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ENVIRONMENTAL SCIENCES DIVISION

GEOPHYSICAL INVESTIGATIONS AT ORNL SOLID WASTE STORAGE AREA 3

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ABSTRACT

ROTHSCHILD, E. R., J. SWITEK, J. L. LLOPIS, and C. D. FARMER. 1984. Geophysical investigations at ORNL solid waste storage area 3. ORNL/TM-9362. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 44 pp.

Geophysical investigations at ORNL solid waste storage area 3 have been carried out. The investigations included very-low-frequency-electromagnetic resistivity (VLF-EM), electrical resistivity, and seismic refraction surveys. The surveys resulted in the measurement of basic geophysical rock properties, as well as information on the depth of weathering and the configuration of the bedrock surface beneath the study area. Survey results also indicate that a number of geophysical anomalies occur in the shallow subsurface at the site. In particular, a linear feature running across the geologic strike in the western half of the waste disposal facility has been identified. This feature may conduct water in the subsurface. The geophysical investigations are part of an ongoing effort to characterize the site's hydrogeology, and the data presented will be valuable in directing future drilling and investigations at the site.

INTRODUCTION

A series of geophysical investigations was carried out as part of the ongoing hydrogeologic characterization of the formerly utilized solid waste storage area (SWSA) 3 at Oak Ridge National Laboratory (ORNL). The approximately 2.8-ha (7-acre) site was used from approximately 1946 to 1951 for the disposal of low-level radioactive wastes (Stueber et al. 1981). The site is located in Bethel Valley on the U.S. Department of Energy (DOE) Oak Ridge Reservation and is underlain by strata of the Chickamauga Group. These strata are characterized by interlayered sequences of limestone and siltstone lithologies.

A geologic data base for the site (Switek, in review) was used as the basis for the geophysical investigations. The geophysical investigations were laid out to address these questions: (1) Is there a cross-strike geologic structure along the western portion of the burial ground? (2) If there is such a structure, what is its nature? (3) Can the solution cavities that appear to be prevalent along the contacts of units E/F and F/G of the Chickamauga Group be located and characterized using geophysical techniques? In an attempt to answer these questions a two-phase program was carried out. The first phase of work involved a very-low-frequency-electromagnetic (VLF-EM) survey (an electromagnetically induced resistivity survey using very-low-frequency radio antennae as energy sources); the work was carried out by ORNL Environmental Sciences Division personnel. The second phase involved resistivity and shallow seismic surveys carried out by Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment

Station personnel (Llopis et al. 1984), in conjunction with ORNL staff under Interagency Agreement No. DE-AI05-83OR21384. This report presents the results of the geophysical surveys performed at SWSA-3. Interpretation of the data will be kept to a minimum here; more detailed discussion of the results will follow later.

GEOPHYSICAL INVESTIGATIONS

VLF-EM SURVEYS

The goal of the very-low-frequency-electromagnetic (VLF-EM) surveys was to identify any large-scale structural anomalies that may occur on the western half of SWSA-3. Of particular interest was the identification of subsurface conduits for groundwater movement. Figure 1 shows the generalized geologic map of SWSA-3. A generalized geologic cross section for the site is shown in Fig. 2. Field mapping and core logs from the site suggest that a cross-strike structural discontinuity may exist (Switek, in review) and that this structure controls water movement in the subsurface.

Electromagnetic surveys are used to detect subtle changes in local magnetic fields along a survey line. These changes or anomalies are due to a response to local conductors in the subsurface that alter fields generated by man-made or natural currents, depending on the receiver being used. Faults, fracture zones, or solution cavities may act as conductors if groundwater is moving within them. This survey method has been used in the past primarily as a tool for locating conductive ore bodies (Patterson and Ronka 1971), and electromagnetic techniques are commonly used to investigate and delineate conductive,

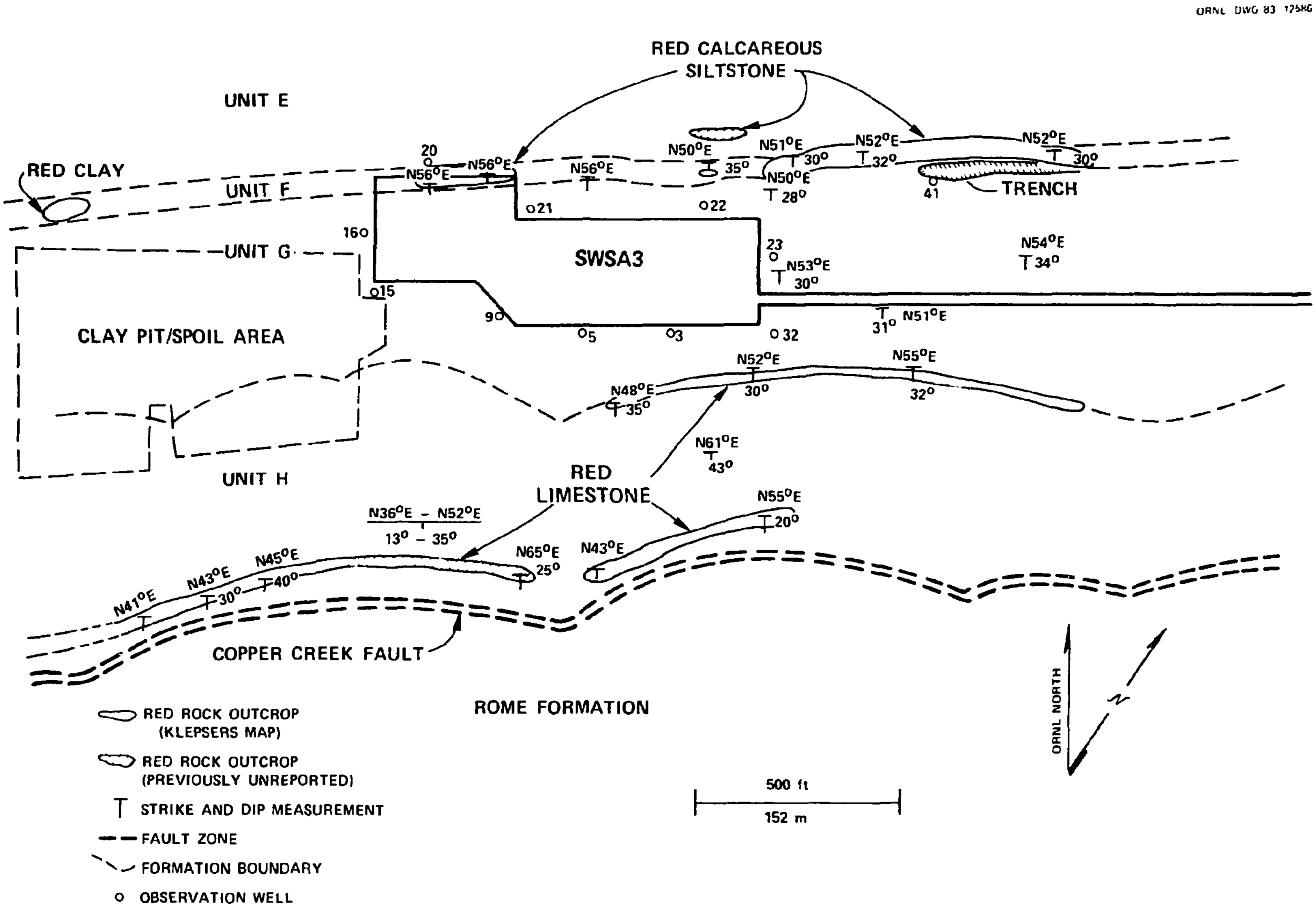
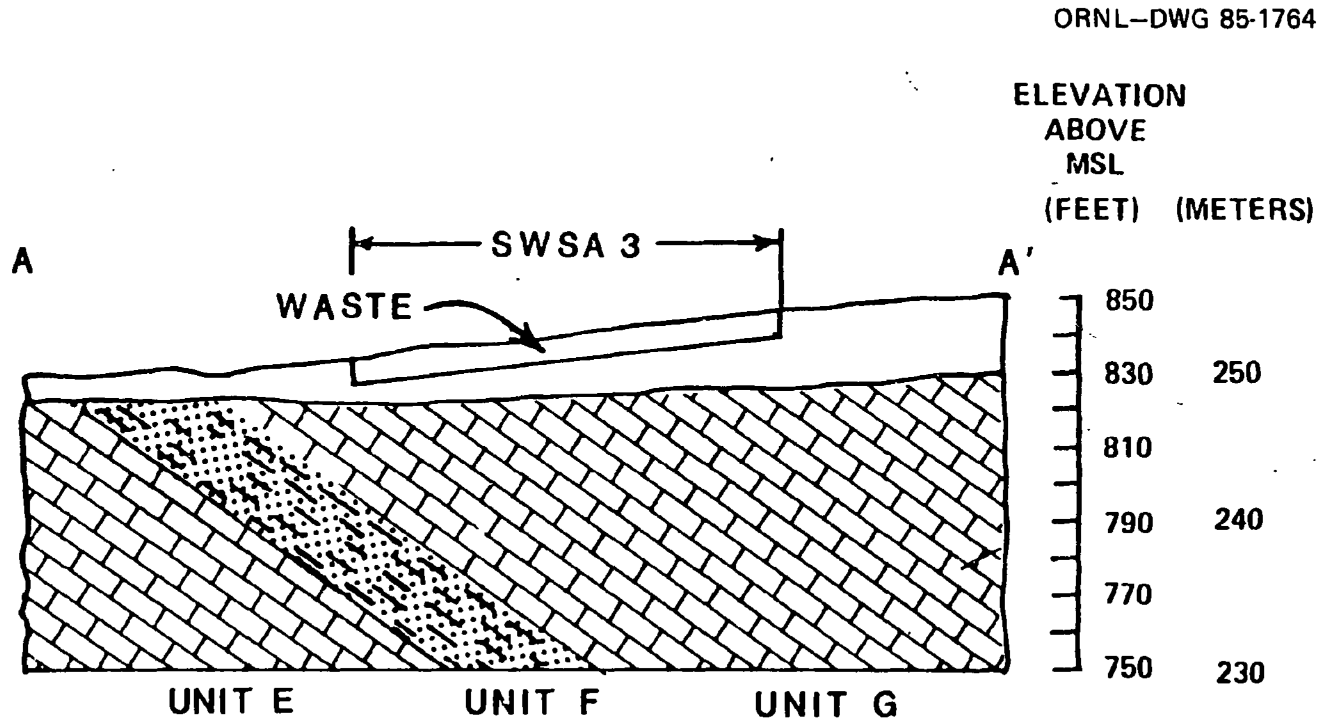
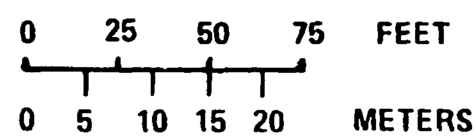


Fig. 1. Generalized geologic map of Solid Waste Storage Area 3 [after Switek (unpublished data)].



LEGEND

Unit E - Limestone with shaley partings
Unit F - Calcareous silts and shale
Unit G - Limestone with shaley partings



(AFTER STUEBER, et al., 1981)

Fig. 2. Generalized geologic cross section for solid waste storage area 3 [along line A-A' (Fig. 1)].

subsurface plumes of contaminated groundwater (see for example Slaine and Greenhouse 1982). Further information on the theory of VLF-EM surveys can be found in Geonics Ltd. (1979). The advantages of VLF-EM surveys over other geophysical methods include the following: (1) they are easy to perform, (2) they require very little manpower, and (3) the raw data can be manipulated and interpreted simply and rapidly.

Five VLF-EM survey lines were run at SWSA-3; their locations are shown in Fig. 3, and results of the surveys are shown in Fig. 4. The data have been mathematically filtered using the method described in Fraser (1970). Filtering serves several purposes: (1) it shifts the field data to cause anomalies to appear as peaks; (2) it lessens general background noise; (3) it eliminates most topographic effects; and (4) it removers large-scale, deep conductors. The data suggest that a linear anomaly exists along the western portion of SWSA-3. Because of the nature of the aquifer, this anomaly is likely to be a zone of subsurface water movement. That is, the aquifer has a very low primary porosity; thus, zones of high secondary porosity (solution cavities) are likely to be subsurface electrical conductors when water filled. In Figs. 3 and 4, the anomaly located on line 5 is probably related to a pipeline or drainage along Bethel Valley Road. The nature of the anomaly on line 4 is uncertain. Two anomalies are present on line 2; the westernmost anomaly appears to be related to the linear feature, the easternmost is located in the stream channel to the south of the burial ground. Although the drainageway south of the facility was dry during the survey, the anomaly is probably a result of the presence of water in the subsurface. It is important to recognize that

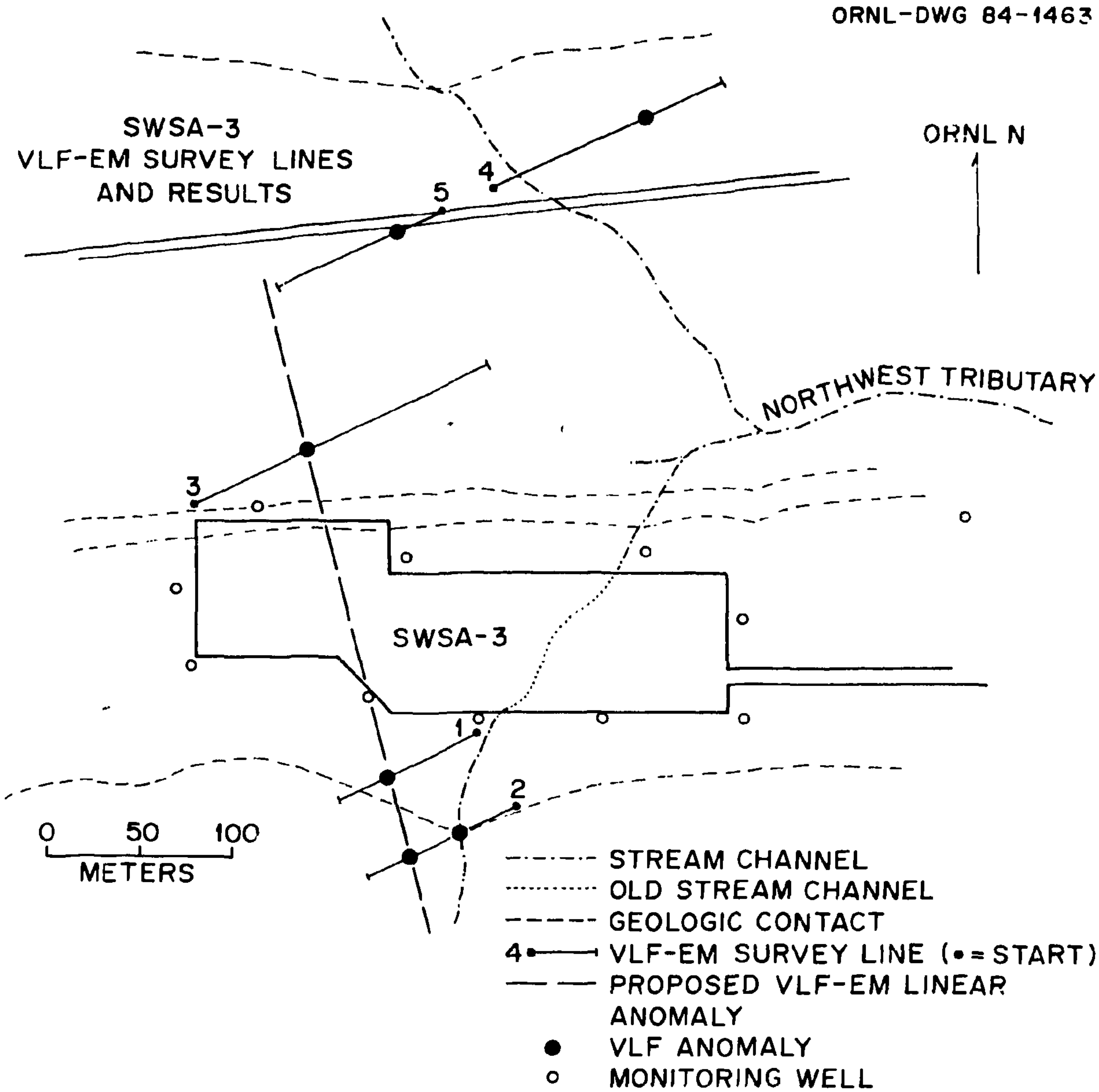


Fig. 3. Solid waste storage area 3 very-low-frequency-electromagnetic survey lines and results.

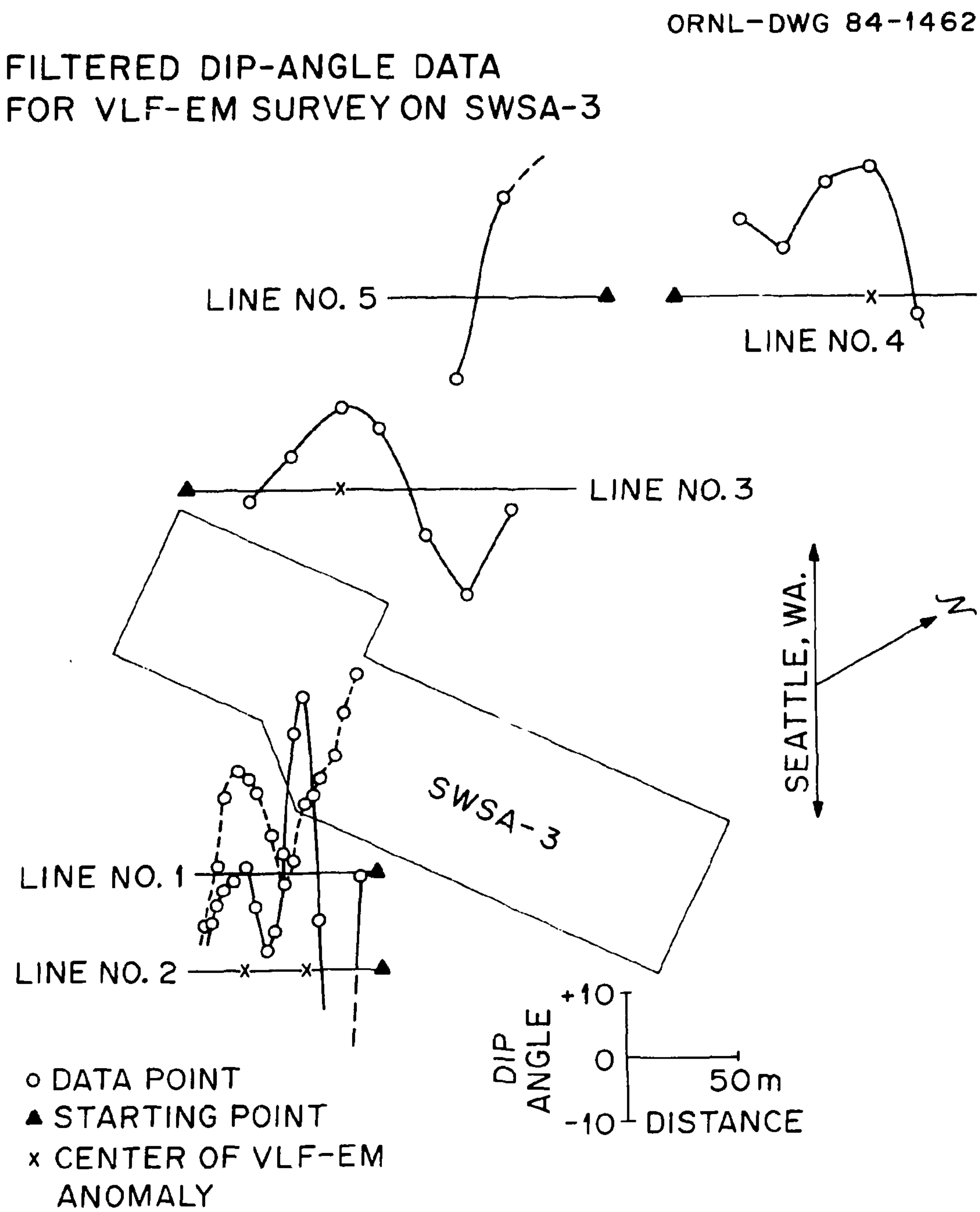


Fig. 4. Filtered dip-angle data for very-low-frequency-electromagnetic survey on solid waste storage area 3. The survey lines are oriented perpendicular to the direction of the energy source (Seattle, Wash.).

the approximate depth to which we investigate using this technique is about 20 to 30 m (based on the resistivities of the soils in the area). That is, the zone of influence for the measurements is relatively deep, and measurements represent an integration of properties to that depth.

HORIZONTAL RESISTIVITY SURVEYS

Locations of the four horizontal resistivity surveys, designated RP-1 through RP-4, are shown in Fig. 5. The surveys were performed using the Wenner array, which consists of two current and two potential electrodes along a line using an equal spacing, "A", between successive electrodes. In general, for a given A-spacing, the resistivity determination can be considered to be influenced predominantly by material shallower or equal to a depth of A. Resistivity profiling involves moving the entire Wenner array along a profile line, keeping a constant A-spacing, to produce a horizontal profile of resistivity variations. Further information on the procedures and interpretation methods used can be found in Telford et al. (1976) and in Engineer Manual 1110-1-1802 (Dept. of Army 1979). All profiles were run using A-spacings of 6 and 12 m (20 and 40 ft). The resulting data for all resistivity profiles are included in Appendix A.

Discontinuities and anomalous features in the data that have previously been found to be associated with seepage paths, fracture zones, or voids can be used to delineate such conditions. In horizontal resistivity profile data, the indicators of anomalous conditions are relatively high or low resistivity values. The

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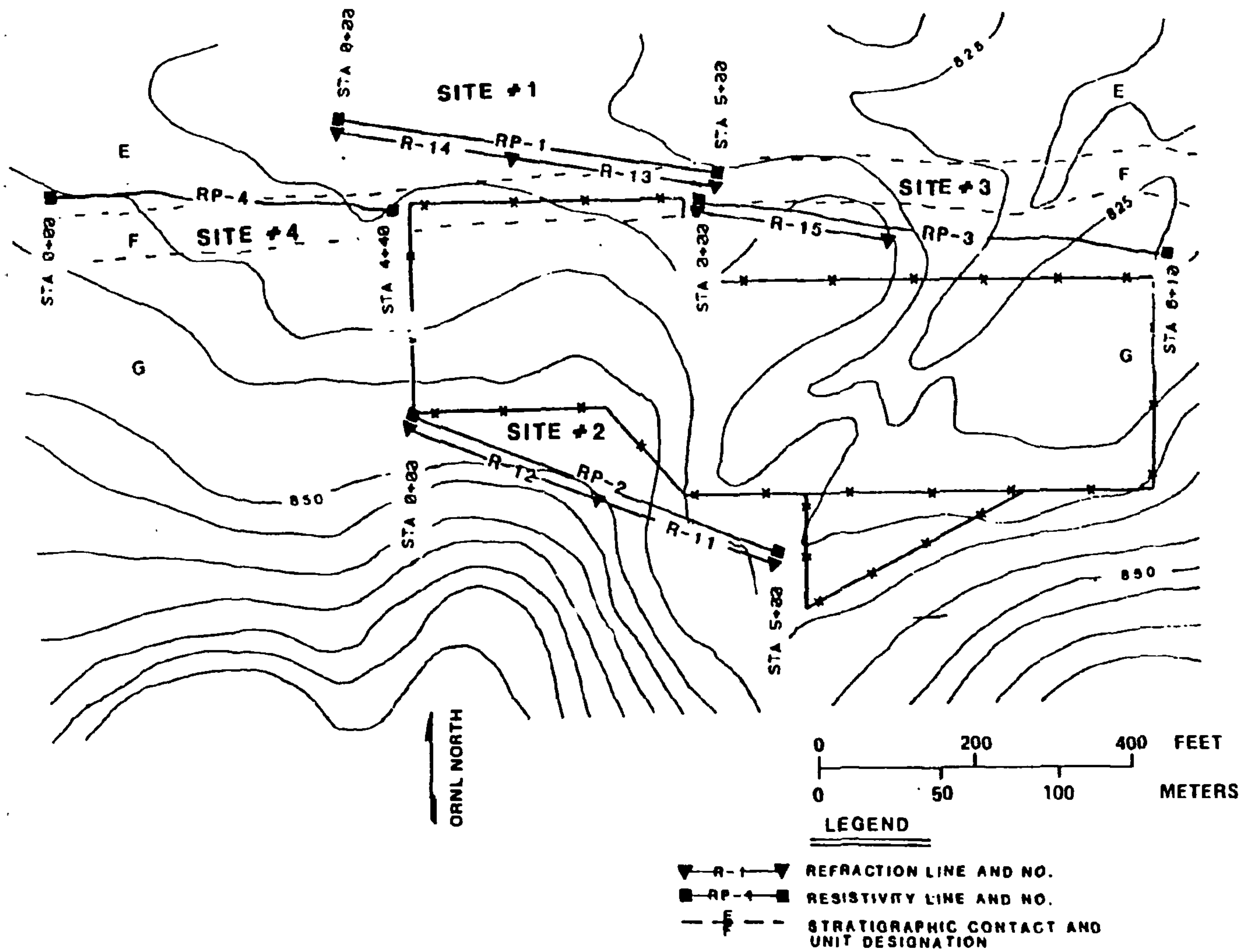

Fig. 5. Site map showing locations of resistivity and refraction surveys.

approximate depth of an anomalous feature can be determined by conducting several horizontal surveys along the same line but with different A-spacings and assuming the depth of investigation to be approximately equal to the A-spacing. For example, consider two resistivity survey lines, one with an A-spacing of 6 m (20 ft), the other with an A-spacing of 12 m (40 ft). If an anomalous feature is detected in the 12-m (40-ft) survey but not in the 6-m (20-ft) survey, it can be concluded that the anomalous feature exists between a depth of 6 and 12 m (20 and 40 ft).

The horizontal resistivity profile RP-1 was conducted at Site 1 between stations 0+00 and 5+00 (Fig. 5). The average apparent resistivity for the 6-m (20-ft) A-spacing is approximately 85 ohm-m (275 ohm-ft). Areas having relatively high resistivity values occur at station 1+50, between stations 1+90 and 2+70, and at station 3+90. The 12-m (40-ft) A-spacing survey shows a relatively high resistivity reading at station 2+20. The data show the structure or anomaly at station 1+50 to occur within the upper 6 m (20 ft), but the other anomalies are probably caused by deeper structures.

Resistivity profile RP-2 was conducted at Site 2 between stations 0+00 and 5+00. The 6-m (20-ft) A-spacing survey shows a decrease in resistivity values between stations 0+30 and 1+70. From stations 1+80 to 3+00 resistivity values increase from approximately 110 to 215 ohm-m (350 to 700 ohm-ft). Between stations 3+00 and 4+60 the survey shows relatively little variation in apparent resistivity. The 12-m (40-ft) A-spacing survey shows an increase in resistivity values between stations 0+60 and 3+00. Between stations 3+00 and 3+80, resistivity values continue to increase but at a greater rate. Between stations 3+80 and 4+60 the survey shows little variation in apparent resistivity. The data from the 12-m (40-ft) A-spacing indicate that the general thickness of the overburden material may be decreasing toward the east. The 6-m (20-ft) A-spacing profile does not show this same trend, but two other anomalous features are noted. These features are probably due to changes in either in resistivity or thickness of the overburden material.

Horizontal resistivity profile RP-3 was conducted at Site 3 between stations 0+00 and 6+10 (Fig. 5). The data for the 6-m (20-ft) A-spacing profile show substantial variability in apparent resistivity values, but a general trend can be inferred. Beginning at station 0+30, average values increase from approximately 60 ohm-m (200 ohm-ft) to a high of approximately 235 ohm-m (775 ohm-ft) at station 2+90. Resistivity values decrease to a low of 60 ohm-m (200 ohm-ft) from station 2+90 to station 4+50, from which point the values increase to the end of the survey line. It should be noted that a dry creek bed was crossed at station 4+50. Data from the 12-m (40-ft) A-spacing survey shows increasing resistivity from a low of 115 ohm-m (375 ohm-ft) at station 0+60 to a high of 160 ohm-m (525 ohm-ft) at station 5+40. The anomaly in the shallow survey (between stations 1+90 and 3+50) is interpreted to be the result of variations in overburden conditions with respect to the remainder of the line.

Profile RP-4 was conducted at Site 4, between stations 0+00 and 4+40 (Fig. 5). The data for the 6-m (20-ft) A-spacing survey show four locations that have anomalously high readings. These occur at stations

1+30, 1+70, 2+50, and 2+90. The 12-m (40-ft) A-spacing line showed relatively little change in resistivity along the profile except at stations 1+80 and 3+40, where relatively high and low values respectively were encountered. The major anomalies at this site were found to occur in the shallow earth materials [at a depth of less than 6 m (20 ft)] and may be due to differences in the overburden material or may be associated with solution features near the contact of the E and F units of the Chickamauga Group.

SEISMIC REFRACTION SURVEYS

Five refraction survey lines (R-11 through R-15) were run at Sites 1 through 3, shown in Fig. 5. Each refraction line was 76 m (250 ft) long, with 3-m (10-ft) geophone spacings. Basically, the refraction seismic method consists of measuring the travel times of compressional waves (P-waves) generated by an impulse energy source. The arrival time from the disturbance to each detector (geophone) is plotted versus the respective distance. This time-distance (TD) information is processed to obtain depths to subsurface strata having different velocities, corresponding P-wave velocities, and anomalous conditions. The interpretations are based on the laws of wave propagation. The surveys were conducted using two 12-channel seismographs, coupled together to produce a 24-channel system. The energy source for the surveys was a two-component explosive equivalent to 1/4 to 1/2 kg (1/2 to 1 lb) of TNT. Shotholes were approximately 0.6 m (2 ft) deep. Further details on the seismic refraction method can be found in Telford et al. (1976) and Engineer Manual 1110-1-1802 (Dept. of the Army 1979).

In trying to detect fractures, voids or other anomalies by using the seismic refraction method, one looks for time delays on the TD plots which cannot be accounted for by changes in topography. These time delays are exhibited on the TD plots as points lying above the straight-line segments. In general, the greater the time delay, the greater the size of the anomaly. The TD plots and bedrock profiles for all survey lines are presented in Appendix B.

W. P. Staub (ORNL Energy Division, personal communication) cautioned that the low average velocities reported for overburden materials below are probably the result of air blasts produced by the explosive charges, in that the average velocities reported [1100 to 1250 fps (335 to 380 mps)] are approximately equal to the velocity of sound in air [1140 fps (348 mps)]. The soil zone at SWSA-3 may be too thin for a seismic velocity to be measured, resulting in a "blind zone," as described by Soske (1959). Because of the blind zone, Staub suggests that actual depth to bedrock may be deeper than is calculated here (Appendix B). This suggestion is supported by core log data from observation wells installed around the periphery of SWSA-3 (Switek, unpublished data).

Two seismic refraction lines, designated R-14 and R-13, were run at Site 1 between Stations 0+00 and 5+00 (Fig. 5). The refraction lines indicate that two velocity zones exist in the shallow subsurface. Their velocities averaged 335 and 4,930 mps (1,100 and 16,175 fps), indicating overburden material and unweathered rock respectively. The depth to rock varies between 1.2 and 2.4 m (4 and 8 ft). The results of refraction surveys R-14 and R-13 indicate no anomalous features were present.

Two refraction lines, designated R-12 and R-11, were run at Site 2 between stations 0+00 and 5+00 (Fig. 5). The seismic refraction data indicate that two velocity zones are present in the near surface earth materials. The average velocities of these zones were 380 and 4,950 mps (1,250 and 16,225 fps), corresponding to overburden and rock respectively. Depths to bedrock ranged between approximately 1.8 and 5.2 m (6 and 17 ft). The profile for refraction lines R-11 and R-12 appears to substantiate a thinning of the overburden material between stations 2+50 and 5+00, evident in the resistivity profiles. The TD plot for R-12 shows much higher overburden velocity at the western end than at the eastern end of the survey line, suggesting that a change in overburden material type may occur between stations 0+30 and 1+10 (as is indicated by the resistivity survey).

One refraction line, designated R-15, was run at Site 3 between stations 0+00 and 2+50 (Fig. 5). The TD plot for the site (Appendix B) indicates that three velocity zones are present. The velocities are 345, 2,820, and 5,075 mps (1,125, 9,250, and 16,650 fps), which correspond to overburden materials, siltstone (Unit F), and limestone (Unit E) respectively. The depth to siltstone varied between 2.1 and 2.7 m (7 and 9 ft). The depth to limestone varied between 10.4 and 12.2 m (34 and 40 ft). Due to the limited length of the line and the number of layers, a bedrock profile was not computed. No anomalous conditions were interpreted from refraction line R-15.

CONCLUSIONS AND RECOMMENDATIONS

A number of anomalous features were interpreted as a result of geophysical investigations at SWSA-3. To summarize the results, the anomalous areas identified by all surveys were superimposed on a site map (Fig. 6). Many of the anomalies were detected from the resistivity surveys having an A-spacing of 6 m (20 ft), indicating that these features occur within about 6 m (20 ft) of the surface. The results of the refraction surveys indicated an overburden thickness of less than 3 m (10 ft), except at Site 2, where depths to bedrock of up to 5.5 m (18 ft) were indicated, however, because of possible blind zone phenomena, these thicknesses may be underestimated. Based on information obtained from the resistivity and refraction surveys, it can be concluded that the anomalous features identified are probably present in the overburden material and/or the upper 3 m (10 ft) of bedrock. The 12-m (40-ft) A-spacing resistivity surveys showed little variation in resistivity values, with the exception of the line run at Site 2. The small variance exhibited in the 12-m (40-ft) A-spacing lines indicates that bedrock between the depths of 6 and 12 m (20 and 40 ft) probably has not been extensively weathered. The seismic test results appear to verify the unweathered condition of the bedrock in that they yield high velocities for the rock below depths of 1.2 to 5.5 m (4 to 18 ft). However, a thin weathered rock layer may not appear on a seismic survey (i.e., may be another blind zone) because high velocity waves from unweathered rock below would overtake the

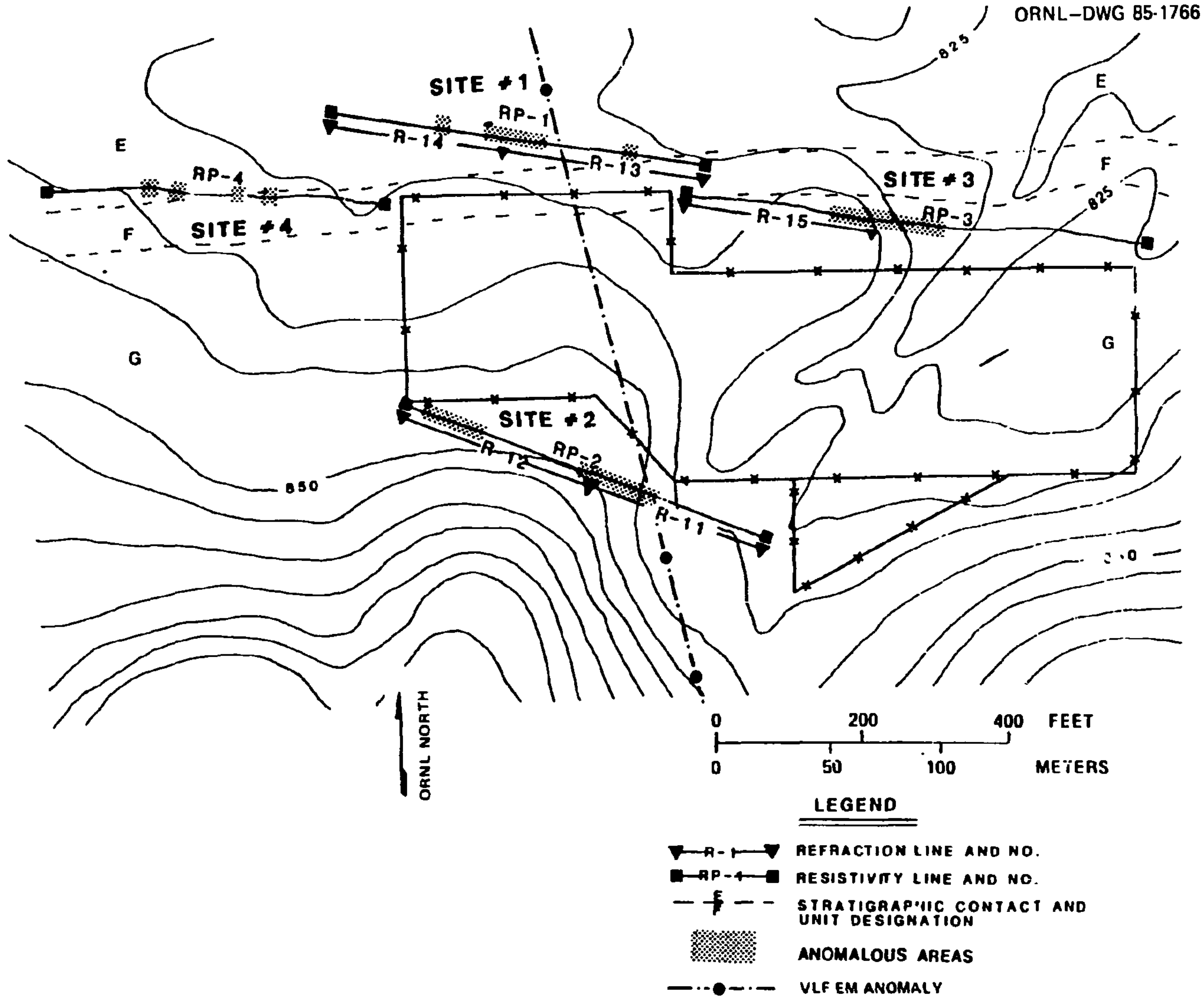

Fig. 6. Site map showing anomalous areas.

slower waves produced by the weathered material and reach the geophones first (W. P. Staub, personal communication).

The results of the VLF-EM survey confirm that an anomalous feature occurs in the western half of the study area. The feature appears to be linear and continuous across the site. The linear feature coincides very well with several of the larger conductive zones identified in the horizontal resistivity surveys. The feature may be a bedrock trough or, possibly, a fracture zone. The data suggest that the zone may conduct groundwater.

None of the geophysical tests performed will definitely confirm the presence of voids or fractures but will, under favorable conditions, indicate possible areas of concern. The results of these investigations help to pinpoint where anomalous features may occur, thus optimizing the layout of a drilling program designed to investigate such features. The data collected also yield information on the geophysical properties of the earth materials at the site, the weathering characteristics, and the general topography of the bedrock/overburden interface.

To better define possible seepage areas, it is recommended that a spontaneous potential (SP) survey be performed around the perimeter of SWSA-3. The grid could be easily and quickly installed, and voltage measurements taken over time could be used to indicate directly the subsurface movement of water (for example, see Rothschild et al. 1984). It is also recommended that several borings be drilled across the proposed linear anomaly and that at least one of the borings be completed as a monitoring well. The borings would yield valuable data on the subsurface conditions of the earth materials, thus confirming the nature and cause of the anomaly. The monitoring well may provide evidence that water is moving selectively through the anomalous zone. The linear feature identified at SWSA-3 may play an important role in radionuclide migration and may influence the type and extent of remedial actions required at the site.

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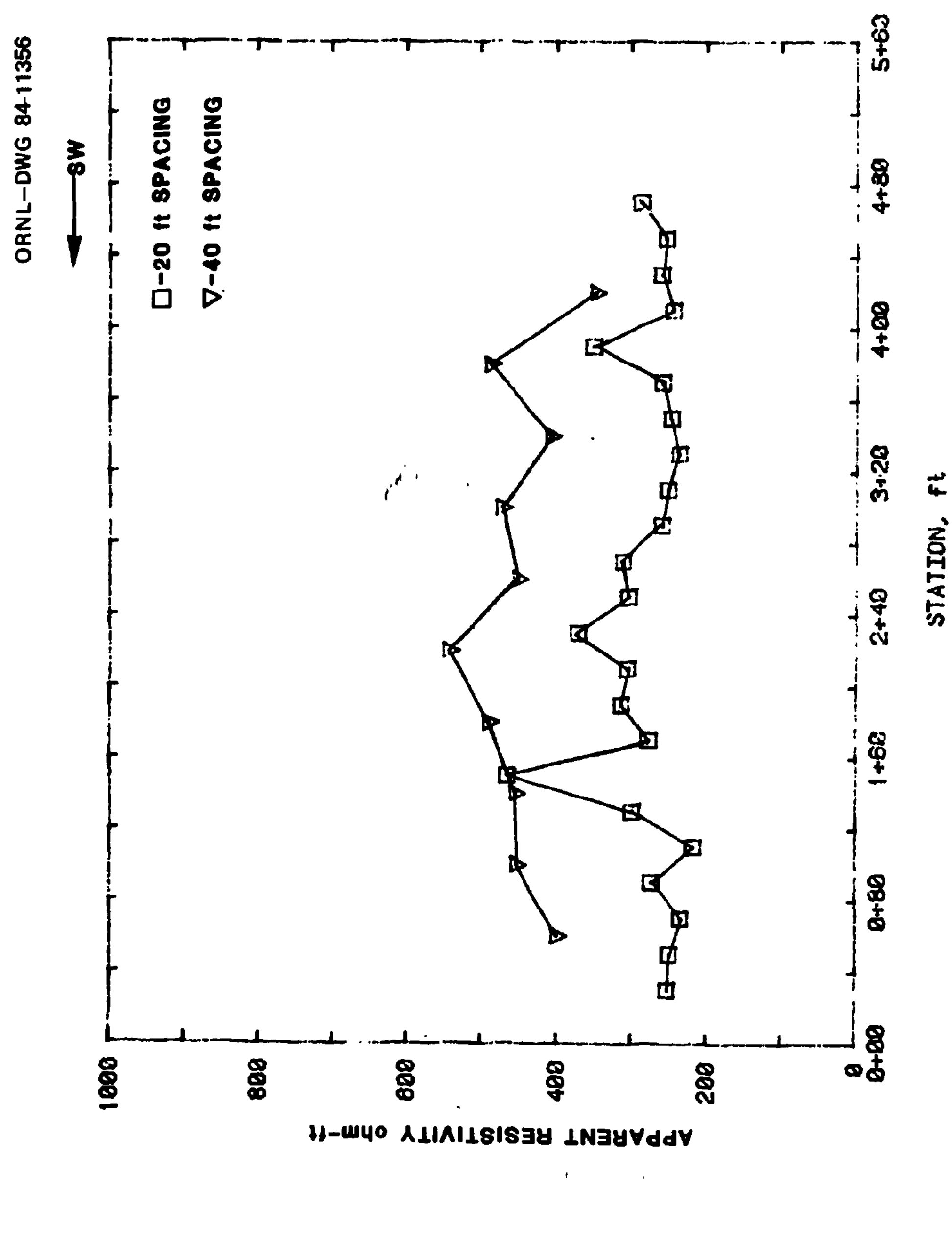
APPENDIX A

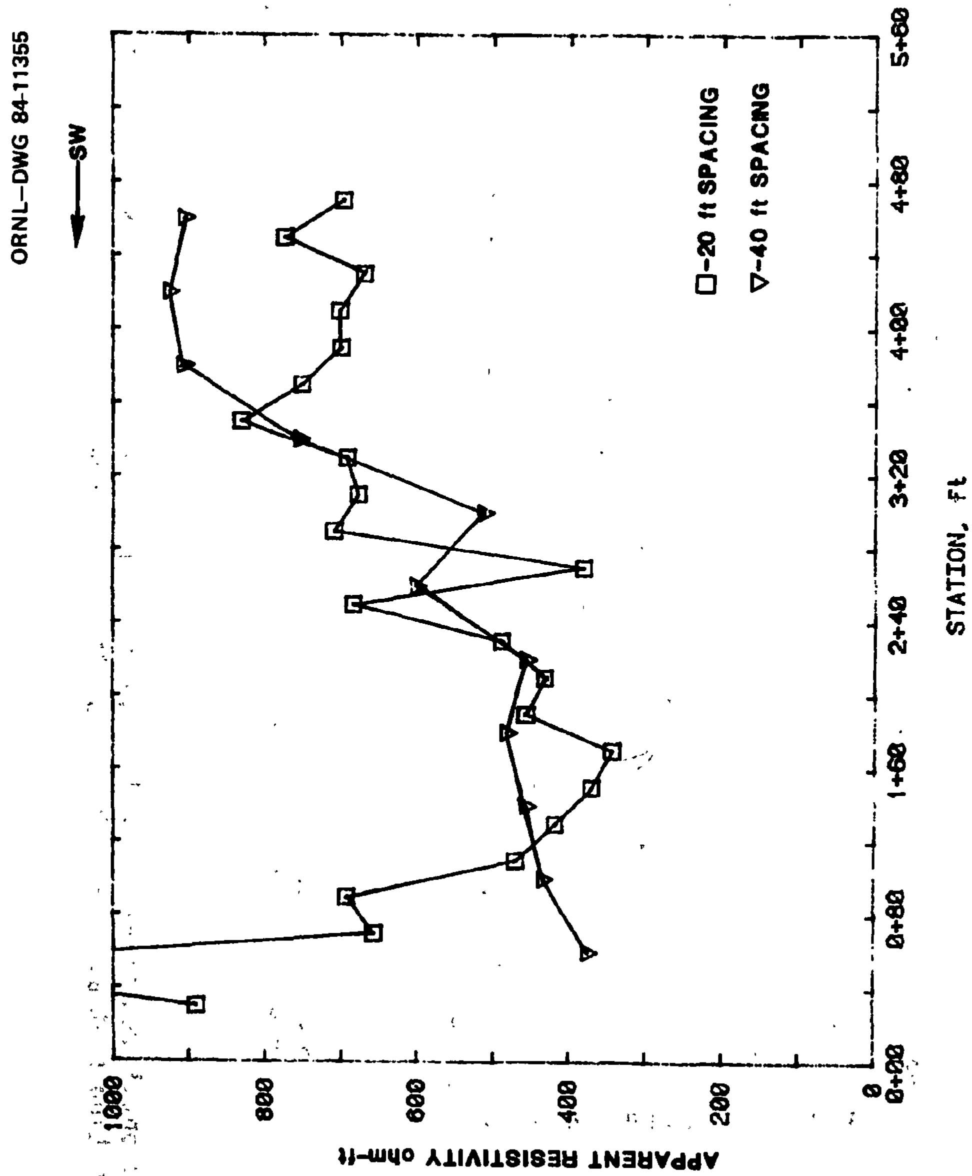
RESULTS OF ELECTRICAL RESISTIVITY SURVEYS

APPENDIX A (CONTINUED)



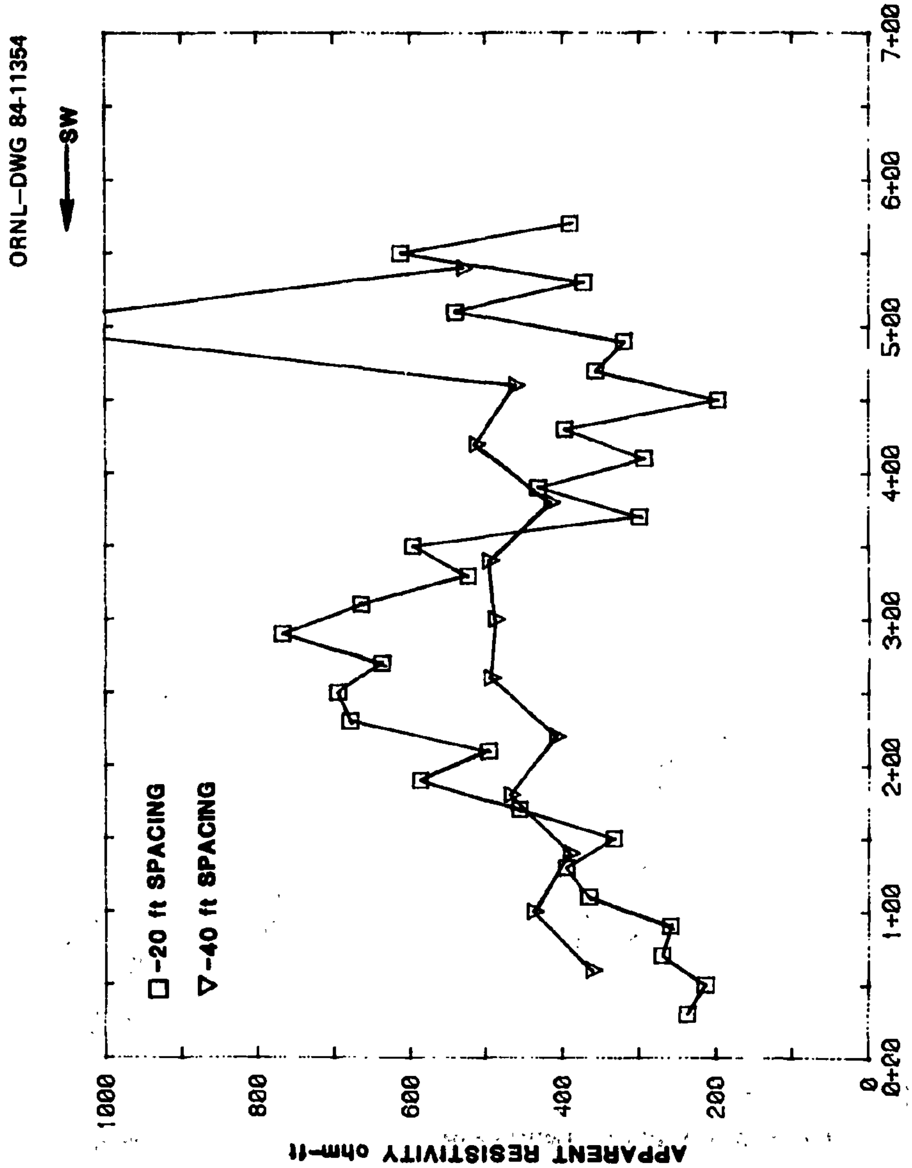
Horizontal resistivity profile (Wenner array), RP-1, Site 1, SWSA-3. Figure adopted from Llopis et al. 1984. Note: 0.304 x ft = m and 0.3048 x ohm - ft = ohm - m.

APPENDIX A (CONTINUED)



Horizontal resistivity profile (Wenner array), RP-2, Site 2, SWSA-3. Figure adopted from Llopis et al. 1984. Note: 0.3048 x ft = m and 0.3048 x ohm - ft = ohm - m.

APPENDIX A (CONTINUED)



Horizontal resistivity profile (Wenner array), RP-3, Site 3, SWSA-3. Figure adopted from Llopis et al. 1984. Note: 0.3048 x ft = m and 0.3048 x ohm - ft = ohm - m.

APPENDIX A (CONTINUED)

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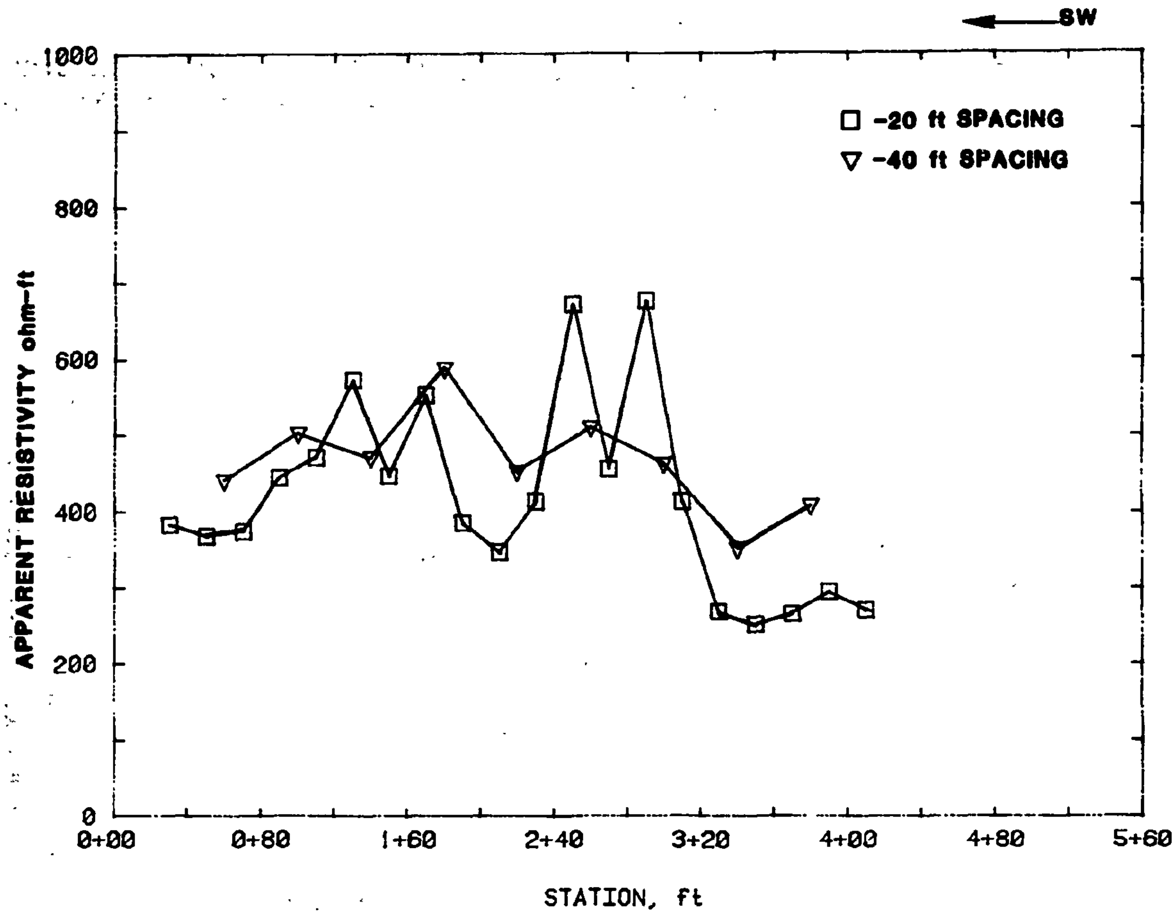
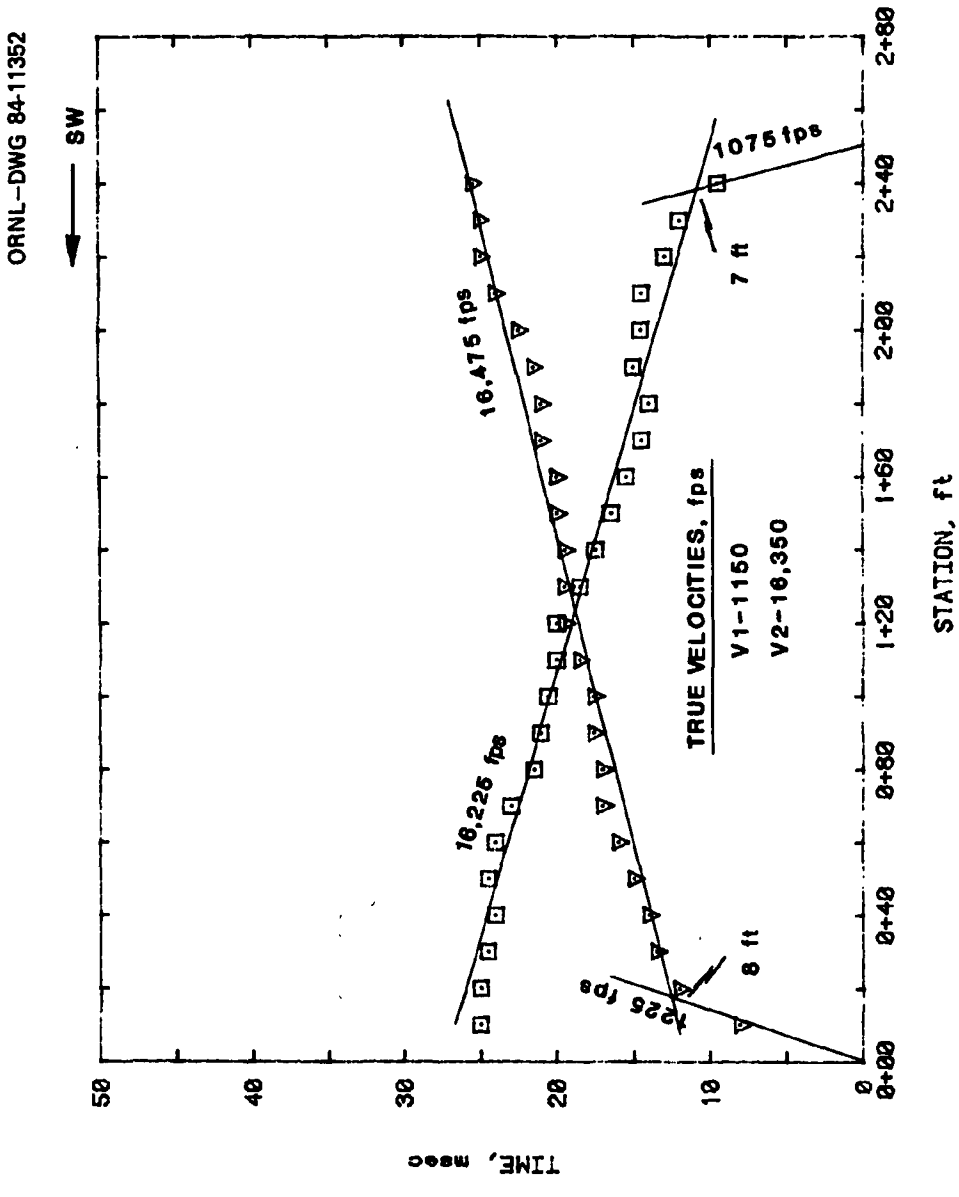


Horizontal resistivity profile (Wenner array), RP-4, Site 4, SWSA-3. Figure adopted from Llopis et al. 1984. Note: 0.3048 x ft = m and 0.3048 x ohm - ft = ohm - m.

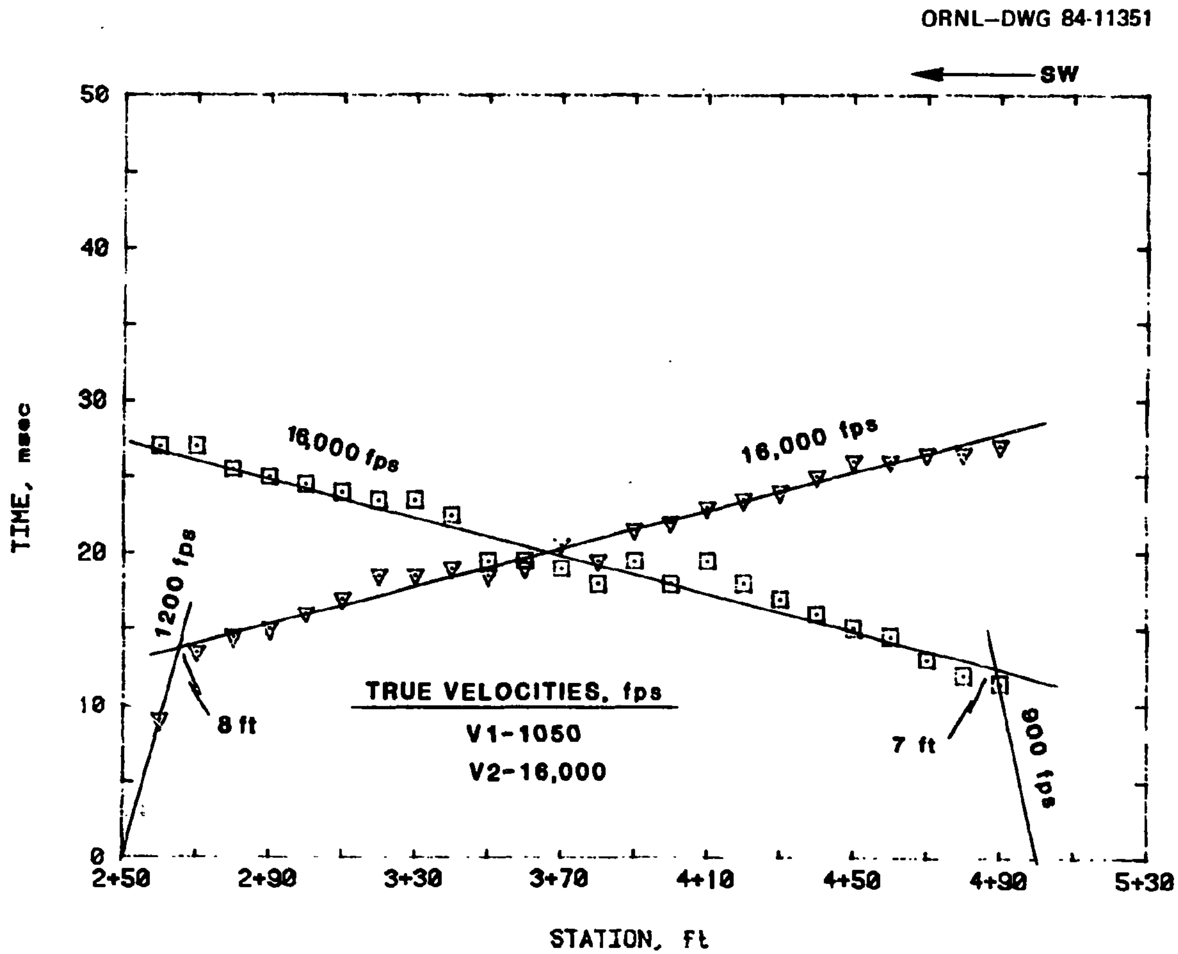
APPENDIX B

RESULTS OF SEISMIC REFRACTION SURVEYS

APPENDIX B (CONTINUED)



Seismic refraction line R-14, Site 1, SWSA-3. Figure adopted from Llopis et al. 1984.
Note: 0.3048 x ft = m and 0.3048 x fps = mps.



Seismic refraction line R-13, Site 1, SWSA-3. Figure adopted from Llopis et al. 1984.
Note: 0.3048 x ft = m and 0.3048 x fps = mps.

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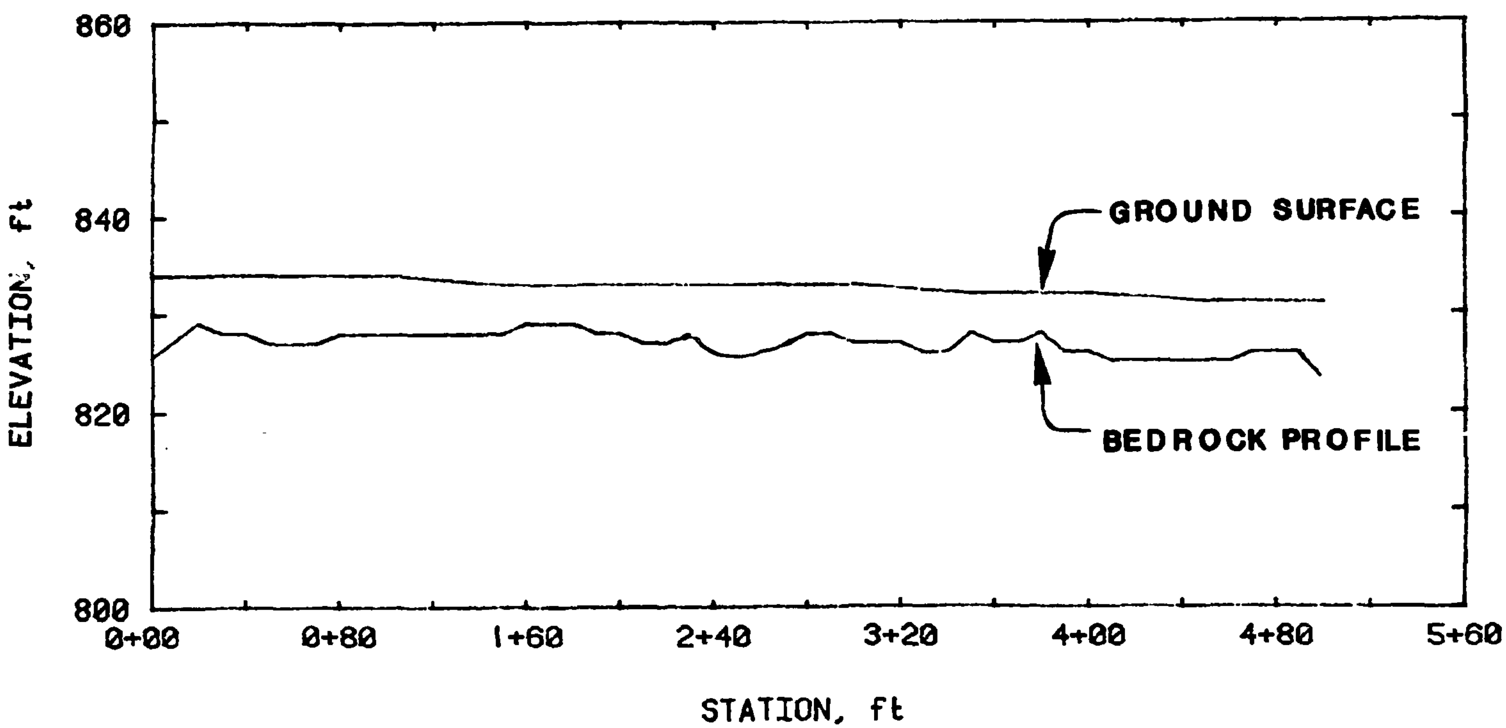
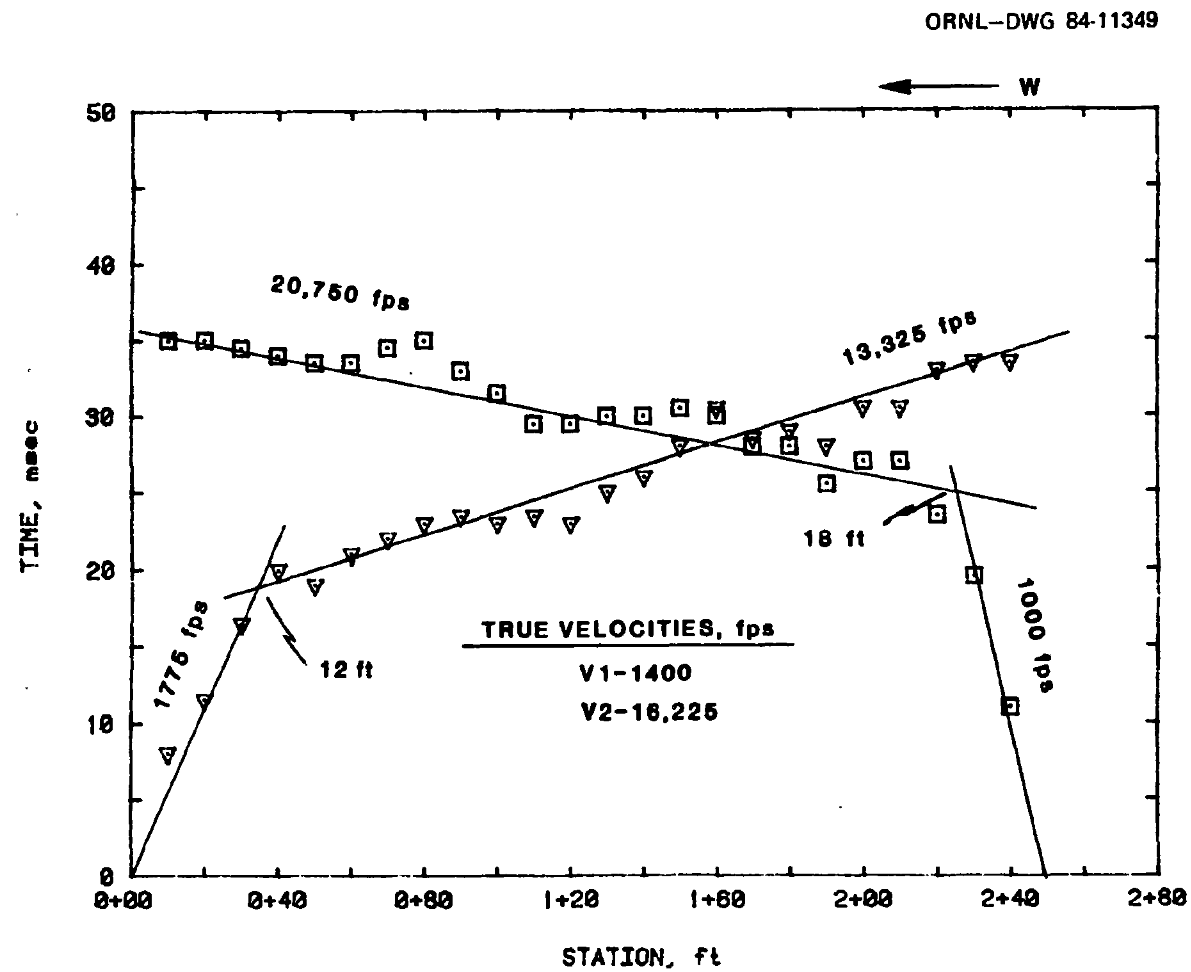
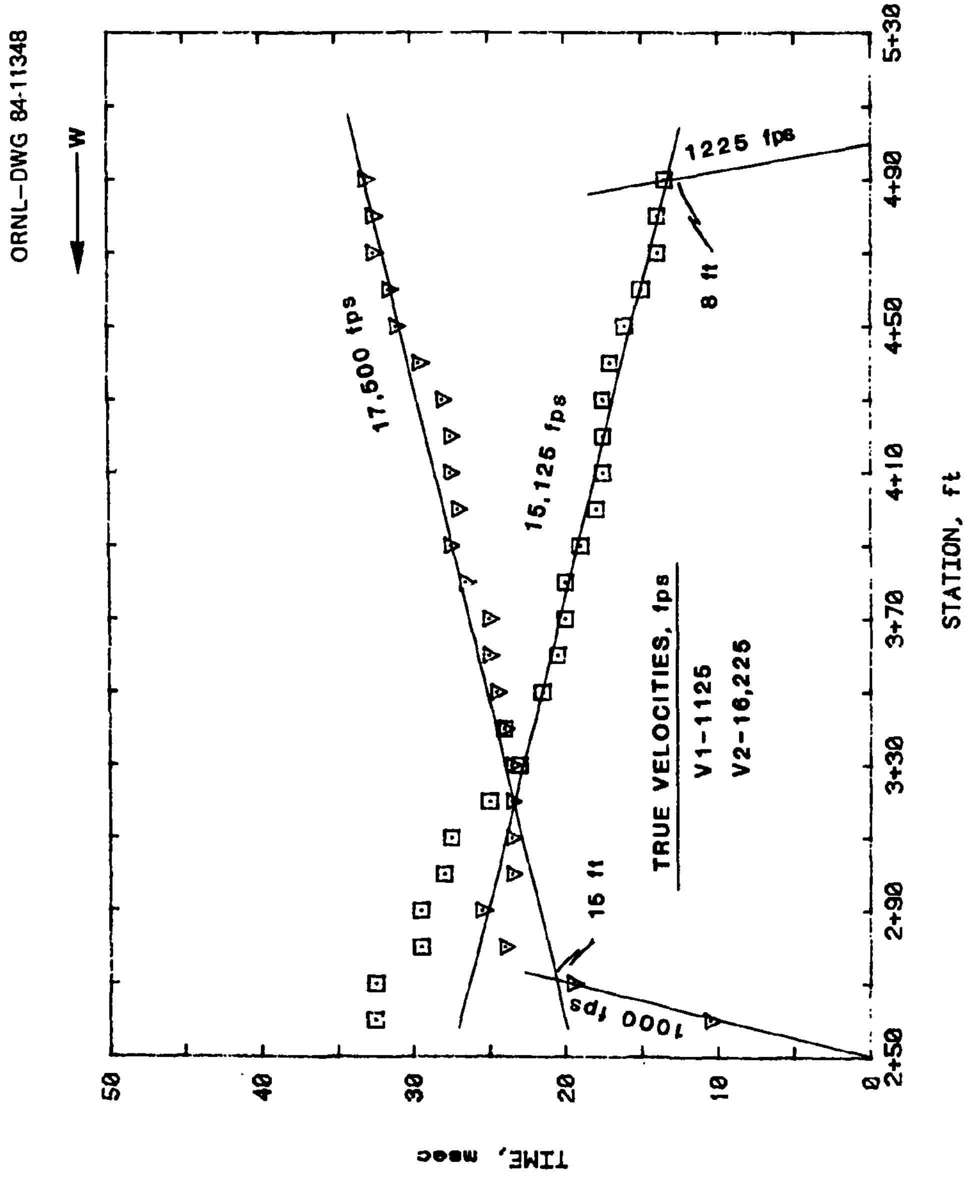


Bedrock profile obtained from refraction lines R-14 and R-13, Site 1, SWSA-3. Figure adopted from Llopis et al., 1984. Note: 0.3048 x ft = m.

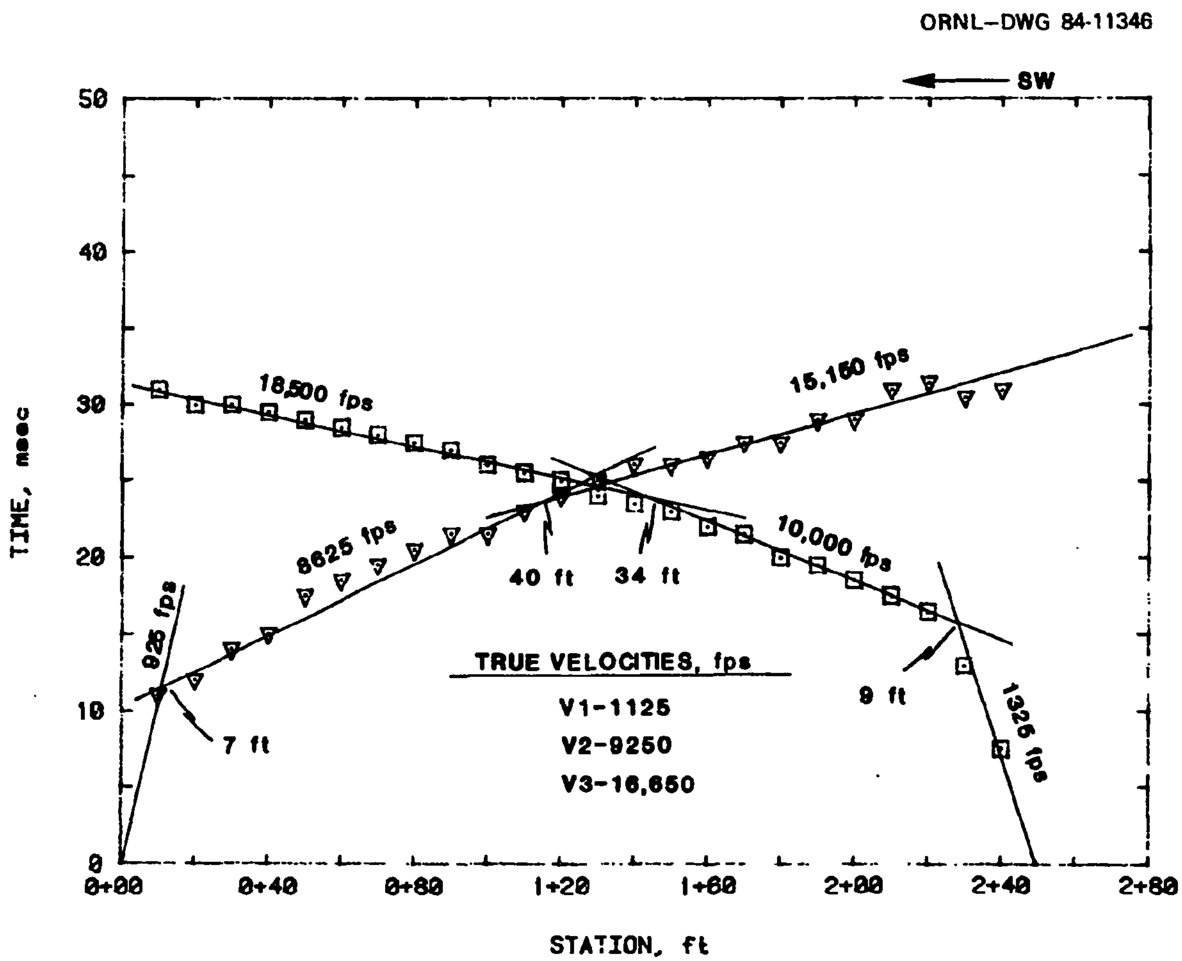


Seismic refraction line R-12, Site 2, SWSA-3. Figure adopted from Llopis et al. 1984.
Note 0.3048 x ft = m and 0.3048 x fps = mps.

APPENDIX B (CONTINUED)



Seismic refraction line R-11, Site 2, SWSA-3. Figure adopted from Llopis et al. 1984. Note 0.3048 x ft = m and 0.3048 x fps = mps.



Bedrock profile obtained from refraction lines R-12 and R-11, Site 2, SWSA-3. Figure adopted from Llopis et al. 1984. Note: 0.3048 x ft = m.

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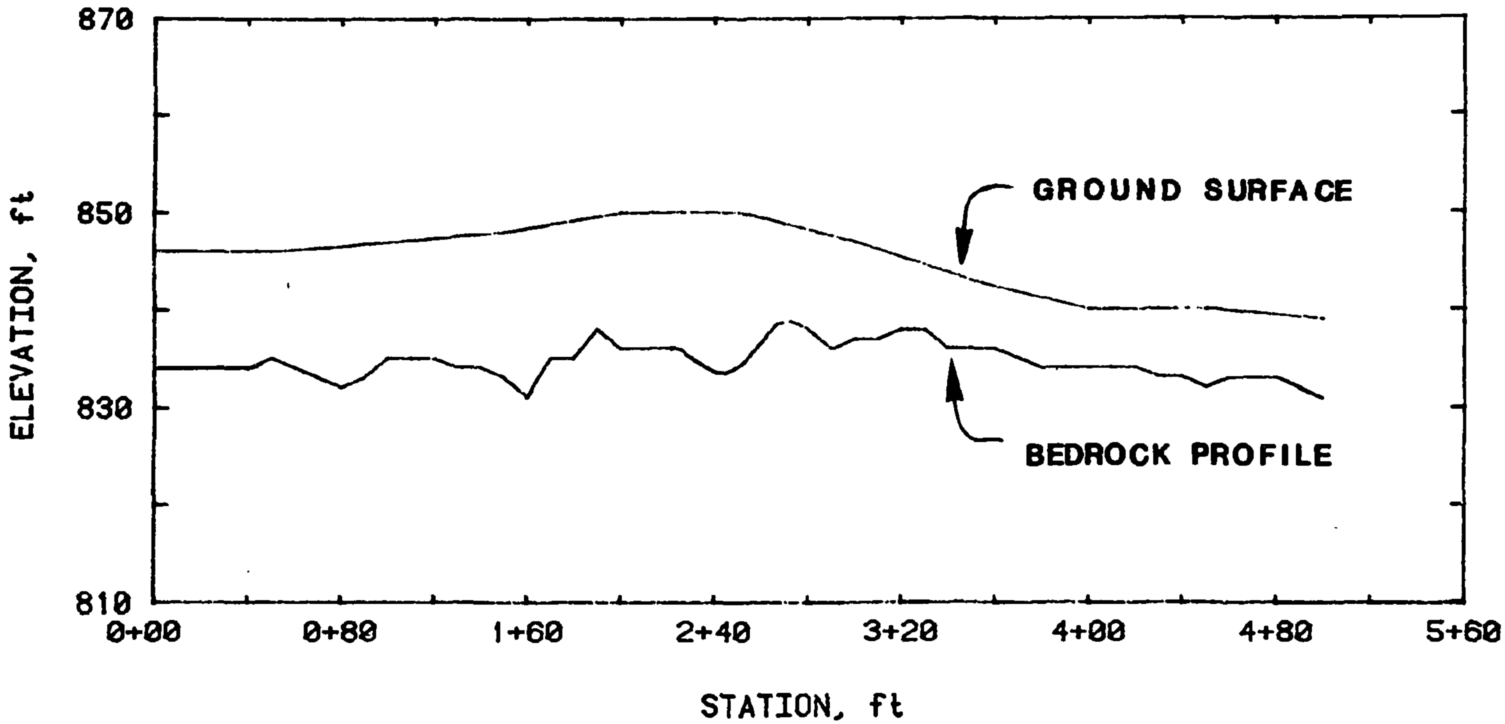

Seismic refraction line R-15, Site 3, SWSA-3. Figure adopted from Llopis et al. 1984.
Note: 0.3048x ft = m and 0.3048 x fps = mps.

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