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GEOLOGICAL SURVEY

GEOPHYSICAL RECONNAISSANCE OF
LEMMON VALLEY, WASHOE COUNTY, NEVADA

By Donald H. Schaefer and Douglas K. Maurer

WATER-RESOURCES INVESTIGATIONS

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CONTENTS

ILLUSTRATIONS

CONVERSION FACTORS AND ABBREVIATIONS

Except for water-quality, geophysical, and related units of measure, only the "inch-pound" system is used in this report. Abbreviations and conversion factors from inch-pound to International (metric) units are listed below.

Multiply	By	To obtain
Feet (ft)	0.3048	Meters (m)
Miles (mi)	1.609	Kilometers (km)

Water-quality units of measure used in this report are as follows:

For concentration, milligrams per liter (mg/L), which are equivalent to parts per million for dissolved-solids concentrations less than about 7,000 mg/L.

For specific conductance, micromhos per centimeter at 25° Celsius (micromhos).

Geophysical and related units are as follows:

For gravity, milligals (mgal).

For density, grams per cubic centimeter (g/cm^3).

For resistivity, ohm-meters (ohm-m).

NATIONAL GEODETIC VERTICAL DATUM OF 1929

In this report, the term "National Geodetic Vertical Datum of 1929" (or its abbreviation, "NGVD of 1929") replaces the formerly used term "mean sea level." The datum is derived from a general adjustment of the first-order leveling networks of both the United States and Canada.

GEOPHYSICAL RECONNAISSANCE OF LEMMON VALLEY, WASHOE COUNTY, NEVADA

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ABSTRACT

Rapid population growth in Lemmon Valley during recent years has placed increasing importance on developing knowledge of ground water stored in the valley. This report discusses two types of data--depth to bedrock and depth to fresh water beneath the playas--that are necessary for a more complete knowledge of the available water supply. Data that would fill voids left by previous studies relate to depth to bedrock and depth to good water beneath the two playas in the valley.

A gravity survey indicates that depths to bedrock in the western part of the valley are considerably greater than in the eastern part. Maximum depth in the western part is about 2,600 feet below land surface. This depression approximately underlies the Silver Lake playa. A smaller, shallower depression with a maximum depth of about 1,500 feet below land surface exists 2.5 miles north of the playa. The eastern part of the valley is considerably shallower. The maximum calculated depth to bedrock there is about 1,000 feet below land surface, but the depth in much of the area is 400 feet or less.

An electrical resistivity survey, consisting of 10 Schlumberger soundings, was conducted around the playas. The maximum depth of poor-quality water (characterized by a resistivity less than 20 ohm-meters) differed considerably from place to place. Maximum depths of poor-quality water beneath the playa east of Stead varied from about 120 feet to almost 570 feet below land surface. At the Silver Lake playa, the maximum depths varied from about 40 feet in the west to 490 feet in the east.

INTRODUCTION

Lemmon Valley, about 8 mi north of Reno (fig. 1), has experienced a rapid population growth in recent years that has paralleled Reno's growth. This increase in population has put demands on the available ground-water supply in the valley and has raised questions as to the ability of that supply to support the increasing population.

Although the general aspects of the hydrologic system have been studied in considerable detail (Harrill, 1973), two types of data are necessary for a more complete understanding of the hydrogeology and the available water supply.

One type of data is the thickness of valley-fill sedimentary deposits in the valley. Limited data on depth to bedrock are available for a few wells, but a more complete picture of the bedrock structure could yield more accurate ground-water storage values. Another advantage of additional data on bedrock depth would be the possible confirmation of several faults in Lemmon Valley inferred by Harrill (1973, p. 18) that may affect ground-water movement. If the faults have offset the bedrock vertically, some depth variations might be apparent along the fault.

The other information not presently known is the depth to fresh water beneath the playas, as mentioned by Harrill (1973, p. 47). If this were known, a more realistic estimate of the amount of good water available in the valley would be possible.

The objective of this study, prepared in cooperation with the Nevada Division of Water Resources, is to determine the depth to consolidated rocks and the variations in depth of good water beneath the playas in Lemmon Valley. The study involved use of a gravity survey of the valley to determine depth to bedrock and electrical resistivity to determine depth to good water beneath the two playas.

GEOLOGIC SETTING

Lithologic Units

For the purpose of this study, the five lithologic units described by Harrill (1973, p. 14) and based on work by Bonham (1969) are simplified into two units: Consolidated rocks and valley-fill deposits.

The consolidated rocks ("bedrock") consist of volcanic, granitic, metavolcanic, and metasedimentary rocks. The valley fill consists of gravel, sand, silt, and clay deposits that overlie consolidated rocks comparable to those composing the surrounding mountain ranges (fig. 1).

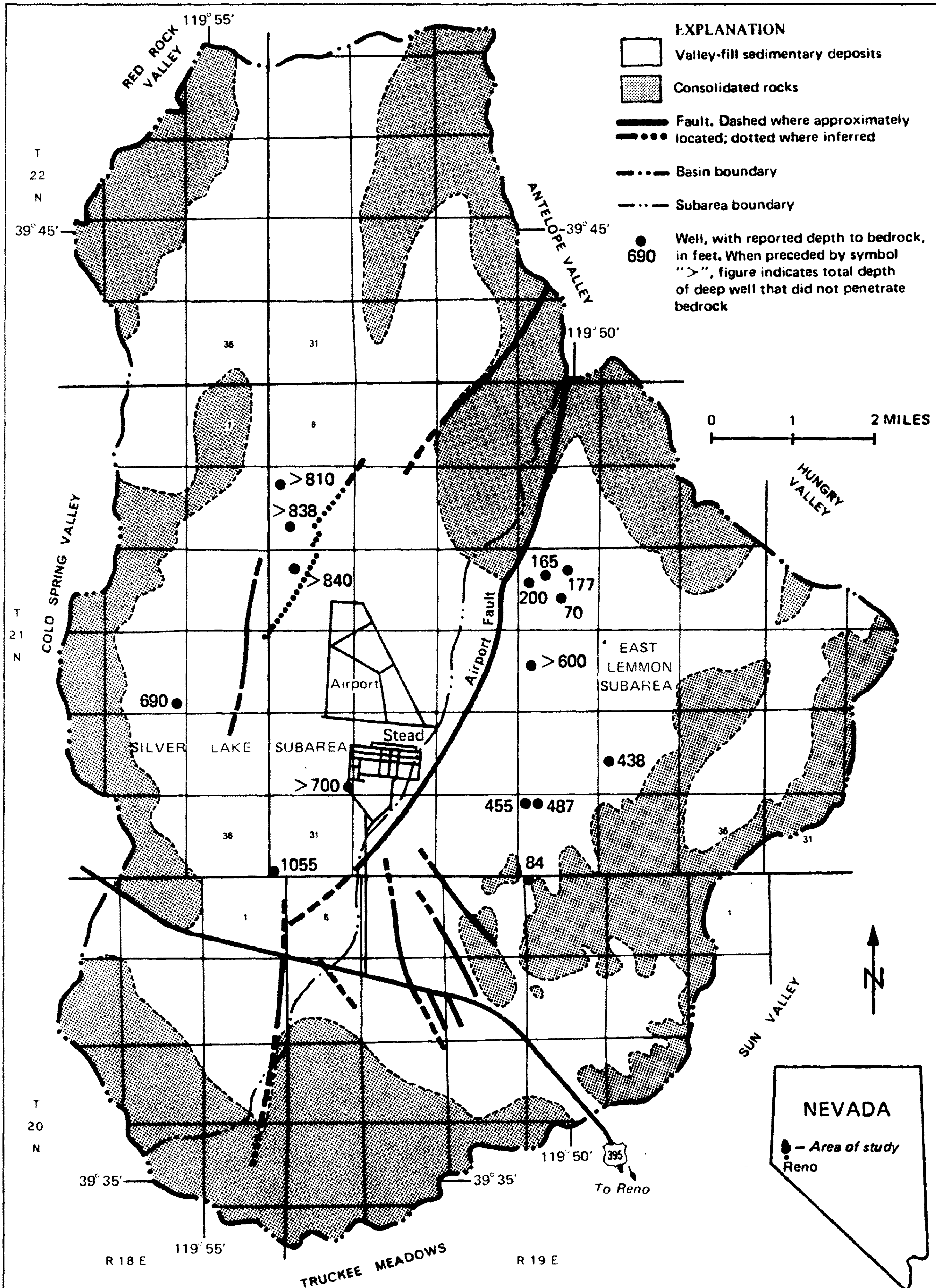

FIGURE 1.——Location of study area, generalized geology, and depth to bedrock. Geology from Harrill (1973, fig. 1).

Depths to consolidated rock below land surface, from well data, are shown in figure 1. Harrill (1973, p. 21) stated that the maximum thickness in the western part of Lemmon Valley is probably greater than 1,000 ft but does not exceed 2,000 ft, and that the part near the Airport fault and east of Stead (fig. 1) probably has a depth to bedrock greater than 600 ft. This correlates well with the depths calculated from gravity data to be discussed later.

Structural Features

The structural features of Lemmon Valley are discussed in some detail by Harrill (1973, p. 12) and Bonham (1969, p. 42-44), but the overall structural information necessary for the interpretation of the gravity data will be briefly summarized here.

The primary structural indicators in the Lemmon Valley area are north-to northeast-trending valleys between mountain ranges (fig. 1). A major fault in the area, the Airport fault, divides the valley into two structural areas. The fault also approximates the divide between two hydrologic subareas in the valley (Harrill, 1973, p. 8). The East Lemmon subarea is in the eastern section of the valley and the Silver Lake subarea is to the west (Harrill, 1973, fig. 1).

GRAVITY SURVEY

Discussion of Method

A gravity survey was made in Lemmon Valley to obtain generalized information about the subsurface configuration of the bedrock.

Briefly, a gravity survey involves measuring the relative gravitational attraction at specific points throughout the study area. The differences in gravity between points are due in large part to differences in the distribution of rock materials beneath the surface. Once corrections to the measurements have been made to eliminate the effect of surrounding materials, differences in the gravity values will be due to lateral variations in density beneath the area examined. From this information, relative thickness of the underlying valley-fill deposits can be determined.

Field Techniques

Gravity measurements were made at 235 locations in Lemmon Valley by using a Worden[1] temperature-controlled gravimeter with a sensitivity of 0.0965 mgal per scale division. The stations were located at points at which established accurate horizontal and vertical controls could be used to minimize errors from latitude and altitude corrections.

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[1]The use of the brand name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

All measurements were referenced to a base station in Lemmon Valley. Measurements at the Lemmon Valley base were made at least three times per day to correct for tidal and instrument drift. The base station in Lemmon Valley was, in turn, referenced by measurements to a network gravity base station in Carson City, Nev., described by Chapman (1966, p. 49). This station is referenced to the international gravity network (Woollard and Rose, 1963).

Of the 235 gravity measurements, 218 were made on the valley floor and 17 were in the surrounding mountain areas on exposed bedrock.

Data Reduction

The gravity data were reduced by means of a computer program developed by Plouff (1977) that makes the necessary corrections to gravity data for latitude, altitude, earth curvature, and terrain irregularities for a radius of 1.42 to 103.6 mi from each gravity station. The terrain corrections from each station to a radius of 1.42 mi were done manually, using the Hayford-Bowie system (Hayford and Bowie, 1912).

The final gravity values for the 235 stations, Bouguer gravity values as well as free-air anomalies and total terrain corrections, were listed by Schaefer and Maurer (1980).

Bouguer Anomaly

The Bouguer anomaly was calculated by using a Bouguer density of 2.67 g/cm^3. Shown in figure 2, the gravity map is superimposed on a generalized geologic map to show the relationship of the contours to the locations of outcrops and fault patterns. The contours in the vicinity of the various faults in Lemmon Valley tend to parallel the faults. This suggests some vertical displacement along the faults, with a resultant drop or uplift of the consolidated rock.

The large negative values of the Bouguer anomaly indicate thick accumulations of unconsolidated material. The larger anomaly approximately underlying Silver Lake northeast of Granite Peak has a maximum difference of about 8 mgal between Granite Peak and the depression. This is apparently the deepest part of the valley; there is a smaller depression northwest of Stead.

Residual Anomaly

Regional gravity values were subtracted from the Bouguer gravity map, so that the remaining anomaly reflects mainly depth to bedrock and local structure. The resultant residual anomaly map gives a more realistic representation of actual depths to consolidated rocks than the Bouguer anomaly map. Residual anomalies in Lemmon Valley are shown in figure 3. The 0-mgal contour indicates the points where the regional gravity equals the Bouguer gravity. The 0-mgal contour also approximatly coincides with the contact between bedrock and valley fill. The depression underlying Silver Lake reaches a maximum of about 13 mgal, and the one to the north, about 10 mgal. Maximum depression in the eastern part of the valley is about 6 mgal.

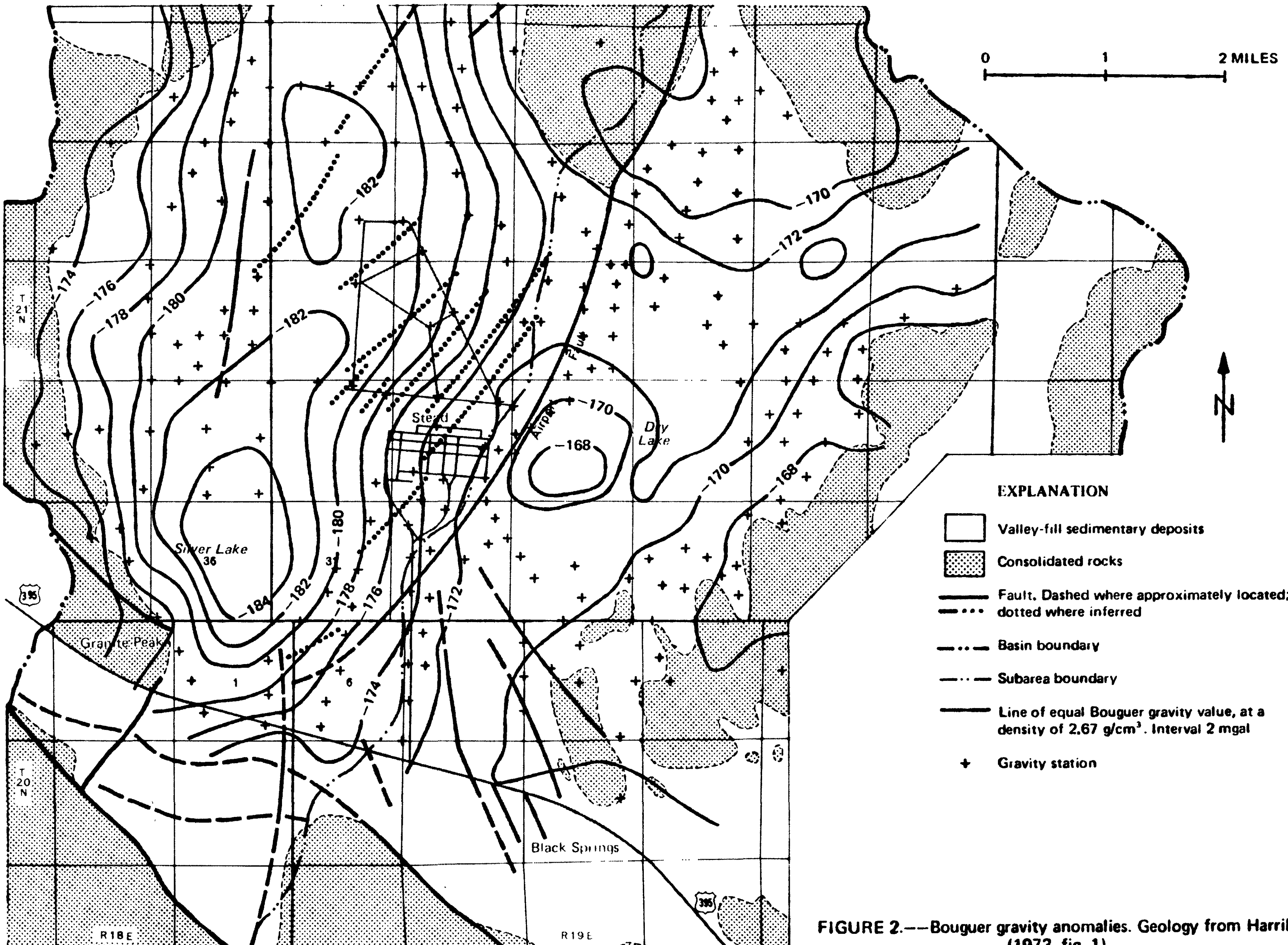

FIGURE 2.--Bouguer gravity anomalies. Geology from Harrill (1973, fig. 1).

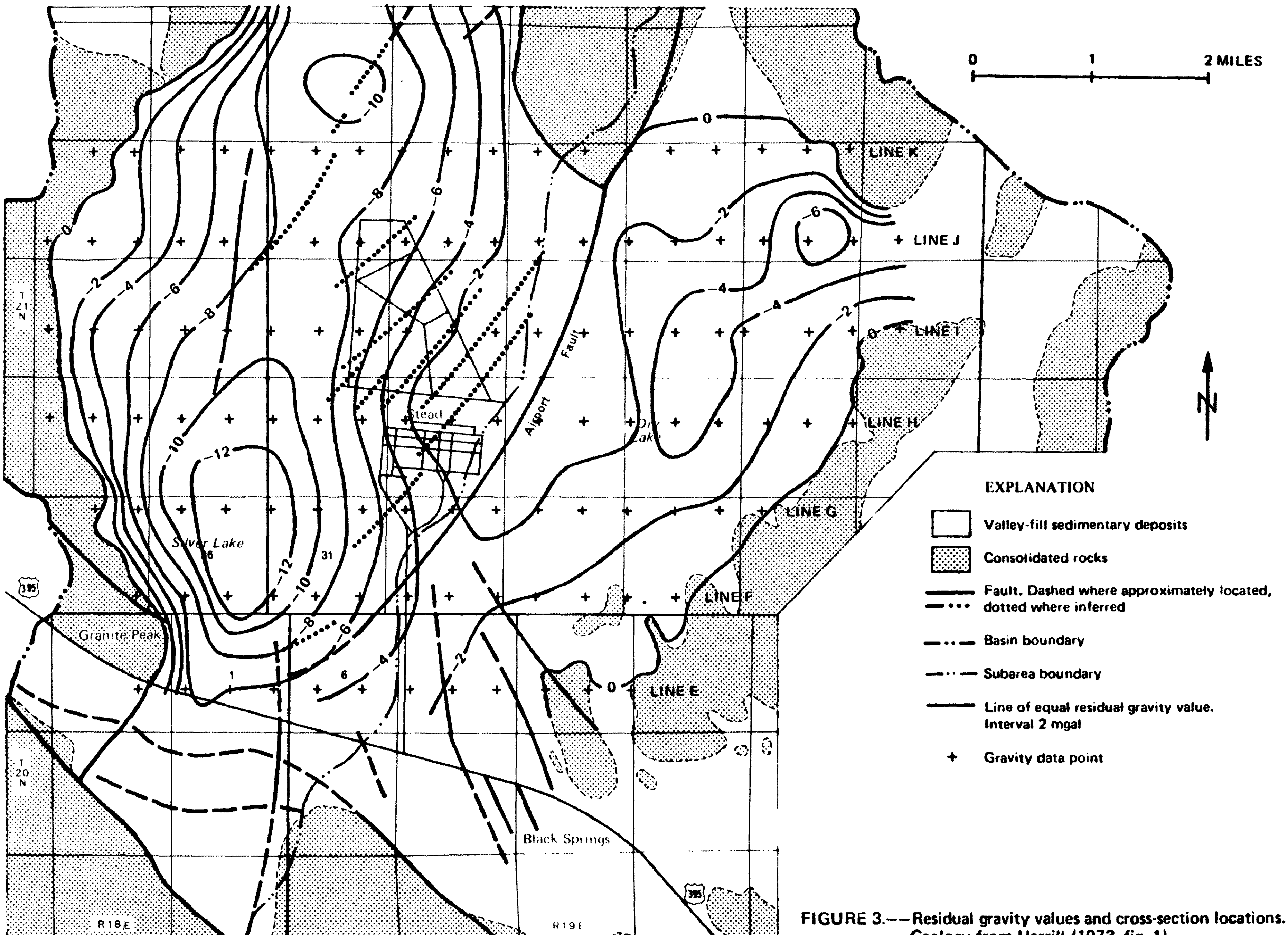

FIGURE 3.—Residual gravity values and cross-section locations. Geology from Harrill (1973, fig. 1).

Prominence of the Airport fault in the contours is somewhat diminished; however, the contours do tend to parallel the fault in places. Inferred faults associated with and northwest of the Airport fault appear to involve some downward movement of the consolidated rocks.

Thickness of the Alluvial Deposits

Computation of the thickness of unconsolidated deposits, or depth to bedrock, from the residual gravity values requires certain assumptions to be made at this point. The most critical assumptions are the densities of the consolidated rocks and unconsolidated deposits. A density of 2.67 g/cm^3 was assumed for the consolidated rock, this being the most commonly used figure if no other density data are available (Zohdy and others, 1974, p. 98). A density of 2.0 g/cm^3 was used for the valley-fill material on the basis of work done by Gimlett (1967, p. 25) for a gravity survey of Warm Springs Valley to the northeast. This density assumption was tested and will be discussed in detail in the next section.

Data points for the residual map were synthesized into eight profiles across the valley floor from the western outcrop of bedrock to the eastern outcrop of bedrock. Locations of seven of these profiles are shown in figure 3. The eighth profile (not shown) is 1.5 mi north of line K. Residual-gravity values were then put into a vertical-prism-profile-inversion model, as developed by Crewdson (1976, p. 97), that divides the section into a series of two-dimensional polygons. The model begins with an initial estimate of depth, and, through a series of iterations, calculates a value of residual gravity and compares this with the observed residual. This is repeated until either the difference between the two gravity values is within a specified tolerance or the specified number of iterations is reached. The output from the model then yields an interpreted depth to bedrock along the profile.

Three representative profiles are shown in figures 4 through 6. The top graph in each figure shows the measured and model-generated residual-gravity profiles, and the bottom graph shows the computed bedrock-surface altitude.

Estimated depth-to-bedrock values from the inversion model were contoured as shown in figure 7. This map also indicates the difference, in feet, between several points at which bedrock was penetrated in a well and the model-generated depth.

Maximum depth to bedrock in west Lemmon Valley is interpreted to be about 2,600 ft below land surface. The shallower depression to the north has an indicated maximum depth of about 1,500 ft below land surface. Depth to bedrock in eastern Lemmon Valley attains an estimated maximum of about 1,000 ft below land surface, but it is generally less than 400 ft below land surface.

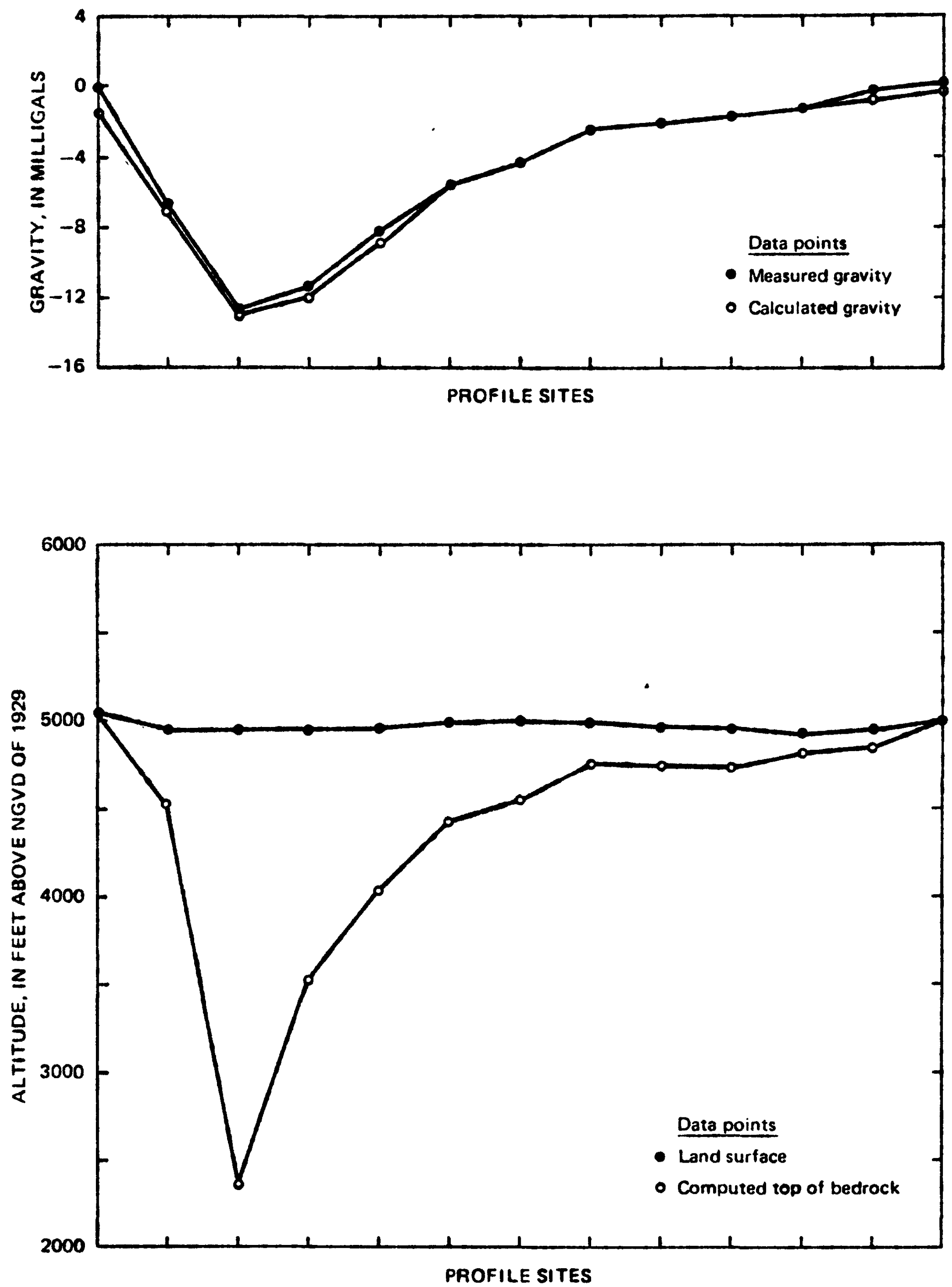

FIGURE 4.—–Profiles of gravity and bedrock-surface altitude, Line F (fig. 3).

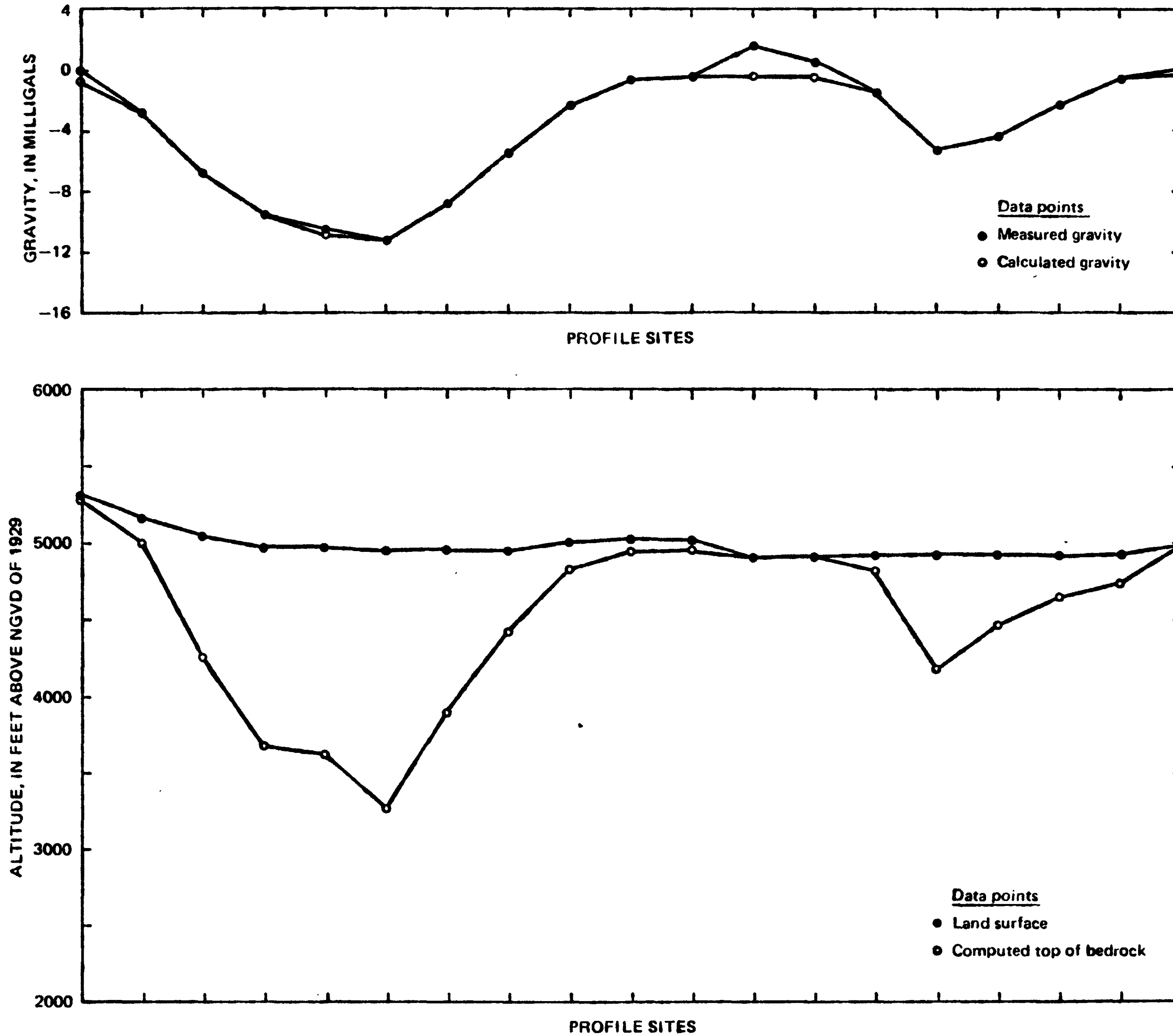

FIGURE 5.—Profiles of gravity and bedrock-surface altitude, Line H (fig. 3).

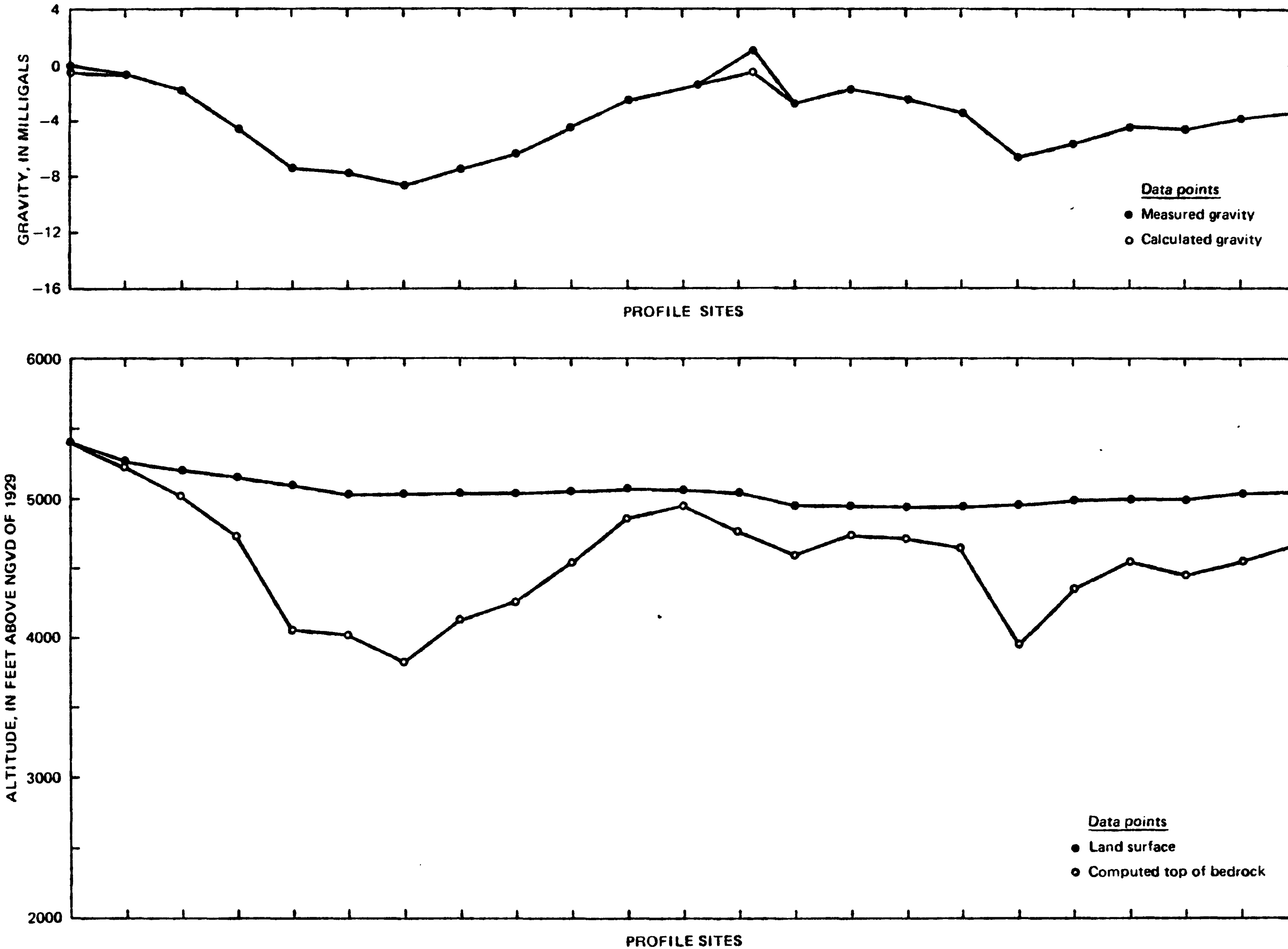

FIGURE 6.—Profiles of gravity and bedrock-surface altitude, Line J (fig. 3).

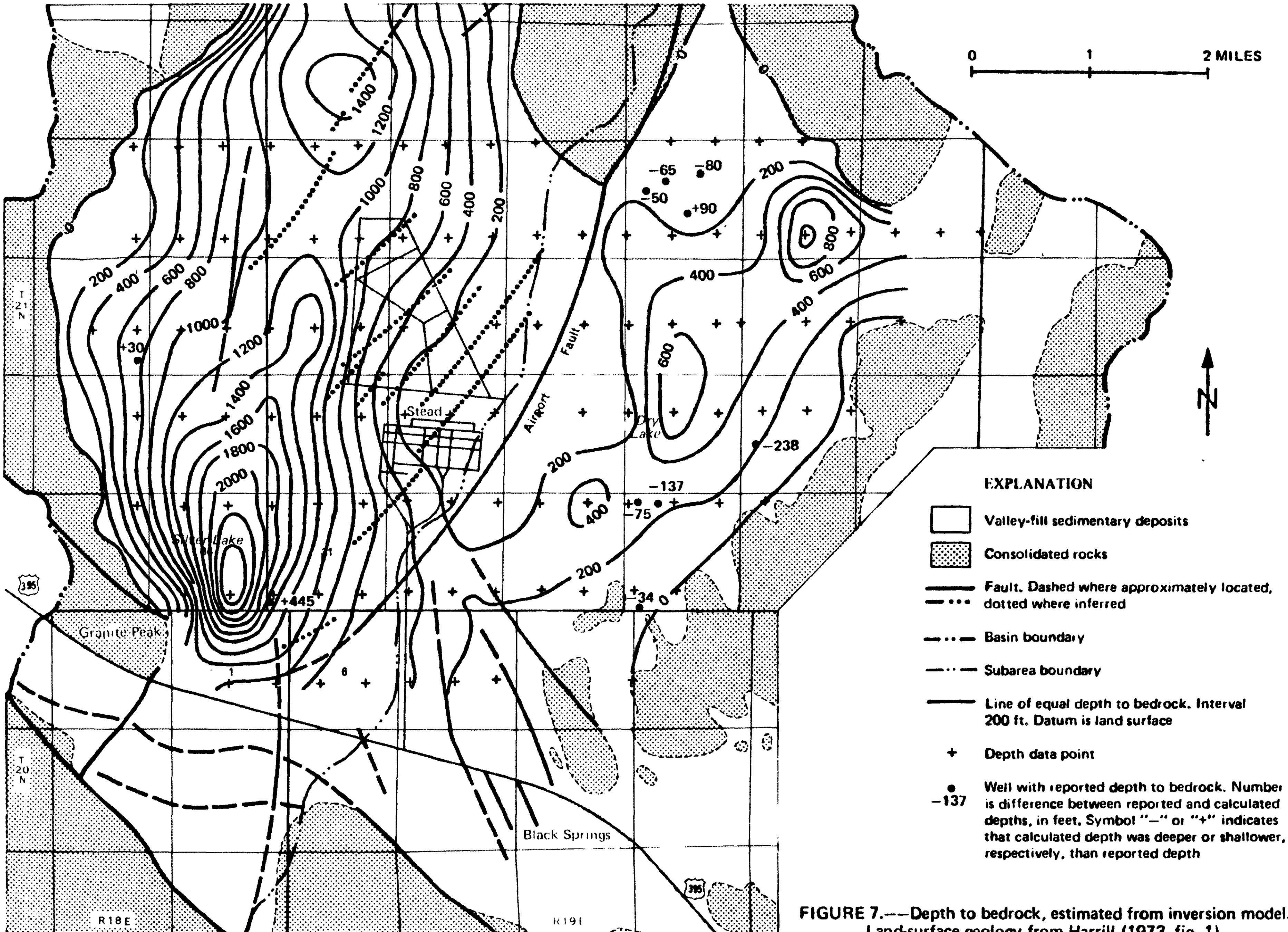

FIGURE 7.—Depth to bedrock, estimated from inversion model. Land-surface geology from Harrill (1973, fig. 1).

Errors in Measurements and Interpretations

In any geophysical technique, errors in measurements and assumptions may make the final interpretation somewhat less exact than desired. Inaccuracies in equipment and techniques are sometimes unavoidable but still enter into the overall error of the interpretation.

A few of the gravity stations were reoccupied for a second reading to obtain a measurement of repeatability for the gravity values. Of the repeat stations, 33 percent were within 0.05 mgal of the original reading, 67 percent were within 0.10 mgal, 83 percent were within 0.15 mgal, and 100 percent were within 0.20 mgal.

The locations of all the stations (plotted on topographic maps with a scale of 1:24,000) are assumed to be accurate within a 100-ft error margin in latitude. This corresponds to a maximum error of 0.03 mgal (0.03 mgal difference per 100 ft change in latitude).

Altitudes for most of the gravity stations were site altitudes on the topographic map at road intersections, section corners, and bench marks. Assuming that the vertical control is no more than 1 ft in error at bench marks, the error in gravity would be 0.06 mgal. For some of the stations, however, the altitudes were interpolated from the topographic contours. The maximum error is probably no more than 5 ft, giving an error in gravity of 0.30 mgal (0.06 mgal error per foot).

If the worst possible case is assumed, in which altitude, latitude, and meter error are maximized, the Bouguer gravity could be in error by as much as 0.53 mgal.

One profile was tested against the model with this maximum error, and the depth results are compared to the depths used in this report. The test case showed that calculated depths along the profile differed by as much as 281 ft but averaged about 55 ft difference.

Another potentially major source of error is the assumed density contrast between bedrock and alluvium. To test the density assumptions, an analysis using the previously described computer program that calculates depth to bedrock for the gravity data was made over an assumed range of density values for the alluvial deposits of 1.90 to 2.30 g/cm^3. This analysis was to determine the range of errors possible with different densities. The analysis showed that the density contrast of 0.67 g/cm^3 resulted in the smallest computing error in the test and the best agreement between the observed and calculated gravities. The results showing the errors and maximum calculated depths computed for various density contrasts are listed below.

Density of valley fill (g/cm^3)	Density contrast (g/cm^3)	Maximum depth (ft)	Error from density variations in program
1.90	0.77	1,800	3.12
2.00	.67	2,600	2.75
2.10	.57	3,200	3.95
2.20	.47	4,300	6.08
2.30	.37	6,300	9.99

The error listed above is the square root of the sum of the squares of the difference between the measured and calculated gravities at each station along the section. An alluvial density of 2.00 g/cm^3 yields the smallest error, as well as yielding depths to bedrock that appear to be reasonable in comparison with known geologic data from well logs.

ELECTRICAL RESISTIVITY SURVEY

Discussion of Method

Electrical resistivity is a physical property of rocks and soils that can be determined by passing a specified current through a measured volume of subsurface materials and measuring the drop in potential between two electrodes. The governing equation states:

$$P = \frac{E}{j}$$

where P = resistivity in ohm-meters;
E = potential gradient in volts per meter;
j = current density in amperes per square meter.

Electrical resistivities of rocks display a wide range in values, depending upon the material, density, porosity, pore size, water content; water quality, and temperature. In relatively porous materials, the resistivity is controlled more by the interstitial water content and quality than by the resistivity of the rock materials. Therefore, the resistivity of the ground water is the governing factor in saturated materials. On the basis of this principle, a difference in resistivity among identical materials can be interpreted in terms of differences in quantity and quality of the ground water. Materials saturated with ground water of high dissolved-solids concentration generally have a lower resistivity (are more conductive) than the same materials saturated with fresher water.

Field Techniques

The Schlumberger sounding method was used in this study because of the many advantages of the method over other types of sounding methods (Zohdy and others, 1974, p. 16). The Schlumberger sounding technique involves two outer current electrodes (A and B) and two inner potential electrodes (M and N). At any given potential-electrode spacing ($\overline{MN}$), the current-electrode separation ($\overline{AB}$) is increased in increments while current and potential readings are taken. A more in-depth discussion of Schlumberger soundings is given by Zohdy and others (1974, p. 8).

Resistivity soundings were taken at 10 locations in Lemmon Valley (fig. 8). To determine the depth to fresh water below the areas of more saline water (Harrill, 1973, p. 47 and fig. 9), seven of the soundings were made on or near the playa areas. Three soundings, however, were made away from the playas in an attempt to determine depth to bedrock and thereby confirm the depths obtained from gravity surveys.

Reduction of Data and Model Interpretation

After the soundings were made and the apparent (field) resistivities calculated, (as described in Zohdy and others, 1974, p. 11), the apparent resistivities were plotted against the $\overline{AB}/2$ spacing (that is, one-half the current electrode spacing) on log-log paper. From this graph, the data curve may be smoothed as necessary, and points along the curve are digitized. These data points are then put into a model that approximates the thickness and depth of specific electric layers and their resistivities (Zohdy, 1973).

Figures 9-18 show the smoothed curves of the apparent (field) resistivity values plotted against electrode spacing, and the layer thicknesses and resistivities generated by the model at 10 Vertical Electrical Sounding (VES) stations.

For the purposes of this study, an arbitrary value for the resistivity of the material saturated with poor-quality water was considered to be 20 ohm-m or less, but no water-quality control exists to confirm this assumption. A previous investigation (Zohdy and others, 1974) has used 10 ohm-m as a boundary for poor-quality water. Using techniques discussed by Brown (1971, p. 25), material with a resistivity of 20 ohm-m and an assumed porosity of 35 percent yields interstitial water with a specific conductance of about 3,000 micromhos. That technique involves bore-hole resistivity which, under normal conditions, is not applicable to surface resistivity, but the figures nonetheless give a general indication of relatively poor water quality. Using the approximation that the dissolved-solids concentration, in milligrams per liter, is about two-thirds of the specific conductance, the 20-ohm-m resistivity may represent a dissolved-solids concentration on the order of 2,000 mg/L.

It should be noted that the resistivity data do not provide an indication of actual quality (i.e., dissolved-solids concentration), and hence, the terms "poor quality" and "better quality" are relative.

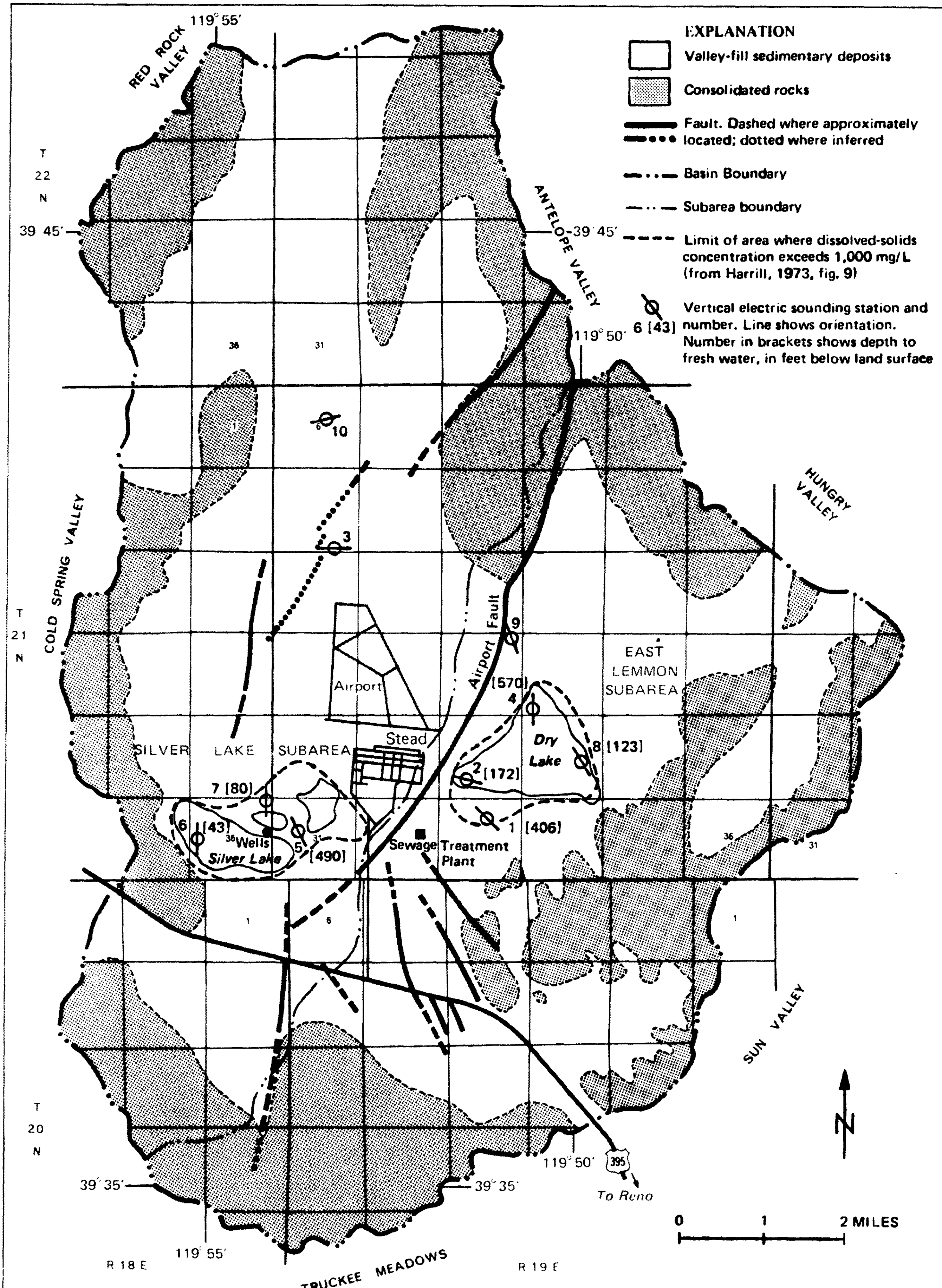

FIGURE 8.—Location of vertical electric sounding stations and areal extent of poor-quality ground water. Geology from Harrill (1973, fig. 1).

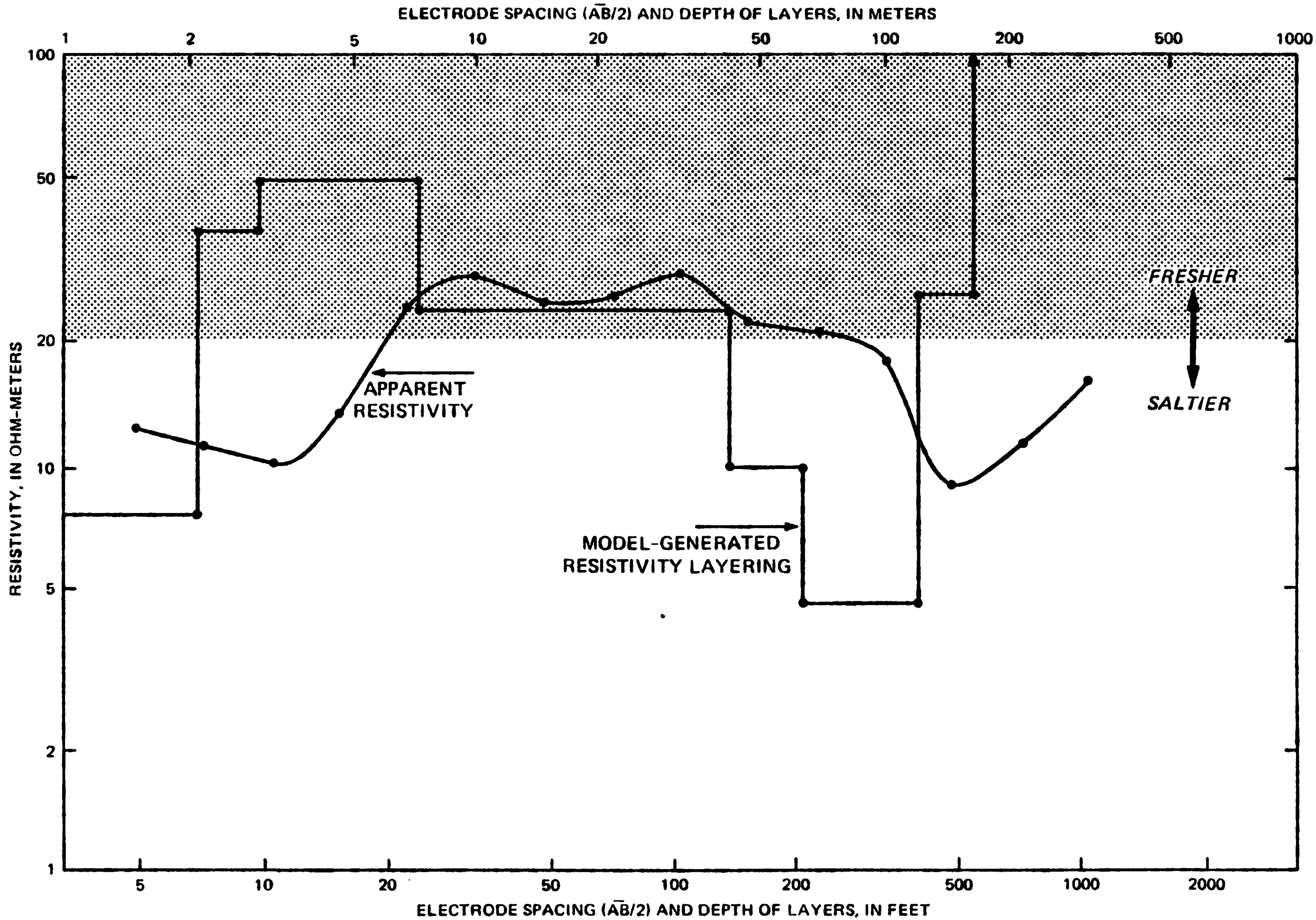

FIGURE 9.—Resistivity field curve and model layering for VES station 1 (fig. 8).

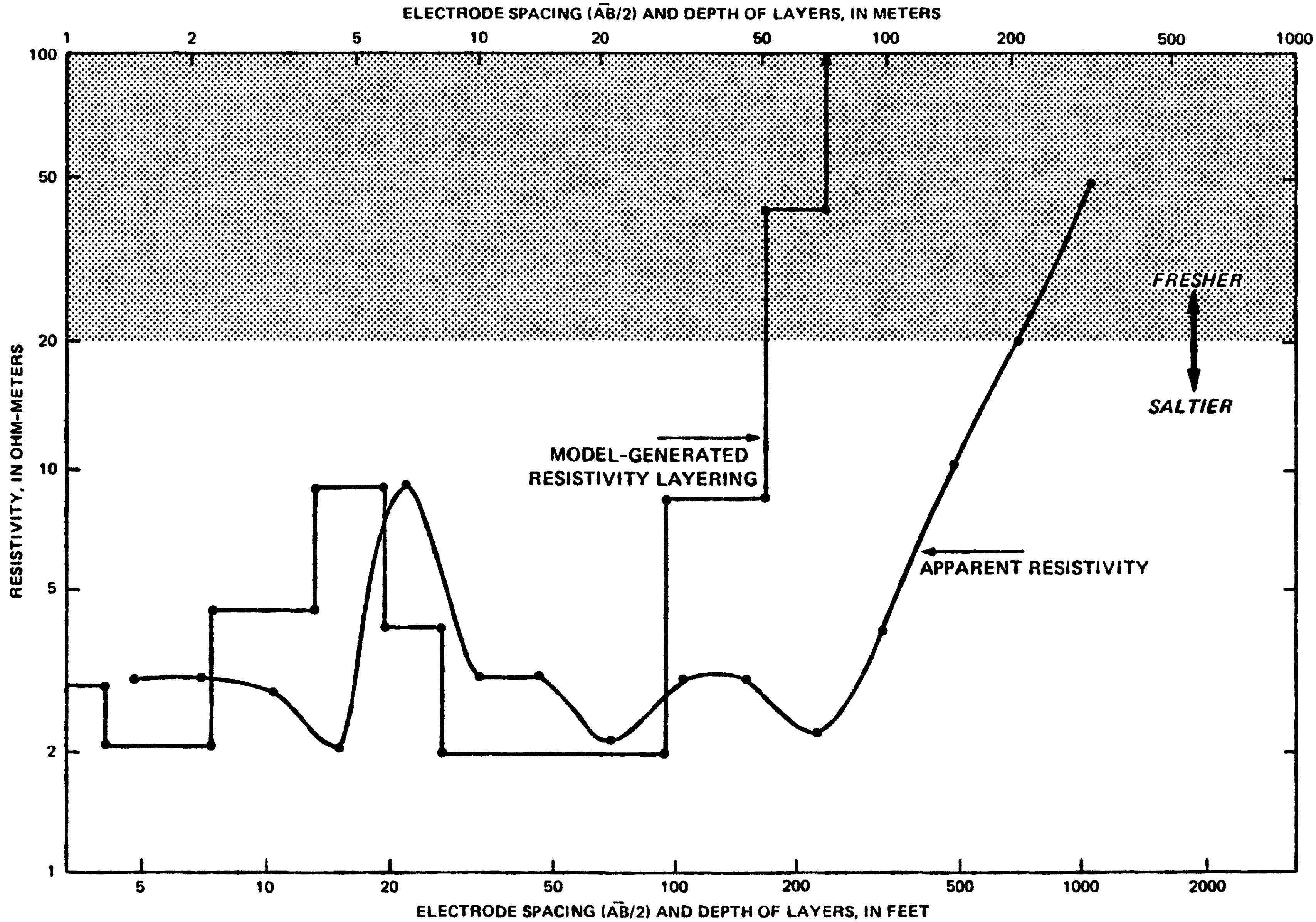

FIGURE 10.---Resistivity field curve and model layering for VES station 2 (fig. 8).

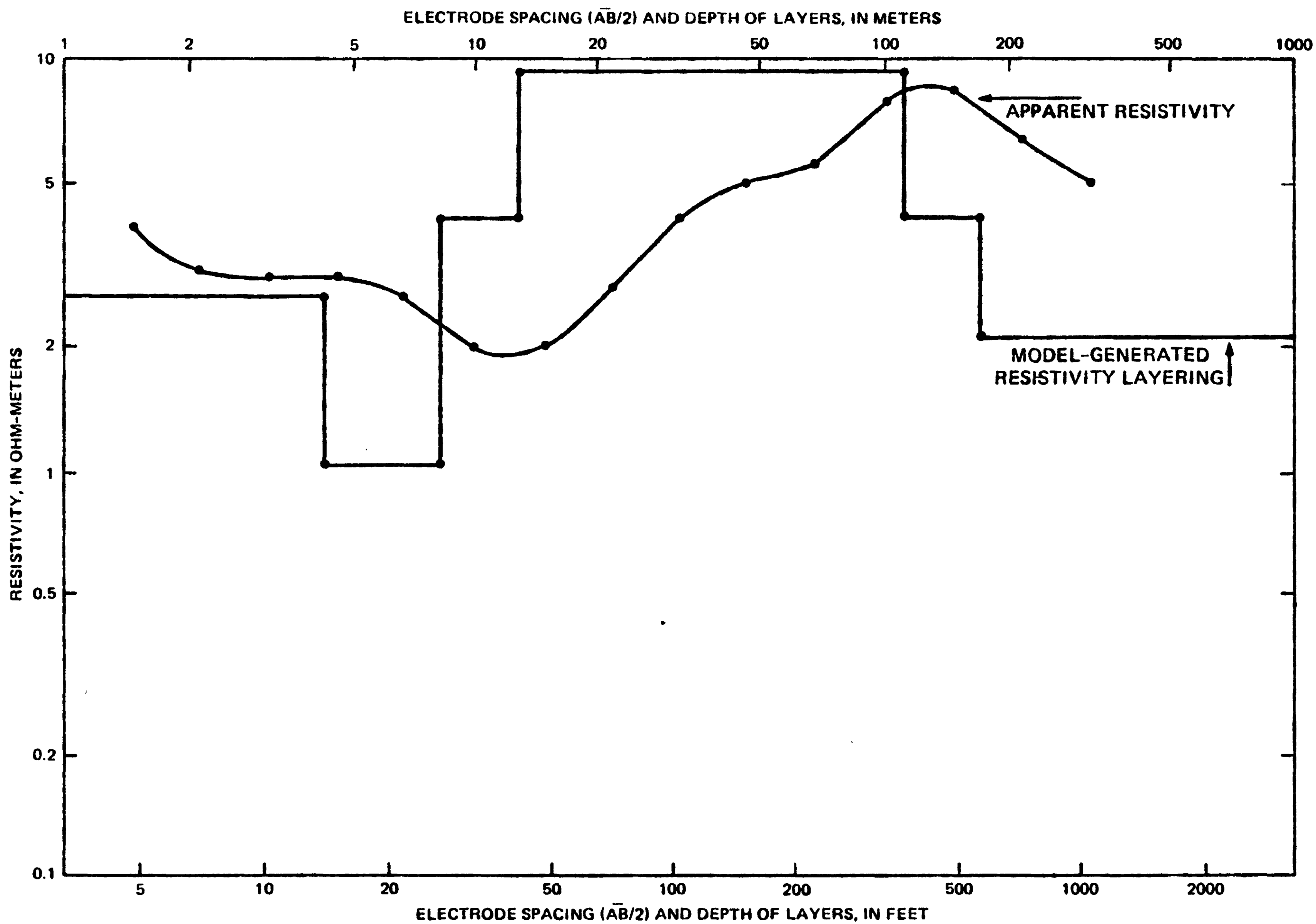

FIGURE 11.—Resistivity field curve and model layering for VES station 4 (fig. 8).

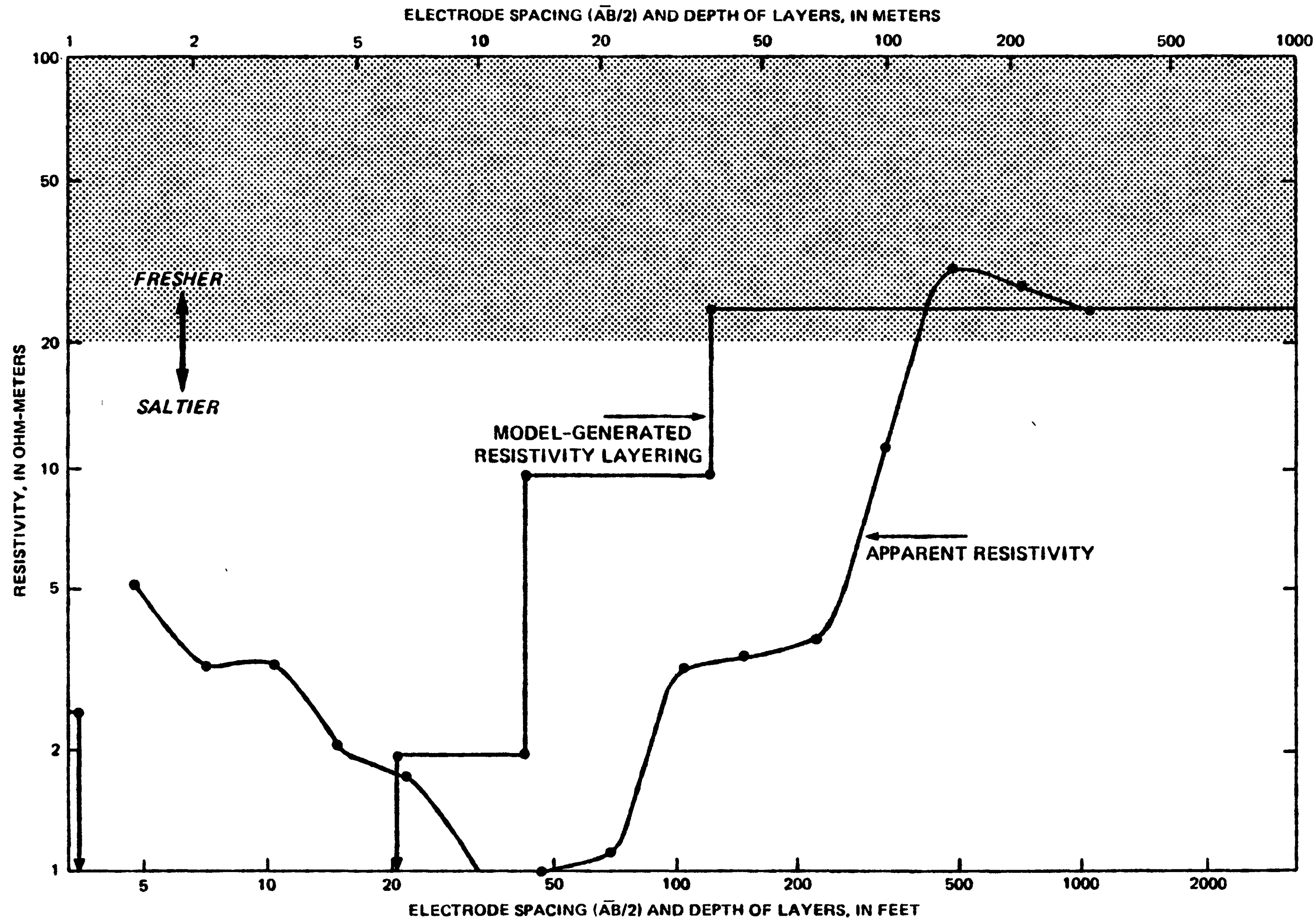

FIGURE 12.——Resistivity field curve and model layering for VES station 8 (fig. 8).

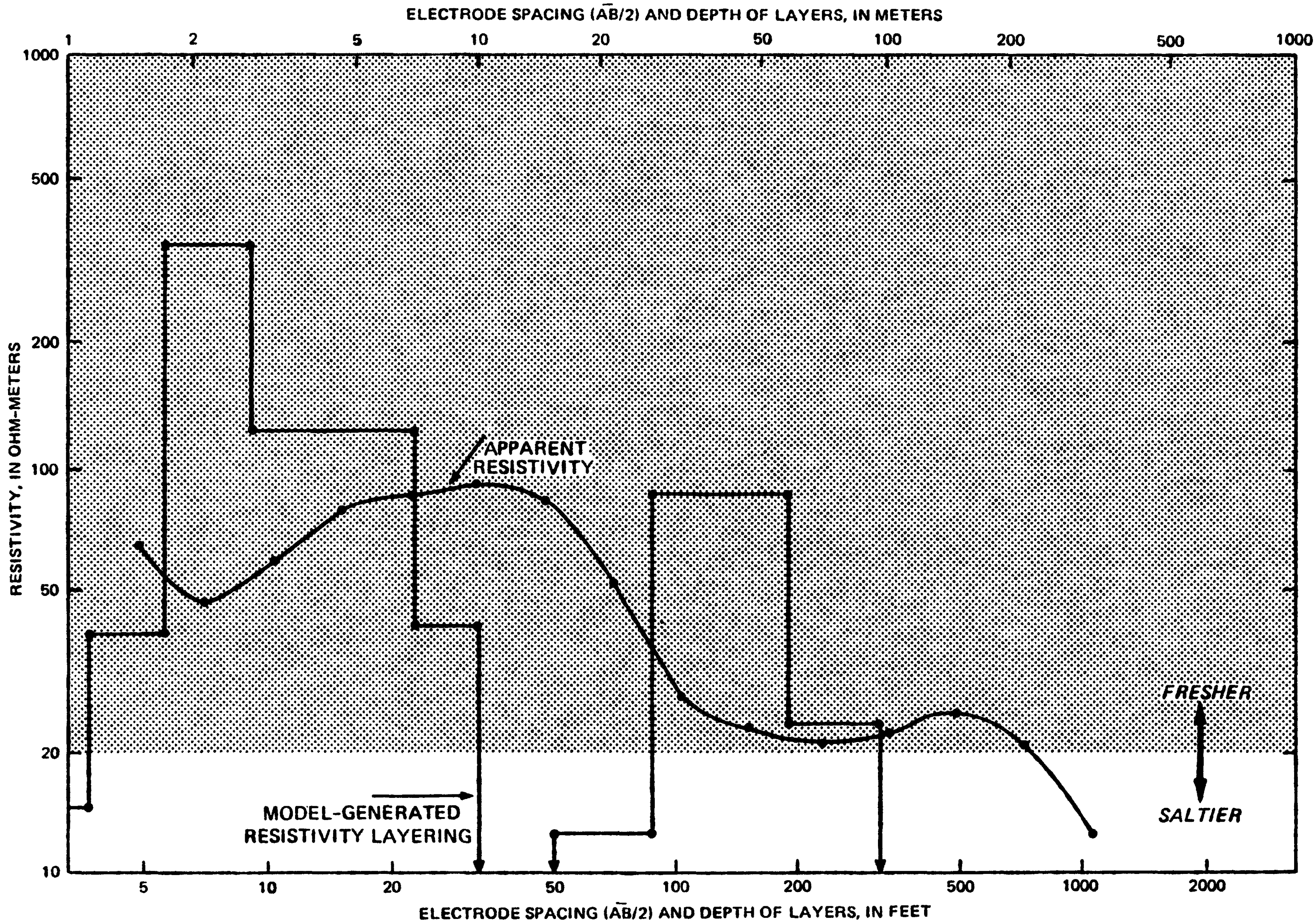

FIGURE 13.––Resistivity field curve and model layering for VES station 9 (fig. 8).

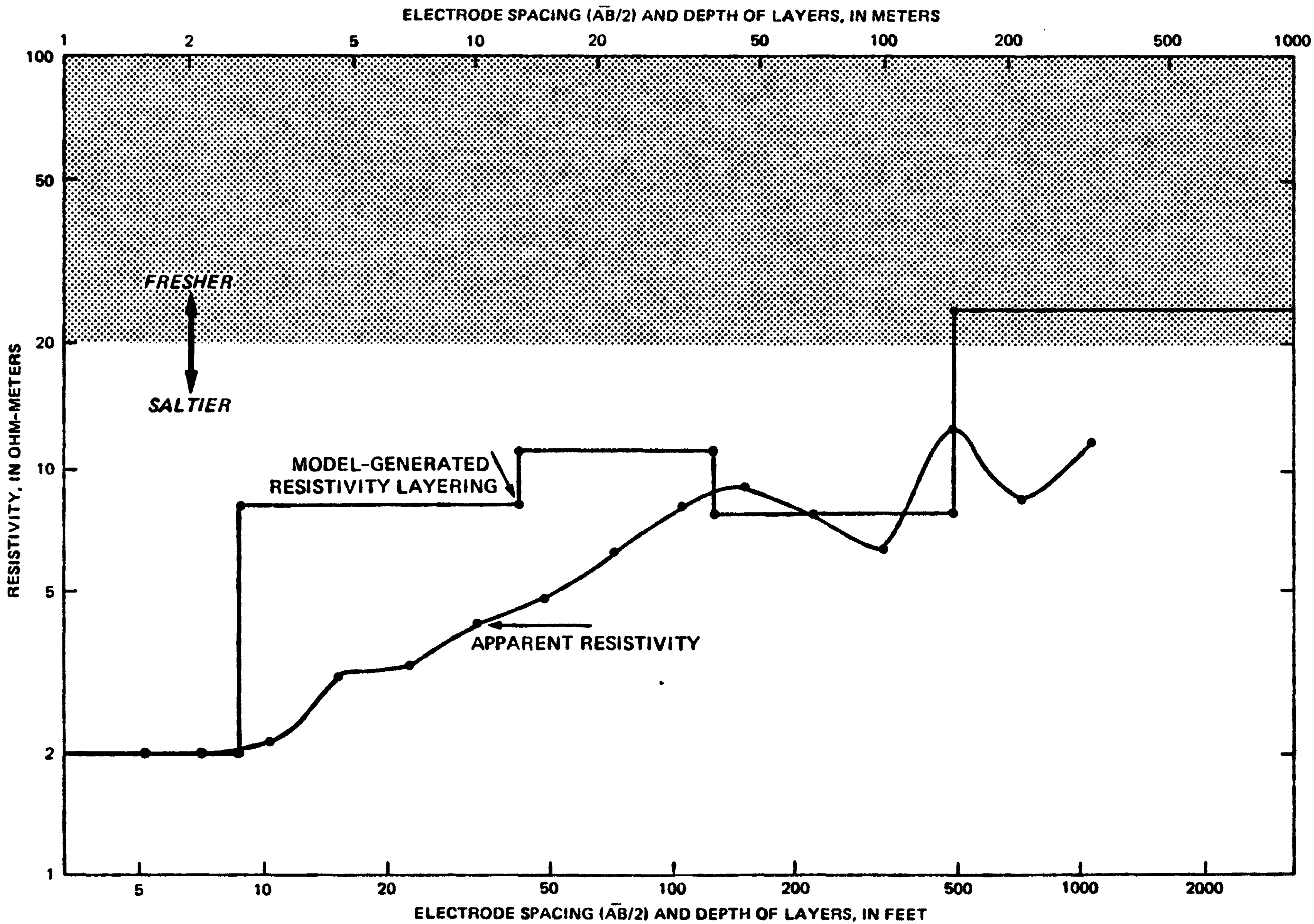

FIGURE 14.––Resistivity field curve and model layering for VES station 5 (fig. 8).

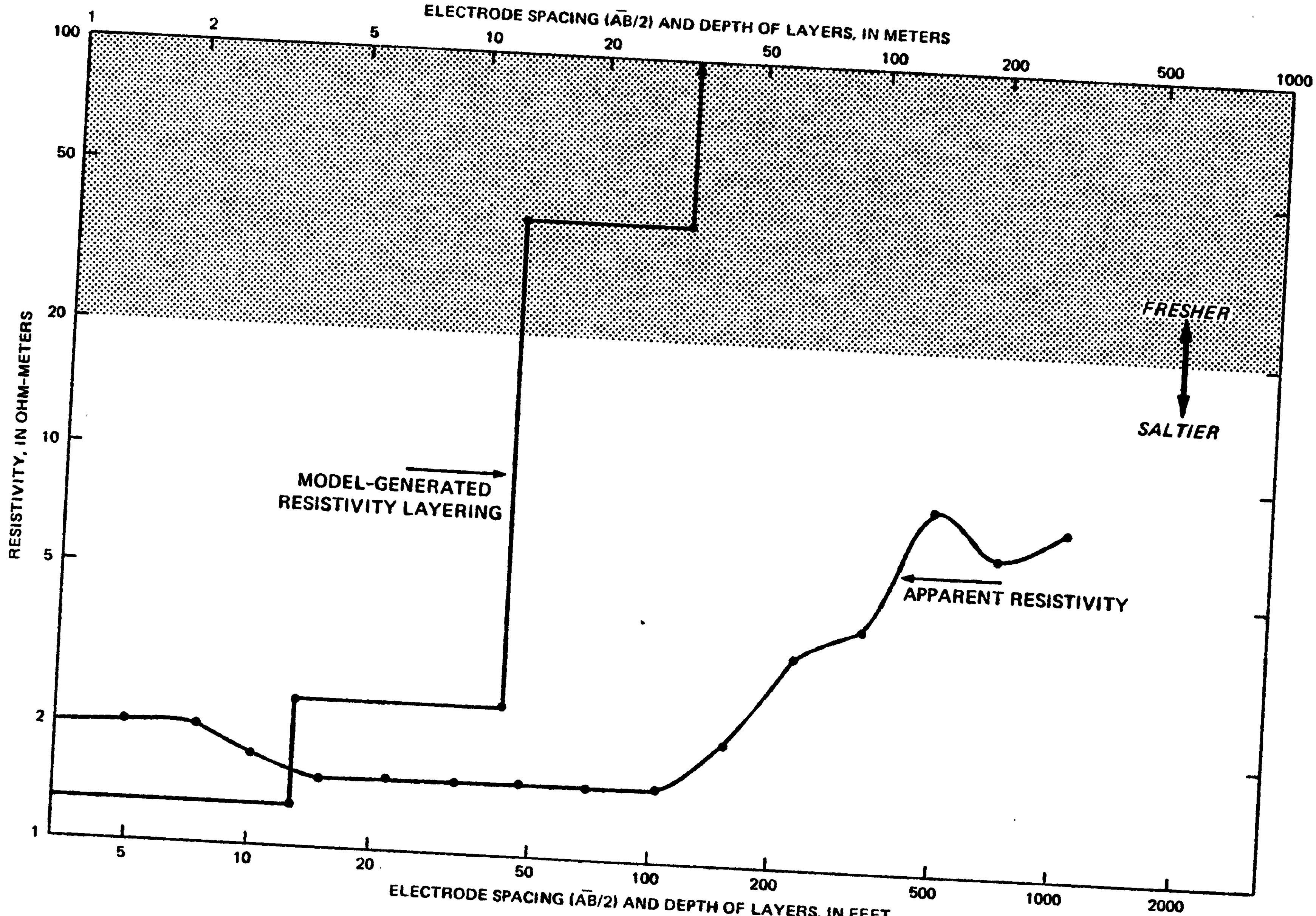

FIGURE 15.—Resistivity field curve and model layering for VES station 6 (fig. 8).

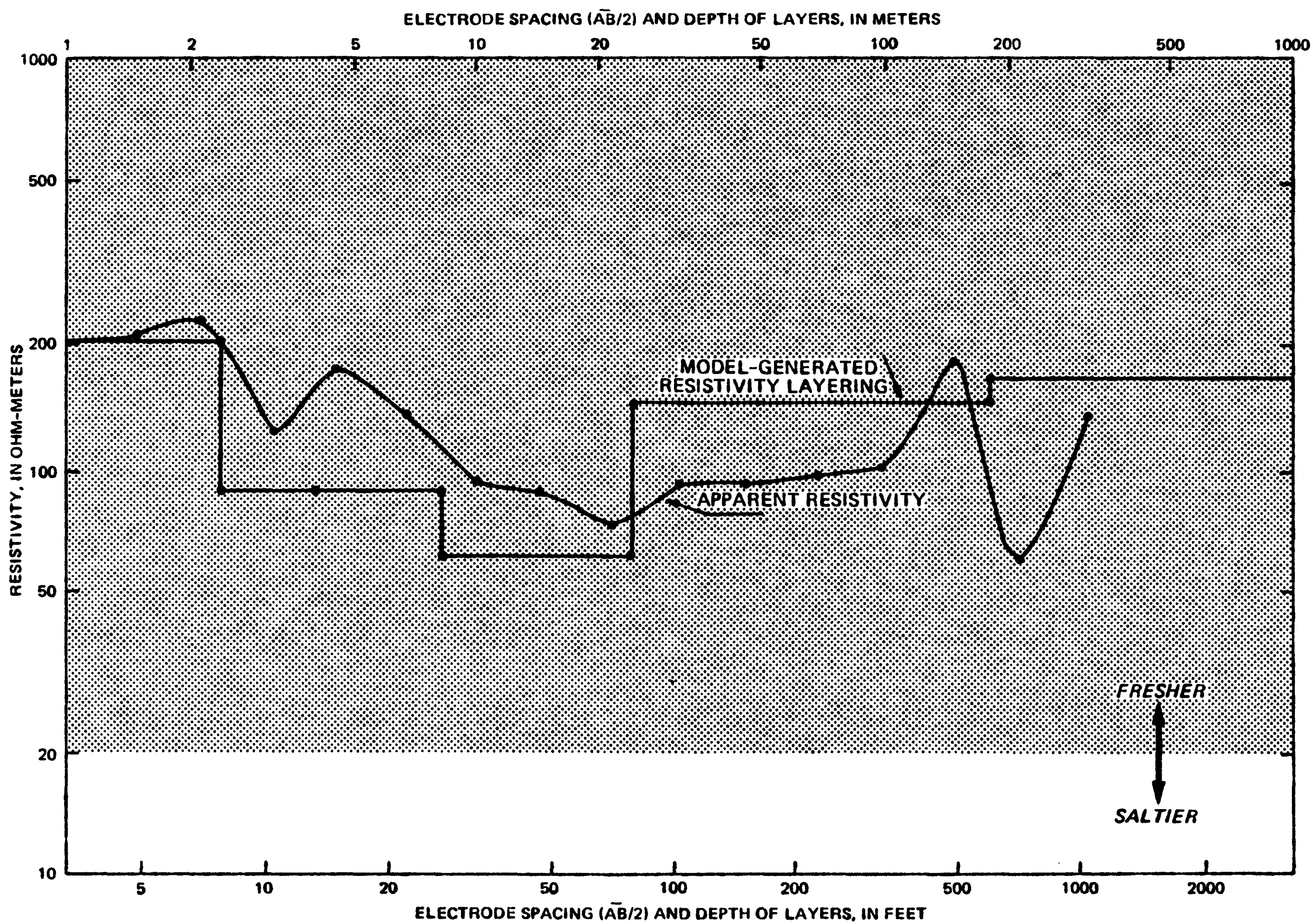

FIGURE 16.——Resistivity field curve and model layering for VES station 7 (fig. 8).

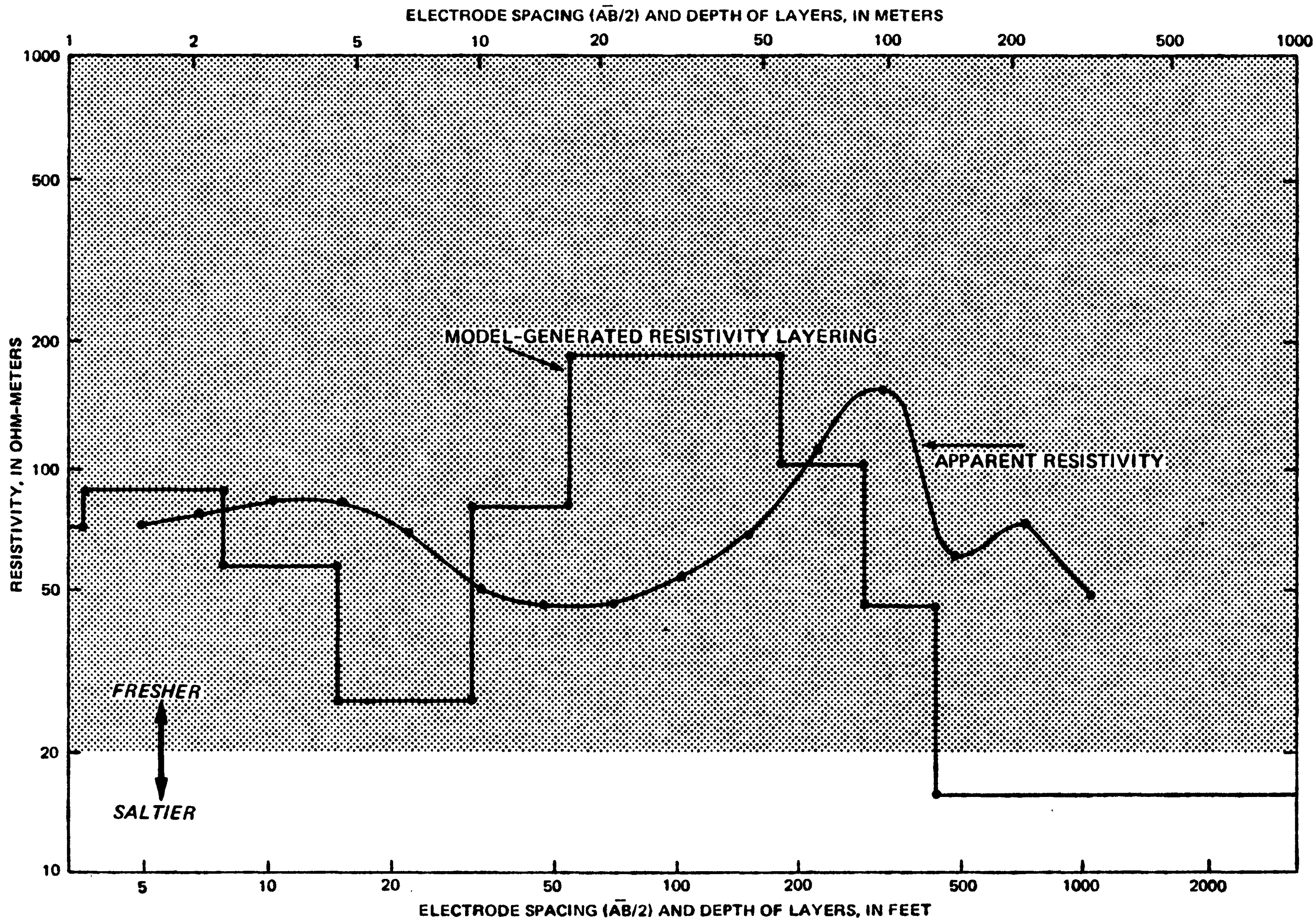

FIGURE 17.—Resistivity field curve and model layering for VES station 3 (fig. 8).

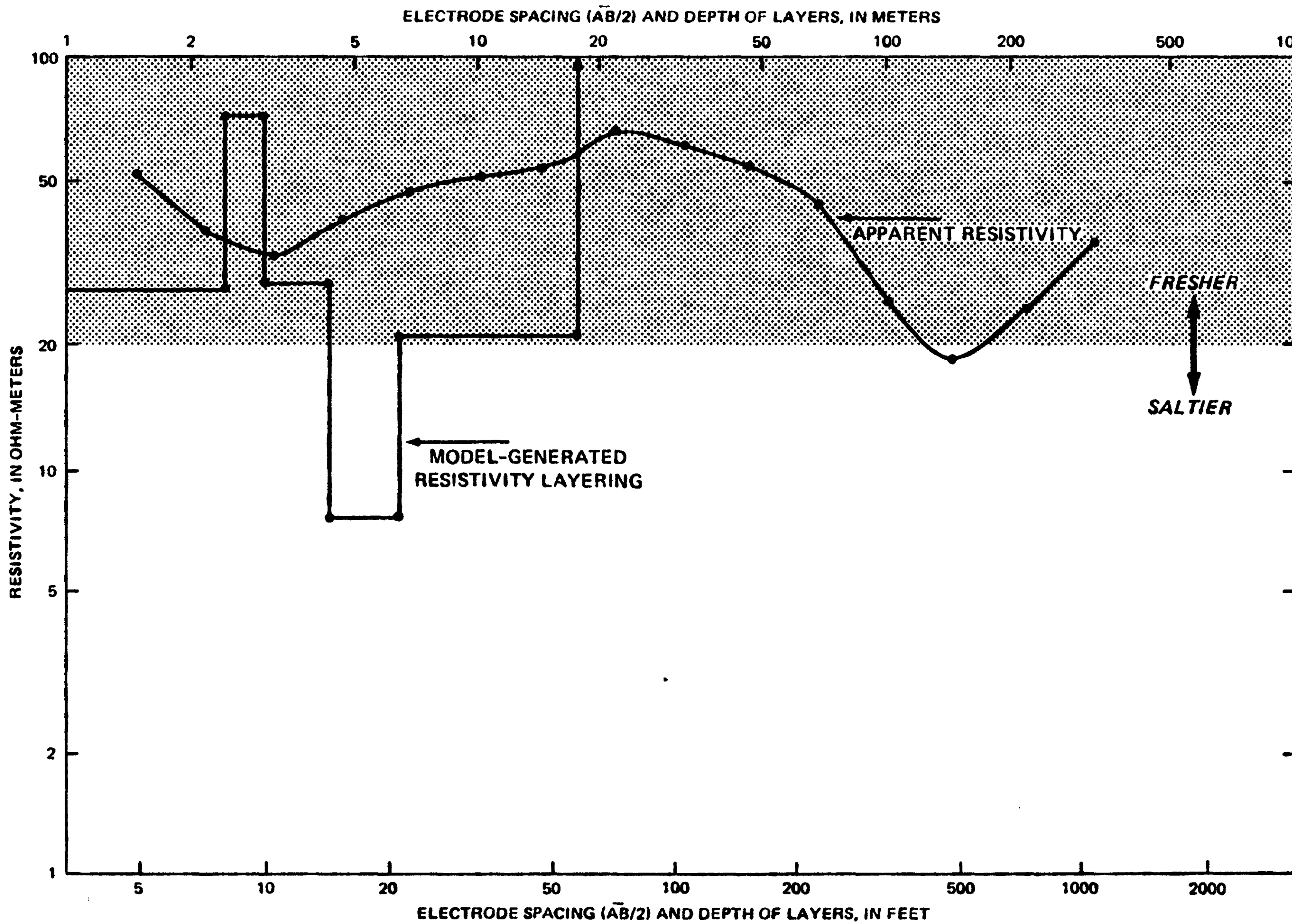

FIGURE 18.—Resistivity field curve and model layering for VES station 10 (fig. 8).

Depths to Fresh Water

Of the five soundings made in eastern Lemmon Valley, four (VES 1, 2, 4, and 8) were on or near the dry lake east of Stead (fig. 8), and VES 9 was taken north of the dry lake. At all four playa stations, a layer of low resistivity (less than 20 ohm-m) was encountered and could be interpreted as being caused by the poor-quality water underlying the playa. Resistivities of subsurface materials similar to the sand and clay found in Lemmon Valley, but saturated with fresh water, should be two to three times higher than 20 ohm-m.

At VES 1 (fig. 9), the resistivity is less than 20 ohm-m in the depth intervals from land surface to about 7 ft and from 140 to 400 ft, and it is greater than 20 ohm-m from 7 to 140 ft and from 400 to 560 ft. One possible interpretation of this situation is a 7 ft layer of relatively poor-quality water overlying about 130 ft of better water, which in turn is underlain by poorer water to 400 ft and better water below. The shallowest layer of poor-quality water might be saturated with discharge from the sewage treatment plant 1 mile to the west (fig. 8). The somewhat better water to about 140 ft might reflect the "flushing" action of ground-water recharge entering the system from mountain areas to the east. The poorer water from about 140 to 400 ft might represent the effects of playa-surface evapotranspiration in the geologic past.

VES 2, 4, and 8 (fig. 10, 11, 12) show layers of low resistivity (less than 20 ohm-m) from land surface to depths of 170, 570, and 120 ft, respectively. The somewhat shallower depth of high resistivity at VES 8 (120 ft) might again be due to recharge from the east. VES 2, 4, and 8 did not exhibit the same electrical stratification of VES 1.

VES 9 (fig. 13), north of the dry lake, showed the following stratification: Resistivities greater than 20 ohm-m from 0 to 30 ft and from 90 to 320 ft and less than 20 ohm-m from 30 to 90 ft and from 320 to 440 ft. The reason for the sequence at this station is not known. Harrill (1973, fig. 9) did not find poor-quality water this far north of the playa. Furthermore, according to gravity data, bedrock should have been encountered at less than 200 ft; however, no high-resistivity layer, as is characteristic for bedrock, was encountered at this station.

Three electrical soundings (VES 5, 6, and 7) were conducted on or near Silver Lake playa in western Lemmon Valley (fig. 8). Two other soundings (VES 3 and 10) were taken several miles north of the playa.

VES 5 (fig. 14) indicated low resistivity (less than 20 ohm-m) to a depth of about 480 ft. VES 6 (fig. 15) indicated low resistivity down to 40 ft, with an increase of resistivity to 110 ft. VES 7 (fig. 6) showed an interval of material with a resistivity greater than 200 ohm-m down to 8 ft, then an interval of less than 100 ohm-m to 80 ft, and finally an interval of greater than 100 ohm-m to about 610 ft. The data at VES 7 correlate reasonably well with a situation mentioned in Harrill (1973, p. 47). Water from two wells drilled within 10 ft of each other to different depths on Silver Lake playa (fig. 8) showed a higher concentration of dissolved solids at 13.5 ft than at 150 ft. VES 7, about half a mile north of the two wells, may have detected this change, with the increase in resistivity corresponding to a decrease in dissolved solids at about 80 ft.

VES 3 and 10, north of Silver Lake playa, did not exhibit any unique features; bedrock was not encountered in either sounding. The maximum depths of current penetration in VES 3 and 10 (fig. 17 and 18) were about 440 and 590 ft, respectively. Gravity data that indicate bedrock was about 1,000 ft deep at these points.

In summary, the soundings show that a low-resistivity (less than 20 ohm-m) layer underlies the two playas in Lemmon Valley, but that higher resistivities characteristically are found at depth. The low-resistivity layer can be interpreted as poor-quality water.

The soundings show that relatively better water underlies the dry lake in eastern Lemmon Valley at depths less than 200 ft on the eastern and western margins, but it may be as deep as 600 ft below land surface in the northern and southern extremes of the dry lake.

The resistivity data suggest that the poor-quality water beneath the playa may be influenced by recharge from the mountains as well as by effluent from the sewage-treatment plant.

The resistivity soundings in the Silver Lake area show that the better water is considerably shallower in places, with depths of 40 and 80 ft on the west and north side, respectively. On the east side of the playa, the better water begins at 490 ft.

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