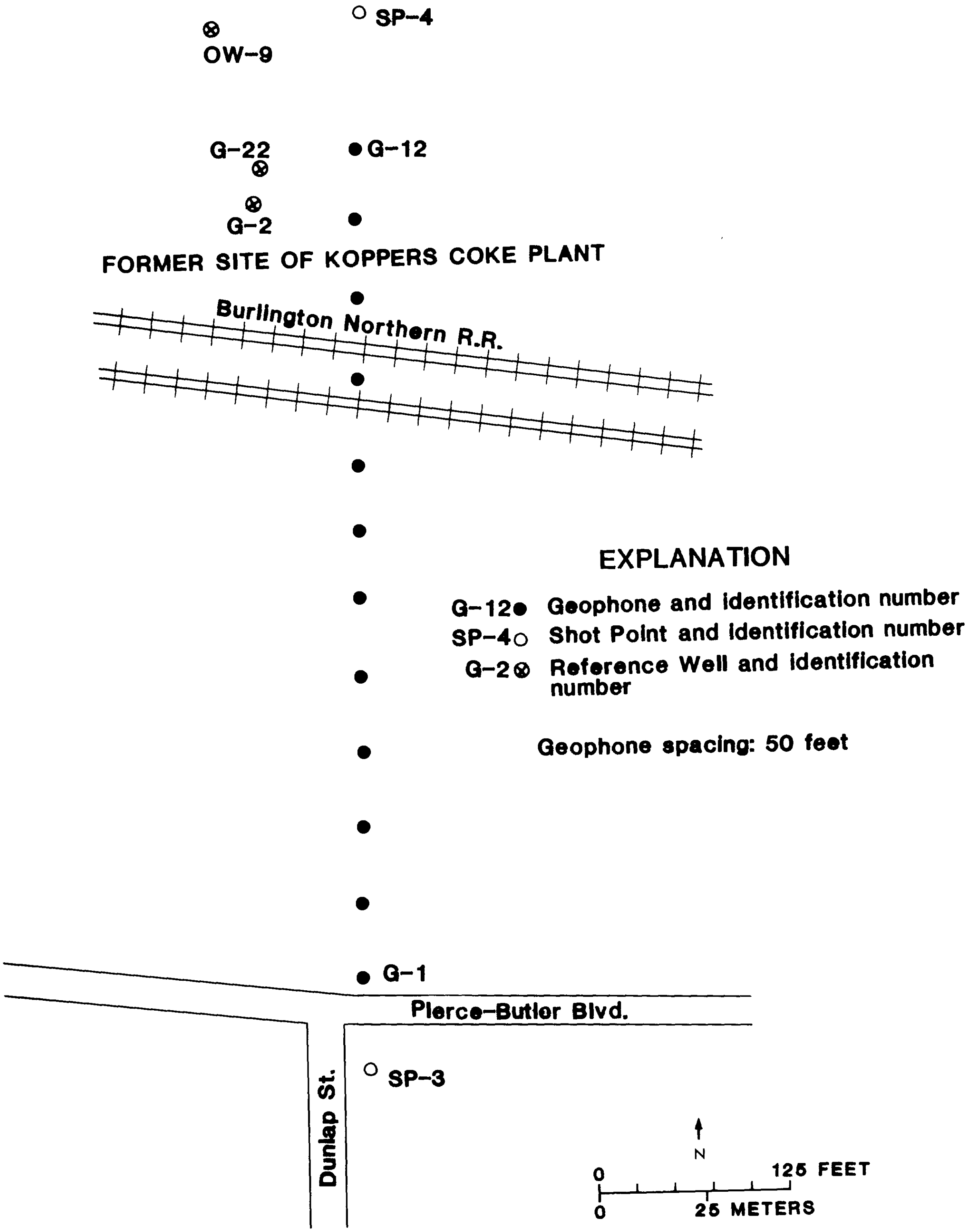


Figure 9.--Field layout for Line 2-Dunlap, Koppers site

corresponds to unsaturated drift. Layer 2 has a velocity averaging about 4,900 ft/s and corresponds to saturated drift. Layer 3 has a velocity averaging about 10,900 ft/s and corresponds to bedrock (probably the Decorah Shale).

The interpretation of Line 1-Cemetery as presented in figure 10 is not conclusive; the discrepancies from the depth approximations of the bedrock surface as determined from each shot point are too large, particularly beneath the geophones at the horizontal distances of 400, 500, and 1,000 feet (fig. 10). The discrepancies could result from lateral velocity differences in the geologic layers within one spread, abrupt changes in the bedrock surface topography, or both. The depth profile interpreted by the model, however, integrates the depth approximations from all the shot points, and this suggests that a bedrock valley may be present in the middle of the line. The suspected valley was believed to incise the bedrock to an altitude of about 780 feet. The bedrock valley shown in figure 10 is interpreted to have downcut to an altitude of about 750 feet.

The travel-time plot of the first-break arrivals from Line 2-Dunlap agrees with geologic evidence that a three-layer earth model should be assumed for the seismic interpretation. Layer 1 has a velocity that averages 1,500 ft/s and corresponds to unsaturated drift. Layer 2 has a velocity that averages about 5,200 ft/s and corresponds to saturated drift. Layer 3 has a velocity that averages about 10,800 ft/s and corresponds to bedrock (probably the Decorah Shale).

The interpretation of Line 2-Dunlap as presented in figure 10 is not conclusive. Although the shot points were offset as far as possible from the geophone spread, larger offset distances were required because not enough geophones recorded refractions from the bedrock surface. Instead of being able to record bedrock refractions from the optimal number of geophones per spread (10 geophones), only the three farthest geophones recorded bedrock refractions for shot point 3, and seven geophones recorded bedrock refractions for shot point 4.

The depth profile interpreted by the model shows that the bedrock surface maintains an altitude of about 830 feet for the southern half of the line, then drops to about 750 feet over a horizontal distance of 100 feet in the northern half of the line (fig. 10). Due to the restricted offset distances previously mentioned, seismic control for the bedrock surface could not be obtained for the northern third of the line. Geologic control for the bedrock surface, however, does exist for this part of the line--bedrock was encountered at an altitude of 817 feet in well G22. The bedrock surface shown in figure 10, then, is a combination of the interpreted seismic model for the southern two-thirds of the line and the geologic control from well logs for the northern third. Depth to the water table measured in observation well G2 closely matches the interpreted water-table depth. The suspected valley was believed to incise the bedrock to an altitude of about 800 feet, and the bedrock valley shown in figure 11 is interpreted to have downcut to an altitude of about 750 feet above sea level.

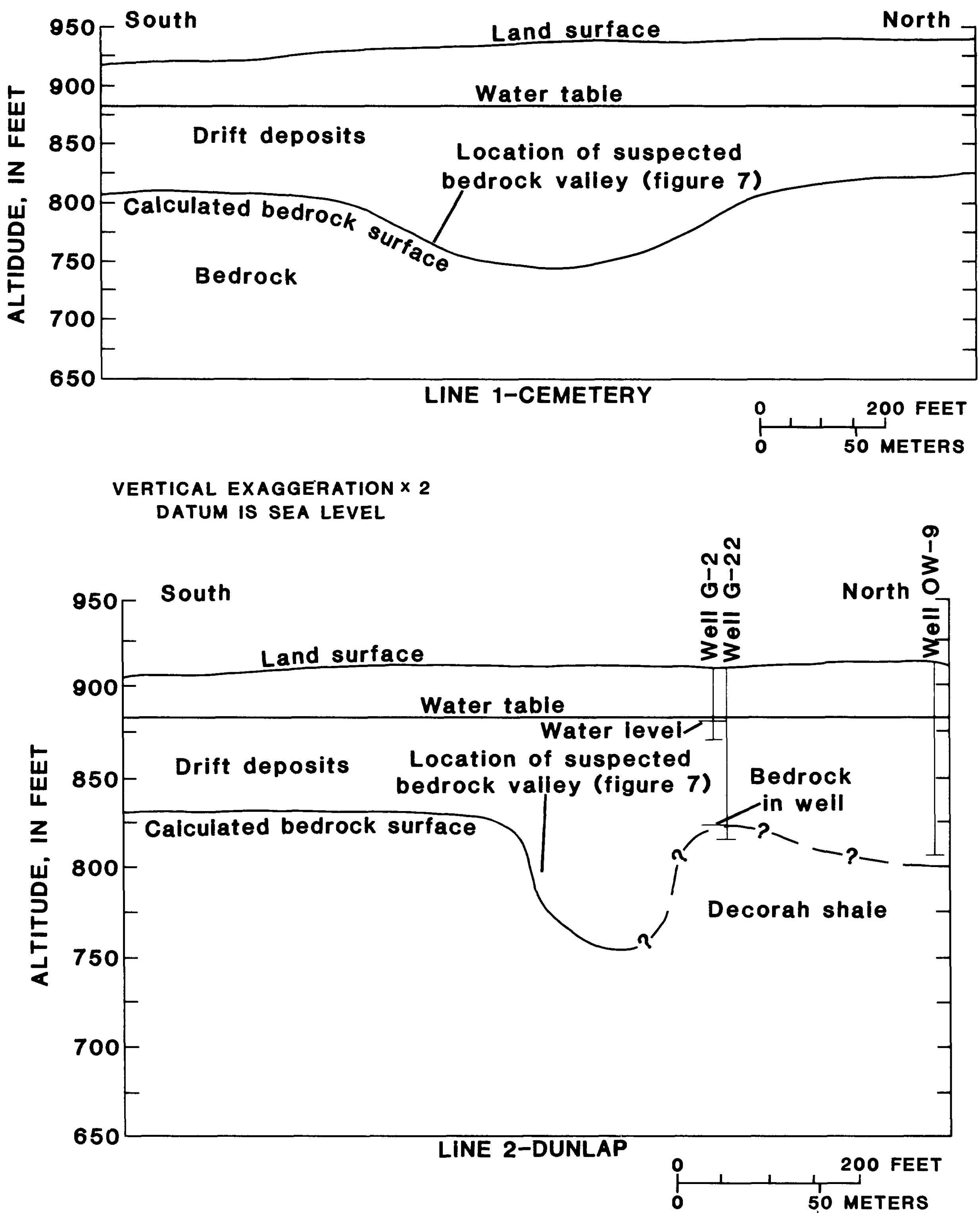


Figure 10.--Hydrogeologic sections showing depth profile for Line 1-Cemetery and Line 2-Dunlap, Koppers site

SUMMARY AND CONCLUSIONS

Refraction-seismic surveys were conducted to investigate suspected drift-filled bedrock valleys believed to occur near two sites of known ground-water contamination, the Twin Cities Army Ammunition Plant (TCAAP) near New Brighton and the former Koppers Coke Plant in St. Paul, Ramsey County, Minnesota. A 12-channel seismograph was used to collect refraction data along two lines at each site; each line traversed the axis of a suspected valley. The data were analyzed using a U.S. Geological Survey computer program that develops a two-dimensional layered-earth model of the subsurface. Interpreted results indicate that refraction-seismic surveys can provide credible information to aid verification of drift-filled bedrock valleys in the Twin Cities area. Because the glacial stratigraphy is complex and nonuniform areally, care must be taken to insure that the theoretical assumptions of the technique are not violated when interpreting the seismic data.

Drift-filled bedrock valleys were thought to incise the Prairie du Chien-Jordan aquifer to an altitude between 500 and 560 feet above sea level at the TCAAP site. The interpretation of Line 1-Butchers, shot across a suspected bedrock valley believed to trend southwest of the TCAAP, indicates that a valley probably does not exist under the area surveyed; the modeled depth profile shows the bedrock surface ranging between altitudes of about 700 to 800 feet above sea level. The interpretation of Line 2-Snelling shot across a suspected bedrock valley believed to trend east-west just south of the TCAAP indicates that a bedrock valley may exist under the northern half of the line.

A drift-filled bedrock valley was thought to incise the St. Peter aquifer to an altitude between 770 and 800 feet above sea level at the Koppers site. The interpretation of Line 1-Cemetery, shot across the suspected bedrock valley believed to trend east-west just south of the Koppers site is not conclusive, but suggests that a bedrock valley may be present in the middle of the line. The interpretation of Line 2-Dunlap, shot across the westward extension of the same suspected valley also is not conclusive, but suggests that a bedrock valley may be present at the north end of the line. The optimal field layout for each line at the site (longer shot offsets) could not be obtained because of limited space available in the densely developed residential neighborhoods.

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