UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geophysical Investigations in Fairfax County, Virginia

by

Vincent J. Flanigan

Open-File Report #78-150

1978

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey Standards and nomenclature.

Table of Contents

	Page
Introduction	1
Field Techniques	1
Discussion of Results	3
International Country Club area	3
Utterback Store Road area	5
Lake Fairfax area	6
Difficult Run area	7
Twin Lakes area	7
Cloverleaf Farm Estates area	8
Fort Belvoir area	8
Feasibility of an airborne VLF survey	9
Conclusions	10

Introduction

The purpose of this report is to present results of a test ground geophysical survey carried out in Fairfax County, Virginia. The survey, using electromagnetic methods was designed to evaluate the feasibility and effectiveness of an airborne VLF (very low frequency) electromagnetic (EM) survey to assist in answering a variety of geologic problems connected with the geologic mapping of Fairfax County, Va. The basic approach used was to make electromagnetic surveys over areas that represented typical rock types present in Fairfax County. The data were analyzed where appropriate to estimate depth of alluvial cover, saprolite thickness, subsurface bedrock topography and the geophysical response to fault structures. Typical VLF data were continued upward to aircraft flight height in order to determine the response that might be expected from an airborne survey.

Seven areas within Fairfax County were selected for this investigation. Reconnaissance geophysical profiles totaled 28.2 km of VLF measurements; in addition 8.4 km of slingram electromagnetic measurements were made to support the VLF measurements.

Field techniques

Areas of investigation were selected which were representative of the local geology and relatively free of cultural interference (e.g. powerline, pipeline, etc.) and with easy access. Survey line orientation was generally normal to the direction to the VLF transmitting station and generally normal to the mean geologic strike. Measurements were made at 30.5 m along the traverses. The VLF method has been described in detail by Patterson and Ronka (1971). Briefly, the method measures four parameters of the electromagnetic waves radiated by one of the several powerful VLF transmitters located in the

Western hemisphere. These parameters are sensitive to the electrical properties of the earth over which the radiated waves travel. In most cases, the apparent resistivity (ρa) trace on the VLF data profiles is the most diagnostic of the four parameters, although the other parameters combine to give added information on a particular area. The apparent resistivity is the combined resistance of the earth beneath the measurement point, e.g., if several layers were present with different resistivities, the apparent resistivity measured would be a combination of these layers depending upon their individual resistances and thicknesses. The phase of the surface impedance (Θ) is useful in determining the relative resistance of an underlying layer, that is, if a more resistive layer underlies a less resistive layer the phase angle is less than 45^o. If the reverse is true the phase angle is greater than 45^o. The tilt or dip and the quadrature (quad.) traces plotted on all of the VLF data profiles is a measurement (within certain limits) of the inclination and eccentricity of the VLF polarization ellipse in the vicinity of an electrical conductor. The inclination and eccentricity reflect the relative field strength and phase of the primary and secondary fields (Patterson and Ronka, 1971). The exploration depth or skin depth of the method is dependent upon the transmitted frequency of the radio wave (about 20KHz) and the local conductivity of the earth. At the frequency of the station used in this survey (Cutler, Maine-17.8 KHz) the skin depth varied from 20 to 60 m.

Profile slingram measurements were made with two different slingram instruments. The method is discussed in the literature by Keller and Frischknecht (1966), Frischknecht (1967), and Wait and Fuller (1972). Basically, the technique is a moving source and receiver method, in which the electromagnetic waves are transmitted at one or more frequencies into the earth thru a small transmitting coil. The secondary electromagnetic field is measured at one of several distances from the transmitting coil by a receiver coil. The amplitude and phase shift of the secondary field is compared to the primary field and the results recorded. The response of the secondary field is a function of the conductivity and thickness of the layers of rock and soil between the transmitting and receiving coils. Thus, lateral changes of conductivity and/or thickness produce measureable changes of response in the secondary field. The method is limited in its resolving power by the limited number of frequencies used. Generally, the method will yield a conductivity-thickness product of up to 2 or 3 layers (at 5 frequencies). If an independent source of conductivity or thickness of any of the layers can be obtained, a more accurate estimation of the geoelectric section can be made.

Upward continuation data presented herein were calculated by a computer program developed by Raymond Watts (1975). Selected slingram data were inverted by a program developed by Walt Anderson (unpublished) for the inversion of loop-loop sounding data.

Discussion of Results

An index map showing the location of Fairfax County, Va., and locations of figures 2-5 and 7 is shown on Figure 1. The location of geophysical profiles at each site are shown on partial topographic quadrangle sheets covering each area on figures 2-7.

International Country Club area

Two long profiles were made in the International Country Club area (fig. 2). The profiles extend from the crystalline Precambrian rocks in the Southeast to well into the sedimentary rocks of the Triassic basin to the northwest. The profile data for the two lines are shown in figures 8 and 9. Line 2, figure 9, had to be offset because of access problems. Pipelines and powerlines are the major source of cultural noise in the geophysical data. They are seen as data disturbances or sharp anomalies extending 50 to 100 m either side of the disturbing feature. These features are indicated on the data profiles as at Station 0, 5000 west, and 7400 west on line 1 fig. 8. Line 1 (fig. 8) shows a sharp break in apparent resistivity from 350 to 80 ohm-meters (Ω-m) at station 1000 East. This change reflects the electrical change between the crystalline rocks on the Southeast and the sedimentary rocks to the northwest. The contact is at about 800 east on line 1, and at station 2500 east on line 2, Fig. 9. The dip of the contact on line 1 is steeper than indicated on line 2. Another level change in apparent resistivity is indicated on line 1 between stations 100 east and 800 east and the lower level to the northwest. On line 2, fig. 9, a similar apparent resistivity level change is seen in the area between stations 2500 East and 400 West and the level to the northwest. Selected slingram data points along line 1 (Fig. 8) were passed to a computer inversion program which computes a geoelectric model to fit the observed data. The observed-computed data fit from the computed model at station 3000 West line 1 is shown on figure 10. In this case, the resultant computed model is a solution which fits the observed data well. The computed geoelectric section along Line 1 is shown on Figure 11. From station 3000 W to about station 800 E a uniform layer of about 200 Ω-m is present and varies in thickness from 7 m on the southeast to 17 m on the northwest end of the profile. This is thought to be the alluvium and/or saprolite layer. The crystalline rocks are indicated by apparent resistivities to 1550 and 2000 -m. Saprolite over the crystalline rocks is less conductive than residuum overlying the sedimentary rocks. Triassic sedimentary rocks below the layer of residuum show apparent resistivities of 310-760 Ω-m. The apparent resistivity level changes mentioned above which are observed from the VLF data are due to the response of a thinner section of Triassic sedimentary rocks near the southeastern contact with the crystalline rocks. This geoelectric section is consistent with the VLF data observed, and is fair geologic solution to the observed geophysical data.

Utterback Store Road Area

The problem addressed in this area was to define a suggested north-northeast trending fault structure which parallels Utterback Store Road. Well and auger drill data indicate an apparent 15 m offset in the bedrock, with the down block to the east. Three VLF profiles were made across Utterback Store Road as shown on Figure 3. Lines 1 and 2 were parallel about 60 meters apart, line 3 was about 1 km south of line 2. The results of the three geophysical profiles are shown on figure 12. Lines 1 and 2 are very similar showing an apparent resistivity of 800-1000 Ω-m east of Utterback Store Road with a rather sharp drop to about 80 Ω-m at station 1000. The data west of Utterback Store Road is not considered valid because the readings were being influenced by a power line at station 1400 and a pipeline at station 2100. Since only two of the parameters measured with the VLF method (apparent resistivity and phase) are directly related to the parameters of a layered earth, it is not possible to determine more than one or two parameters of the earth. Using a simple VLF 2 layer curve for interpretation at station 500 line 1, the conductance (product of thickness and conductivity) is about .07 mohs for the upper layer, assuming the lower layer to have a resistivity at 2000 Ω-m. Assuming the conductance is fairly uniform to station 1200, and using 90′

(27.4 m), known from the drill data, to control the saprolite layer thickness, the resistivity of saprolite is 375 Ω-m at station 1200. Using 375 Ω-m for resistivity ρ_1 at station 500 line 1, the saprolite layer would have to be 22 m thick. An independent measurement of the conductivity of saprolite layer by dc resistivity, or another auger hole at station 500 line 1 could ascertain the validity of this simple interpretation. A simple geologic model was assumed for line 1 and the VLF response for the model computed using a finite element modelling program adapted from Kisak and Silvester (1975). The resultant computed data fit the observed data fairly well in the area east of Utterback Store Road (figure 13), but does not fit the observed data west of the road. This probably confirms the fact that the observed data west of the road is being influenced by cultural interference. We know from well and drill hole data that the geologic model is fairly accurate west of Utterback Store Road, and from the computed model it is fairly certain that the saprolite layer is somewhat thinner east of Utterback Store Road. A fault may be present in the Utterback Store Road area, alternatively, these data may reflect variations in the bedrock topography. Line 3, figure 12 has cultural interference from station 800 to station 1600, so that interpretation of this line did not yield much useful data. On the eastern end of the line between stations 0 and 800 the apparent resistivity varies between 100 and 300 Ω-m, the lower values relate to a more conductive swampy area crossed at about station 300.

Lake Fairfax area

Two VLF profiles were run across a serpentinite body south of Lake Fairfax in the country park area (fig. 4). The VLF data profiles are shown on figure 14. Unfortunately a pipeline thru the center of the serpentine body rendered the data almost useless for comparison to the response of the schists on either side. No attempt was made to define saprolite thickness in this area.

Difficult Run Area

Two geophysical profiles were made across Difficult Run just south of Browns Mill Road (fig. 4). An attempt was made to determine the depth of alluvial cover overlying crystalline rocks. VLF and slingram data are presented on figure 15. Two frequencies of the five-frequency slingram are shown on line 2 (fig. 15), in addition the diamond (Δ) symbols represent the apparent resistivity measured by slingram unit of 3.6 meter coil separation. The short-spaced slingram unit is designed to measure the electromagnetic response of the upper (0-5 m) surface of the earth. Depth computations were made using the short-spaced slingram data. A geoelectric cross section is shown on figure 16. The slingram data indicates a channel has been cut in the bedrock near station 1100 and has subsequently been filled with alluvium. The VLF data, particularly the dip and quad anomaly at station 1100 suggests that there may be a conductive zone in the bedrock rather than a deeper section of alluvium. More work in this area is necessary to resolve this ambiguity.

Twin Lakes Area

Three VLF profiles were made across the Twin Lakes Golf course and Cloverleaf Farm Estates as shown on figure 5. The purpose of the survey was to define the electromagnetic response of mafic basement rocks which were covered with some thickness of overburden. The data for the Twin Lakes Golf Course are shown on figure 17. Much of the data are influenced by powerlines, sprinkler systems, and buried pipes or phone lines along the highway on the eastern end of the line. At a rock outcrop on the east side of the lake crossed by line 2, the data suggest that from 1.5-2 m of saprolite cover unweathered rock of about 200 Ω-m resistivity. At other places along this profile, such as at station 2400, the alluvium and/or saprolite may be from 3 to 8 m in thickness. Near surface changes or overburden and weathering such as this would probably be detectable by an airborne VLF survey.

Cloverleaf Farm Estates Area

The data covering one long (1.5 km) VLF profile are shown on figure 18. Here, power lines along Popes Head road, Knollbrook road, and at station 1400 influence the data 50-100 m on either side of their location. From stations 1600 to 4000 the data shows a 30 Ω-m layer of conductive overburden lying over rock of about 3000 Ω-m apparent resistivity. At stations 2000 and 3200 there probably is 20 or more meters of alluvium and saprolite.

Fort Belvoir Area

The final problem approached in this pilot survey was that of exploring the possibility of locating and or tracing northeast trending faults thought to cross Fort Belvoir in the eastern part of Fairfax County. In order to gain some insight on what type of electromagnetic expression we might expect from a typical fault, we made several profiles across the site of a known fault. The location selected is about 3 km northwest of Stafford, Va. (fig. 6). Here the Dumfries fault has been mapped and confirmed by trenching and drilling (Newell, et. al., 1976). The geophysical data for 2 lines are presented on fig. 19. The lower Cretaceous Potomac Group sediments east of the fault were 20 Ω-m or less in apparent resistivity, the phase angle (above 45^{o}) indicating that they probably are more conductive at depth, possibly due to a near surface water table. The rocks to the west, lower Paleozoic Quantico Slate, were somewhat higher in apparent resistivity, being about 40 Ω-m. At the location of the fault along line 1 (station 900) the VLF dip angle has a pronounced low, and there is a drop in apparent resistivity to 5 Ω-m. This same relationship is seen on line 2, suggesting that the fault crosses line 2 at about station 950. No attempt was made to model the slingram data to determine the bedrock offset because the data indicates in-phase anomalies which are related to topography and errors in coil alignment. The question of whether or not we could identify a fault on the basis of the VLF data if we did not know the location is raised. The answer is: probably not. We would know only that a conductive zone exists and might be related to one of several geologic features. However, in a airborne survey, features such as this would form linear anomalies crossed by a number of flight lines, therefore they might be identified as suspected fault locations. Two profiles were made in the Fort Belvoir area to see if there might be electromagnetic anomalies which could be associated with the northeastern projection of faults mapped along the Piedmont-Coastal Plain boundary. The location of the geophysical lines are shown on fig. 7. Here, the data shown on figure 20, did not indicate positive results. The reason for this may be twofold. First, this part of the County is covered by a very conductive overburden, so that the skin depth of the VLF radio waves is less than 20 m, and features below this depth could not be seen. Secondly, cultural interference produced anomales which masked any that might be expected from geologic features in the near surface.

Feasibility of an airborne VLF survey

In order to determine what the VLF anomalies would look like from an airborne VLF survey, three anomalies were selected for upward continuation from data along line 1 of the International Country Club Area fig. 8. These anomalies are the response seen over the crystalline-sedimentary contact (station 1100E), the powerline at Rugby Road (Station 0), and a pipeline crossed at station 7300W. The results of continuation of the ground observed data to 100m above the ground (normal flight elevation) is shown on figure 21. Over the geologic contact the airborne anomaly decreases in amplitude from -24% in tilt (dip) for the ground data to -4.5% for the airborne data. Further, the anomaly broadens from 180 meters on the ground to about 300 meters as seen from the air. The ellipticity (quad) shows a similar decrease in amplitude and broadening of the anomaly as seen from the air. This same relationship is true of the cultural interference also, the pipelines and powerlines would be sensed for about 150 m either side of their location by an airborne EM survey. Because interference from pipelines and powerlines was encountered so frequently in the ground survey, county maps were examined to gauge the magnitude of the interference problem. It is estimated that less than 30% of the area in Fairfax County could be considered for inclusion in an airborne survey. Of this 30%, perhaps 50% would yield good data. These estimations are based on maps showing major power transmission line location, and on the assumption that most roads will have either a secondary powerline, a telephone line, or a pipeline associated with it. An airborne survey would yield some useful data, but it is the opinion of the writer that a ground based geophysical survey directed at assisting in answering specific geologic questions would be more useful and efficient.

Conclusions

Ground based EM data have been found to be useful geologic tools when directed at specific problems such as depth of weathering, thickness of alluvial cover, and sounding of basement depths. The VLF and slingram EM techniques are limited in their exploration depths to about 100 m, thus problems requiring probing to greater depths would be approached using geophysical techniques having greater depth sounding capabilities. Areas which yielded the most useful information in this pilot survey are the International Country Club area, where the contact between the crystalline rocks and Triassic sediments was defined. The traverses across the Utterback Store road defined the bedrock configuration underlying alluvium and saprolite.

Upward continuation of ground VLF data to airborne flight elevation shows that anomalies of geologic interest can be detected from an airborne survey, but are harder to distinguish from cultural interference than on ground level.

Interference from pipelines, powerlines, and telephone lines in Fairfax County was found to be a considerable problem for the ground survey. Because of the scarcity of undeveloped land in Fairfax County, less than 30 percent of the county would be free from interference for an airborne survey. A ground based geophysical survey directed at answering geologic problems would be more useful and efficient than an airborne VLF survey in Fairfax County.

Selected References

Frischknecht, Frank C., 1967, Fields about an oscillating magnetic dipole over a two-layer earth and application to ground and airborne electromagnetic survey; in Quarterly of the Colorado School of Mines, v. 62, no. 1, p. 326.

Keller, G. V., and Frischknecht, F. C., 1966, Electrical methods in geophysical prospecting: Pergamon Press, Oxford. p. 278-427.

Kisak, E., and Silvester, P., 1975, A finite-element program package for magnetotelluric modelling; in Computer Physics Communications v.10, p. 421-433.

Newell, Wayne L., Prowell, David C., and Mixon, Robert B., 1976, Detailed investigation of a Coastal Plain-Piedmont Fault Contact in northeastern Virginia: U.S. Geol. Survey Open-File No. 76-329, 13 pg, 3 fig.

Paterson, M. R., and Ronka, V., 1971, Five years of surveying with the very-low-frequency-electromagnetic method: Geoexploration, v. 9, p. 7-26.

Wait, J. R., and Fuller, J. A., 1972, Argand representations of the mutual electromagnetic coupling of loops on a two layered earth: Geoexploration, v. 10, p. 221-227.

Watts, Raymond D., 1975, A Fortran IV program for analytic continuation of VLF electromagnetic data: U.S. Geol. Survey Open-File Report 75-159.

Figure Captions

Figure 1. Index map showing location of Fairfax County, Va.

2. Part of the Herndon, Va. quadrangle showing location of geophysical profiles.

3. Part of the Seneca, Md.-Va. quadrangle showing location of geophysical profiles.

4. Part of the Vienna, Va.-Md. quadrangle showing location of geophysical profiles.

5. Part of the Manassas, Va. quadrangle showing location of geophysical profiles.

6. Part of the Stafford, Va. quadrangle showing location of geophysical profiles across the Dumfries fault.

7. Part of the Fort Belvoir, Va. quadrangle showing location of geophysical profiles.

8. Line 1. International Country Club area, Fairfax County, Va.

9. Line 2. International Country Club area, Fairfax County, Va.

10. Diagram showing comparison of computed data to observed slingram data from computed model.

11. Interpreted geoelectric section along line 1, International Country Club area, Fairfax County, Va.

12. VLF profiles across Utterback Store Road, Fairfax County, Virginia.

13. Geoelectric model of VLF data across Utterback Store Road, Fairfax County, Va.

14. VLF profiles across serpentine body, Fairfax County, Virginia.

15. Geophysical profiles across Difficult Run, Fairfax, County, Virginia.

16. Interpreted geoelectric section showing thickness of alluvium over bedrock at Difficult Run area, Fairfax County, Virginia.

17. VLF profiles across Twin Lakes Golf Course, Fairfax County, Virginia.

18. VLF profiles in the Cloverleaf Farm Estates area, Fairfax County, Virginia.

19. Geophysical profiles across the Dumfries fault.

20. Geophysical profiles, Fort Belvoir area, Fairfax County, Va.

21. VLF anomalies continued upward to 100 m flight elevation. The solid lines are the ground based data, the dashed lines and crosses represent the response that would be seen from an airborne survey.

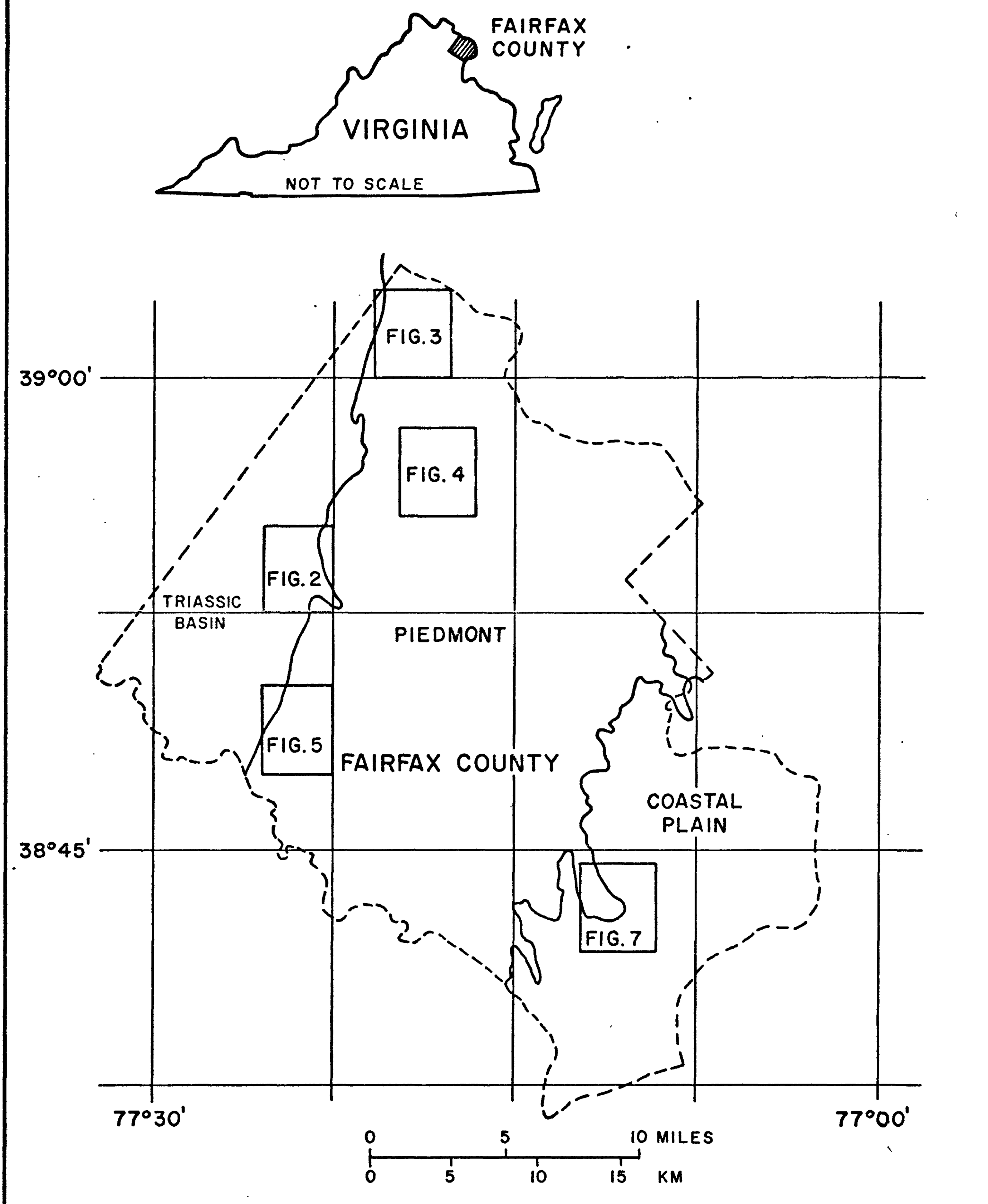


Figure 1. Index map showing the location of Fairfax County, Virginia, and general location of areas of geophysical investigations.

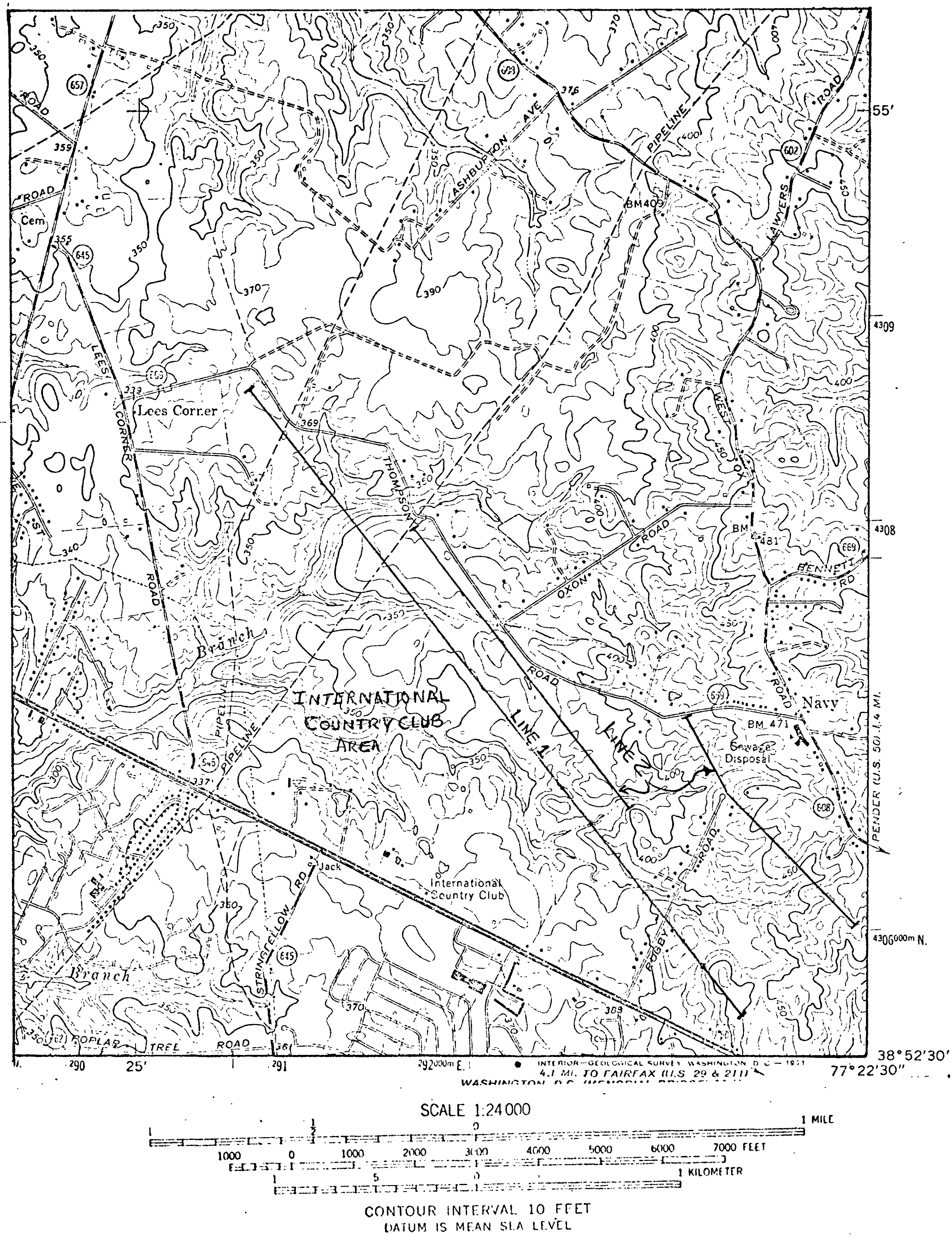
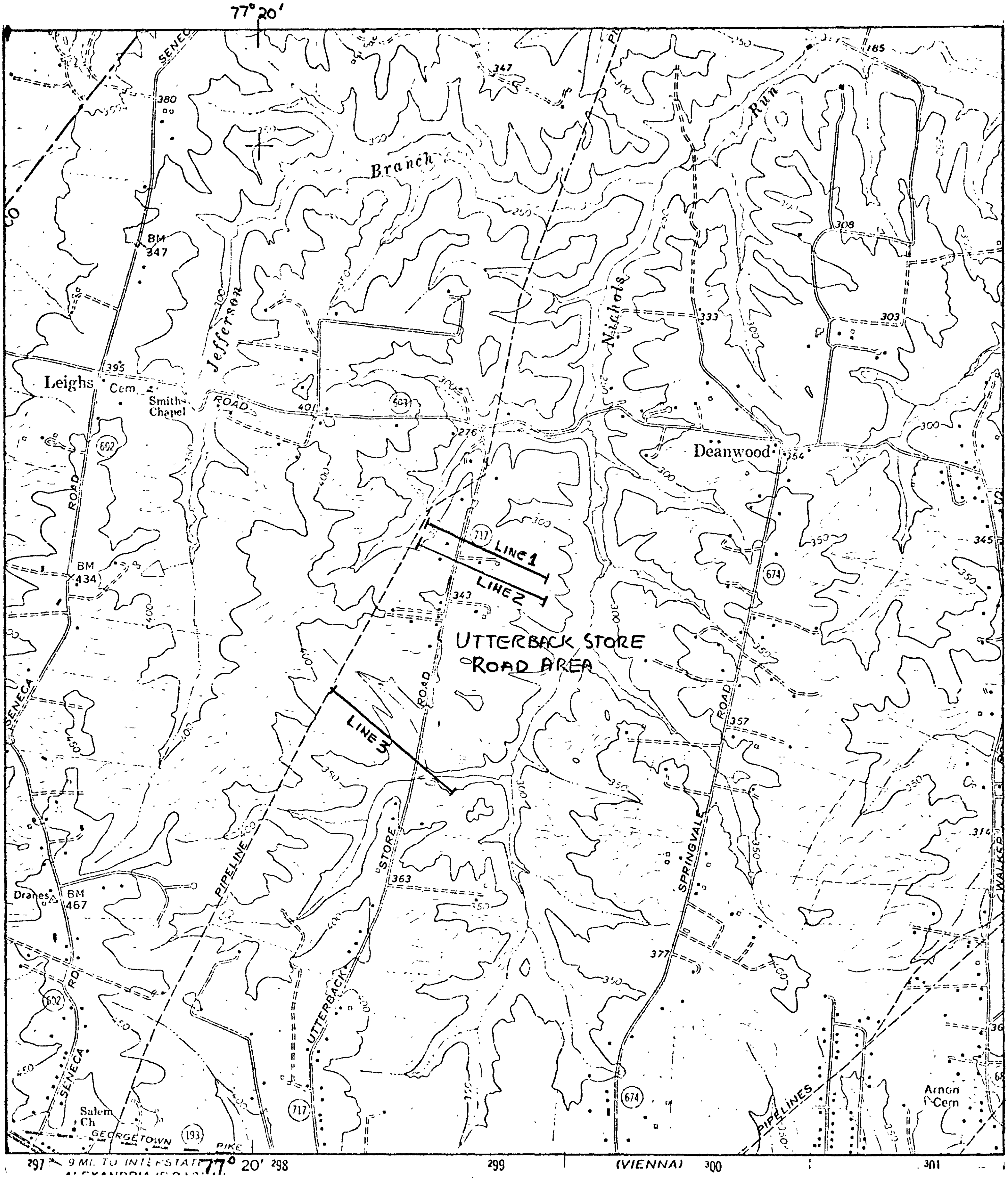


Fig.2 PART OF THE HERNDON, VA. QUADRANGLE SHOWING LOCATION OF GEOPHYSICAL PROFILES



SCALE 1:24 000

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

Fig. 3 Part of the Seneca, MD.-VA quadrangle showing location of geophysical profiles.

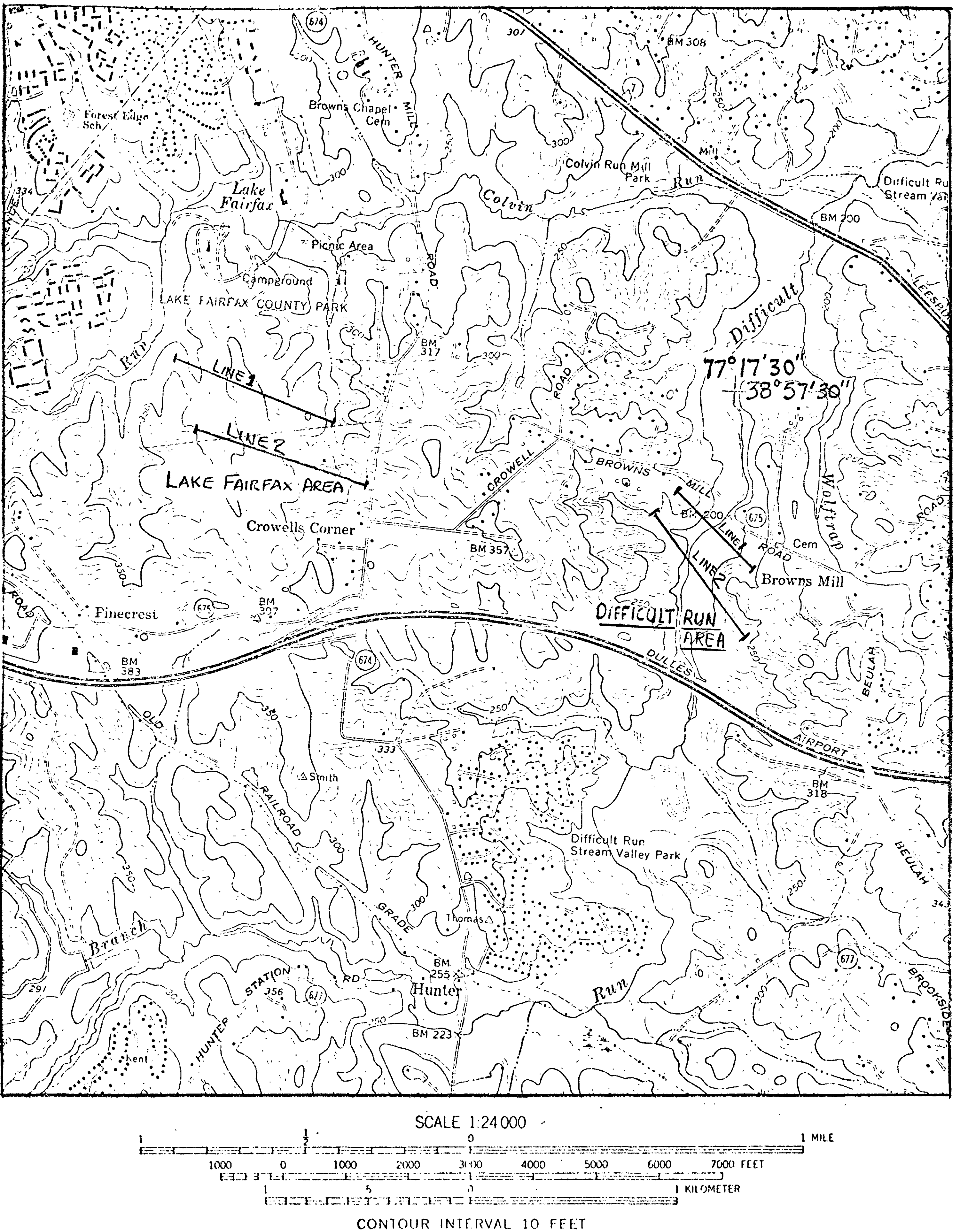


Fig. 4 PART OF THE VIENNA, VA.-MD. QUADRANGLE SHOWING LOCATION OF GEOPHYSICAL PROFILES.

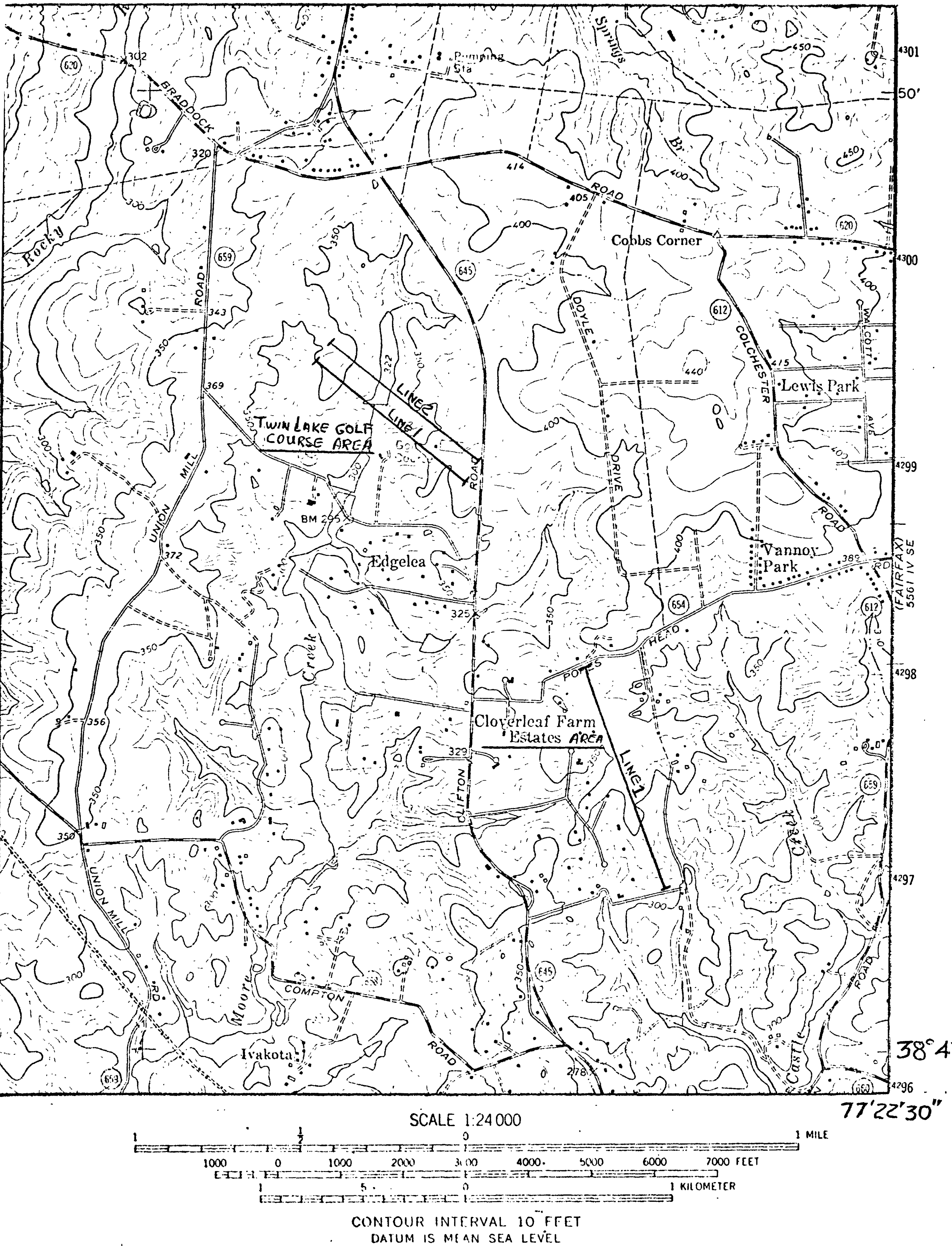


Fig 5. PART OF THE MANASSAS, VA. QUADRANGLE SHOWING LOCATION OF GEOPHYSICAL PROFILES.

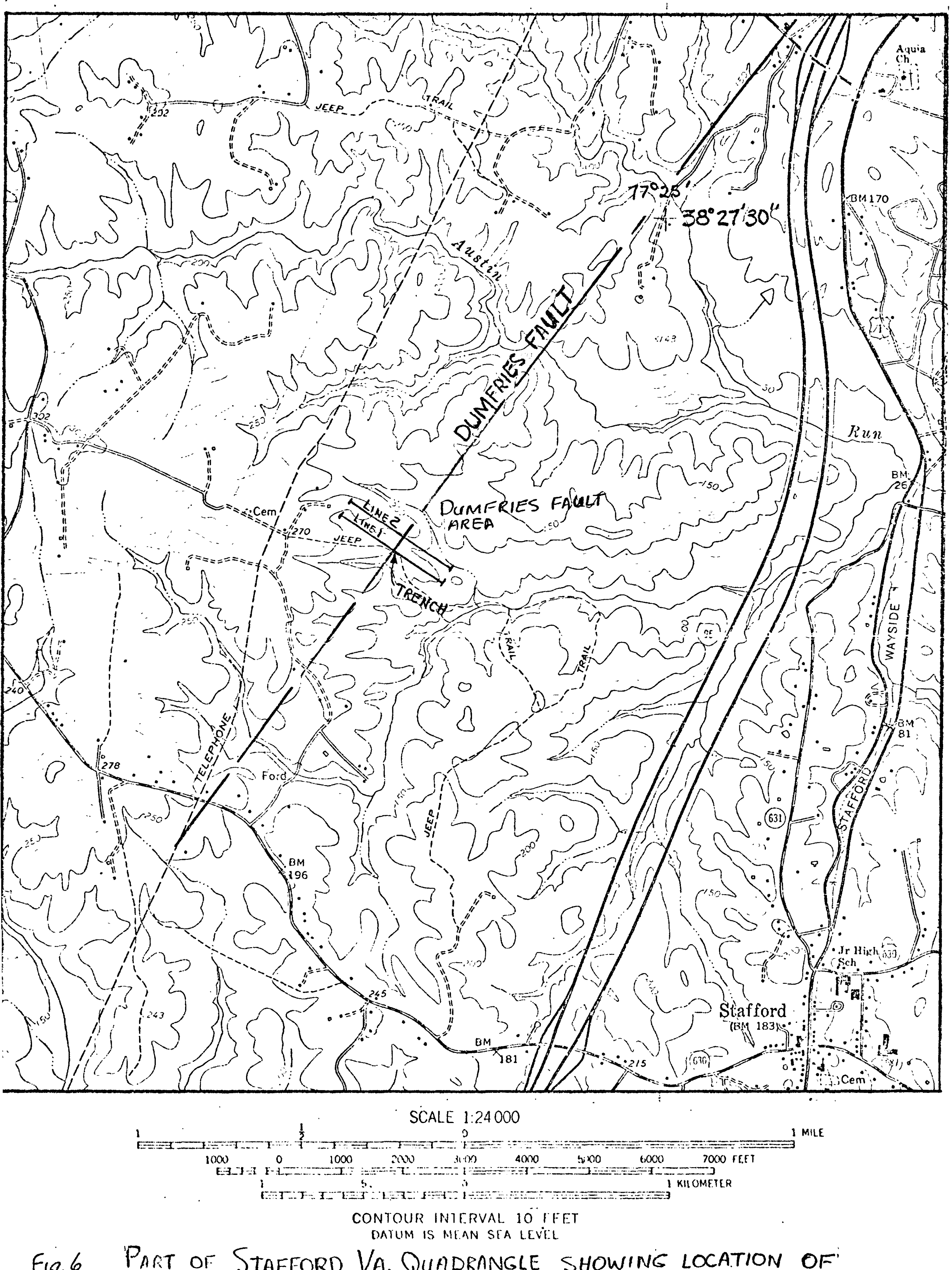


Fig. 6 PART OF STAFFORD, VA. QUADRANGLE SHOWING LOCATION OF GEOPHYSICAL PROFILES ACROSS THE DUMFRIES FAULT.

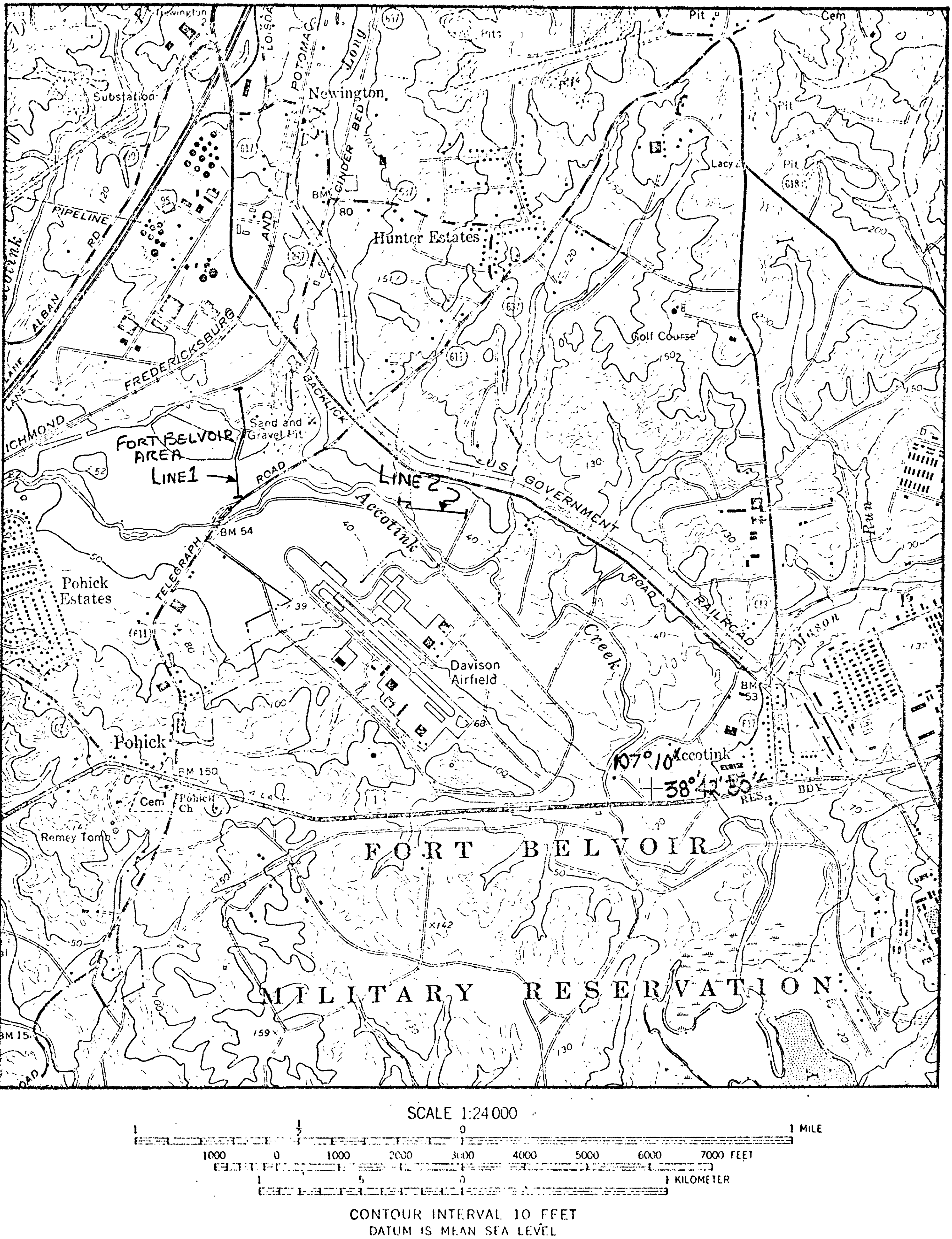


Fig. 7 PART OF THE FORT BELVOIR, VA. QUADRANGLE SHOWING LOCATION OF GEOPHYSICAL PROFILES.

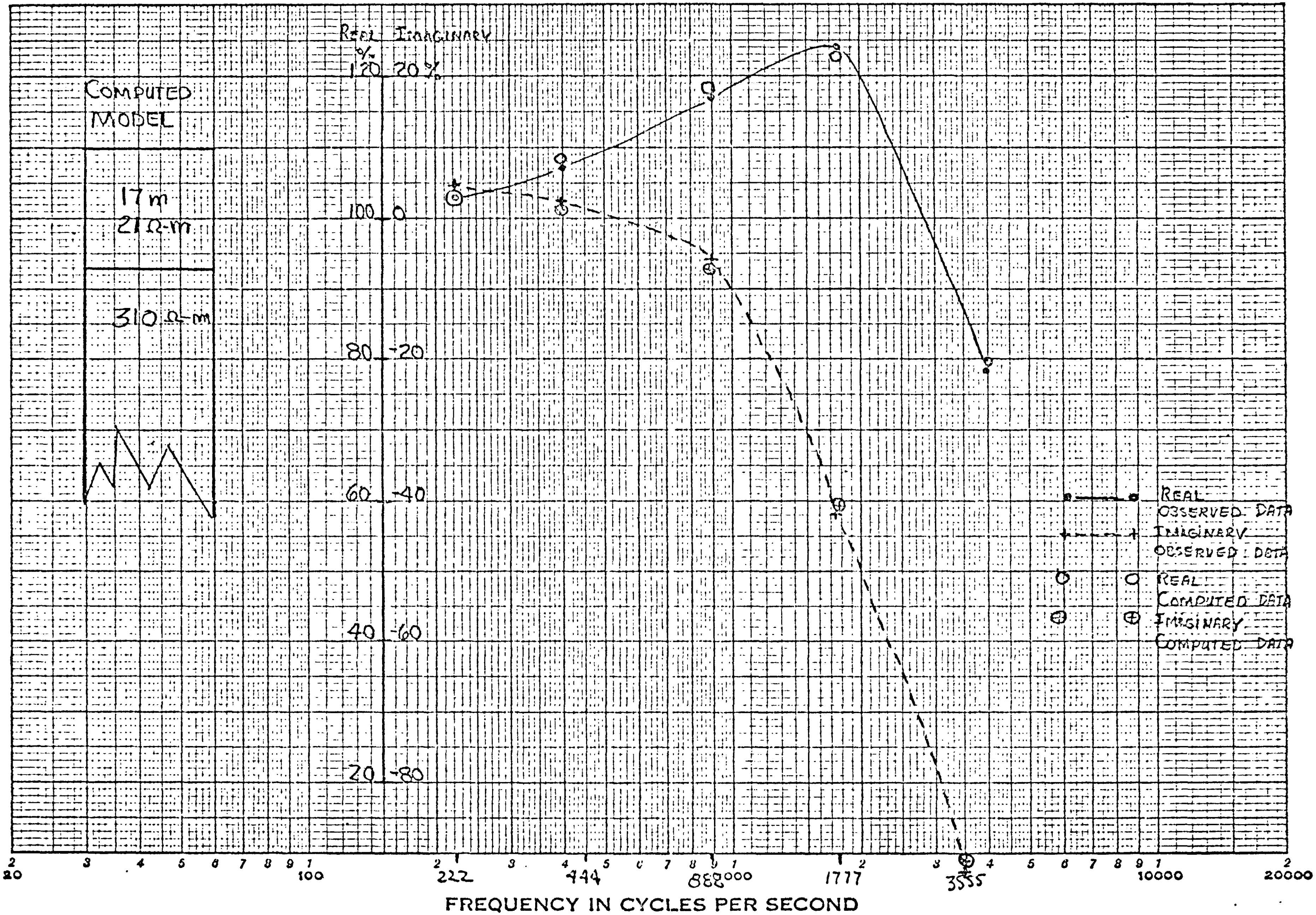


Fig. 10. Diagram showing comparison of computed data to observed Slingram data from computed model.

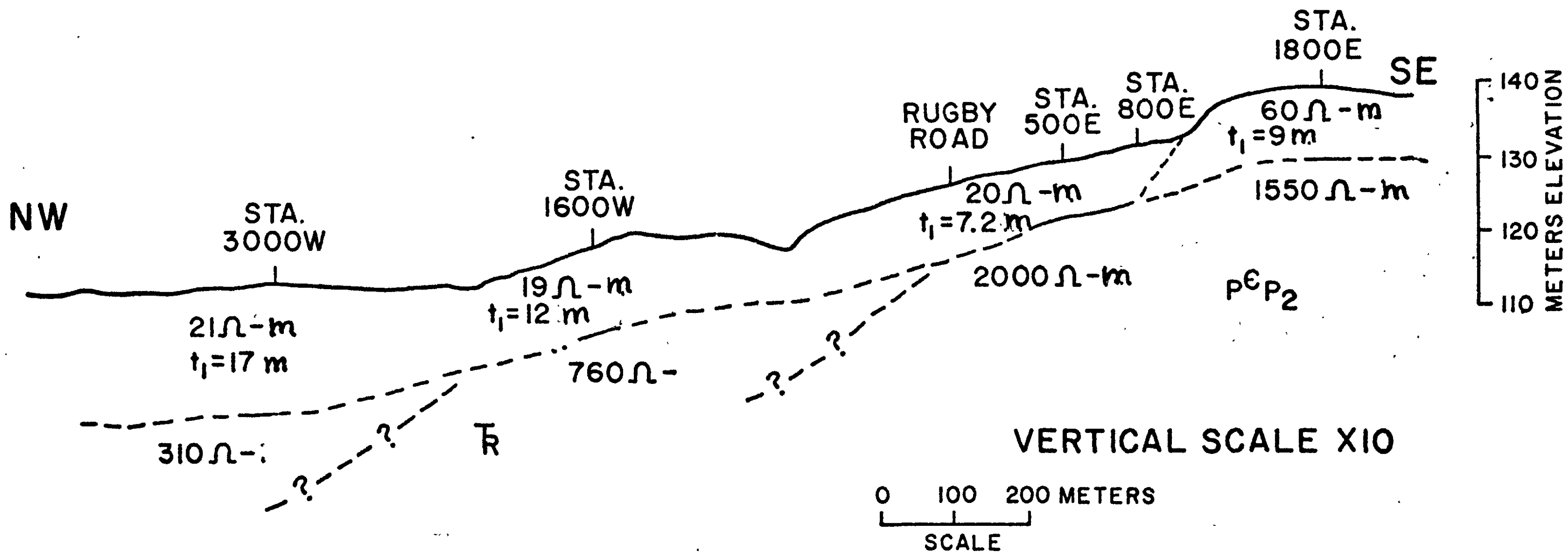


Figure 11. Interpreted geoelectric section along line 1, International Country Club Area, Fairfax County, Virginia.

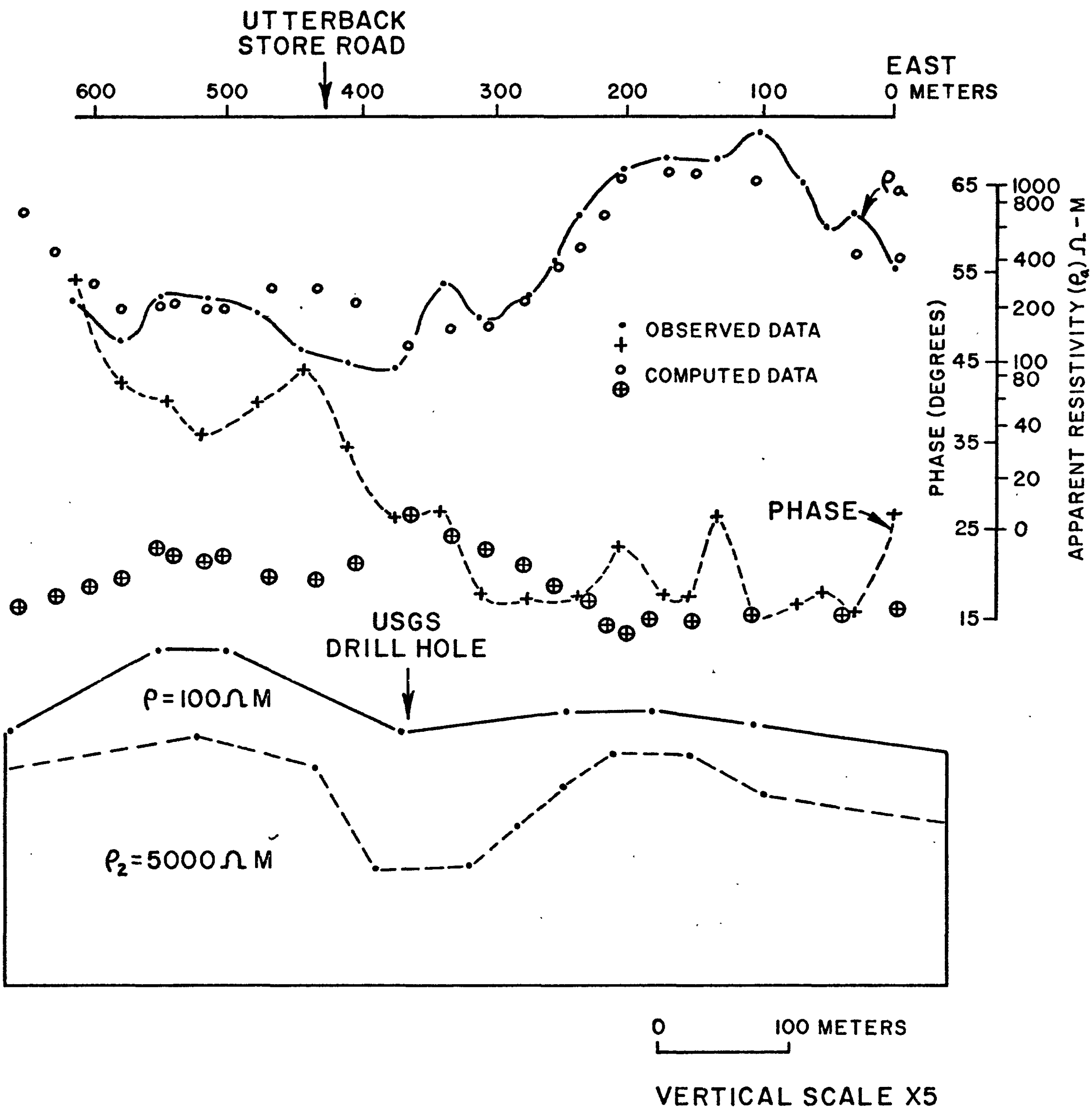


Figure 13. Geoelectric model of VLF data across Utterback Store Road, Fairfax County, Virginia.

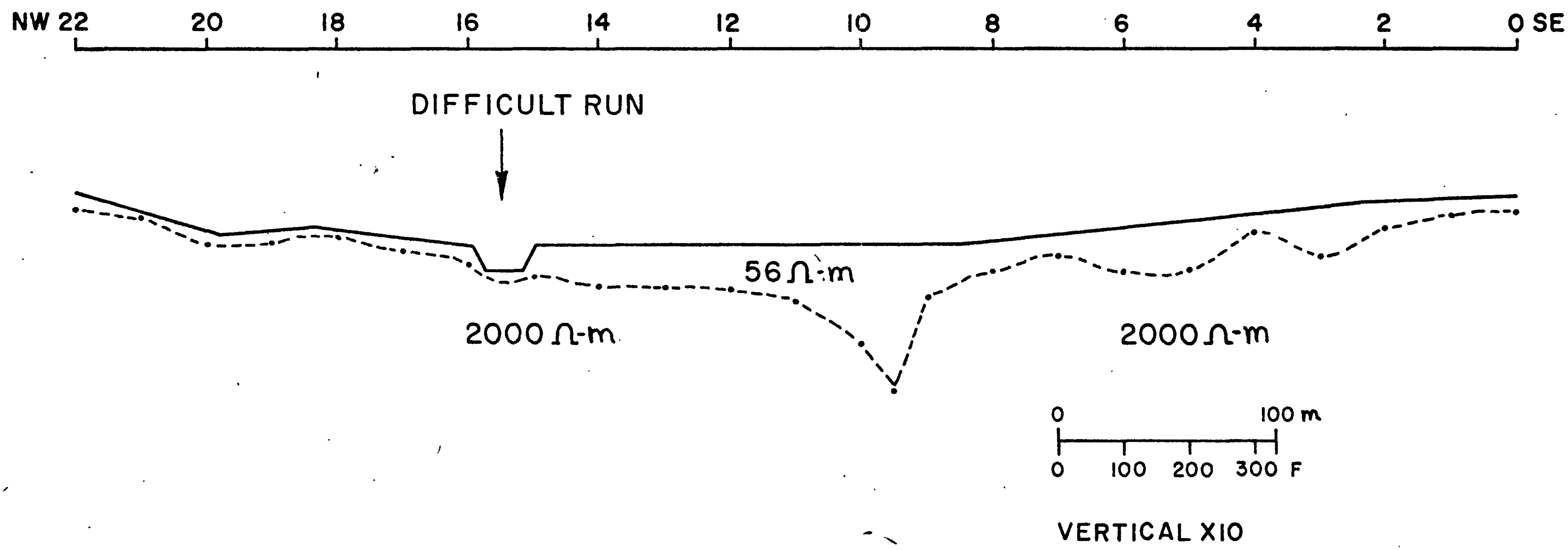


Figure 16. Interpretated geoelectric section showing thickness of alluvium over bedrock (line 2) at Difficult Run Area, Fairfax, County, Virginia.