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Electrical Studies at the Proposed Wahmonie and Calico Hills Nuclear Waste Sites, Nevada Test Site, Nye Co., Nevada

Open-File Report 82-466

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Prepared by the U.S. Geological Survey

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Nevada Operations Office
U.S. Department of Energy
(Interagency Agreement DE-AI08-78 ET 44802)

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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Nuclear Waste Sites, Nevada Test Site, Nye Co., Nevada

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Abstract

Two sites in the southwest quadrant of the Nevada Test Site (NTS) were investigated as potential repositories for high-level nuclear waste. These are designated the Wahmonie and Calico Hills sites. The emplacement medium at both sites was to be an inferred intrusive body at shallow depth; the inference of the presence of the body was based on aeromagnetic and regional gravity data. This report summarizes results of Schlumberger VES, induced polarization dipole-dipole traverses and magnetotelluric soundings made in the vicinity of the sites in order to characterize the geoelectric section.

At the Wahmonie site VES work identified a low resistivity unit at depth surrounding the inferred intrusive body. The low resistivity unit is believed to be either the argillite (Mississippian Eleana Formation) or a thick unit of altered volcanic rock (Tertiary). Good electrical contrast is provided between the low resistivity unit and a large volume of intermediate resistivity rock correlative with the aeromagnetic and gravity data. The intermediate resistivity unit (100-200 ohm-m) is believed to be the intrusive body. The resistivity values are very low for a fresh, tight intrusive and suggest significant fracturing, alteration and possible mineralization have occurred within the upper kilometer of rock. Induced polarization data supports the VES work, identifies a major fault on the northwest side of the inferred intrusive and significant potential for disseminated mineralization within the body. The mineralization potential is particularly significant because as late as 1928, a strike of high grade silver-gold ore was made at the site.

The shallow electrical data at Calico Hills revealed no large volume high resistivity body that could be associated with a tight intrusive mass in the upper kilometer of section. A drill hole UE 25A-3 sunk to 762 m (2500 ft) at the site revealed only units of the Eleana argillite thermally metamorphosed below 396 m (1300 ft) and in part highly magnetic. Subsequent work has shown that much if not all of the magnetic and gravity anomalies can be attributed to the Eleana Formation. The alteration and doming, however, still argue for an intrusive but at greater depth than originally thought. The electrical, VES, and IP data show a complex picture due to variations in structure and alteration within the Eleana and surrounding volcanic units. These data do not suggest the presence of an intrusive in the upper kilometer of section. The magnetotelluric data however gives clear evidence for a thick, resistive body in the earth's crust below the site. While the interpreted depth is very poorly constrained due to noise and structural problems, the top of the resistive body is on the order of 2.5 km deep. The IP data also identifies area of increased polarizability at Calico Hills, which may also have future economic mineralization.

Introduction

The U.S. Geological Survey (USGS) working under a memorandum of understanding with the Department of Energy (memorandum EW-78-A-08-1543), is engaged in a broad program to assess and identify potential repositories for high-level nuclear waste on the Nevada Test Site (NTS fig. 1). The USGS program consists of integrated geologic, hydrologic, and geophysical studies of regional and site-specific scope. This report discusses the results of electrical studies from Schlumberger vertical electrical soundings (VES), dipole-dipole induced polarization (IP), and magnetotelluric soundings (MT) at the Calico Hills and Wahmonie sites. The aim of this work is to characterize the geoelectrical section at and immediately adjacent to the sites.

The two sites are in the southwest quadrant of NTS adjacent to Jackass Flats (fig. 1). The two sites were originally selected based on previous geologic, aeromagnetic, and regional gravity data suggesting that a shallow intrusive was present at each site. The aeromagnetic data was particularly convincing because of similarity in signature with known granitic intrusions elsewhere in the region. The sought-for repository medium at these two sites was the inferred intrusive. At Calico Hills, Paleozoic argillite of the Eleana Formation also was present at the surface. Secondary consideration was given to the argillite as a potential repository medium should a sufficiently large and homogeneous body be identified.

Site-specific characterization work started in the fall of 1978 with emphasis on the Calico Hills site because it was thought to have the larger intrusive body. At the same time as the geological and geophysial studies were undertaken, a 2500 ft exploratory drill hole UE25a-3 was drilled at Calico Hills (Maldonado and others, 1979).

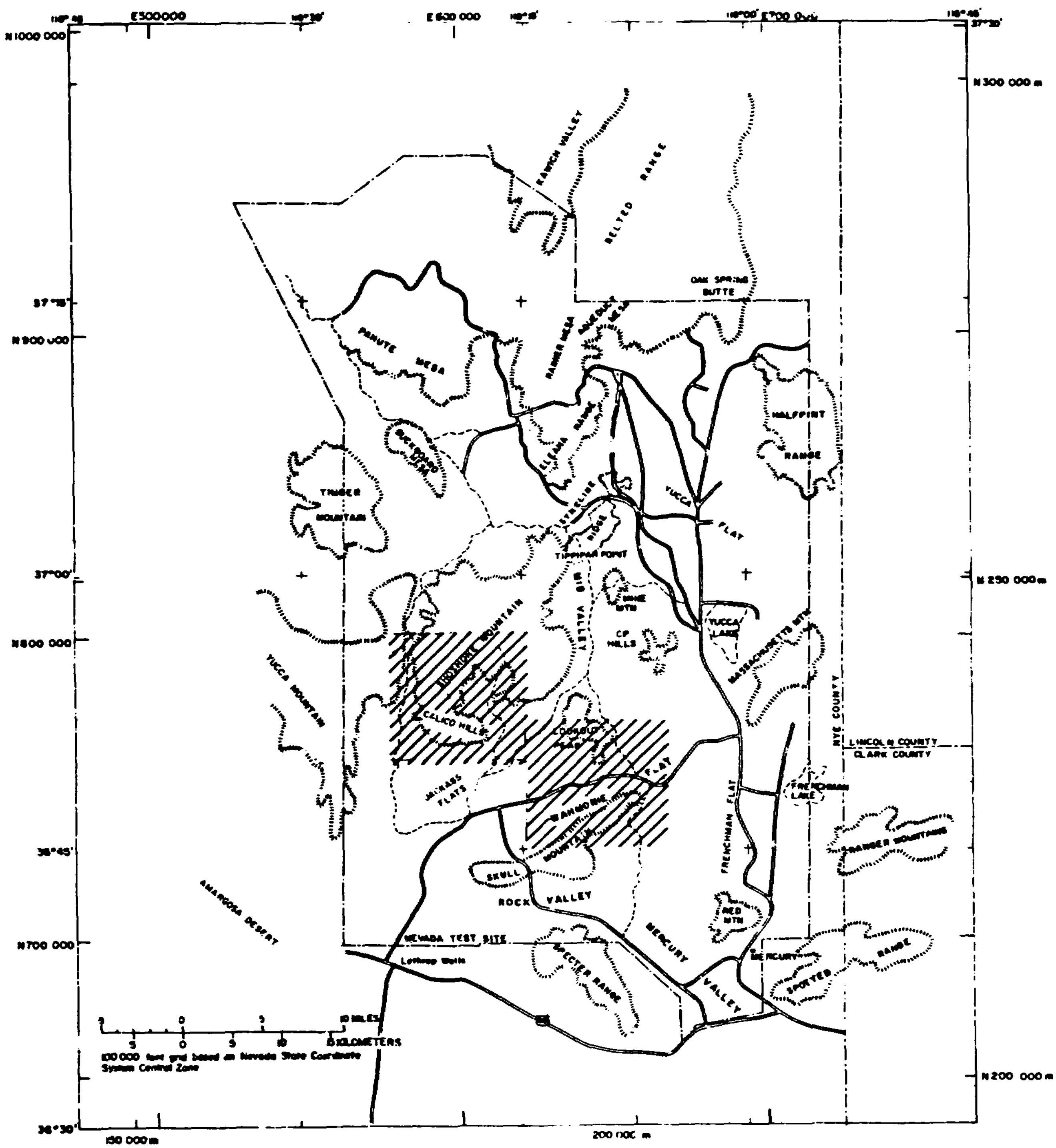

Figure 1. Index map of the Nevada Test Site showing the location of Calico Hills and Wahmonie Flat

Generalized repository criteria used in this program were the identification of a large homogeneous rock mass having low permeability in the depth range of 300 to 1500 m (1000 to 5000 ft). The areal extent is to be two square miles or more. The repository volume is to be relatively simple geologically so that it can be readily characterized. The geological conditions at the site should be such that potentially adverse conditions, high seismicity, uplift, faulting, fracturing, and so forth will not be present or can be demonstrated to not adversely affect the repository performance. Additional criteria may be found in the Nuclear Regulatory Commission Technical Criteria 10CFR Part 60 (1980).

Acknowledgments

We wish to express our sincere appreciation to the many people at the NTS who helped resolve the various problems that arose in the daily operations of our contractors-particularly the staffs of the DOE security and communications divisions and of the USGS core library at Mercury. Our appreciation also goes to the various geologists of Fenix and Scisson, Inc.[1] of Mercury, Nevada, who assisted Mr. M. P. Chornack in providing background information, guidance and monitoring of the contract operations. We also express our thanks to Mr. Charles Stearns who ran many of the VES inversions.

Electrical Methods Used

This report discusses results from Schlumberger VES, induced polarization IP, and magnetotelluric MT surveys. Other electrical methods were tried at Calico Hills on an experimental basis but will be reported on separately. Field data acquisition was contracted to private concerns for all three electrical methods (VES, IP, and MT). The VES field data was provided by Phoenix Geophysics Inc. of Denver, Colo. The IP field data provided by Heinrichs Geoexploration of Tucson, Arizona, were lines TR1, TR2, and CH1 on

Calico Hills, the remaining IP data were provided by Phoenix Geophysics, Inc., of Denver, Colo. The MT field data, data processing and one-dimensional inversion were provided by Williston McNeil, Inc., Denver, Colo.

Field procedures followed standard methods that have been discussed by Zohdy (1974) and Flathe and Liebold (1976) for VES and by Sumner (1976) for IP. The MT procedures in general followed those described by Vozoff (1972) or see Gamble and others (1979).

One-dimensional inversion of the VES data was done using computer programs of Zohdy (1974, 1975). The VES expansions were confined to areas of relatively flat topography because the inversion cannot take into account effects due to topography.

The IP data is presented as conventional pseudosections with qualitative interpretation Sumner (1976). Two-dimensional modeling was applied to selected data using an interactive computer code of Killpack and Hohmann (1979). This finite element program, originally developed by Rijo (1977), is able to take into account the effects of two-dimensional structure and topography. Four of the IP lines were modeled using this code by the University of Utah Research Institute, (UURI) Earth Science Laboratory. IP data is emphasized in this work because it provides good definition of lateral variations in electrical properties and it can be acquired in topographically rough and difficult terrain. The presence of the Horn Silver mine at Wahmonie and various small prospects at Calico Hills also suggested mineralization potential that might be identified by IP methods.

The MT data were processed and inverted by the contractor using proprietary computer programs. Much of the MT data is quite noisy. The noise could be due in part to low natural signal levels during the field operations.

Wahmonie Site

Geology

A simplified geological map of the Wahmonie site is shown in figure 2 adapted from Ekren and Sargent (1965). Figure 3 shows topography, the location of all the electrical data at the site, and identifies the principal geographic features. In figure 2 Tertiary volcanics have been lumped into a single unit because individually mapped units are not directly pertinent to the problem.

Surrounding Wahmonie flat and the Horn Silver mine is a zone of hydrothermal alteration (fig. 2 and fig. 3), which corresponds approximately with the inferred intrusive. Within the zone of alteration a north-northeast-trending horst block is present 1.5 km wide and 4 km long, which can be identified by a lack of alteration (fig. 2). On the southeast margin of this horst are two small granodiorite bodies giving distinct magnetic highs in low-level aeromagnetic data (G. D. Bath, oral communication, 1980). Within the horst and outside the area of alteration the exposed bedrock is principally rhyodacite. A small patch of Mississippian Eleana Formation, not shown in figure 2, overlies part of the Tertiary granodiorite within the horst.

Extensive block faulting is present in the exposed areas with the principal trends being northwest and northeast. The narrow southwest nose in the alteration pattern is probably an expression of hydrothermal solutions moving along an extension of a major fault zone on the southeast side of the horst.

The water table in the area is at approximately 732 m (2400 ft) above sea level or about 580 m (1900 ft) below the surface at Wahmonie flat (Winograd and Thordarson, 1975). The nearest well information is at J 11 (also called well 74-6) 10 km southwest of the Horn Silver mine. Water in J 11 is high insulfate content in contrast to water from wells J 12 and J 13 (Winograd and Thordorson, 1975) located further west along Forty Mile Canyon.

Mining took place along faults in and adjacent to the southeast corner of the horst, at the Horn Silver Mine prior to 1905. In 1928 the district was reopened with a strike of high grade silver-gold ore (Cornwall 1977). Ball (1907) reports quartz stringers with gypsum present with the ore in the mine. The gypsum presumably comes from oxidation of primary sulfides and provides a possible source of sulfate for the water in J 11.

Geophysics

Both high level (8000 ft barometric) and draped (400 m terrain clearance) aeromagnetic surveys and a regional gravity map were available prior to this study. The aeromagnetic and gravity data supported inferences from the geology of the presence of a buried intrusive and some idea of its extent (G. D. Bath, oral communication, 1980; H. W. Oliver, oral communication, 1980). The high-level aeromagnetic map, figure 4, shows anomalies identified with both the Wahmonie and Calico Hills sites. The major anomalous magnetic body at Wahmonie is contained within the alteration halo and centered near the Horn Silver mine.

Ground magnetic, detailed gravity, seismic refraction, and seismic reflection studies have been done in addition to the electrical studies reported here. Results from the non-electrical studies are not yet available so reference to the supplementary studies are preliminary and tentative.

Schlumberger VES data

Individual sounding curves are shown in appendix 1 with their corresponding one-dimensional inversions. Figure 5 shows a cross-section interpreted from the inverted data. The section begins with sounding 79-3 in Jackass Flat (not shown in fig. 3) 4.7 km west-southwest of sounding 79-8,

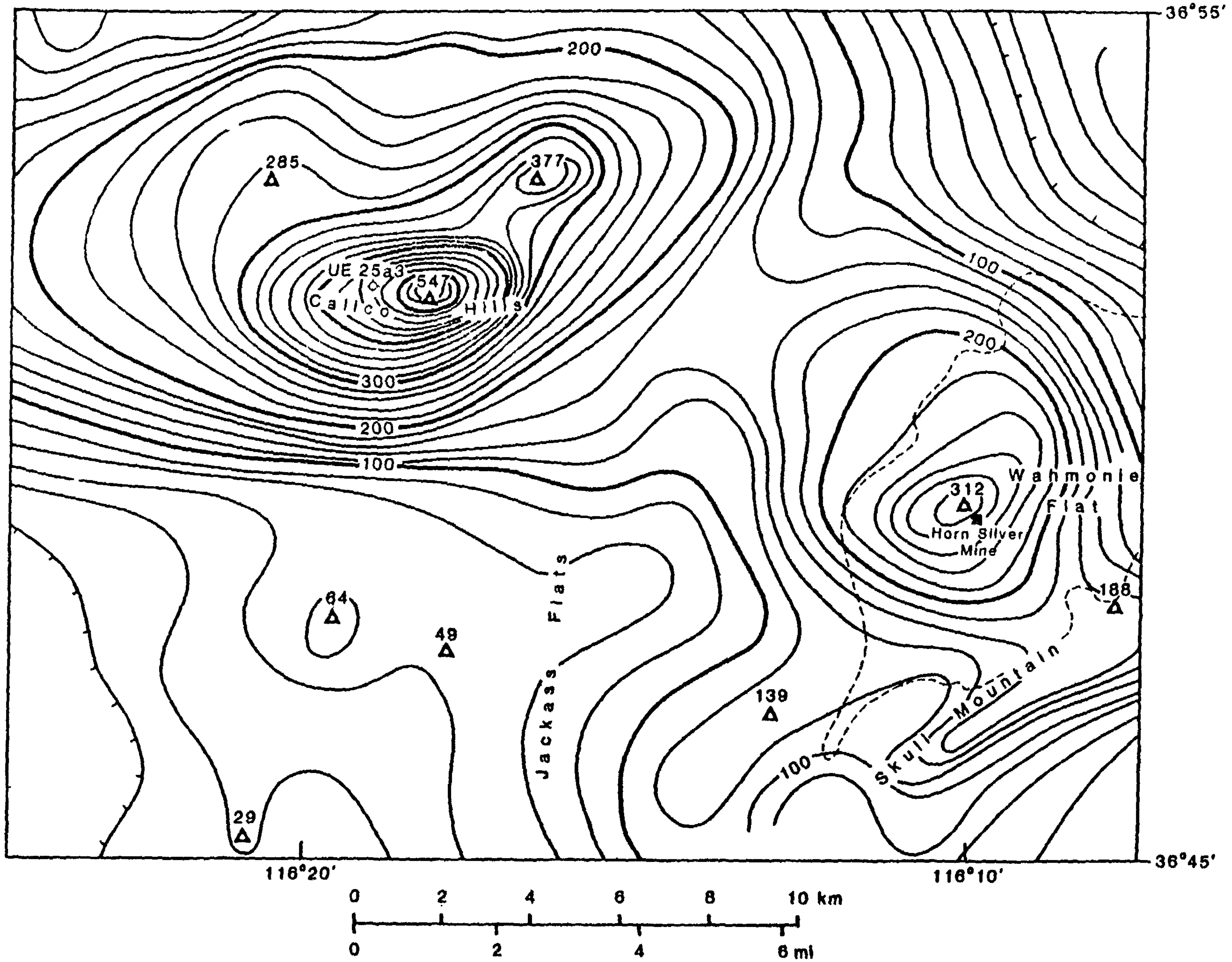

Figure 4. Aeromagnetic map of the Wahmonie and Calico Hills sites. Flight elevation in 8000 ft barometric and contour interval is 20 nT.

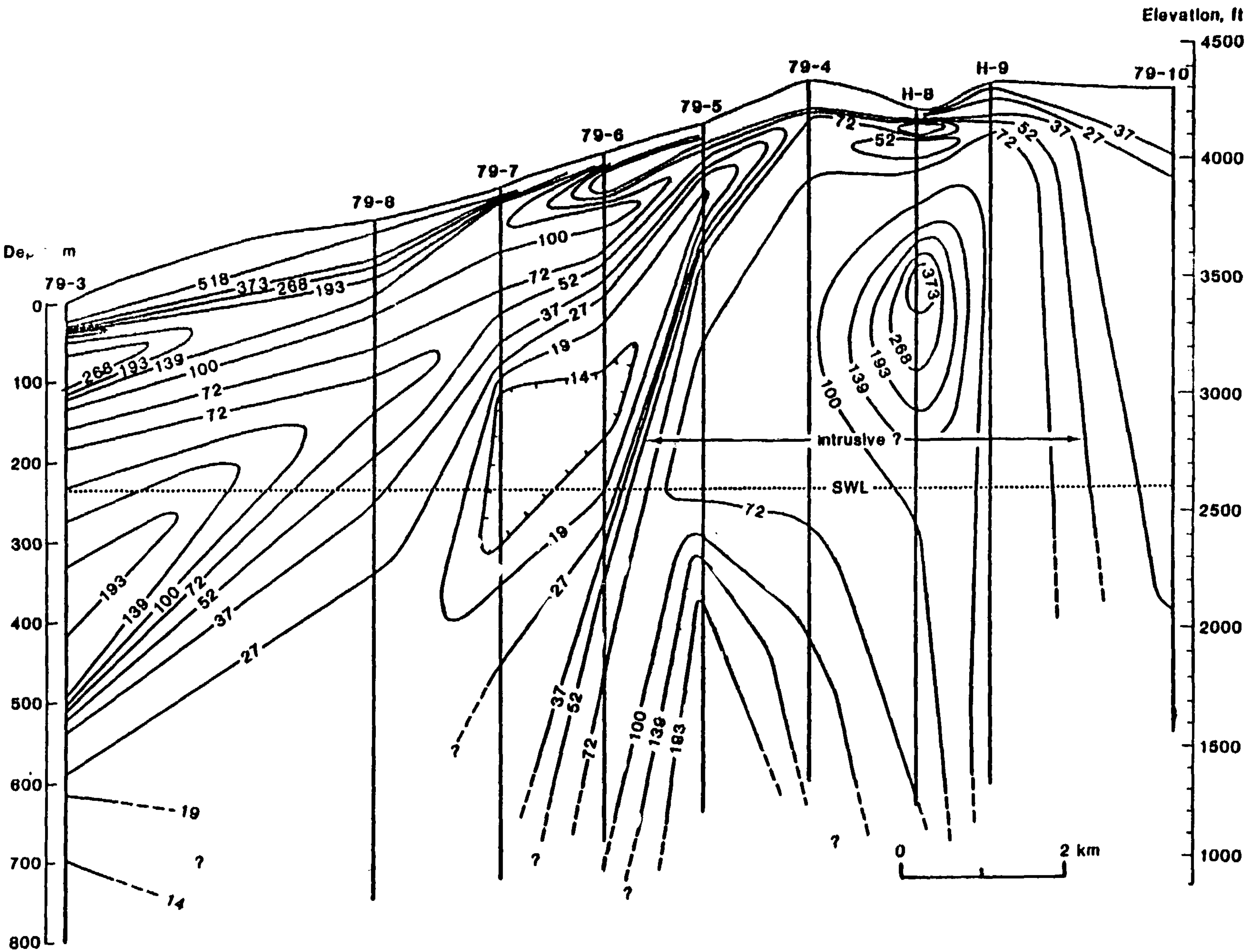

Figure 5. VES geoelectric cross-section at the Wahmonie Site. Contour interval is logarithmic and resistivities are in ohm-meters.

proceeds eastward to 79-8, 79-7, 79-6, 79-5 and 79-4. At 79-4 the section bends northward to H-8, H-9 and 79-10 (fig. 3). Soundings 79-4, 79-5, H-8, and H-9 are within the alteration halo. Near surface detail in the sounding data was omitted for clarity in figure 5.

Data from J-11 2.5 km northwest of sounding 79-3, provides the nearest lithologic control for the soundings at Wahmonie. A thick alluvial section (300 m) was found at J-11 below which basalt and tuff were encountered to a total depth of 406 m. Correlating the lithology with sounding 79-3 (appendix 1) suggests that the alluvium has a wide variation in resistivity (about 70-1000 ohm-m). The basalt and tuff correlate with a horizon of about 200 ohm-m at approximately 300-400 m depth. Below 500 m depth, the resistivity drops to 60 ohm-m or less and remains low indicating a minimum thickness of 400 m for this unit. This deep low resistivity unit is identified in the geoelectric section as the wedge shaped block defined by the 52 ohm-m contour. The depth to the top decreases and the thickness decreases as the alteration halo is approached.

The thick, low resistivity body cannot be directly correlated with a known lithology in the absence of deep drilling information. Either Eleana argillite or altered volcanics are believed to be the most probable lithologies correlative with the low resistivity body. Eleana Formation crops out within the horst at the Wahmonie Site but with very limited extent. However, it crops out extensively at Calico Hills (fig. 1) 12 km northwest of the Horn Silver mine and has the necessary thickness and resistivity. The electrical characteristics of the Eleana argillite at Calico Hills will be discussed later in this paper. Altered volcanic units crop out or are inferred to be beneath shallow alluvium. Resistivity inversions within the alteration halo all show a thin low-resistivity horizon at about 10 m depth which probably correlates with the mapped altered volcanics. If altered volcanics correlate with the thick, low-resistivity body in the western half of the geoelectric section then alteration about the inferred intrusive is more extensive than surface mapping indicates.

The geoelectric section (fig. 5) shows a significant change going from sounding 79-6 to 79-5. VES 79-5 is 1200 m northeast of VES 6, 600 m inside the zone of alteration and presumably above the intrusive body. At a depth of about 150 m a more resistive body is inferred from the data; it extends in depth to the limit of the sounding gradually increasing in resistivity with depth. The sounding curve at this point however is not rising steeply enough for the resistive body to be several thousand ohm-m representative of a tight intrusive. This suggests that the intrusive is sufficiently altered, mineralized, or fractured in the upper part so as to reduce its resistivity.

VES 79-4 shows only a single shallow, low-resistivity zone that could be either argillite (Eleana) or altered volcanics. At 30 m depth, the resistivity increases to 70-100 ohm-m and remains fairly uniform to a depth of 700 m.

A resistive body reaching 300-400 ohm-m at a depth of 200-350 m is seen in the section below sounding H-8. This may represent a less altered part of the intrusive. The decrease in resistivity below 350 m may be due to lateral effects. The last data point on this sounding was dropped as it was believed to be perturbed by underground utilities.

VES H-9 shows a similar picture to VES 79-4 with the electrical basement found at 40-50 m but the resistivities are very low not rising above 100 ohm-m. An intrinsic resistivity of 100 ohm-m is a very low value for an unaltered, unfractured and unmineralized intrusive body. These data from H8 and H9 are in excellent agreement with results from an IP line, W1, run close to these two soundings and discussed below.

The last sounding in this cross-section, VES 79-10, on the northwest side of the intrusive shows a single thick, low-resistivity zone similar to VES 79-7 again presumed to be the Eleana Formation or altered volcanics.

The other soundings (VES 79-1, 79-2, H10 and 79-9, appendix 1,) are all on the edges of the intrusive and give a similar picture to those of figure 5 except for details in the upper part, which most likely represents the alluvial cover.

Induced Polarization Data IP

Two dipole-dipole IP lines were run across the central region of the inferred intrusive in a northwest-southeast direction (lines w1 and w2 in figure 3) and close to old workings of the Horn Silver mine. Line W1 was measured using a 305 m (1000 ft) dipole spacing; it is the only line at Wahmonie modeled by UURI (Smith and others, 1981). The modeling results and the observed pseudosection from line W1 are shown in figure 6 and the observed pseudosections from line W2 are shown in figure 7.

Because there are no large variations in topography along line W1, the modeling was not corrected for two-dimensional topography. Between stations 80W to 110W (8000-1100 ft west of the zero position) the small hills to the side of the line would have a small perturbation on the apparent resistivity values measured from these positions. The frequency effect values shown on the sections provide a measure of polarizable minerals within the rock matrix. These are the metallic-luster sulfides, magnetite and some clays and zeolites for the most part. Sumner (1976) discusses the responses of various rocks which have been noted as giving greater than normal background response. Metallic sulfides are not stable in the oxidizing environment above

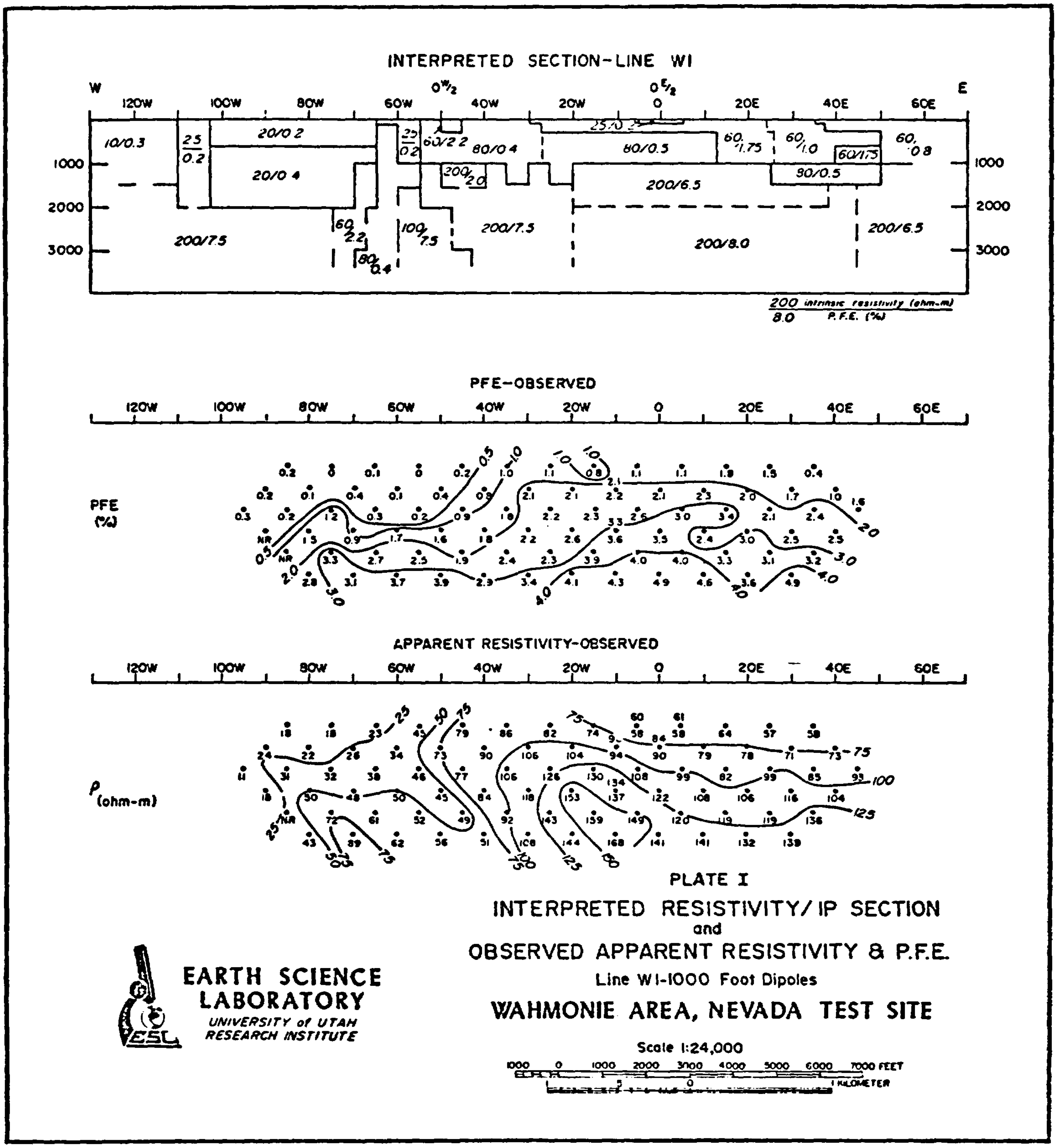

Figure 6. Induced polarization line W1 at the Wahmonie Site showing the derived two-dimensional model and the pseudosections.

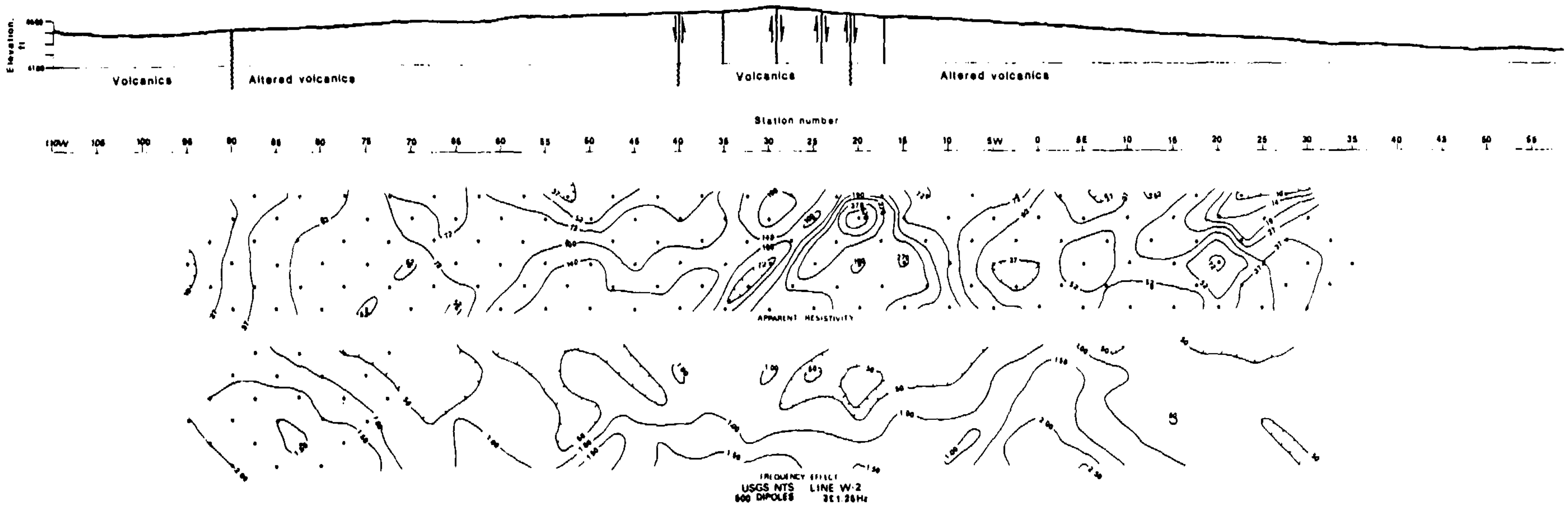

Figure 7. Induced polarization line W2 at the Wahmonie Site showing the surface lithologies and pseudosections. The resistivity pseudosection is contoured logarithmically and values are in ohm-meters.

the water table but are chemically changed to secondary minerals which have very low polarizability. We would not expect to see much polarization from altered sulfides above the water table and in fact we see low polarizability in the upper part of the inverted model in figure 9. The intrinsic polarizability increases significantly below about 300 m depth with another increase inferred at 600 m depth. This is the approximate water table. The modeled intrinsic polarizabilities go as high as 8% frequency effect, PFE, and large values are seen at depth along almost the whole line. A large disseminated mineral deposit is consistent with these data.

Smith and others (1981) estimated the grade using an empirical relationship of

$$W = \frac{45 \times PFE^{1/2}}{\rho},$$

where w = weight percent sulfide

ρ = intrinsic resistivity

PFE = intrinsic percent frequency effect,

which implies a minimum grade of 1 to 2 weight percent sulfide. Using the relationship w = PFE/3 (Sumner, 1976) gives 2.7% sulfide. Metal factor is another measure used to indicate the grade of a deposit (Sumner, 1976). The apparent metal factor on line W1 at depth is in the range of 150 to 180. We made a brief search of case histories to see if a similar prospect had been reported in the literature. A similar prospect at Quartzite Arizona, was found (McPhar Geophysics Corp., 1966) where a very uniform 200-300 ohm-m resistivity section showed apparent metal factors increasing with depth to 100-150 or 3-5% PFE. The line was about 5000 ft long with mineralization indicated at depth all along the line. The similarity with Wahmonie data on line W-1 is striking. The drilling results showed thick Tertiary overburden, a thick schist sequence with oxidized sulfides and granite at depth containing

2 to 4% sulfides. Drilling depths and thicknesses are not given in the case history.

The IP evidence for disseminated mineralization and the presence of the Horn Silver Mine provides strong evidence for a large disseminated sulfide body at depth. The area near the Horn Silver Mine offers an exceedingly attractive minerals exploration target. The data do indicate that the shallowest disseminated mineralization is between 20W and 20E. This zone is closest to and on the trend of the Horn Silver Mine workings.

Some structural information can also be obtained from the data on line W1. Approximately at station 60 W, faulting is inferred from the pseudosections and model data. To the northwest the section appears to have been downdropped about 300 m (1000 ft). This is consistent with a steep gravity gradient at this position (H. W. Oliver, oral communication, 1980) that also suggests a major fault or lithologic boundary. The upper 300-600 m of section in this northwest block was modeled with 10-20 ohm-m material, which we infer to be the Eleana argillite or altered volcanics. Several faults are inferred from geological data to cross line W1 east of station 60W yet the entire line southeast of 60W shows no distinct boundaries that could be inferred as faults. The fact that the faults were not sensed may be due to the large dipole length, (300 m), which makes the data show values averaged over large volumes of rock.

Line W2 runs across prospects and between shafts of the Horn Silver Mine. The line has not been modeled, but qualitative interpretations can be based on the pseudosection of figure 7. The dipole spacing on this line was 152 m (500 ft) so that at an "n" of six, we are at best just starting to sample rocks below the water table (550-670 m depth on line W-2). At an "n" of six the PFE values are about 1.5; this value is consistent with the observations on line W1 at an equivalent depth. The increase in PFE with depth suggests that the survey may just be beginning to sense sulfides.

The resistivity section suggests the existence of a high-resistivity block near 20W that is probably fault bounded. The Horn Silver Mine workings were in a northeast-trending zone that crosses line W2 in the 15-25 W interval. No increased polarization is noted in this region presumably because the sulfides have been oxidized. The high-resistivity zone between 10W and 20W may also be due to induration of the host rock by mineralizing solutions. The horst is mapped geologically between 20W and 40W on line W2 and as mapped is distinguished by a lack of rock alteration. The eastern boundary is clearly seen in the electrical data near 15W but there is no clear evidence for an electrical boundary on the west. Neither the resistivity nor the frequency effect pseudosection show a significant change in value across the mapped contact between altered and unaltered volcanic units on the western edge of the horst.

Conclusions Wahmonie Study Area

The foregoing data interpretation is considered preliminary as much additional geophysical data is presently being analyzed, which should provide additional constraints. However, the tentative conclusions to be drawn from these data suggest that the Wahmonie site is inappropriate for a nuclear waste repository.

There may be a volume of intrusive rock at the site sufficient to hold a waste repository. The resistivity of the mass, however, shows that it is not a fresh, tight, and unaltered intrusive. The resistivity indicates significant porosity attributable to fracturing, faulting, alteration, mineralization or any combination of these. Many mapped faults do not appear to be reflected in the electrical data, but two prominent faults were identified; one at station 20W line W2 on the southeast margin of the horst and another at station 60W on line W1.

The data show the edges of the inferred intrusive correspond approximately with the alteration halo. This correspondence is not substantiated on the north and east sides due to a lack of data.

The most significant finding is the disseminated sulfide mineralization in the intrusive. IP data suggest that 2% or more sulfides may be present below the water table. This evidence of mineralization with the presence of once-active silver-gold mining at the site suggest that it is a very attractive exploration target. This serendipitous result, although detrimental to siting of a waste repository, indicates that further exploration and drilling might outline a deposit of importance to our inventory of strategic metals.

Calico Hills

Geology

A simplified geological map of the Calico Hills region is shown in figure 8, adopted from Orkild and O'Connor (1970) and McKay and Williams (1964). All extrusive volcanic units were lumped in preparing the map. The Calico Hills are part of a structural dome, (Maldonado and others, 1979) elongate in a northeast direction, on the north-central edge of Jackass Flat (fig. 1, fig. 8). Extensive radial and ring faulting is associated with the doming. Faults not associated with the doming are high-angle Basin and Range faults generally trending north-south or thrusts which have left some remnants of Devonian limestone on the structurally higher parts of the dome. The Mine Mountain fault is a major northeast-trending strike-slip fault 5.5 km southeast of the dome axis. A fault has been inferred (Orkild and O'Connor, 1970) along the center of Topopah Wash on the long axis of the dome, which parallels the Mine Mountain fault (fig. 8).

The oldest rock units in the area are thin islands of Devonian carbonate rocks that are remnants of an upper thrust plate. The Devonian carbonates overlie younger Mississippian rocks of the Eleana Formation composed primarily of argillite with some quartzite. The Eleana crops out in the south central part of the dome (fig. 8) and is assumed to exist beneath thin alluvial cover along Topopah Wash. Unconformably overlying the Mississippian rocks, extrusive Tertiary volcanics 8-14 m.y. old (Maldonado and others, 1979) crop out principally along the margins of the dome and also to the north. The extrusive volcanic units are composed of rhyolite flows and welded to non-welded tuffs. Several small rhyolite intrusions are present within the outcrop area of the Eleana Formation. Quaternary alluvium is present along Topopah Wash and in Jackass Flat to the south.

A generalized lithologic section from drill hole UE25a-3 (fig. 9) along with VES data and electric logs are shown in figure 10. Unit J of the Eleana Formation composed principally of argillite in unaltered or essentially unaltered condition, occurred in the upper 415 m (1360 ft). The clay minerals (kaolinite, nacrite and dickite) found in fractures indicate that hydrothermal solutions moved along fractures but caused little alteration in the main mass (Maldonado and others, 1979). From 415 m to 721 m (1361 to 2364 ft) of depth, unit J is present but has been thermally altered. The lowest 46 m (150 ft) of this interval is composed of a calcareous argillite. The remainder of the hole (721 to 772 in depth) was drilled through marble believed to be unit I of the Eleana Formation.

Nine fault zones, some of which showed brecciation, were encountered in the core; their apparent dips ranging from 45° to -90°. Bedding plane dips measured in the argillite ranged from 10° to 52°. The calcareous argillite was essentially horizontal, while the marble dipped at about 50°.

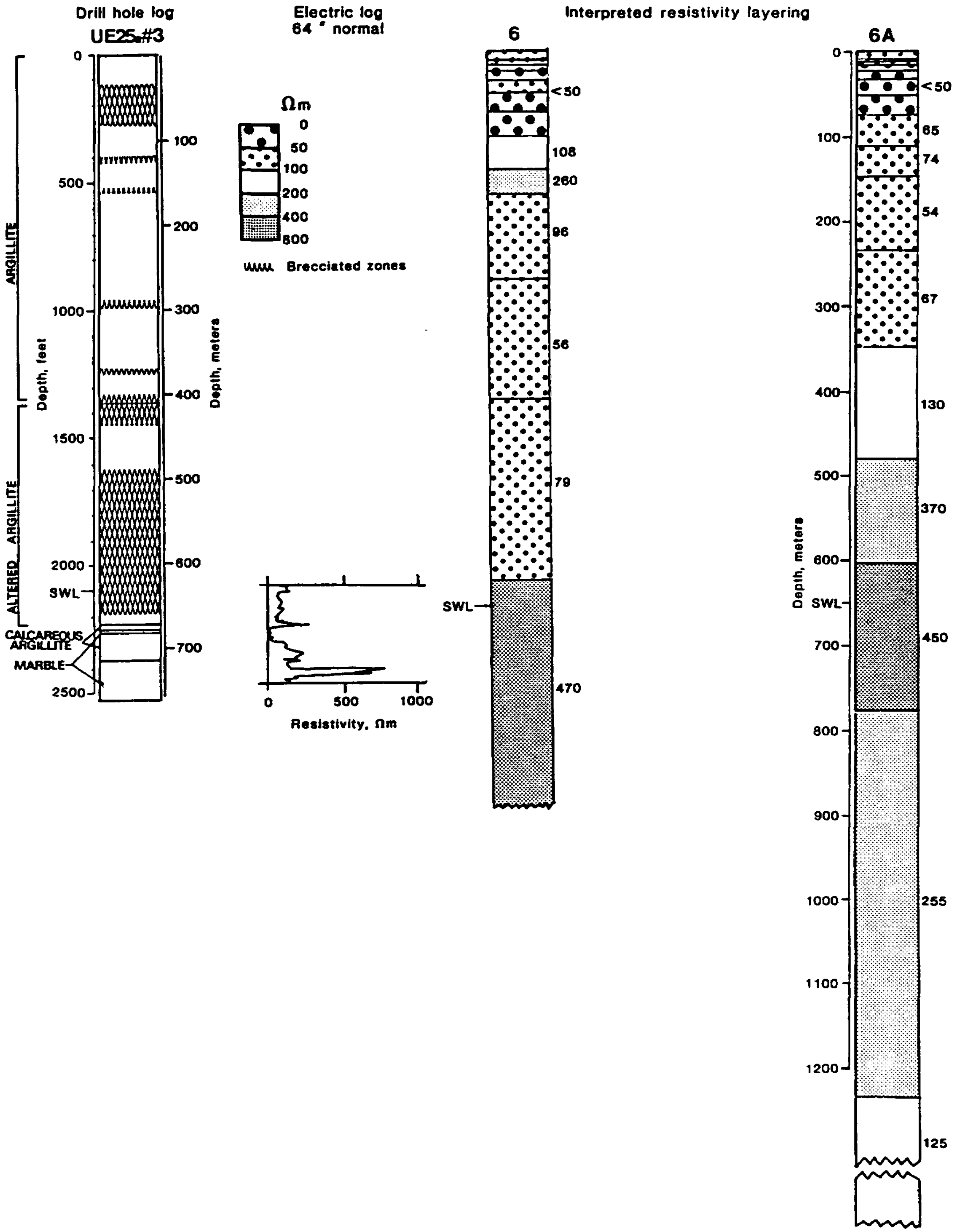

Figure 10. Diagram comparing the lithologic log of UE 25A-3 with crossed VES 6 and 6A at the well site.

Magnetite and pyrite are present along fractures in the argillite. Within the altered part sufficient magnetite occurs so that a significant part if not all of the magnetic anomaly (discussed below) can be attributed to the argillite rather than a buried intrusive (G. D. Bath, oral communication, 1980). Measured porosity on 10 core samples of the unaltered argillite averaged 10.8%, and on nine samples of altered argillite 6.7% (Maldonado and others, 1979).

The measured static water level in UE25a-3 is at an elevation of 748 m (2453 ft) or 639 m (2097 ft) below the surface. Temperature logs were run in April 1979 after the hole had reached thermal equilibrium. The average thermal gradient in the lower part of the drill hole was 45°C/km and the temperature on bottom was 46.8°C. The calculated heat flow is quite high, (3.3 HFU), which suggests an upwelling hydrothermal system below the bottom of the hole (Sass, 1980).

Geophysics

The aeromagnetic data on which much of the inference of a shallow intrusive was based is shown in figure 4. Drilling has shown that the intrusive, if present, is deeper than 2500 ft near the center of the dome and that much of the magnetic anomaly can be attributed to magnetic mineralization within the argillite. Subsequent detailed gravity work has also shown that the gravity anomaly can be attributed to a density contrast between the Paleozoic rocks and the surrounding low density Tertiary volcanics, (Snyder and Oliver, 1981). Nevertheless the doming and alteration provide evidence that an intrusive is present at depth. The electrical studies presented here are an attempt to identify the intrusive and to characterize the subsurface geoelectric section including the extent and location of unit J of the Eleana Formation.

VES data and results

Figure 10 shows the interpreted electrical sections from two coincident, orthogonal soundings (6 and 6A) made at the site of drill hole UE25a-3. The lithologic log is also shown for comparison. The soundings were completed prior to the drilling so they are not perturbed by drill casing. The interpreted sections are similar; the observed differences are attributed to lateral variations in electrical properties. The unaltered argillite in the lithologic section correlates with an electrical section having an average resistivity of about 50 ohm-m. The high-resistivity unit at 150 m depth on sounding 6 is attributed to a narrow remnant of carbonate rock that was crossed while making the sounding. At 350-400 m depth the resistivity increases reaching a maximum of about 460 ohm-m. This interval correlates with the altered argillite and marble observed in the drill hole. Electric logs run below the static water table (Daniels and Scott, 1980; Maldonado and others, 1979) show an average resistivity for the Eleana argillite about 250 ohm-m and the carbonates variable but generally higher in value. Sounding 6A was expanded to 2440 m (8000 ft) so as to obtain information from greater depth. The interpreted resistivities below the 450 ohm-m interval then decrease to 130 ohm-m at 1300 m depth, the approximate limit of the sounding. This deep lower resistivity unit cannot reliably be associated with particular lithologies. The resistivity is an order of magnitude too low for a tight unaltered intrusive body. If this sounding is sensing the intrusive then significant alteration and fracturing has taken place.

An electrical cross-section (figure 11) is presented along the line of soundings 79-11, 6A, 7, 12, 13, 14, 15, and 20, (figure 9). This is essentially along the long axis of the dome extending to the upper end of Topopah wash at sounding 20.

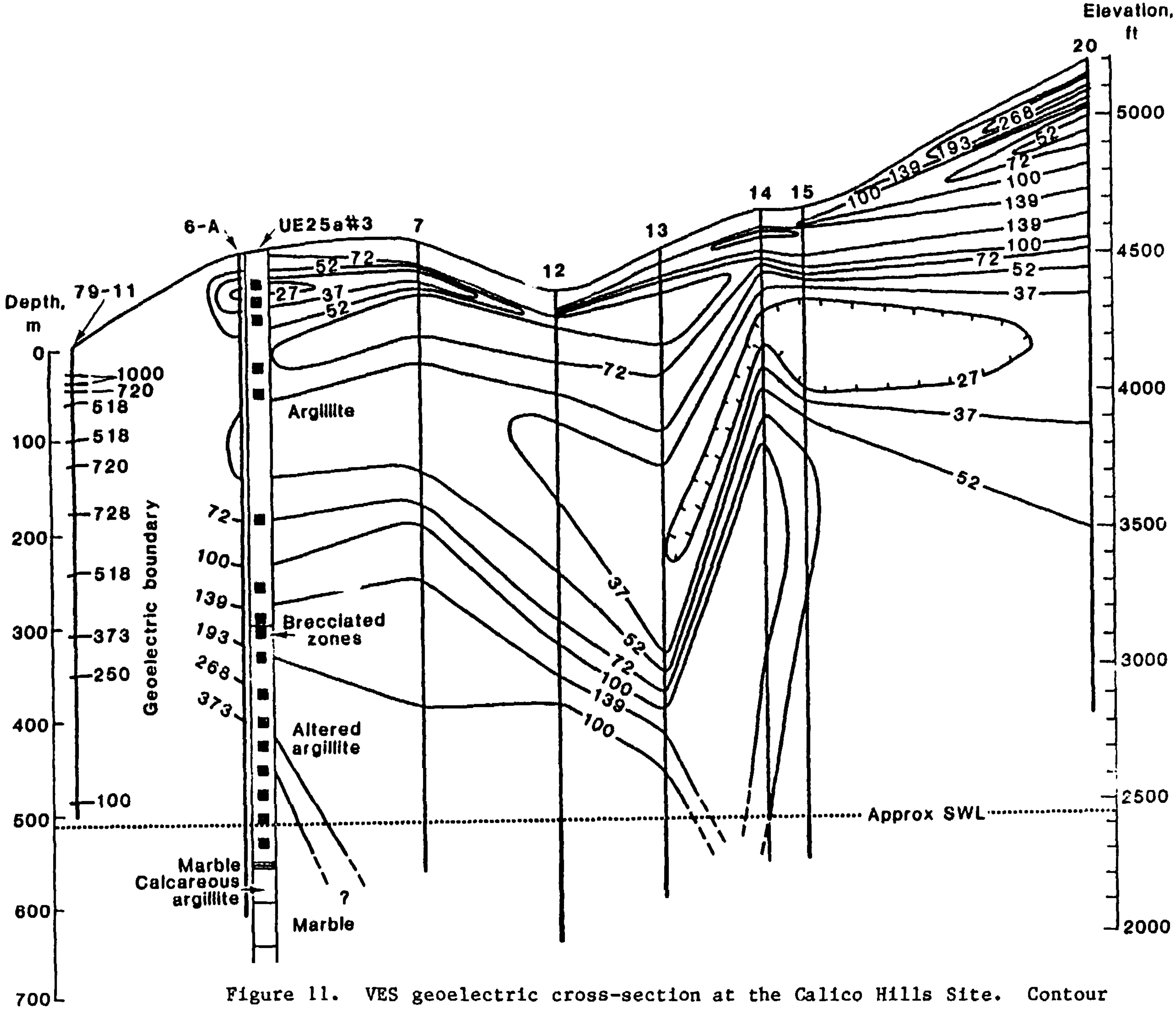

Figure 11. VES geoelectric cross-section at the Calico Hills Site. Contour interval is logarithmic and resistivities are in ohm-meters. Breccia zones observed in drill-hole UE 25a3 are shown as black boxes.

The cross-section shows that between VES 6A and 79-11 a major boundary must exist. The inversion of 79-11 doesn't show any interval of the geoelectric section that can be identified with the Eleana Formation. The Eleana is either missing entirely, is too deep or too thin to be identified, or is altered to much higher resistivities. VES 79-11 was sited on shallow Quaternary alluvium underlain by Tertiary volcanics. The high resistivities (200 ohm-m and greater) seen in the inversion of 79-11 are assumed to be typical of the unaltered volcanics in this area. No attempt was made to contour between VES 6A and 79-11. Faulting is inferred between these two soundings along which uplift of the dome has occurred.

From sounding 6A to the northeast, the resistivities seen in the geoelectric section are generally less than 50 ohm-m. Based on the lithology of drill hole UE25a-3, Eleana argillite, both altered and unaltered, is inferred to be present at least to a depth of 600 m. The higher resistivities (above 100 ohm-m) seen at shallow depth on the northeast end of the section may in part be attributed to Tertiary volcanics overlying the Eleana Formation. Between VES 13 and 14 faulting is inferred from the vertical offset seen in the section contours. Based on the 27 ohm-m contour displacement of 200 m may be present. Mapped north-trending faults that are exposed south of the section may extend under alluvial cover in Topopah Wash.

From sounding 6, at a depth of 400 m corresponding to the interface between altered and unaltered argillite, an arcuate (concave downward) resistivity gradient can be seen in the geoelectric section extending to sounding 13. Higher resistivities associated with the altered argillite become deeper northeast of VES 7. This pattern is inferred to reflect the thermal alteration halo in the argillite. A similar pattern was noted in seismic refraction data along this same line of section (L. W. Pankratz, oral communication, 1980). All the VES soundings and inversions are shown in appendix 1.

Because of the complex structure in the Calico Hills area, a more detailed examination of the individual VES data will not be made. However A few additional results will be mentioned. Low resistivities over a thick vertical interval were not identified on soundings 1, 2, 10, 11, and 28. Soundings 16 and 17 showed what is inferred to be Eleana argillite at relatively great depth, 200 to 600 m. All other soundings showed the top of the Eleana at relatively shallow depth with Nos. 3, 4, 5, and 6 showing it at the surface consistent with the mapped geology. Sounding 28 was positioned near some old mining prospects and on outcrop of Eleana. Interpreted resistivities were in the range of 100 to 300 ohm-m suggesting that altered Eleana argillite is near the surface.

Dipole-dipole induced polarization data and results

Six IP traverses were run across the Calico Hills area, three near the central part of the dome and three profiles crossing Topopah wash (fig. 8). The three profiles that ran across the central part of the dome TR-1, TR-2, and CH1 used 500-, 1000-, and 1000-ft dipole separations respectively and expanded only to an "n" of four. The other three (CH 4, 5, and 6) each used 500-ft dipoles expanded to an "n" of six. Lines TR-1, TR 2 and CH 1 were modeled by the University of Utah (Ross and Lunbeck, 1978). The results are summarized below along with the derived models.

Ross and Lunbeck (1978), by correlating modeled intrinsic electrical parameters with known and inferred geologic units, presented a table of probable bulk electrical properties for the lithologies present at the Calico Hills site. These are reproduced as table 1. They state in their report that the Eleana argillite is 50-100 ohm-m for the most part, while the low range for the Topopah Spring Member of the Paintbrush Tuff is 60 ohm-m. From all the data presented the low range for the Topopah Spring is inferred to be associated with limited areas of extensive alteration. The results of table 1 agree well with inferences made from VES and drilling data.

Line TR-1 (fig. 12) was run near drill hole UE25a-3 along the same path used in the expansion of VES 6. More near-surface detail is given in the modeled data along TR-1 (fig. 13) because shorter dipole separations (500 ft) were used than on TR-2 and CH-1. The exploration depth however is correspondingly reduced. Drill hole UE25a-3 is adjacent to station E-7. At this position the interpretation of the IP data shows a low-resistivity unit of 45 ohm-m identified as Eleana overlying a 100 ohm-m unit at 460 m (1500 ft) below surface. This is in excellent agreement with the boundary of altered argillite at 416 m (1365 ft) and with the two corresponding VES soundings 6 and 6A (fig. 10).

Further comparison of the modeled IP and VES data give reasonable agreement. VES 3 is near position 12.5 E of TR1, the sounding interpretation is similar to 6A but the more resistive lower layer, corresponding to altered Eleana, is a bit shallower than given in the IP model. VES 2 is a short distance south of position 15.5 E of TR1 and shows a high-resistivity section about 700 ohm-m above 100 m descending to an average of about 200 ohm-m. This sounding interpretation corresponds well with the IP model near station 19E but not with that at the nearer position (15 1/2E). It would appear that a major interface occurs between IP station 15 and VES 2. VES 10 close to IP station 21 E does not see the modeled low resistivity unit (50 ohm-m) but otherwise is in good agreement. We suggest that the lower resistivity units seen in the modeled IP data within zones of known volcanics are zones of

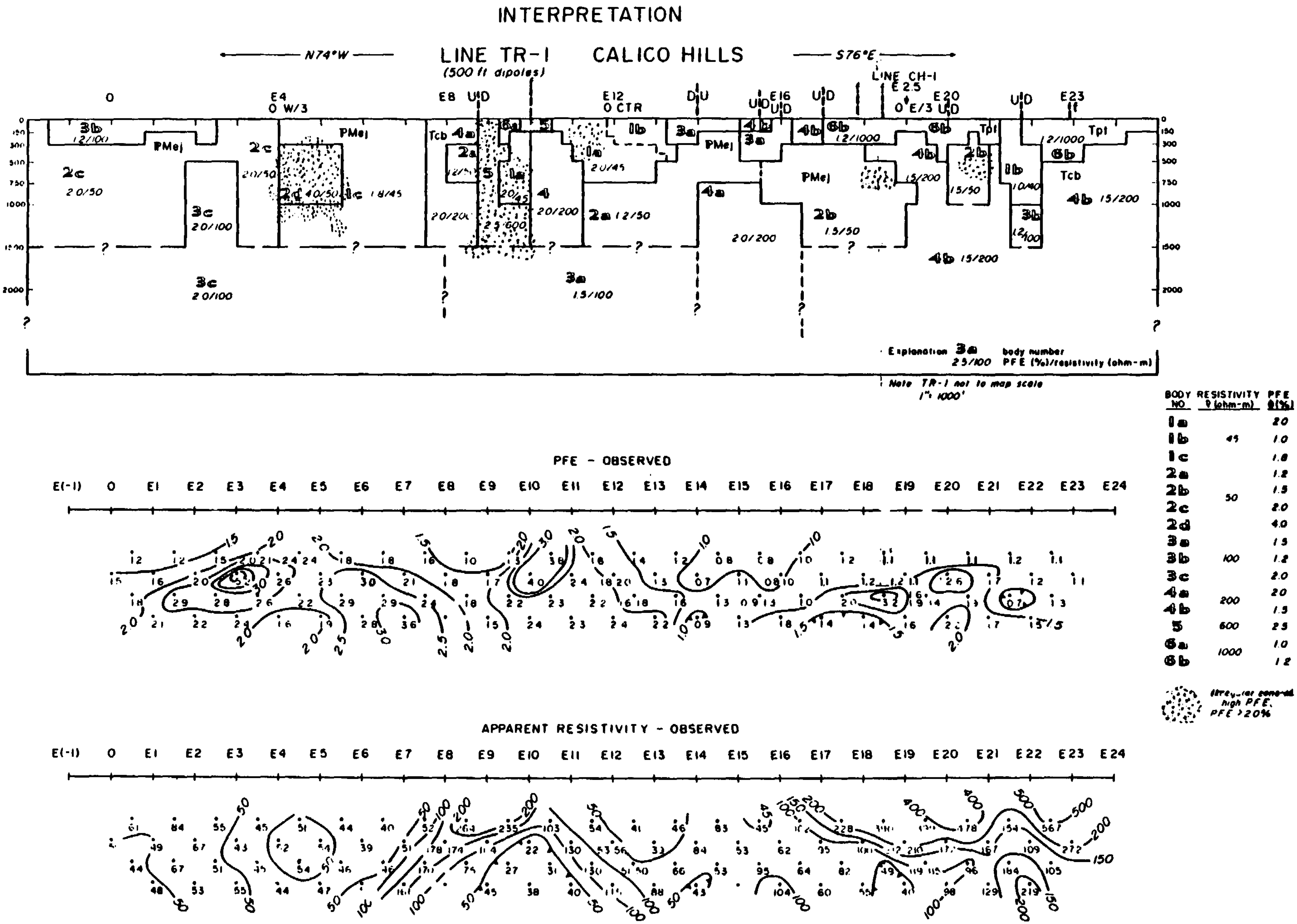

Figure 13. Induced polarization line TR 1 showing the derived two-dimensional model and the pseudosections.

TABLE 1

STRATIGRAPHIC SECTIONS FOR CALICO HILLS WITH PROBABLE

BULK ELECTRICAL PROPERTIES

		Thickness (feet)	PEE (%)	Resistivity (Ohm-m)
Qac	Alluvium and colluvium gravels and sands	0-1.025	0.5-2.0	45-200
Tpt	Piapi Canyon Group Paintbrush Tuff, Topopah Spring Member, ash flow devitrified welded tuff;	300-800	1.2-2.0	100-1000
	pervasive alteration: silicified, alunitized, kaolinized; porphyritic		3.0-4.0	60-200
Tcb	Tuffaceous beds of Calico Hills non-welded ash flows and debris; beds of rhyolitic and pumice;	1000±	1.5	100
	may be silicified, alunitized and kaolinized		4.0	200
Tci	Rhyolite intrusions silicified, kaolinized; porphyritic	?	not defined in this study	
PMaj	Eleana Formation, unit J. thin bedded argillite and thin to thick-bedded quartzite and conglomerate; forms sole of thrust fault	350±	.5-1.5	60-200
MDld	Limestone and dolomite aphanitic crinoidal limestone, thin bedded limestone and dolomite; occurs in upper plate of thrust over PMaj	100±	not well defined	
Ddn	Devil's Gate(?) Limestone fine- to coarse-grained, brecciated dolomite and limestone; occurs in faulted blocks thrust over MDld and PMaj	400±	not well defined	

alteration, fracturing and faulting, which were not readily identified in the VES data.

Associating the large units of 50 ohm-m material modeled on line TR-1 with the unaltered argillite indicates its present along the line generally from the western end to about station E 19 on the east. The surface contact between Eleana argillite and volcanics occurs at station E 17. The significance of a thick 600 ohm-m unit modeled near IP station 9E is not clear since it cannot be attributed to the thin overthrust plate of carbonates at that position. The IP model suggests geoelectric complexity, which may be due to structural complexity or to variations in alteration, but probably is a combination of both.

Line TR 2 (fig. 14) is parallel to TR 1 and 800 m to the north. Dipoles spaced 305 m (1000 ft) apart were used on this line so poorer definition of fine structure results but greater depth of investigation is achieved. The line from the west end to station E 7 crosses surface exposures of Eleana or remnants of the overthrust carbonates. The IP data indicate that low-resistivity material corresponding to unaltered Eleana is generally present to depths of 460 m (1500 ft) except for a narrow zone at E(-4) and a broad zone from E1 to E5. These two zones are modeled at 100 ohm-m and probably indicate increased alteration of those parts of the Eleana argillite. Zones of increased polarizability are indicated at E-4 and between E-7 and E-10. The eastern zone between E-7 and E-10 correlates with a large zone of increased silicification, alluvitization and kaolinization mapped in the volcanics. Strongly magnetic Eleana argillite is present at the surface between station E-5 and E-6, yet the magnetic mineralization does not appear to contribute to polarizabilities above background at this location. The lack of correlation between magnetic argillite and higher polarization values gives additional

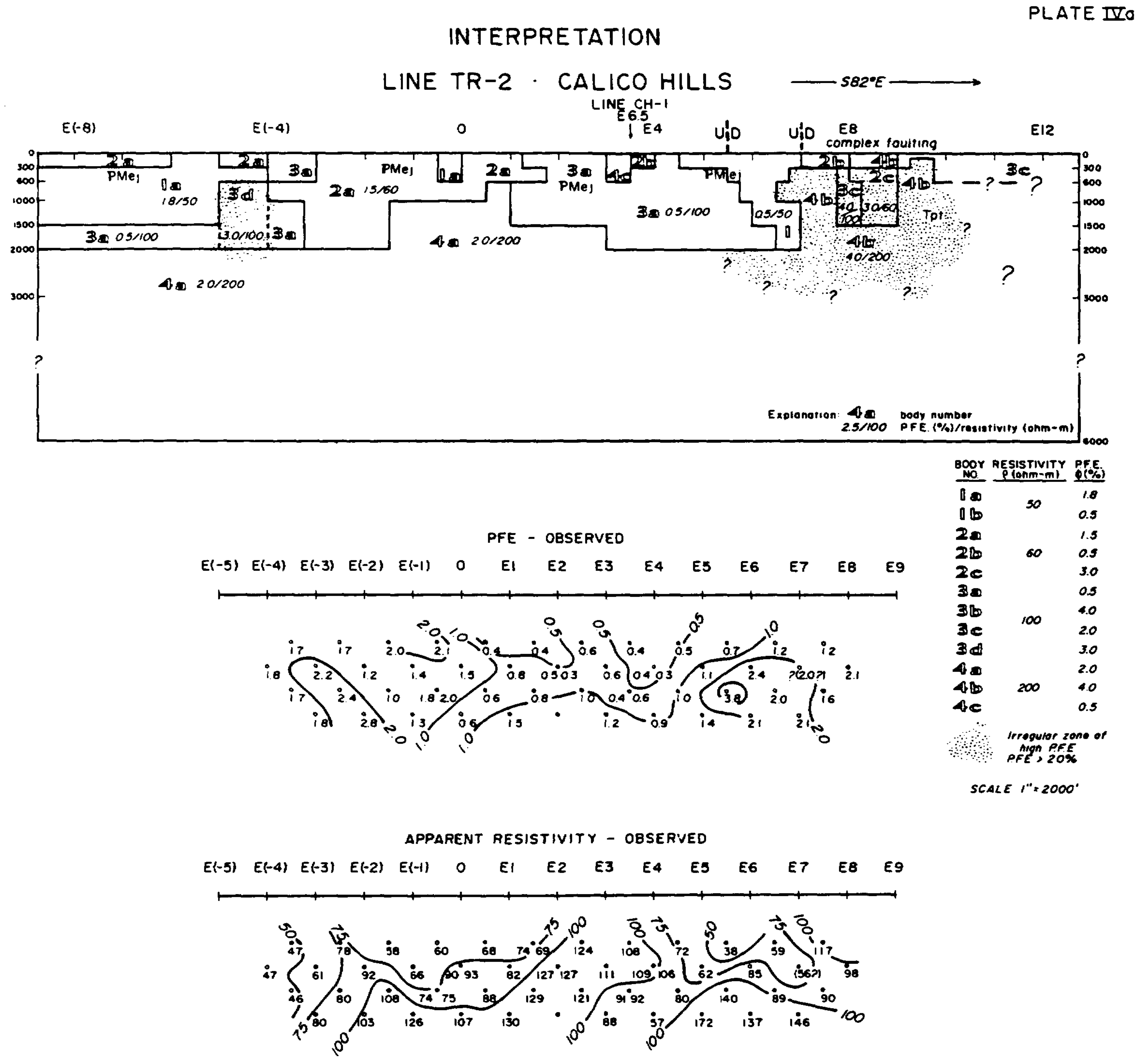

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Figure 14. Induced polarization line TR 2 showing the derived two-dimensional model and the pseudosections.

evidence for disseminated sulfides as the cause of polarization anomalies in the Eleana Formation on the other IP lines. Line CH 1 (fig. 15) runs northwest-southeast in part along one of the access roads into the area. The surface contact between Eleana argillite and volcanic units is between station E3 and E4. Near the contact and throughout the surface exposure of the volcanic units, the modeling indicates a fair amount of geoelectric complexity. Also no large blocks of low resistivity, correlative with unaltered Eleana argillite, are identified as in the other two lines. Where the line runs across surface exposures of predominantly Eleana Formation the model data shows units of 100 and 160 ohm-m material. Ross and Lunbeck (1978) suggested that the deeper 100 ohm-m material may be an intrusive, but here we suggest this is more probably altered Eleana extending essentially to the surface in this region. As on TR 2, an extensive region of higher intrinsic polarizability is seen in the altered volcanics.

These three indicate a complex geoelectric section, but no through-going trends can be discerned. The central part of the dome, to the depth of exploration, is inferred to be underlain by the Eleana Formation with faulting and variations in alteration contributing to the observed complexity. The contact with the surrounding volcanics can be seen and is easily identified where alteration increases polarizability. There is no clear evidence that an intrusive is present within the depth of exploration.

Subsequent to the completion and modeling of the IP lines just discussed, three other IP lines were run across Topopah Wash (fig. 12) to give better definition of the Eleana argillite and its structural relations along the northeastern part of the area. These are lines CH 4, 5, and 6 which roughly parallel CH 1. All three lines used 500 ft dipoles. The lines are

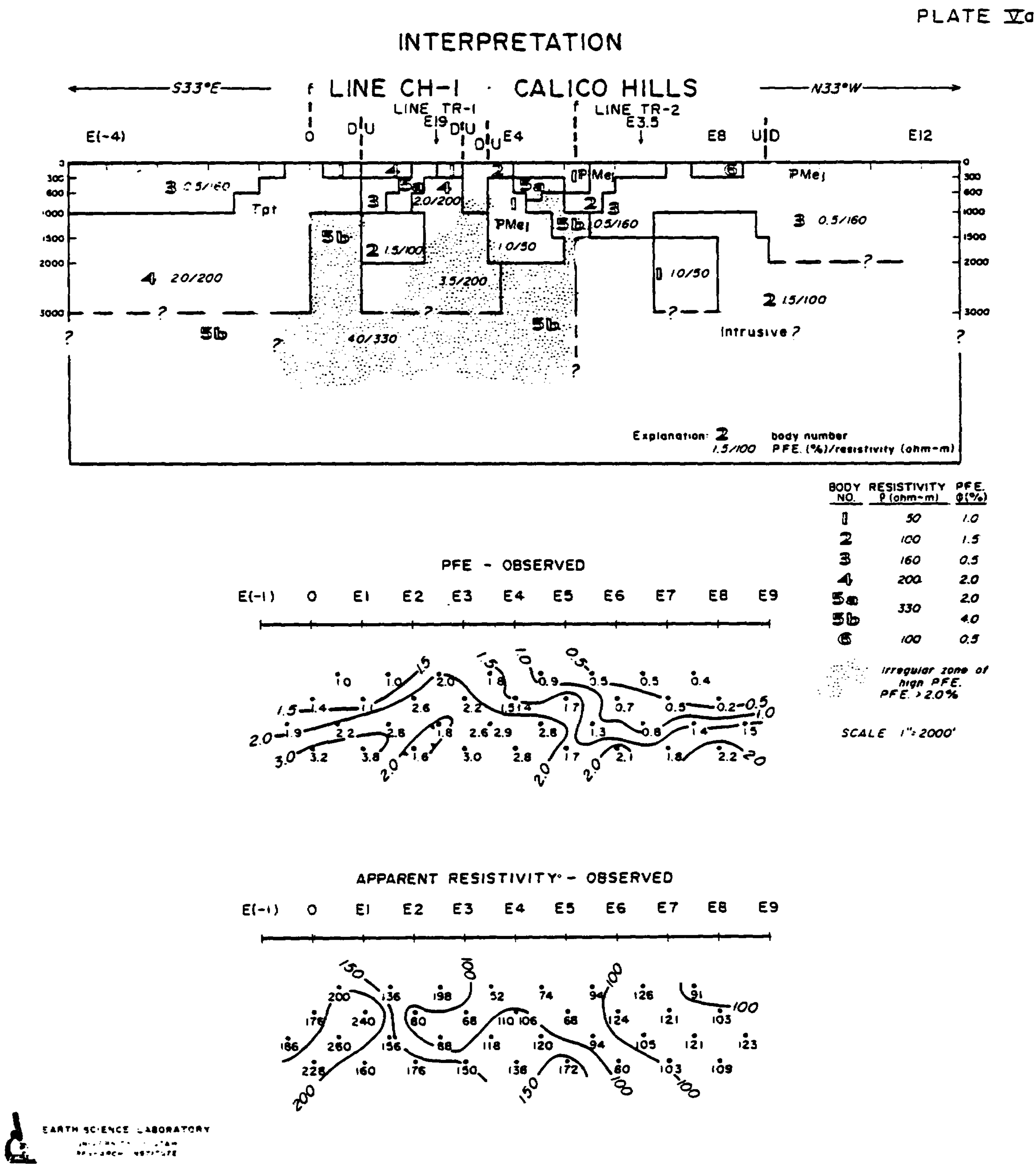

Figure 15. Induced polarization line CH 1 showing the derived two-dimensional model and the pseudosections.

not yet modeled; however, a number of conclusions can be made based on qualitative examination of the data. Line CH 4 (fig. 16) runs across the Eleana Formation either exposed or buried beneath shallow cover between stations 95W and 10E. Volcanics crop out on each end of the line. These data (fig. 16) show a distinct resistivity boundary at 45W-50W between low resistivities to the southeast (50± ohm-m) which we associate with the unaltered Eleana and higher resistivities (150± ohm-m) to the northwest. Between 80W and 85W, another resistivity boundary appears to be present, but the data is insufficient to give it adequate definition. The frequency effect pseudosection shows relatively high polarizability west of station 50W.

One prominent feature observed in the Eleana Formation is a zone of slightly higher resistivity and increased polarizability between station 15W and 25W. The feature shows most distinctly in the PFE pseudosection where it is defined by large gradients along 45-degree lines beginning at 25W and 15W. Such an anomaly would be produced by a broad near-vertical zone between 15W and 25W containing material of increased polarizability. This is believed to be the electrical expression of the inferred northeast-trending fault along Topopah Wash. From 10E to about 35E a thin, high-resistivity horizon is seen. This correlates with volcanics crossed in outcrop along this portion of the line. The low resistivities seen at greater depth in the pseudosection imply that unaltered Eleana argillite underlies the volcanics.

In a broad sense, line CH 5 (fig. 17) shows a similar picture. At 25W-30W there is a contact between low-resistivity material, on the east corresponding to unaltered Eleana argillite and higher resistivity material on the west. Faulting has been mapped in the volcanics near 35W. The frequency effect pseudosection shows increased polarizability and appears in this same region suggesting alteration and possible mineralization. The southeastern

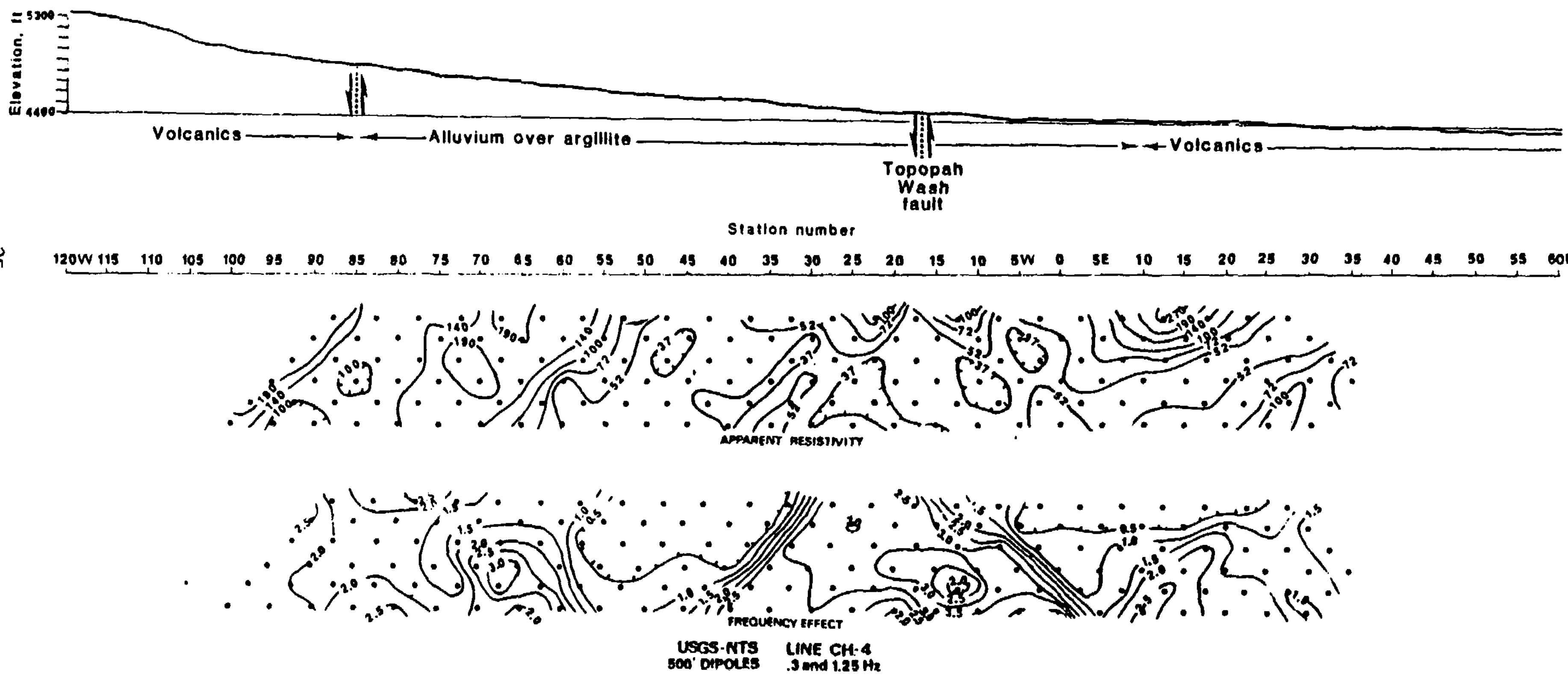

Figure 16. Induced polarization line CH 4 showing the surface lithologies and pseudosections. The resistivity pseudosection is contoured logarithmically and resistivities are in ohm-meters.

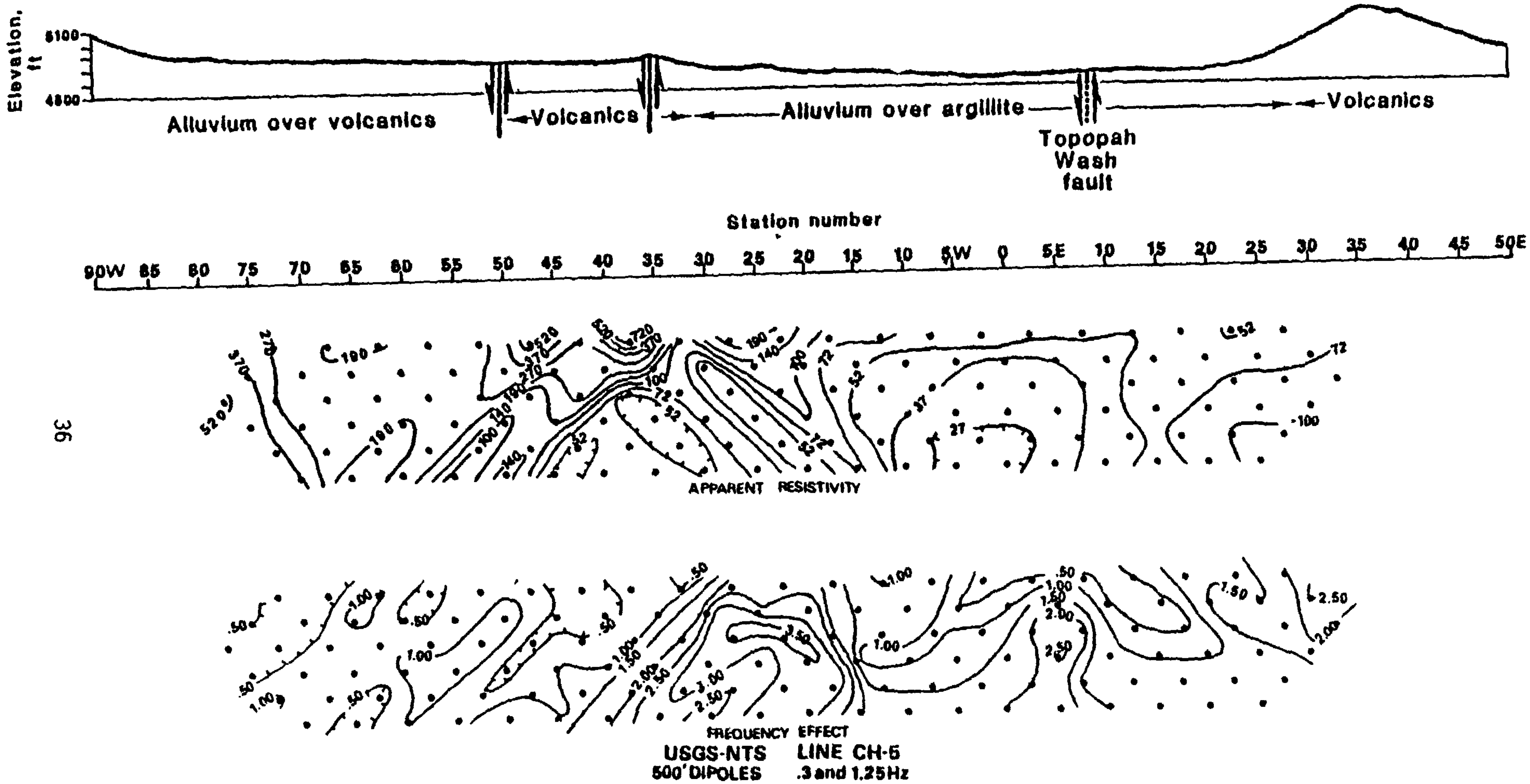

Figure 17. Induced polarization line CH 5 showing the surface lithologies and pseudosections. The resistivity pseudosection is contoured logarithmically and resistivities are in ohm-meters.

part of the line shows low resistivities (unaltered Eleana) and a narrow zone with significantly increased polarizability at about 5 E. This is believed to be the northeast extension of the fault inferred on line CH 4 at station 20 W.

Line CH 6 (fig. 18) was run across the northeastern part of Topopah Wash alluvium presumably overlying Eleana argillite is present along most of the line (25W to 80E) and Tertiary volcanics crop out on each end. Low resistivities seen in the pseudosection suggest that the subsurface consists of Eleana argillite except on the extreme southeastern end where the effect of higher resistivity, volcanic rocks appear. The central fault seen on CH 4 and 5 appears to cover a broader zone (30E to 50E) which may be due to branching of the fault. Modeling is needed to resolve some of the detail seen in the pseudosections. The zone of higher polarizability associated with the inferred central fault along Topopah Wash suggests that alteration and probably mineralization has occurred along the fault and into the surrounding rock.

Table 2 summarizes the major electrical parameters with their possible associated lithologies in the Calico Hills area. The low resistivity units (under 100 ohm-m) can with reasonable certainty be assigned to the Eleana argillite, and to narrow fault zones in the volcanics. Polarizability however for these low resistivity units can be either high or low. This suggests that local alteration and(or) mineralization has taken place that increases polarizability but not resistivity. Units of intermediate resistivity can be associated with either Eleana Formation or volcanics. The inability to distinguish these two distinct lithologies, when using electrical methods places a severe constraint on interpretation without the use of other geophysical data. The high-resistivity units can reliably be associated with volcanics at Calico Hills.

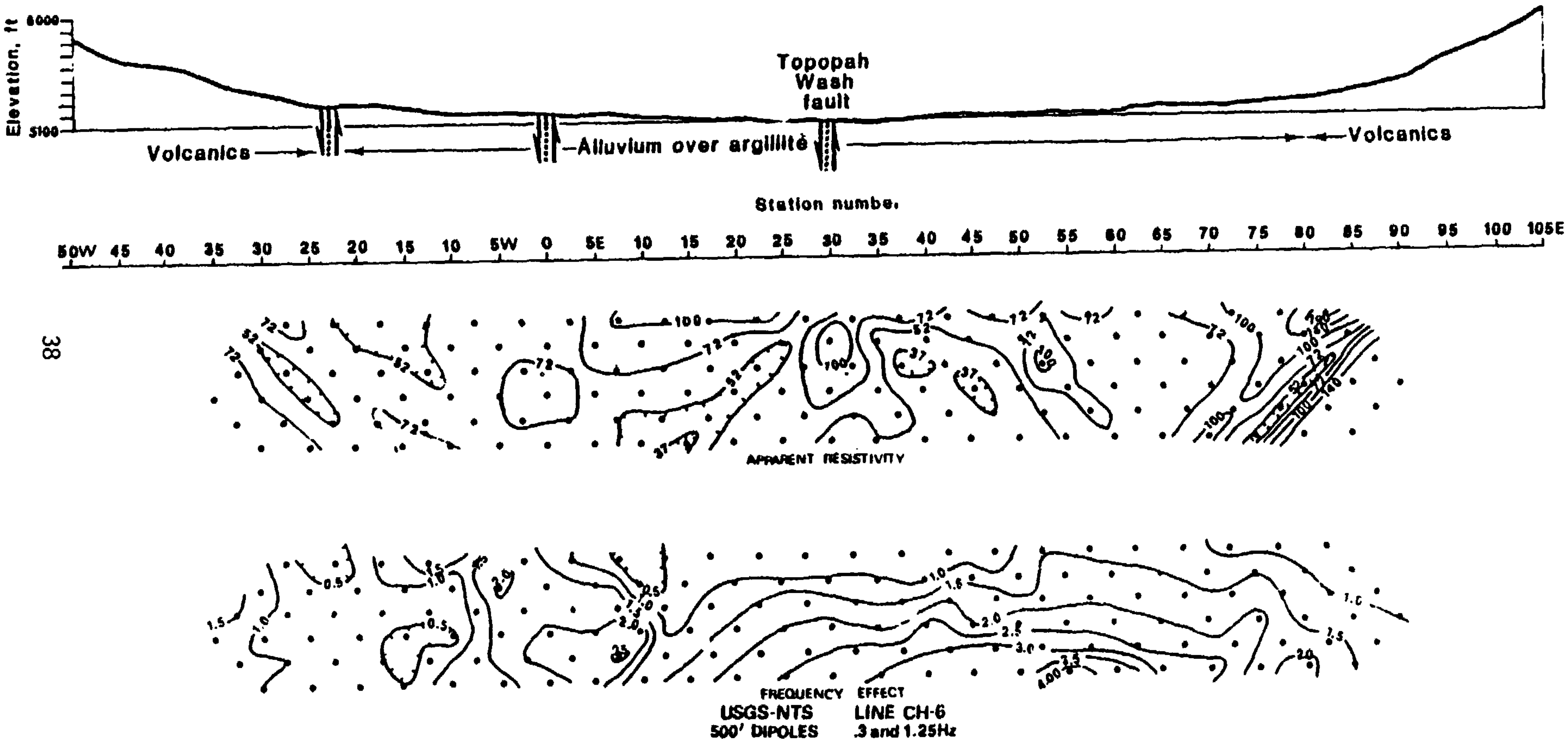

Figure 18. Induced polarization line CH 6 showing the surface lithologies and pseudosections. The resistivity pseudosection is contoured logarithmically and resistivities are in ohm-meters.

Table 2.--General geoelectric parameters and possible correlative lithologies

Polarizability less than 1.5% is considered low

and greater than 1.5% is considered high

Resistivity (ohm-m)	Polarizability	Lithology
Low (less than 100, average 50)	low	Eleana argillite
Low	high	Eleana argillite with hydrothermal? alteration
Intermediate 100-250	low	Thermally altered Eleana, argillite, or fractured, partially altered Tertiary volcanics
Intermediate	high	Fractured and altered volcanics, altered Eleana argillite
High 500 and greater	low	Volcanics relatively unfractured and unaltered Devonian limestone, or Tertiary intrusive dikes

Magnetotelluric Data

Sixty magnetotelluric (MT) soundings within the NTS area provide information on the variation in the geoelectric section within the crust and upper mantle. The frequency range used was 25 Hz to 0.003 Hz. The complete results are given in a report submitted to the USGS (Williston McNeil and Assoc. 1979). Five stations were occupied on or near the Calico Hills dome (fig. 12.); the results of the one-dimensional inversion of these data are on figure 19. Owing to known data distortions and geologic complexity the results should be considered in a semi-quantitative sense.

The results support the existence of a deep and thick, high-resistivity body beneath stations 14, 13, and 19. The modeled intrinsic resistivities are in the range of 3500-6200 ohm-m, an appropriate range for dense igneous rocks or metamorphic basement. The top of the resistive body given by the one-dimensional inversion at stations 13 and 19 is 2.7 km (9000 ft) and the bottom at 100 km. It is possible that the top of the resistivity body seen in this geoelectric model represents the buried intrusive, which was responsible for the uplift and alteration of the overlying units.

Conclusions

The inferences made from the present electrical data have not been adequately constrained by other geophysical data. The electrical data however do suggest some general conclusions.

Intrusive bodies are probably present at both sites, very shallow at Wahmonie and deep at Calico Hills. At Wahmonie the inferred intrusive shows a relatively simple geoelectric picture, although at least one fault is present with significant vertical offset. At Calico Hills the geoelectric section appears significantly more complex and probably comprises principally the Eleana Formation and various Tertiary volcanic units. The complexity is due

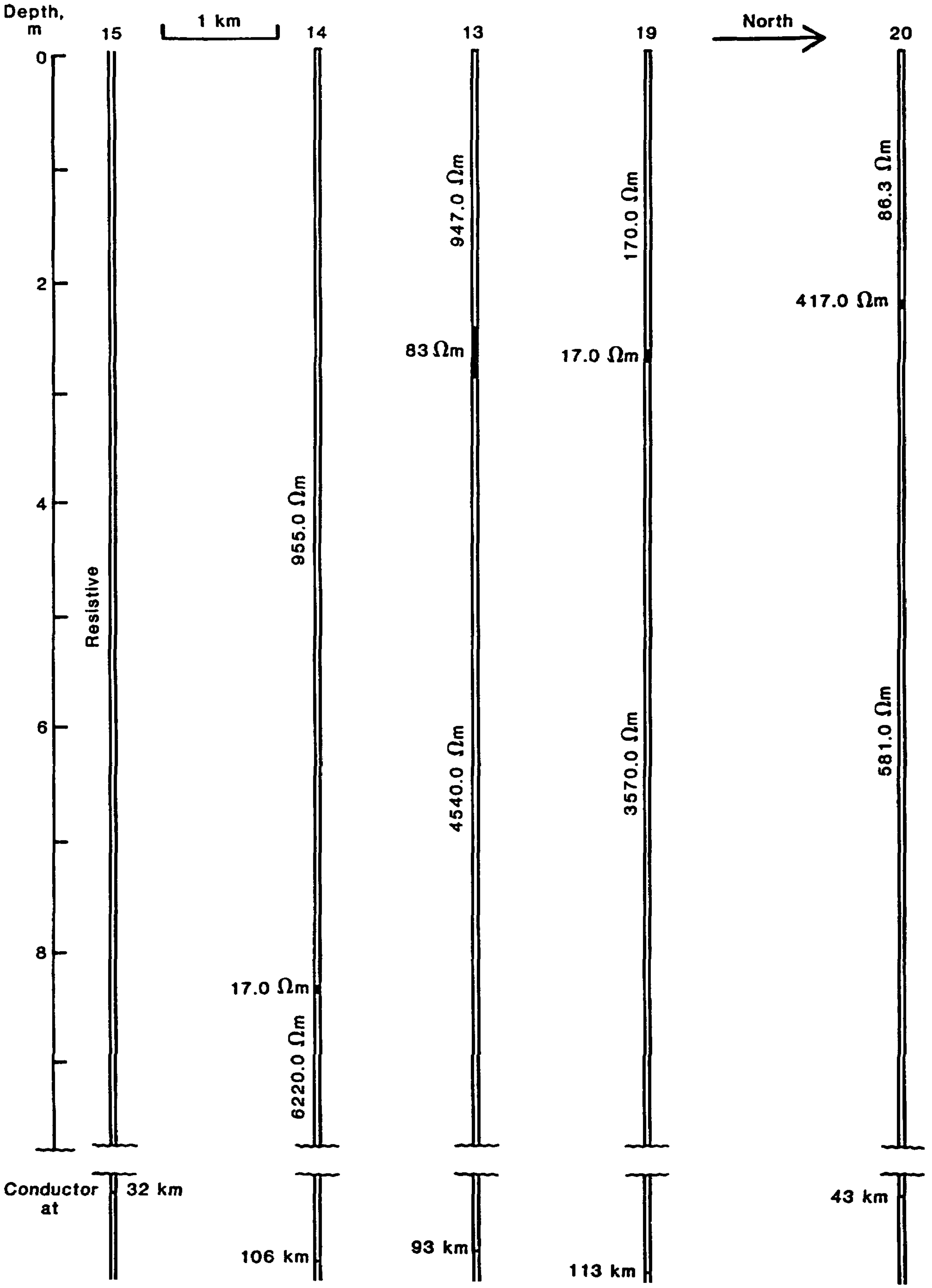

Figure 19. Geoelectric cross-section derived from one-dimensional inversion of magnetotelluric data at Calico Hills.

to structure and to metamorphism. Hydrothermal processes have significantly altered the electrical properties of various rock units. There are indications that sulfide mineralization is present at both sites. The inferred extent and grade of mineralization at the Wahmonie site is such as to make it an attractive economic exploration target. These results imply that the two sites studied have serious short comings for the emplacement of nuclear waste.

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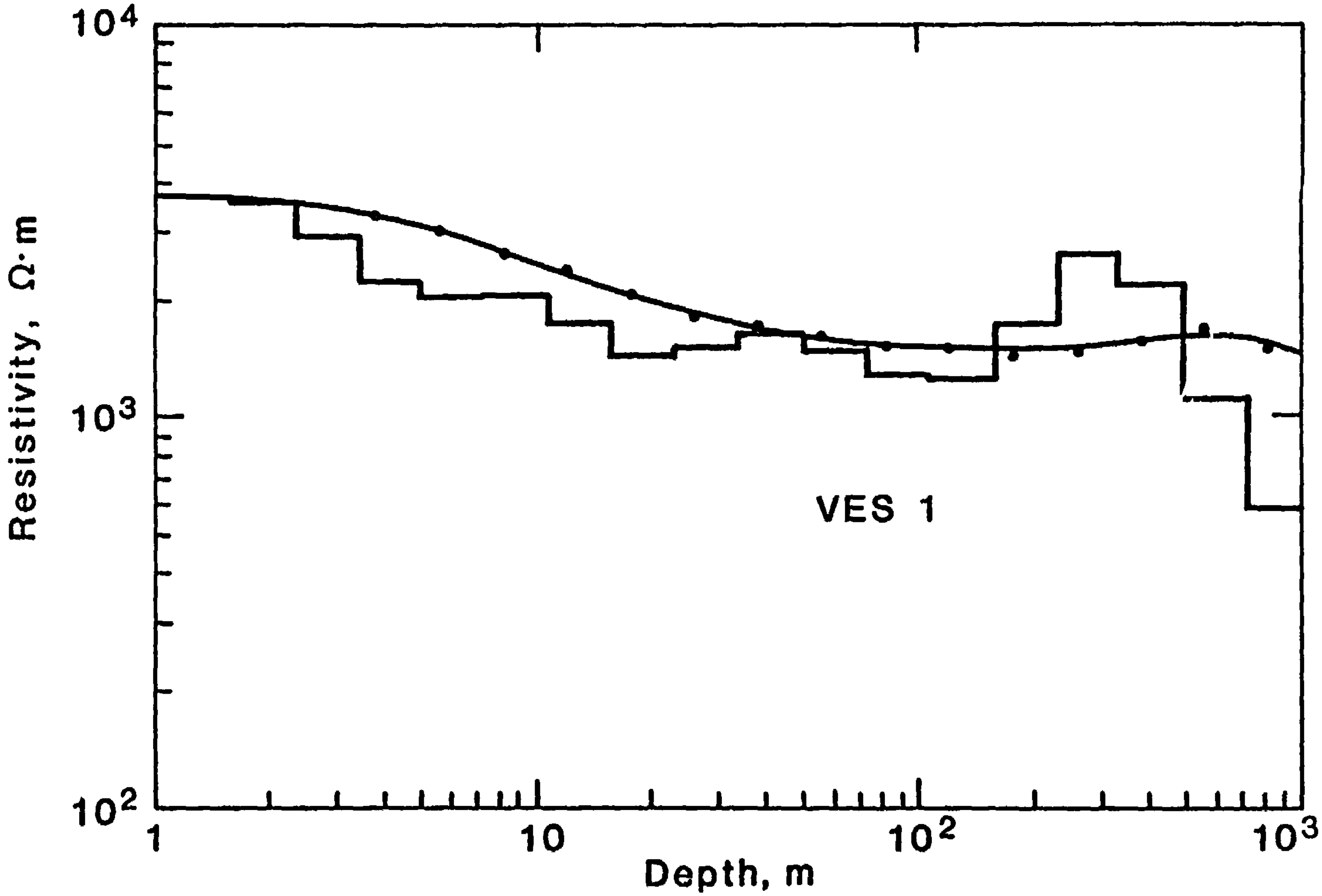
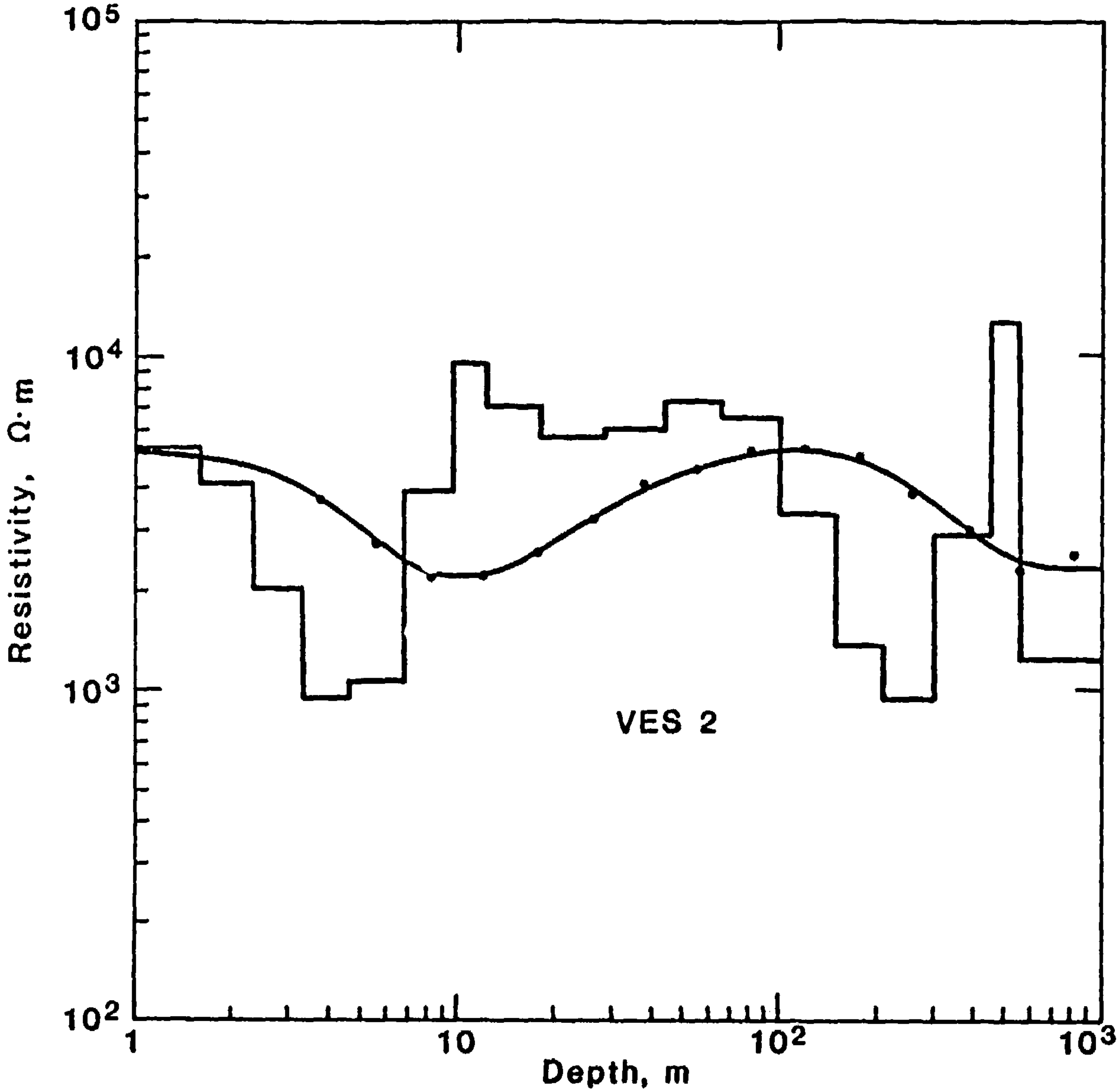
Appendix 1

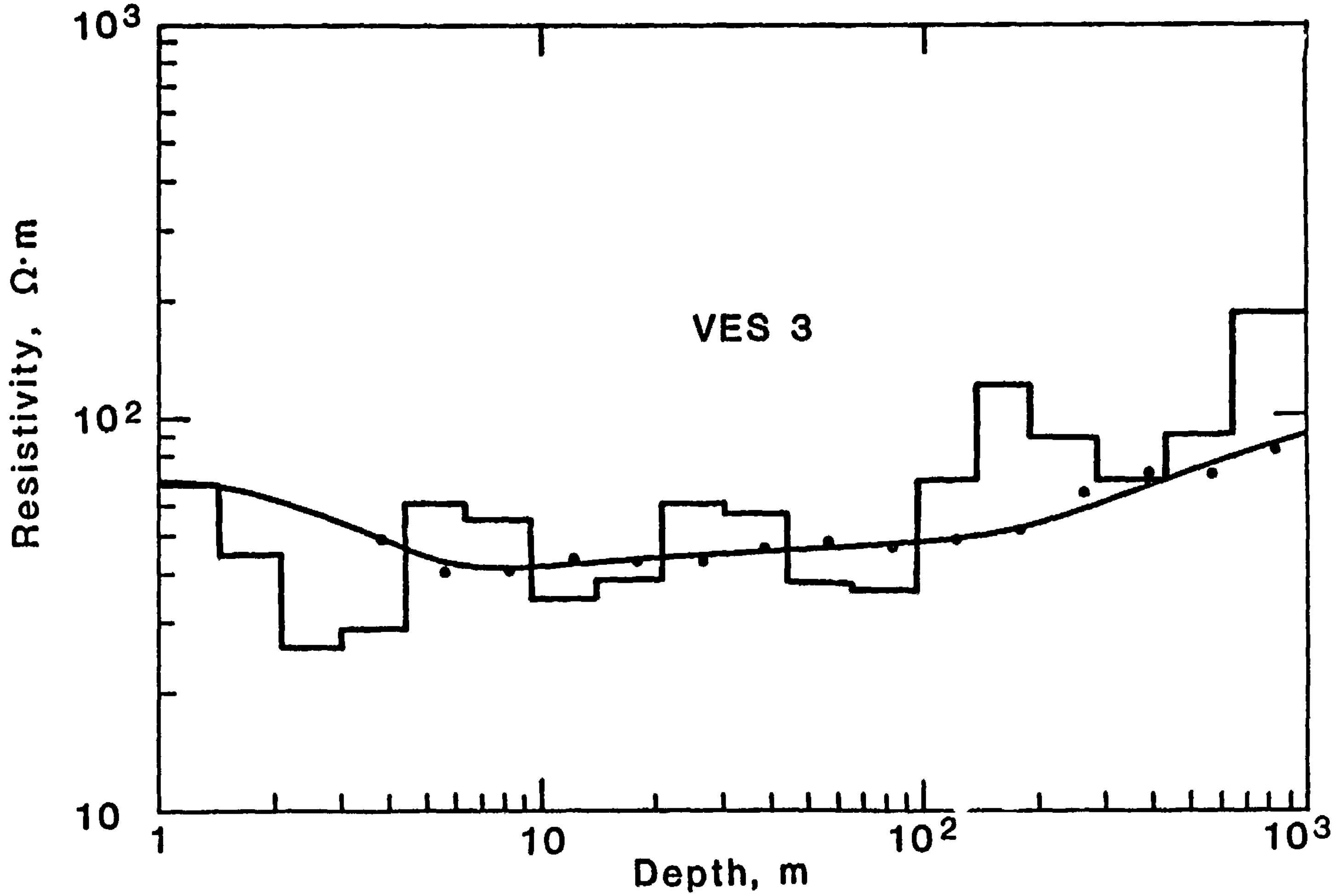
Vertical electrical soundings, VES, 1 through 23, 28, 79-1 through 79-10 and H8, H9, and H10 represent all the VES data obtained at the Calico Hills and Wahmonie area. Additionally VES 24, 25, 26, 27, and 29 are soundings made in Jackass Flat. On each graph the crosses represent the data shifted (Zohdy, 1974) to adjust for jumps when the MN spacing is changed. The plus symbols are theoretical data points on the Dar Zarrouk curve. The columnar graph is the computed one-dimensional model fit to the field data with the horizontal segments representing the intrinsic resistivity of each individual layer. The program gives one layer for each data point except at the upper surface where the curve is extrapolated. The solid curved line is the fit of the model to the data.

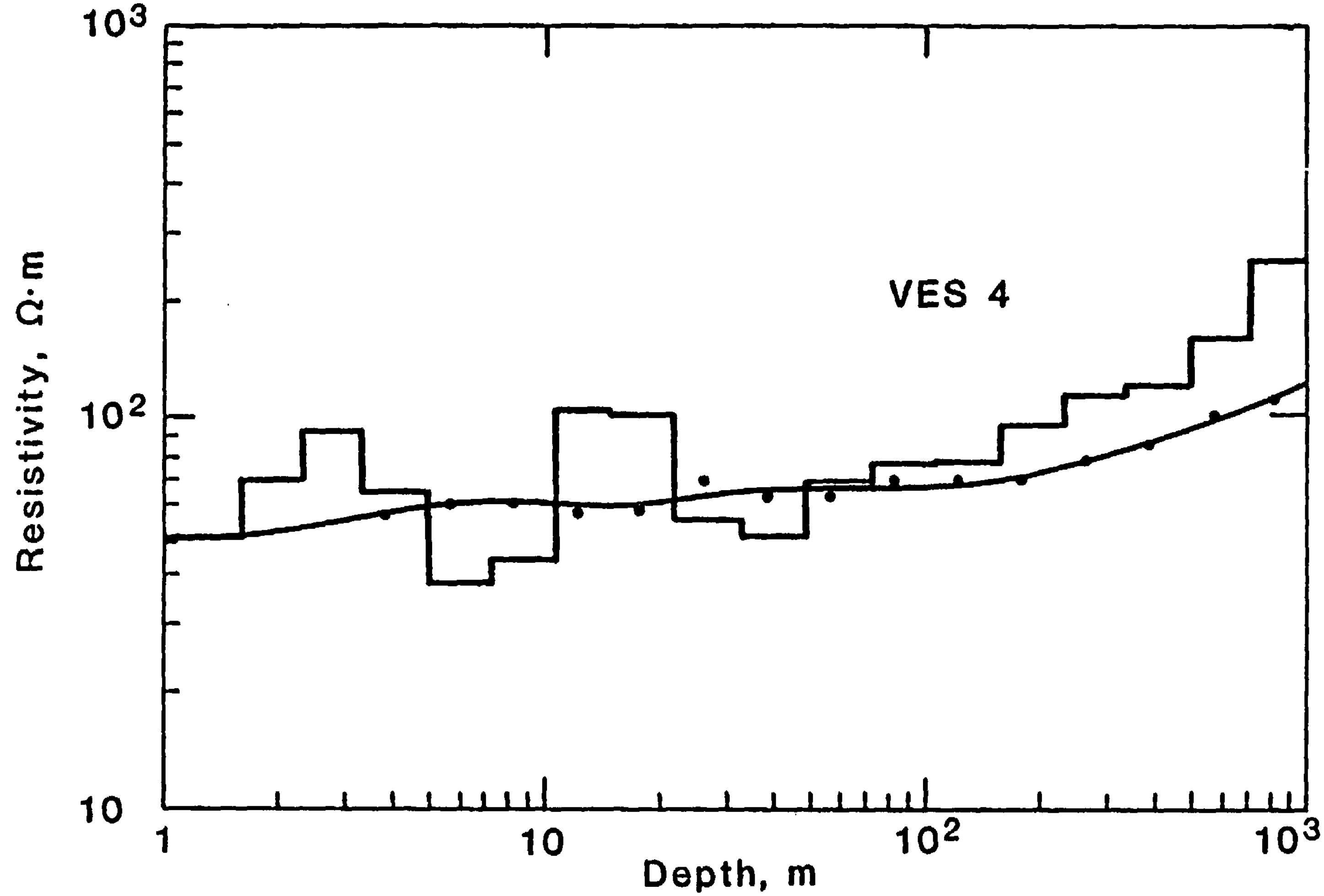


10^4
10^3
10^2
Resistivity, Ω·m
VES 1
1
10
10^2
10^3
Depth, m

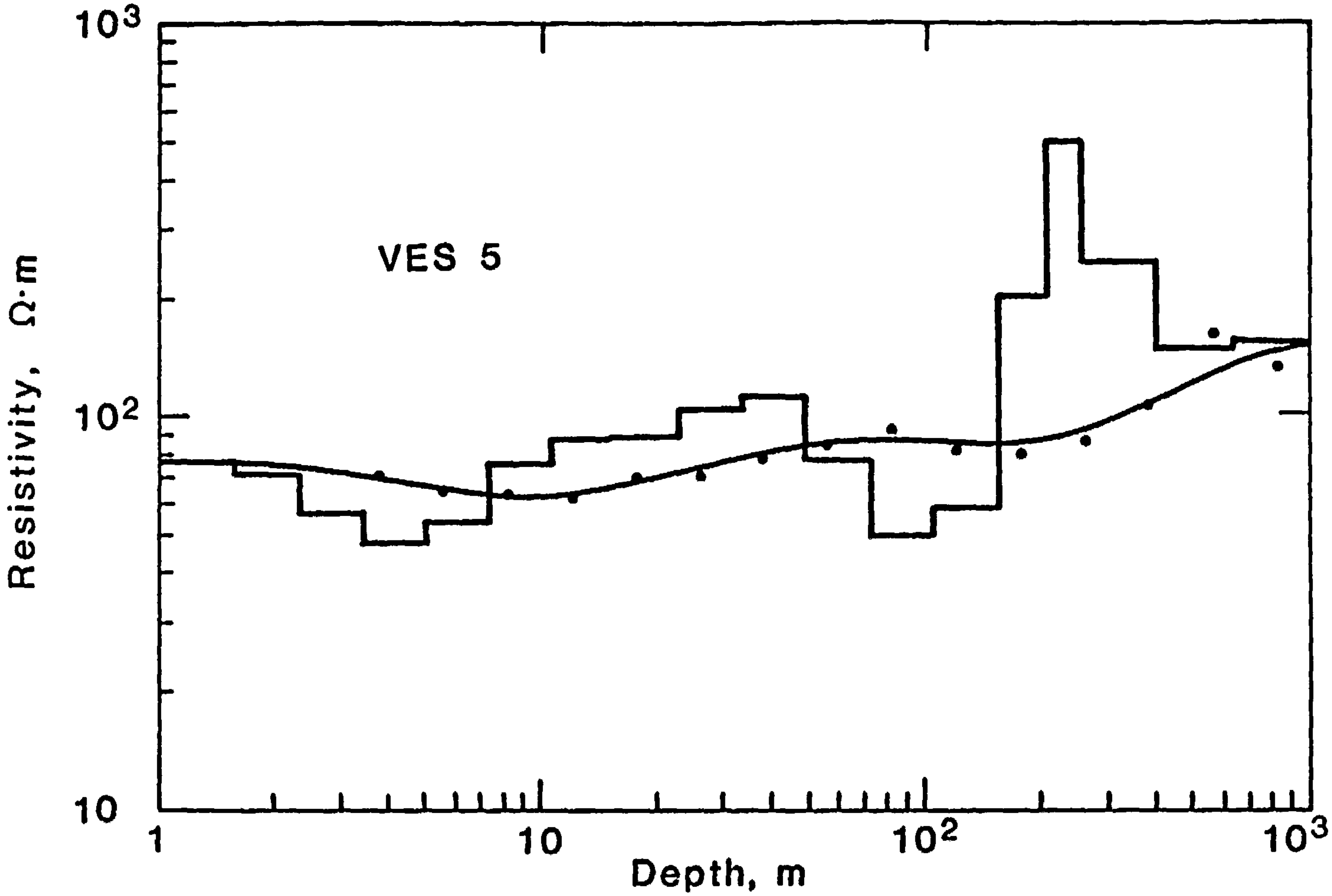


10^5
10^4
10^3
10^2
Resistivity, Ω·m
VES 2
1
10
10^2
10^3
Depth, m

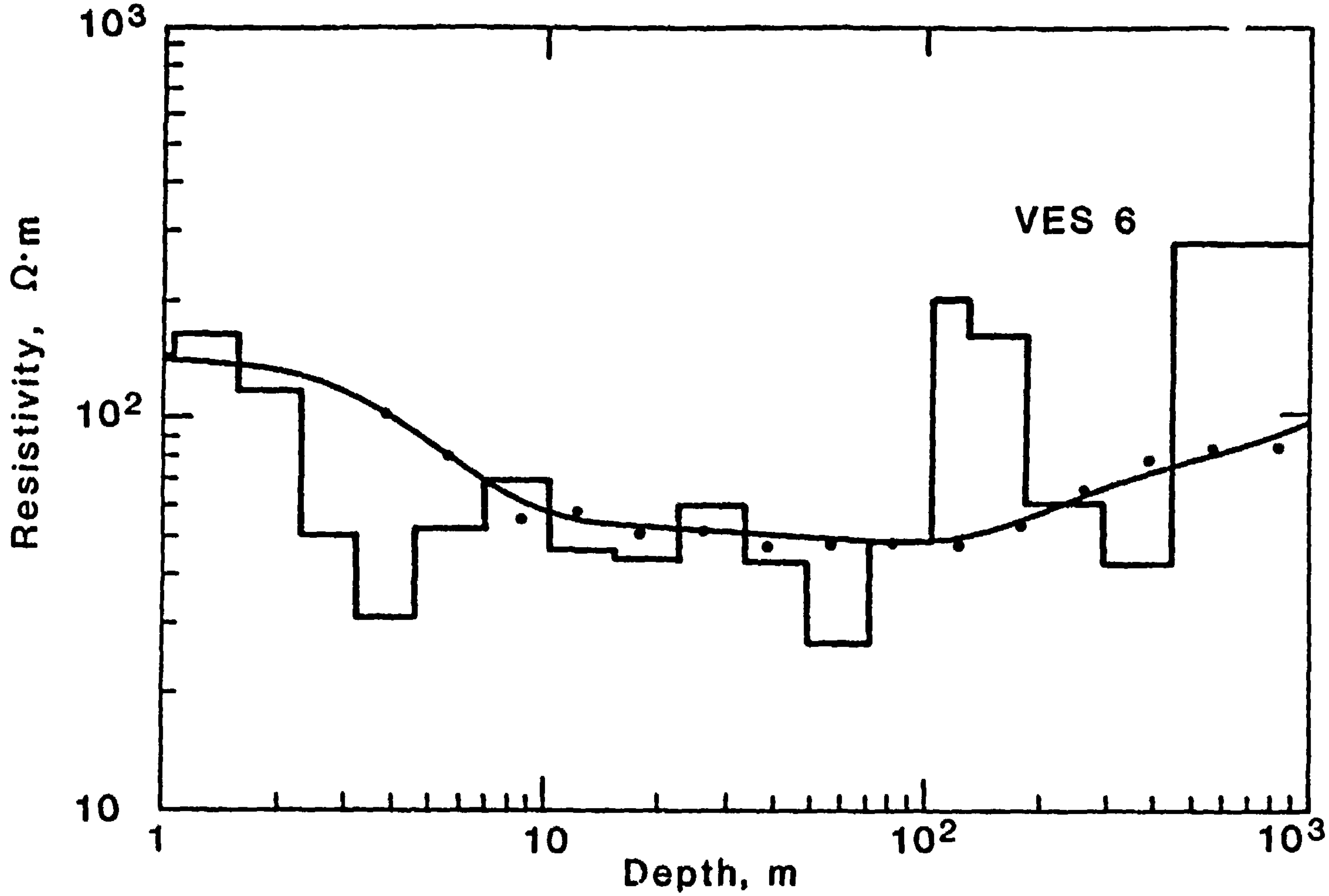

VES 3
Resistivity, Ω·m
Depth, m
10
10²
10³
1
10
10²
10³



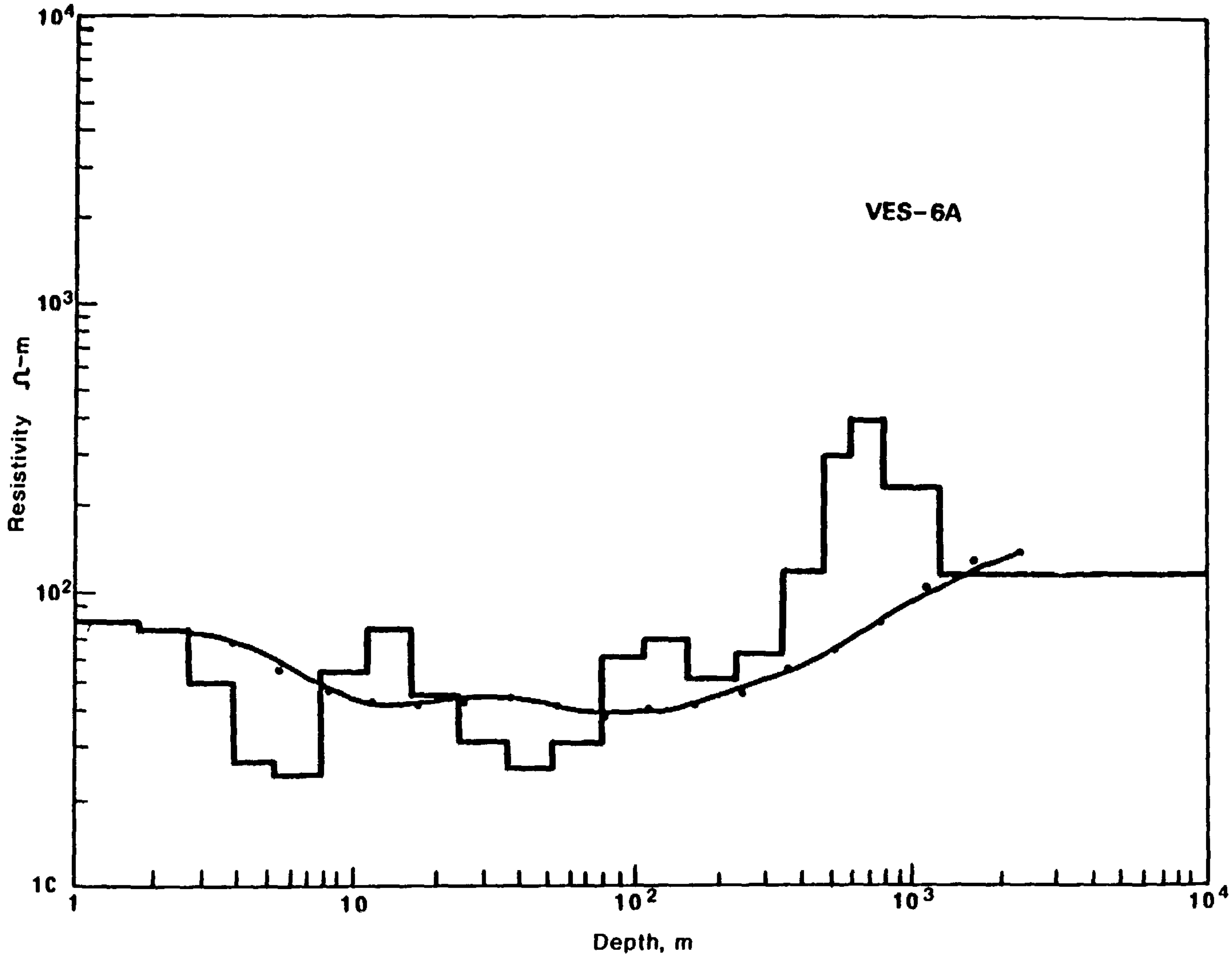
VES 4
Resistivity, Ω·m
Depth, m
10³
10²
10
1
10
10²
10³



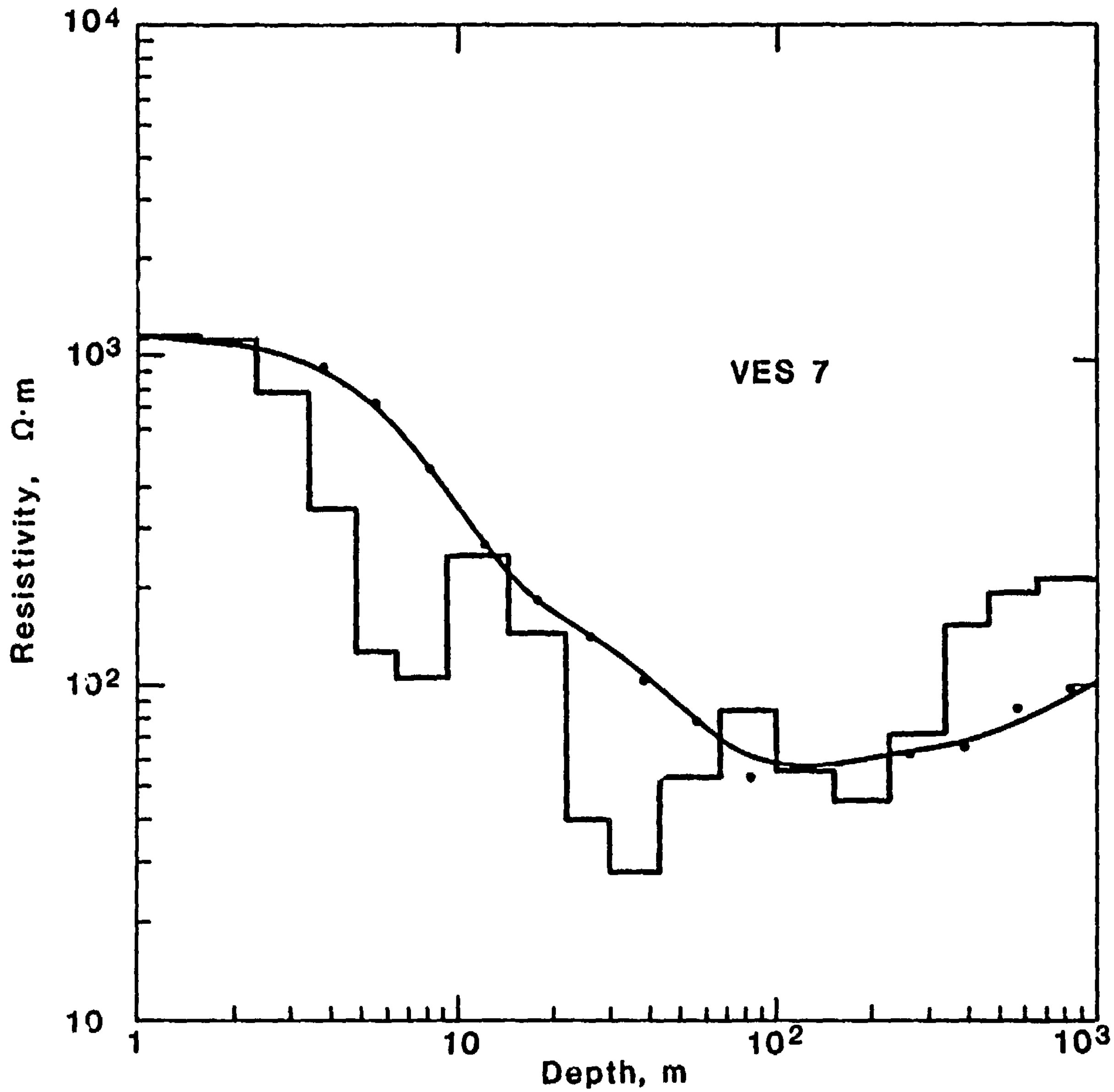
VES 5
Resistivity, Ω·m
Depth, m
10³
10²
10
1
10
10²
10³



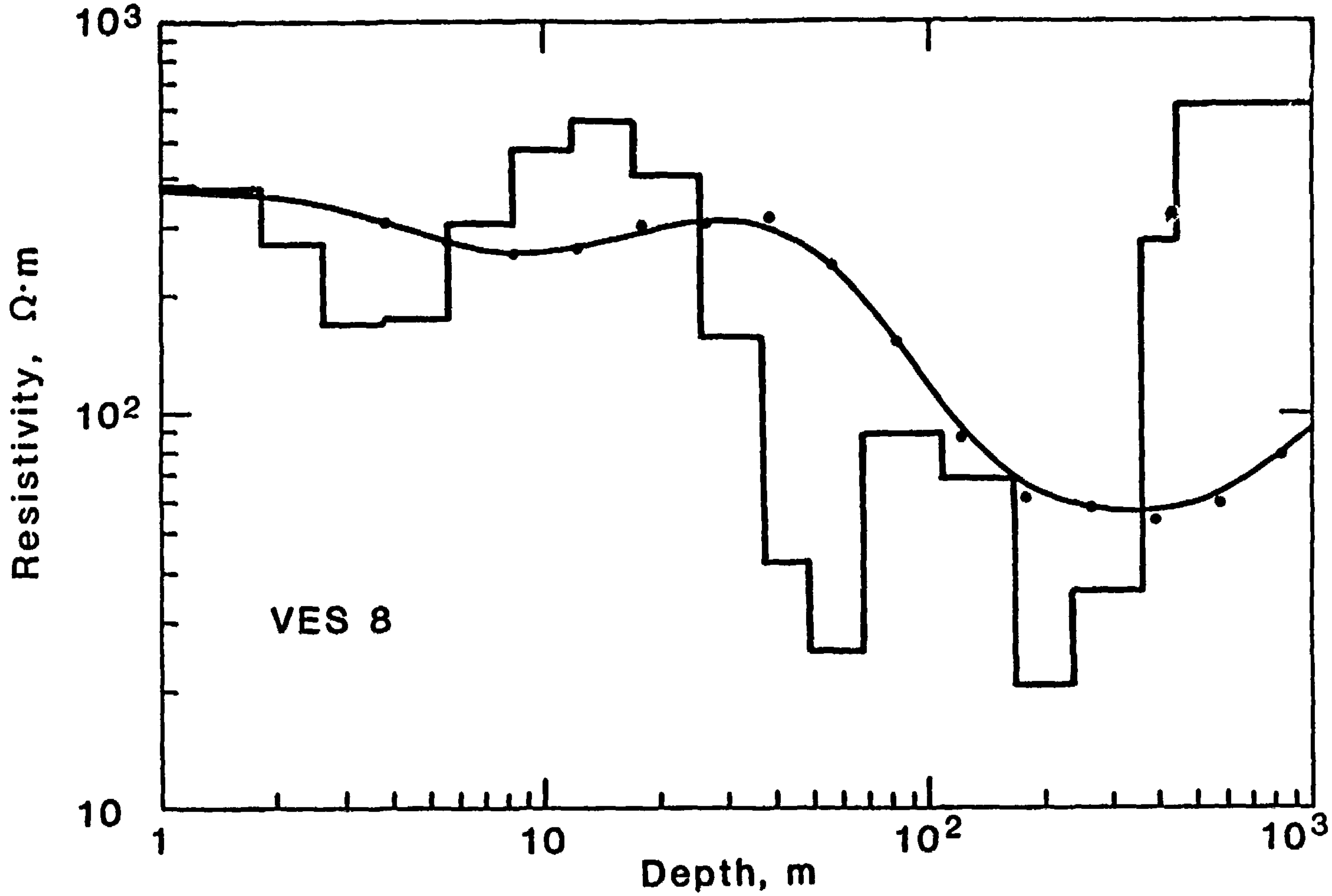
VES 6
Resistivity, Ω·m
Depth, m
10
10²
10³
1
10
10²
10³



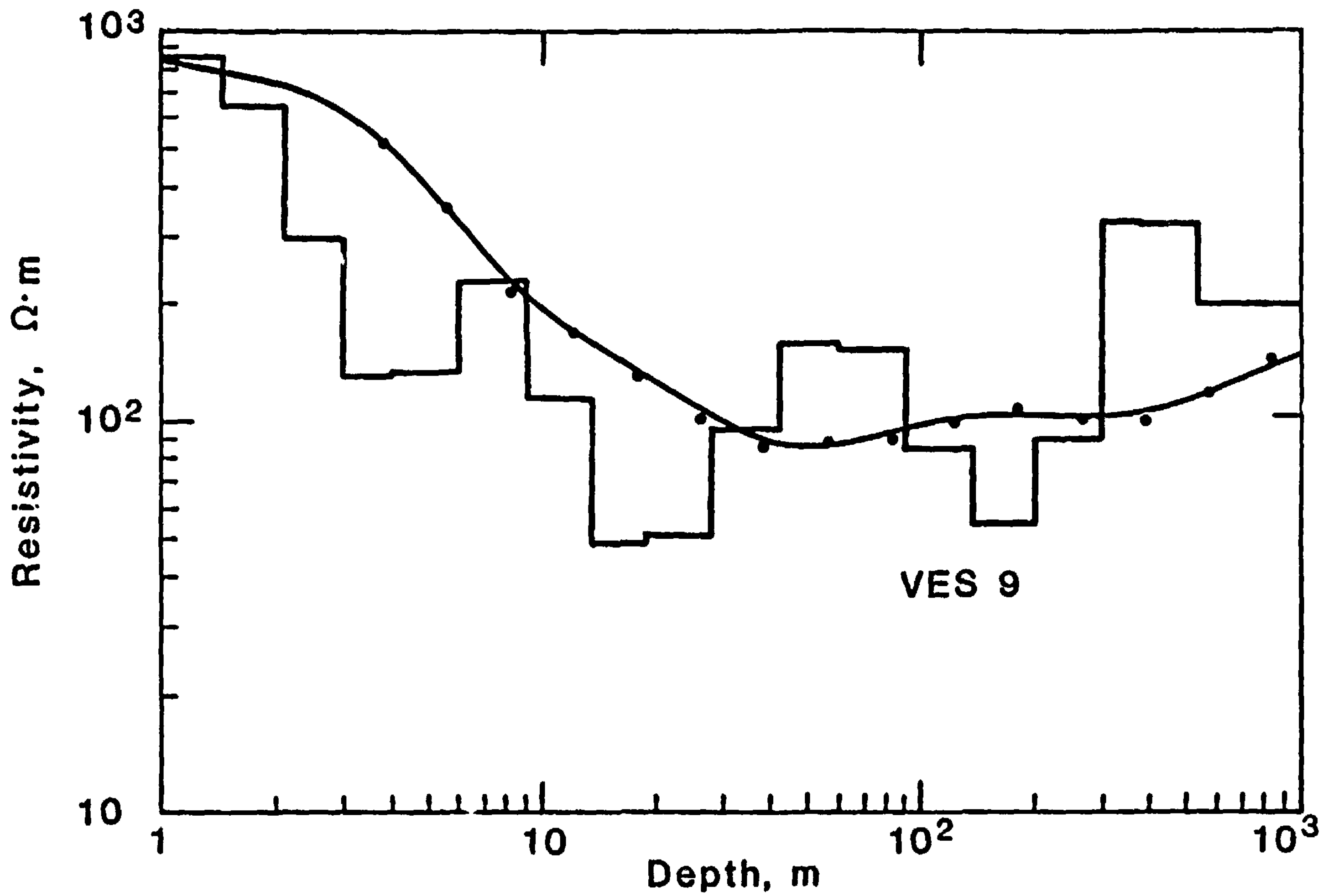
VES-6A
Resistivity Ω-m
Depth, m
10^4
10^3
10^2
1C
1
10
10^2
10^3
10^4



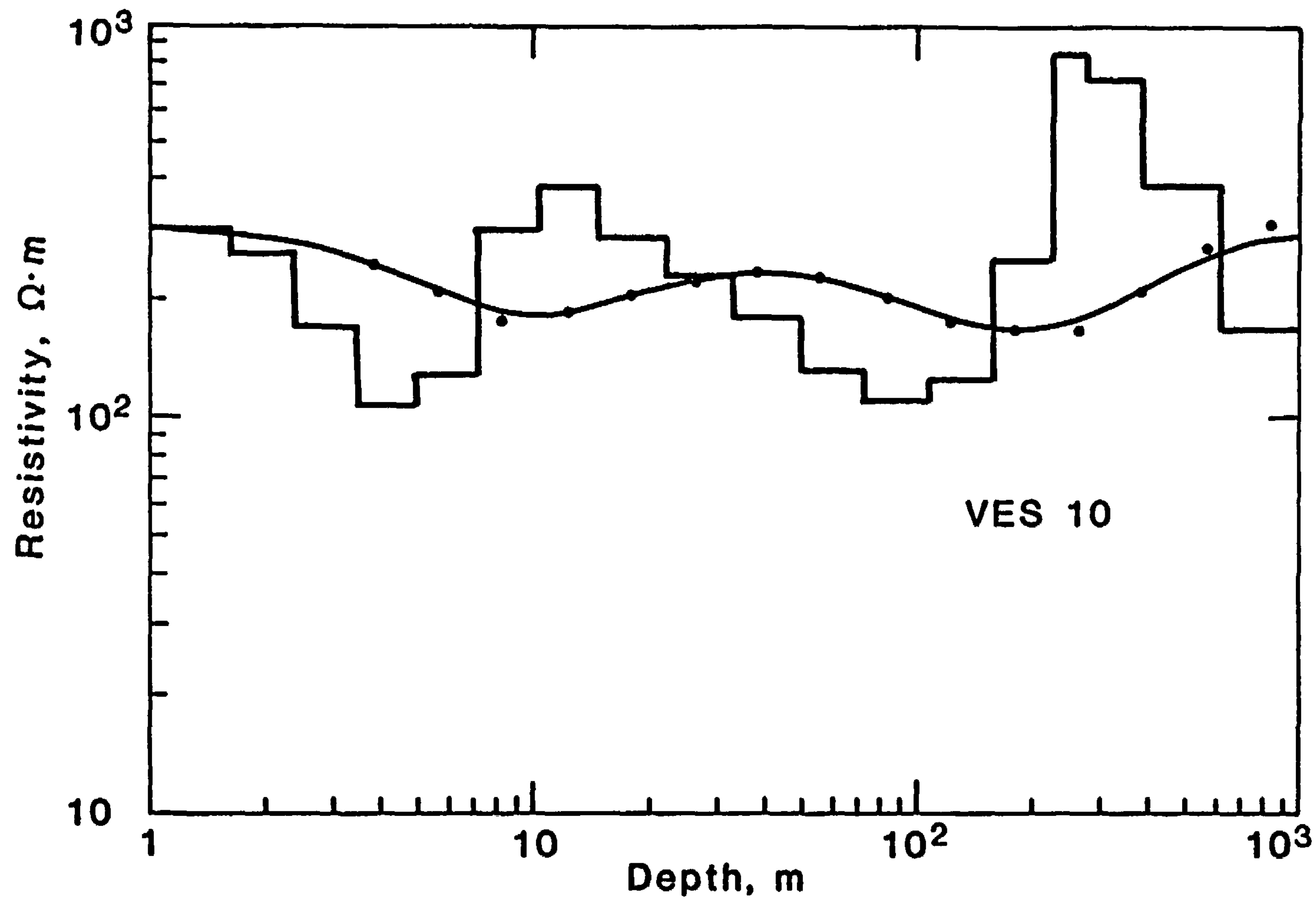
VES 7
Resistivity, Ω·m
10^4
10^3
10^2
10
Depth, m
1
10
10^2
10^3



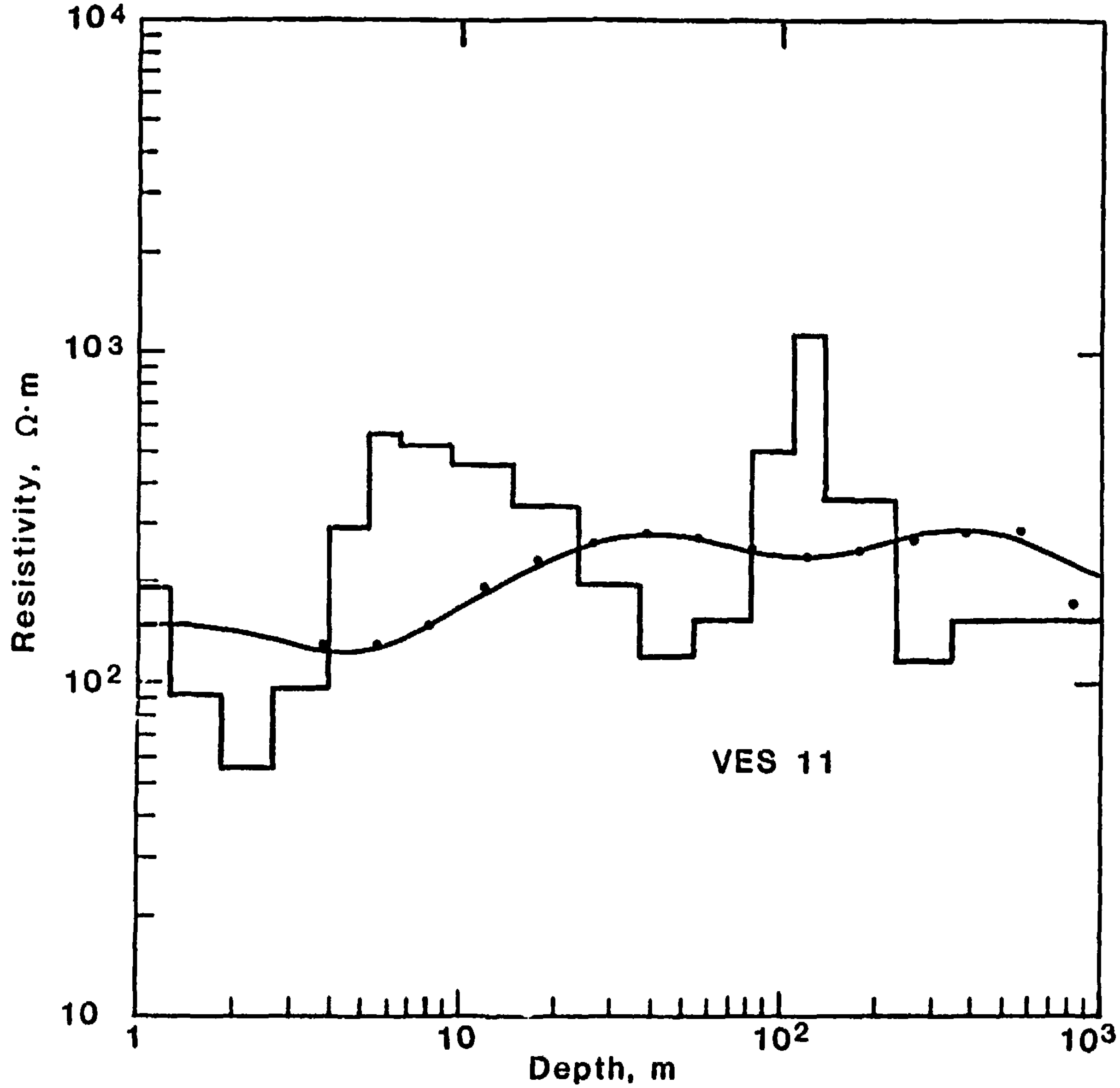
VES 8
Resistivity, Ω·m
Depth, m
10³
10²
10
1
10
10²
10³



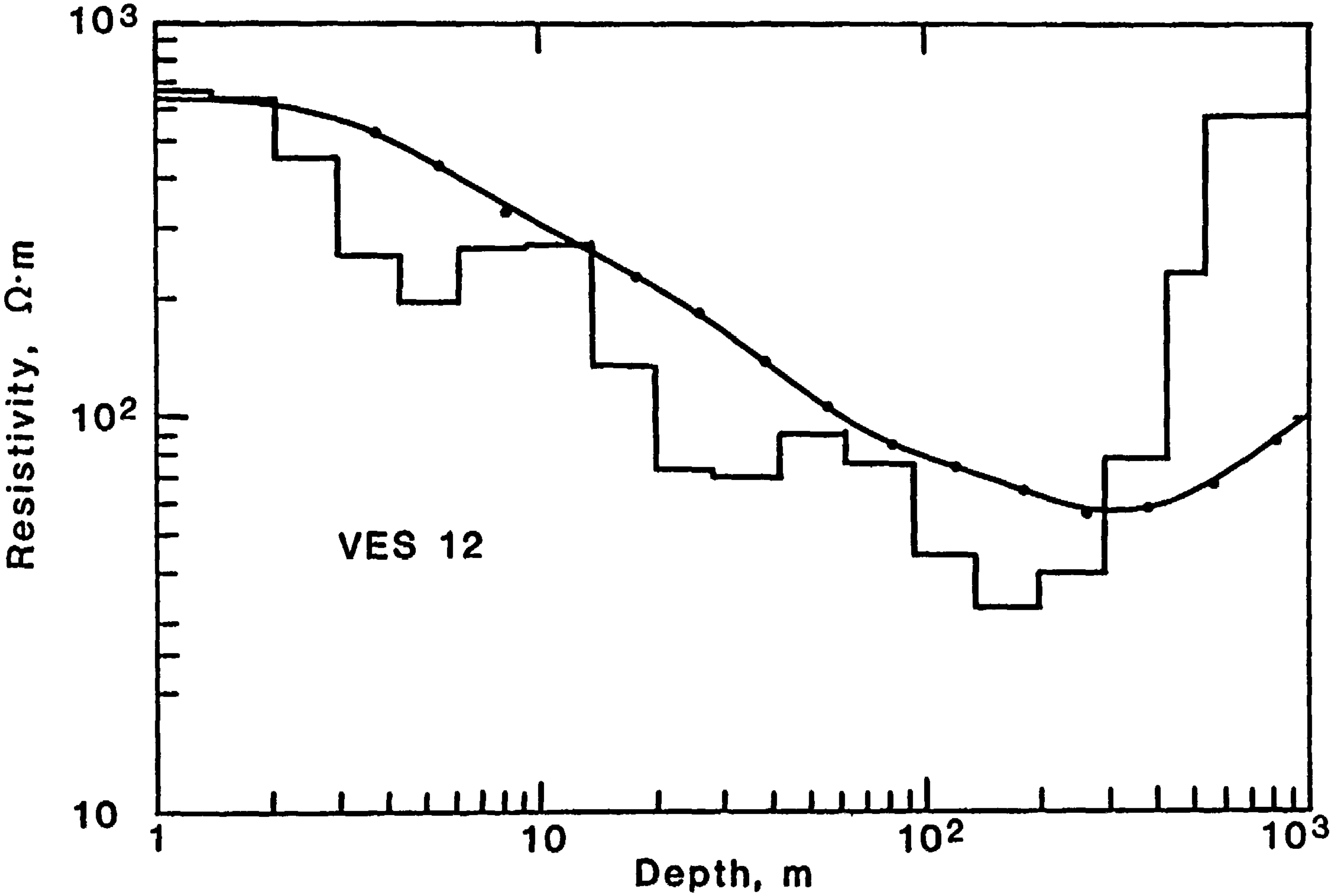
10^3
10^2
10
Resistivity, Ω·m
VES 9
1
10
10^2
10^3
Depth, m



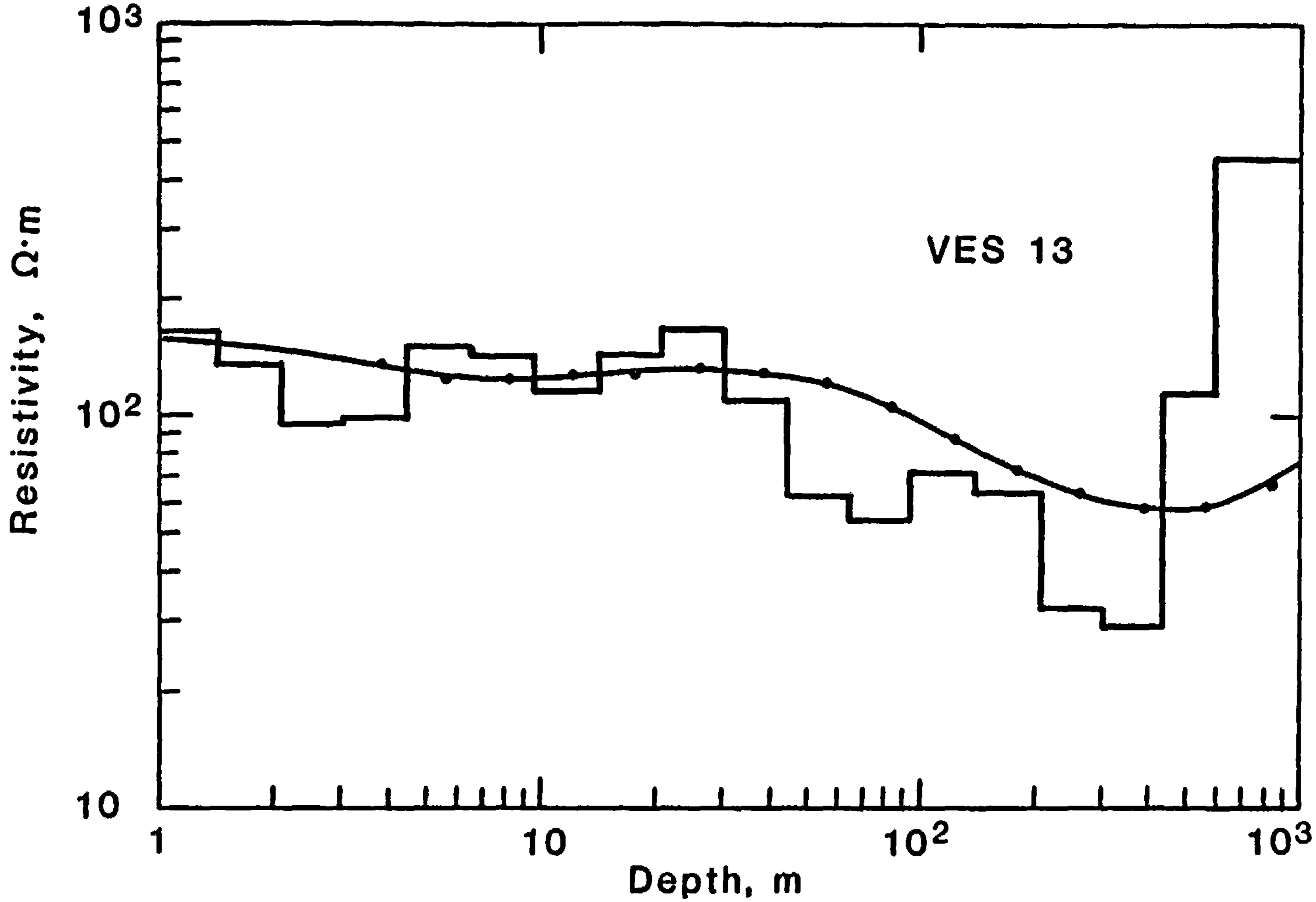
10^3
10^2
10
Resistivity, Ω·m
VES 10
1
10
10^2
10^3
Depth, m



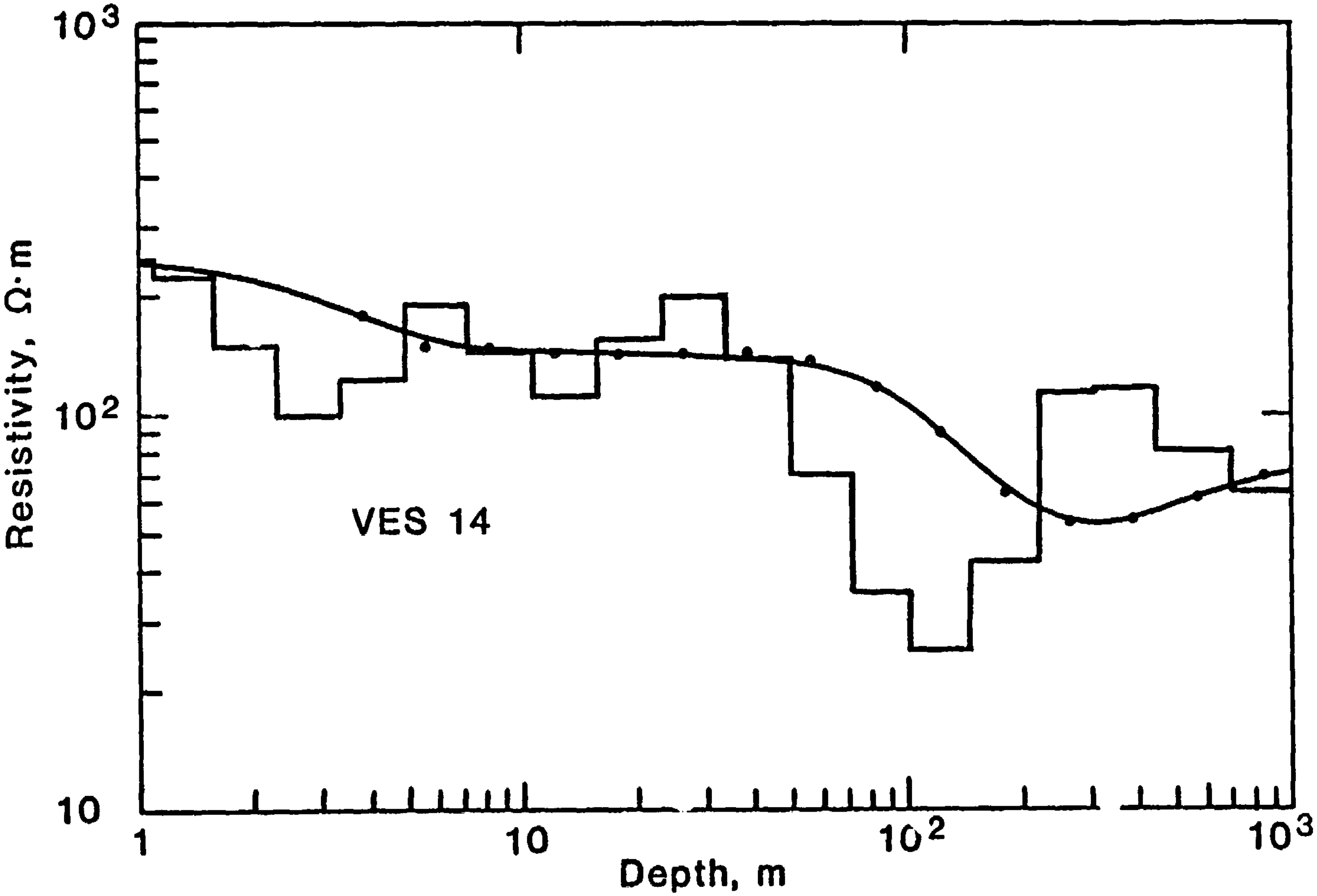
10⁴
10³
10²
10
Resistivity, Ω·m
1
10
10²
10³
Depth, m
VES 11



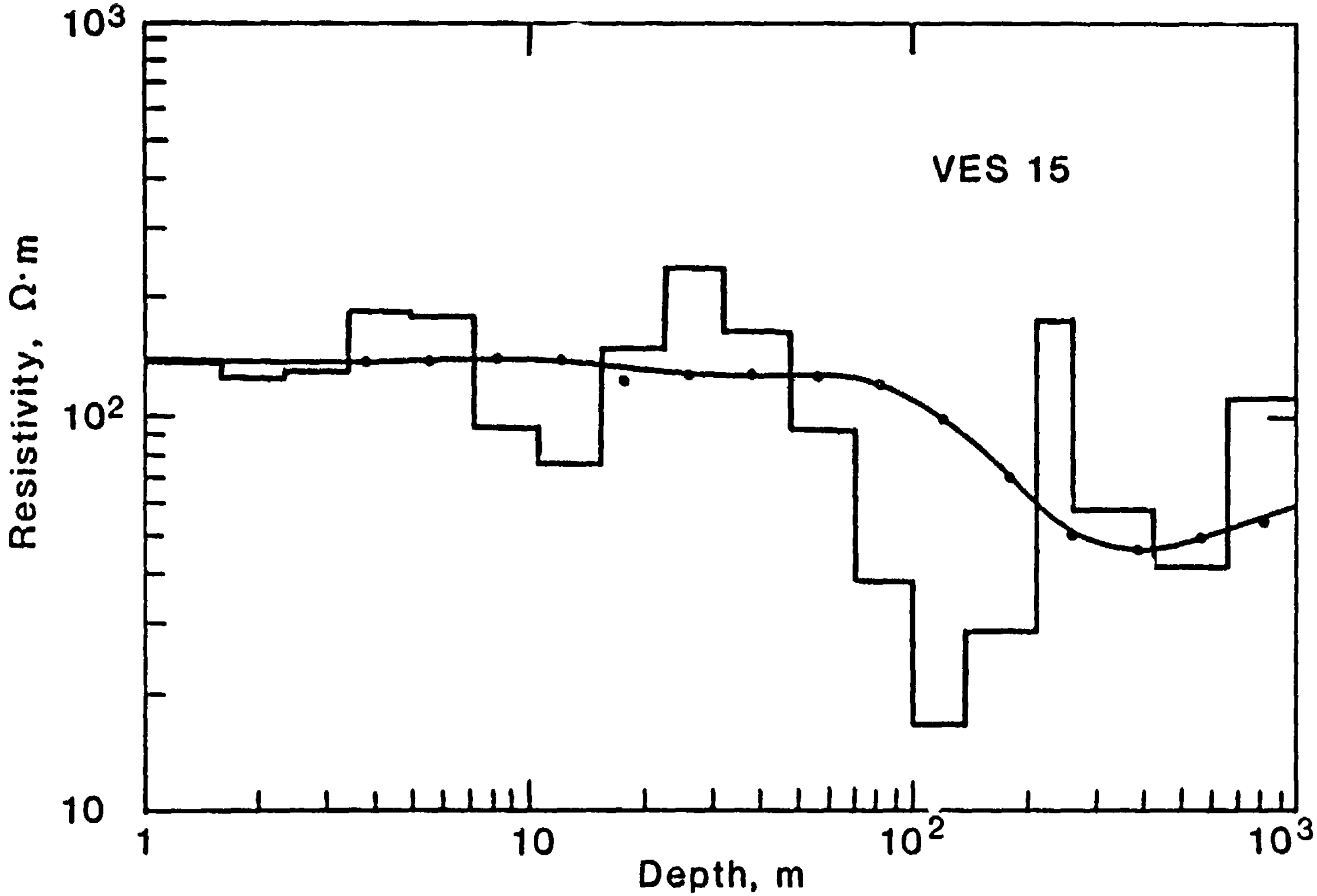
10³
10²
10
Resistivity, Ω·m
VES 12
1
10
10²
10³
Depth, m



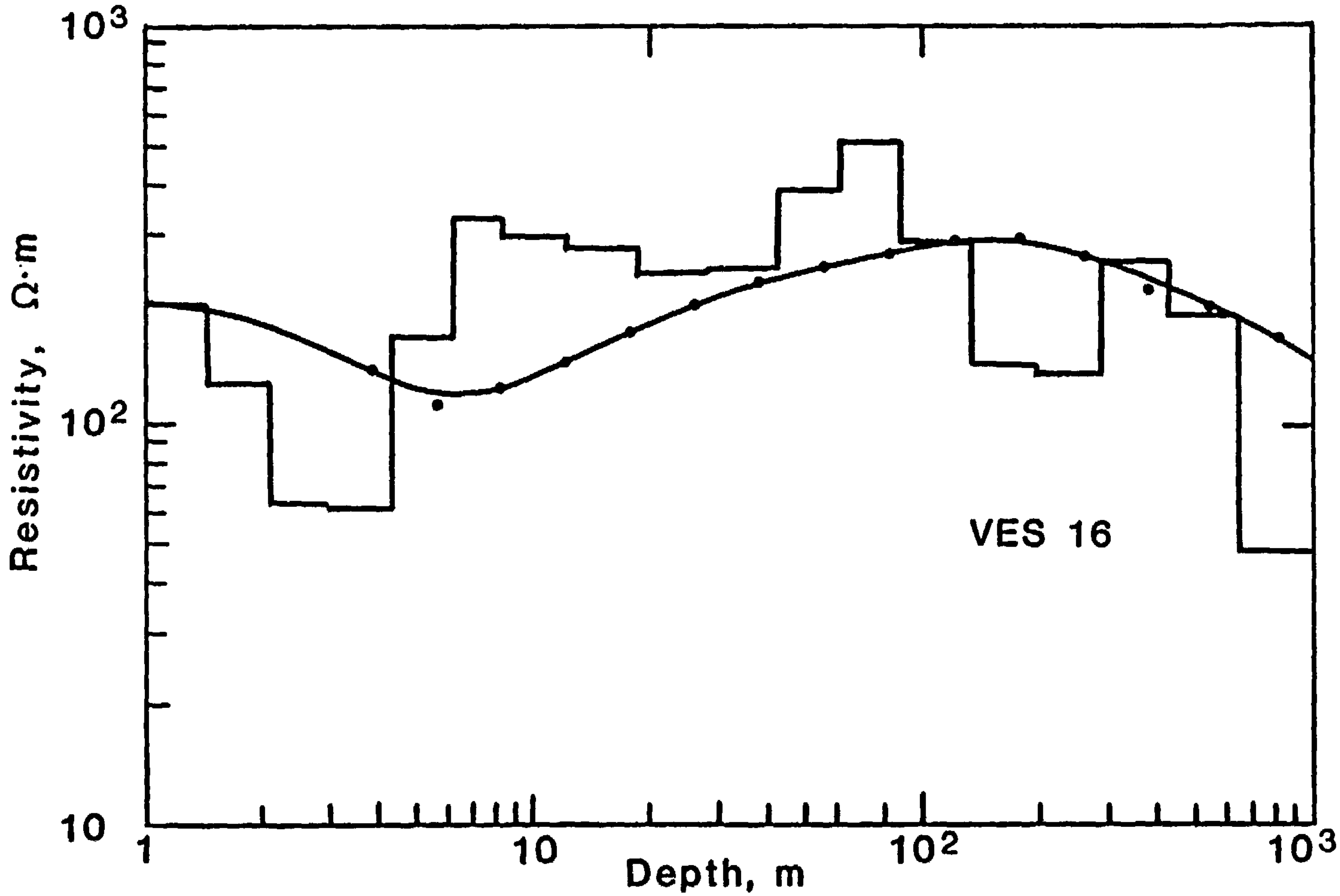
VES 13
Resistivity, Ω·m
10³
10²
10
1
10
10²
10³
Depth, m



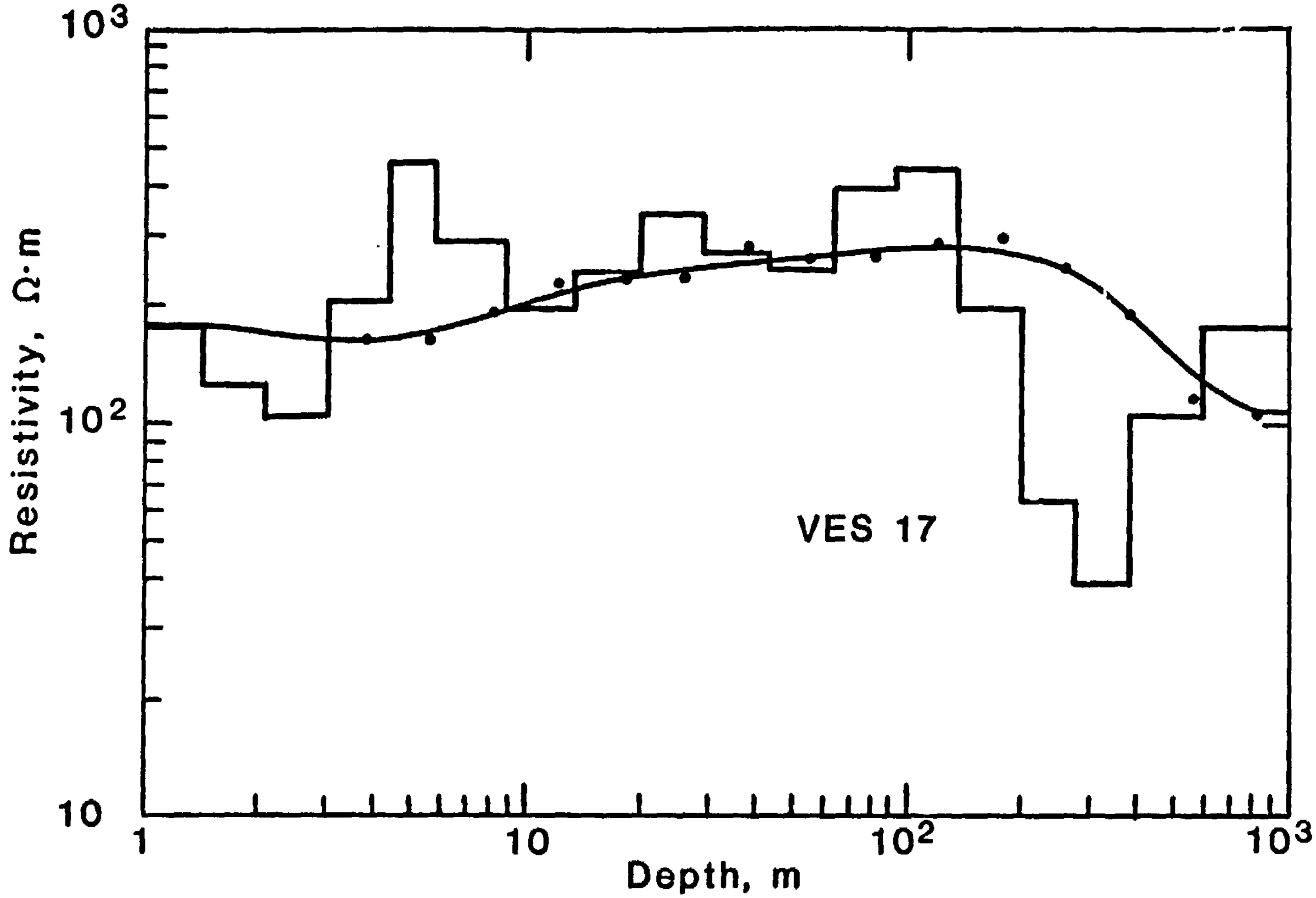
10³
10²
10
Resistivity, Ω·m
VES 14
1
10
10²
10³
Depth, m



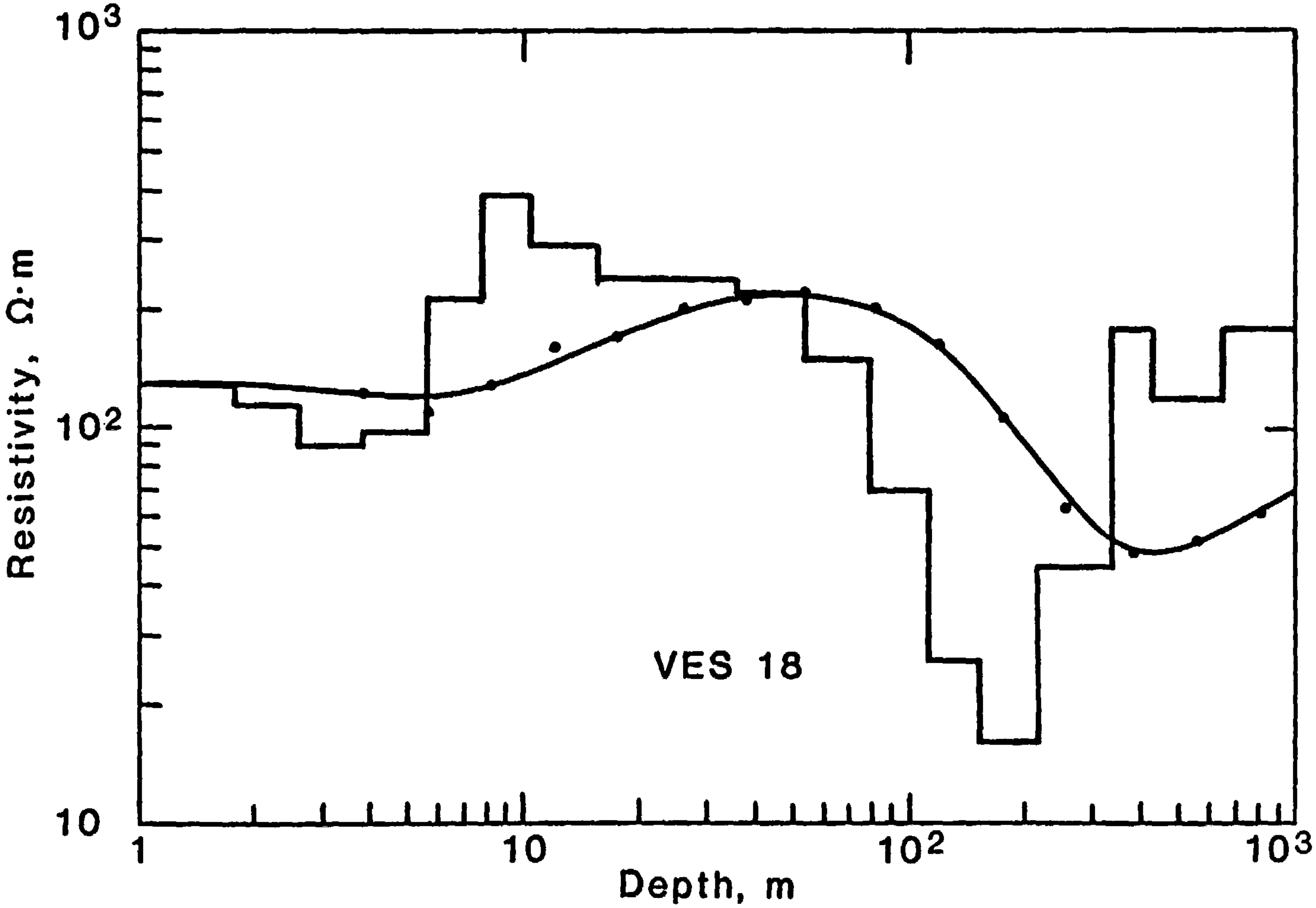
VES 15
Resistivity, Ω·m
Depth, m
10³
10²
10
1
10
10²
10³



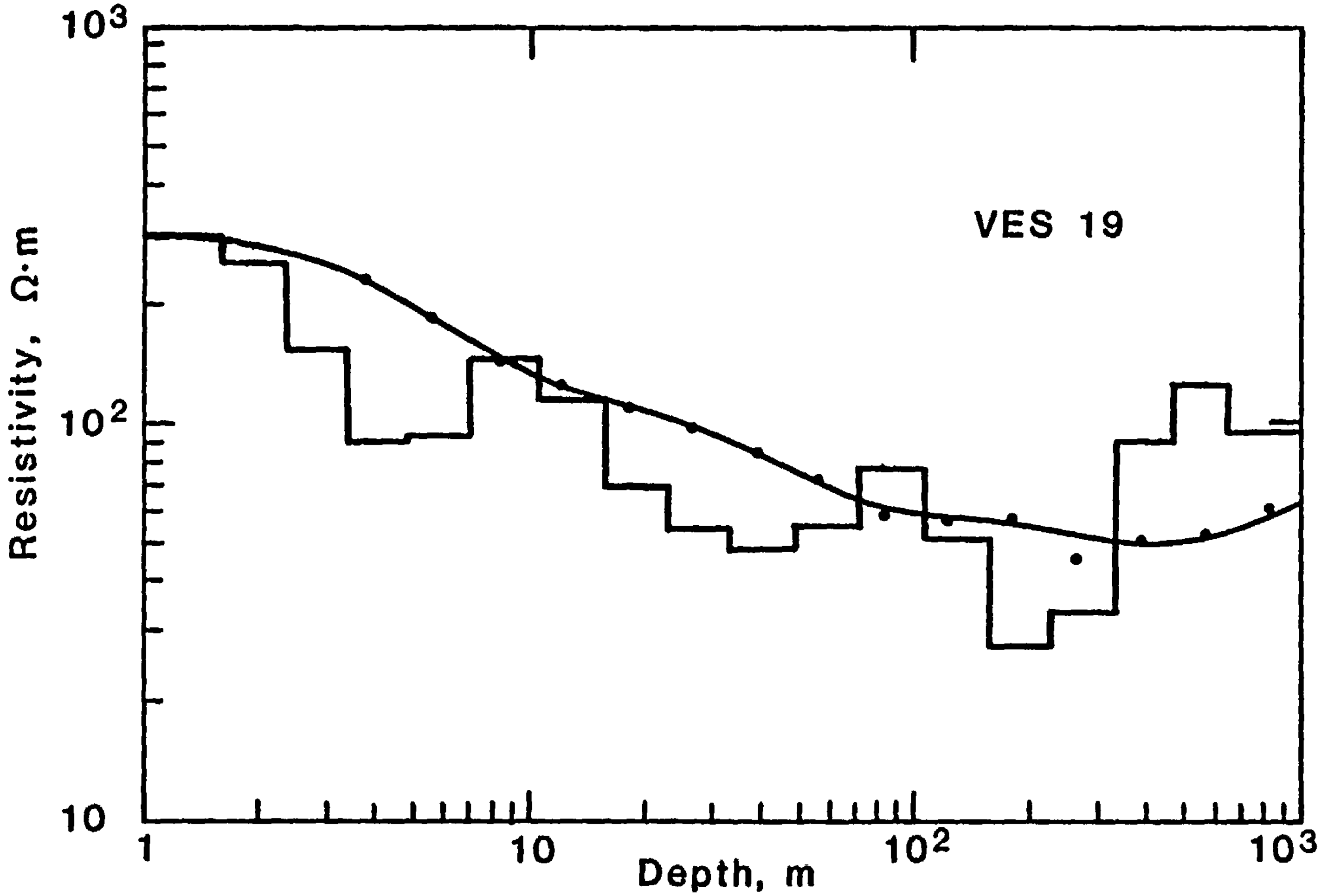
10³
10²
10
Resistivity, Ω·m
1
10
10²
10³
Depth, m
VES 16

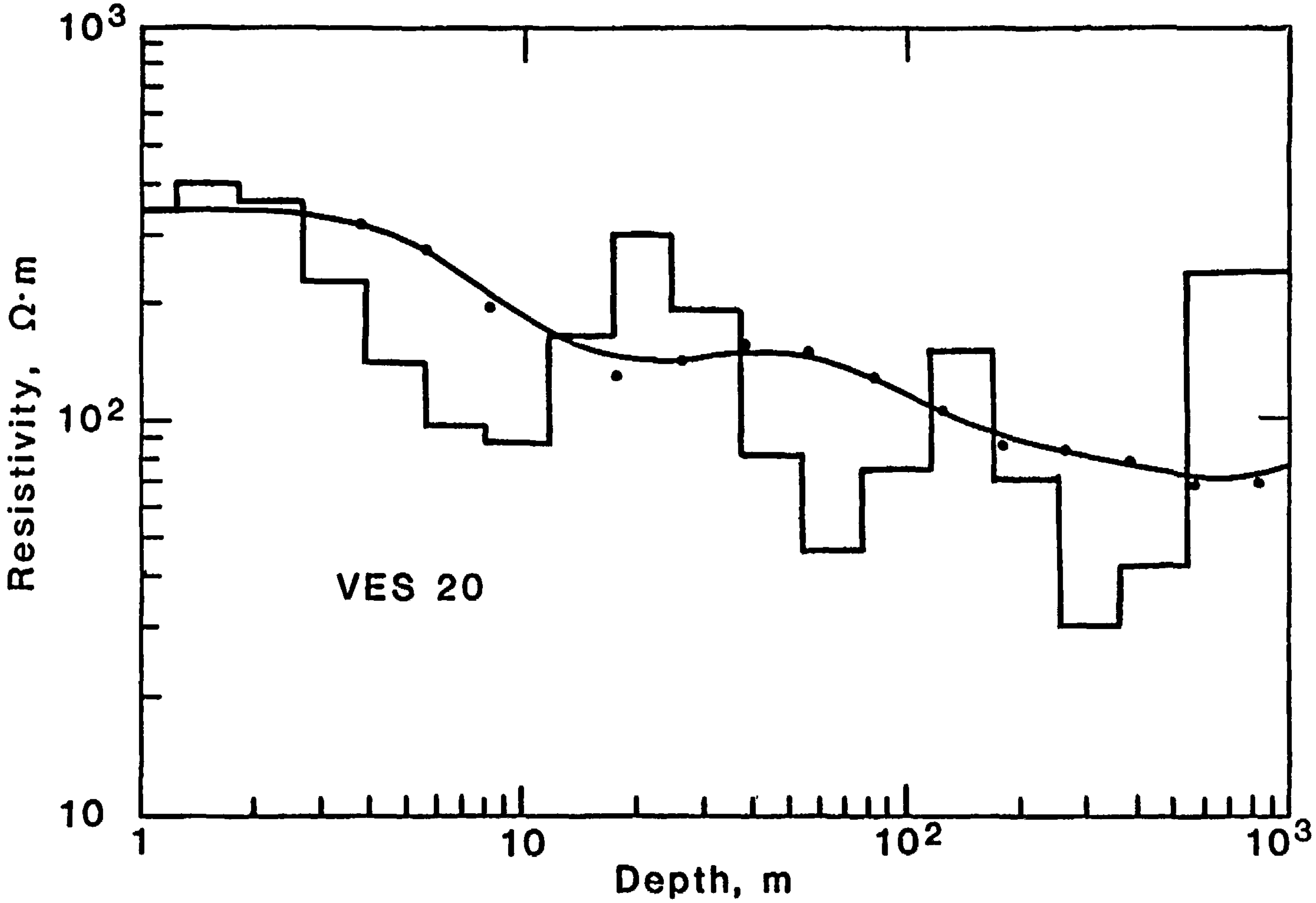


10^3
10^2
10
Resistivity, Ω·m
VES 17
1
10
10^2
10^3
Depth, m

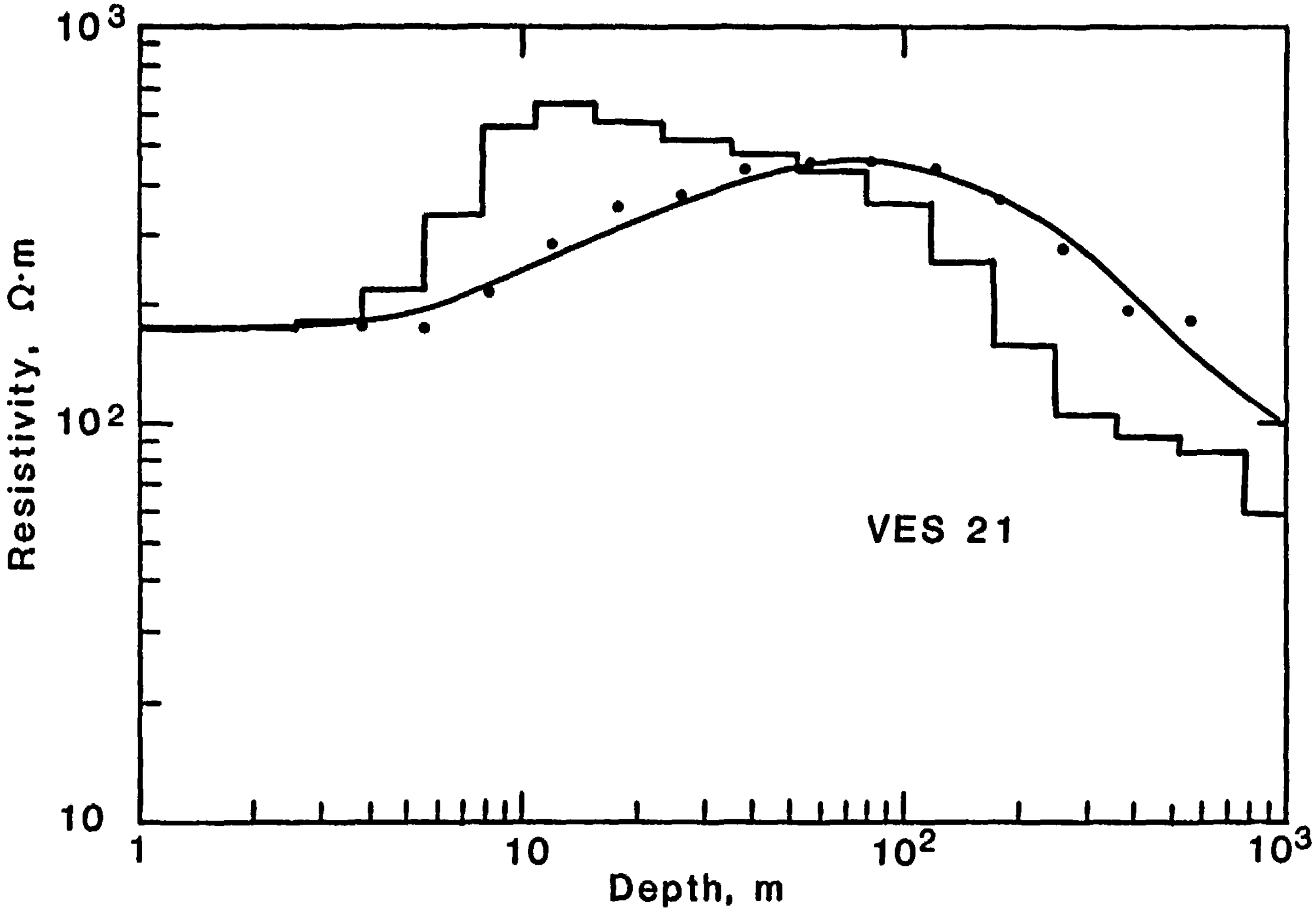


Resistivity, Ω·m
Depth, m
VES 18
10^3
10^2
10
1
10
10^2
10^3

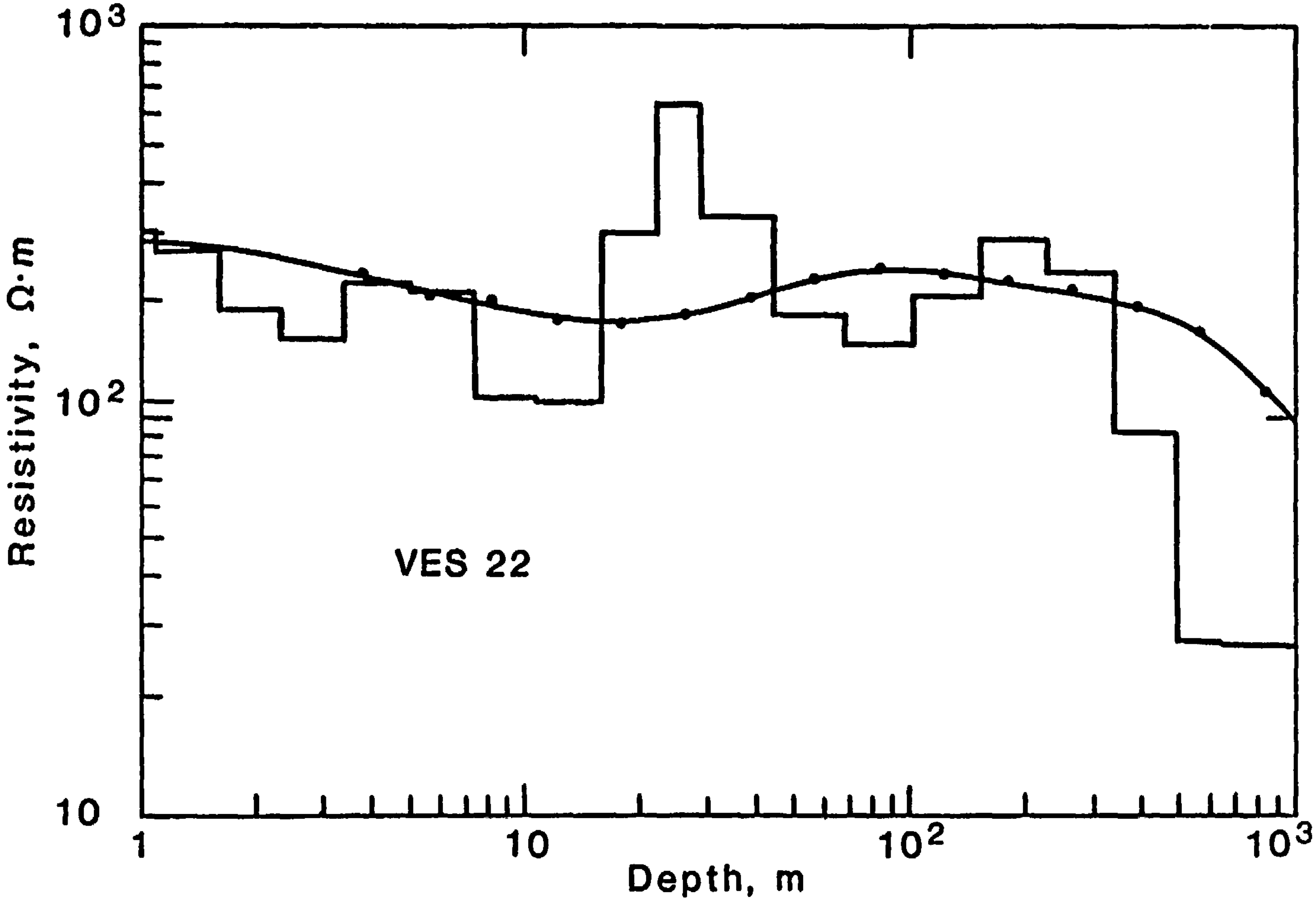

VES 19
Resistivity, Ω·m
Depth, m
10
10²
10³
1
10
10²
10³



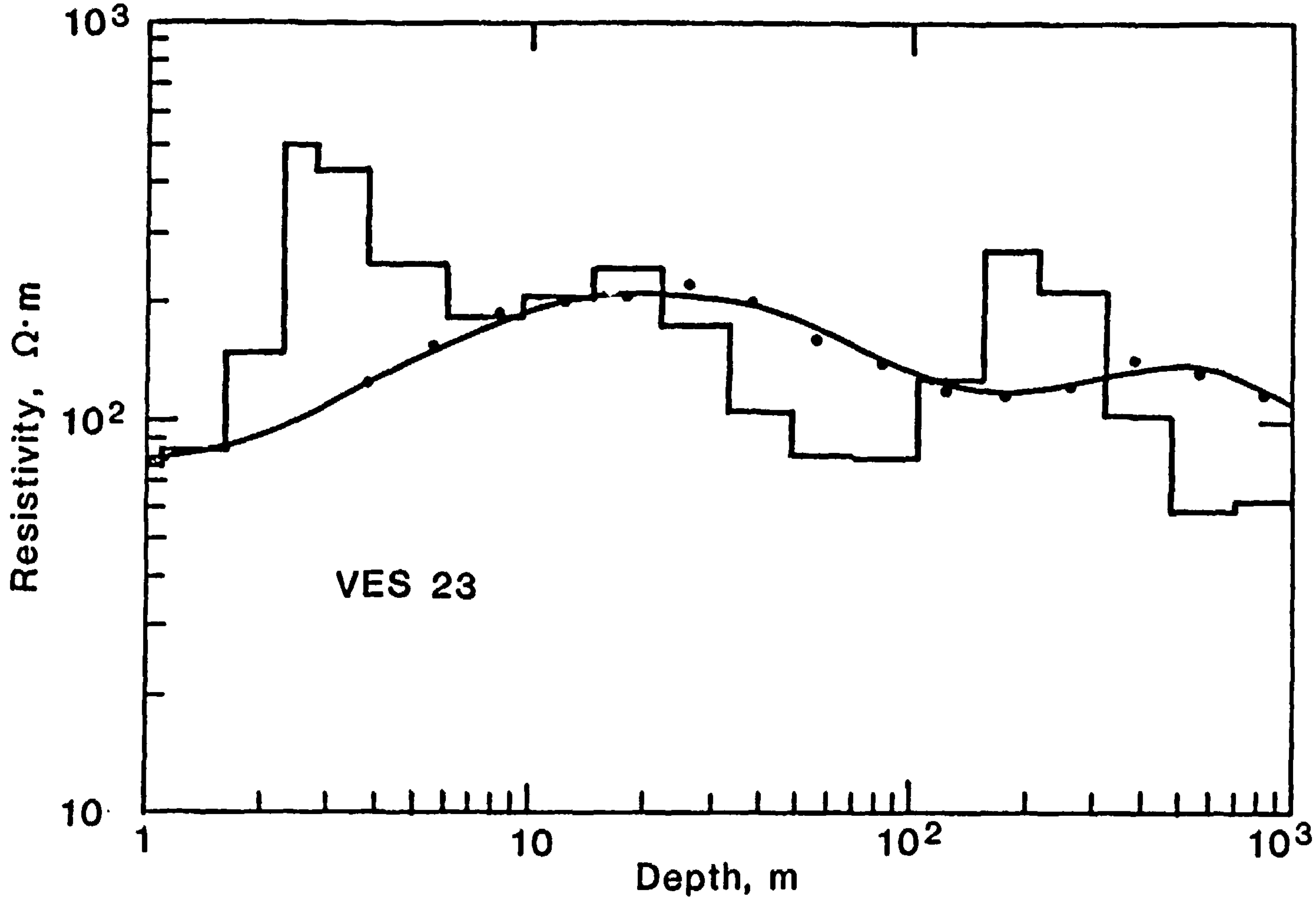
10^3
10^2
10
Resistivity, Ω·m
VES 20
1
10
10^2
10^3
Depth, m



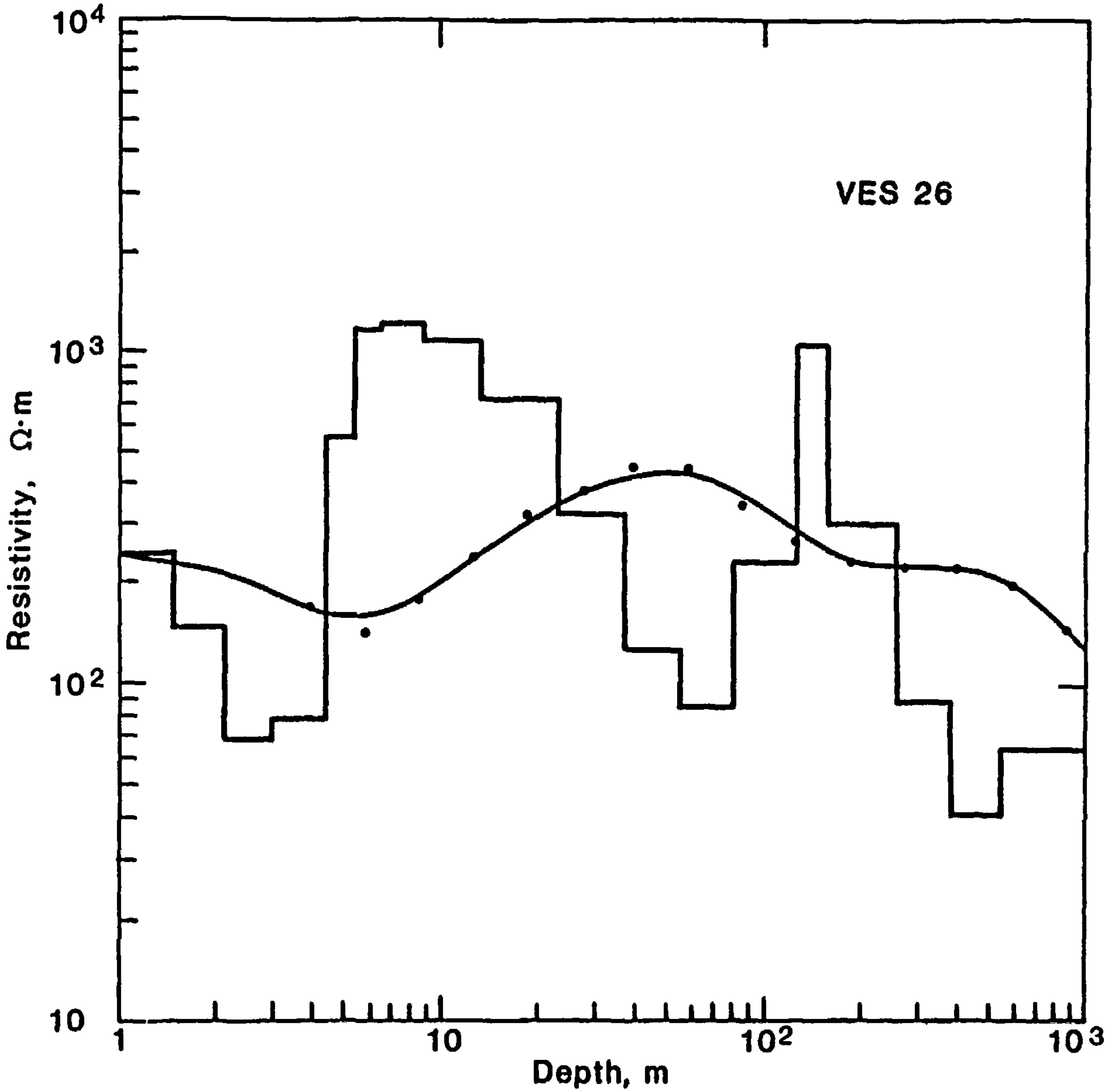
10^3
10^2
10
Resistivity, Ω·m
VES 21
1
10
10^2
10^3
Depth, m



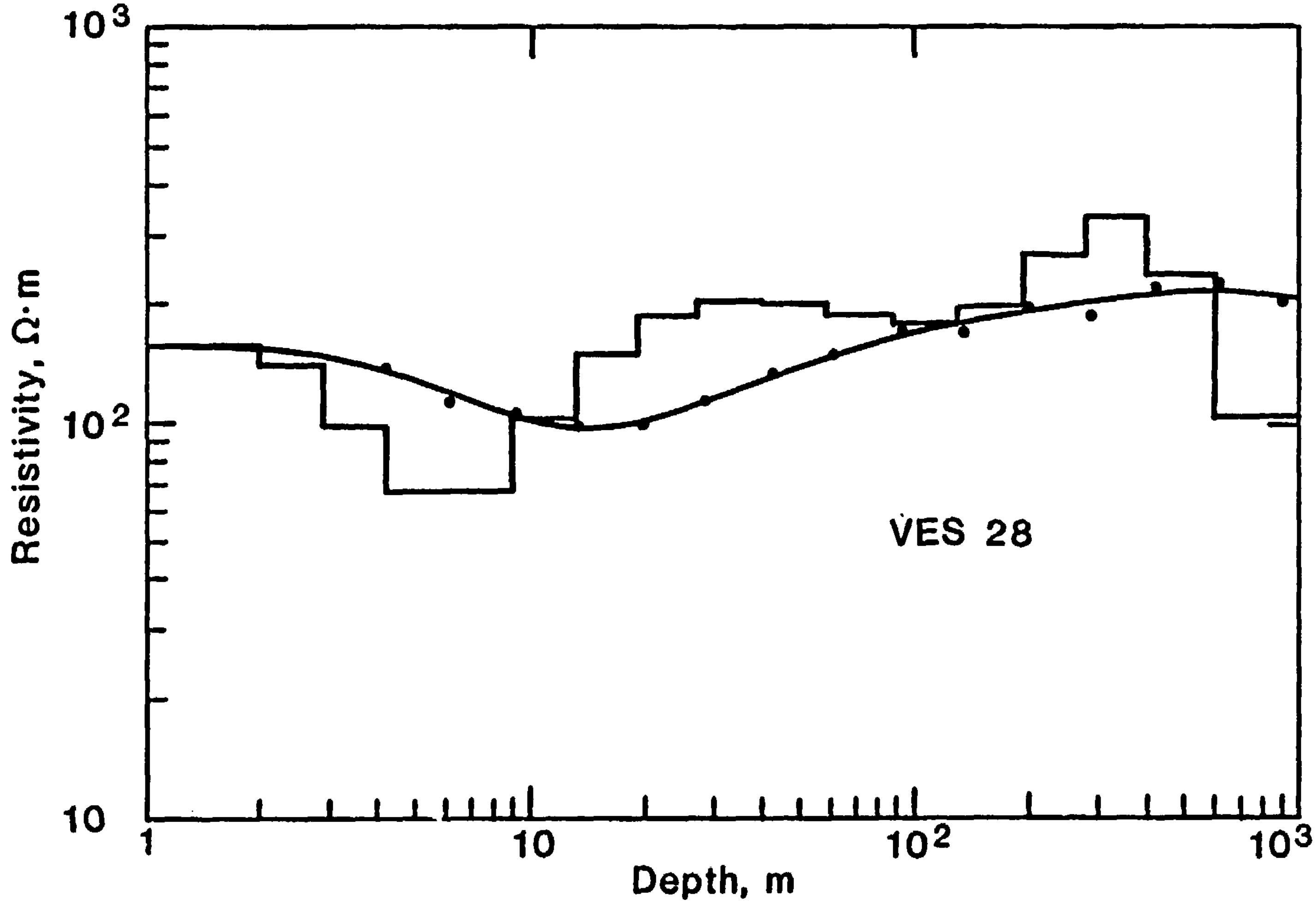
10³
10²
10
Resistivity, Ω·m
VES 22
1
10
10²
10³
Depth, m

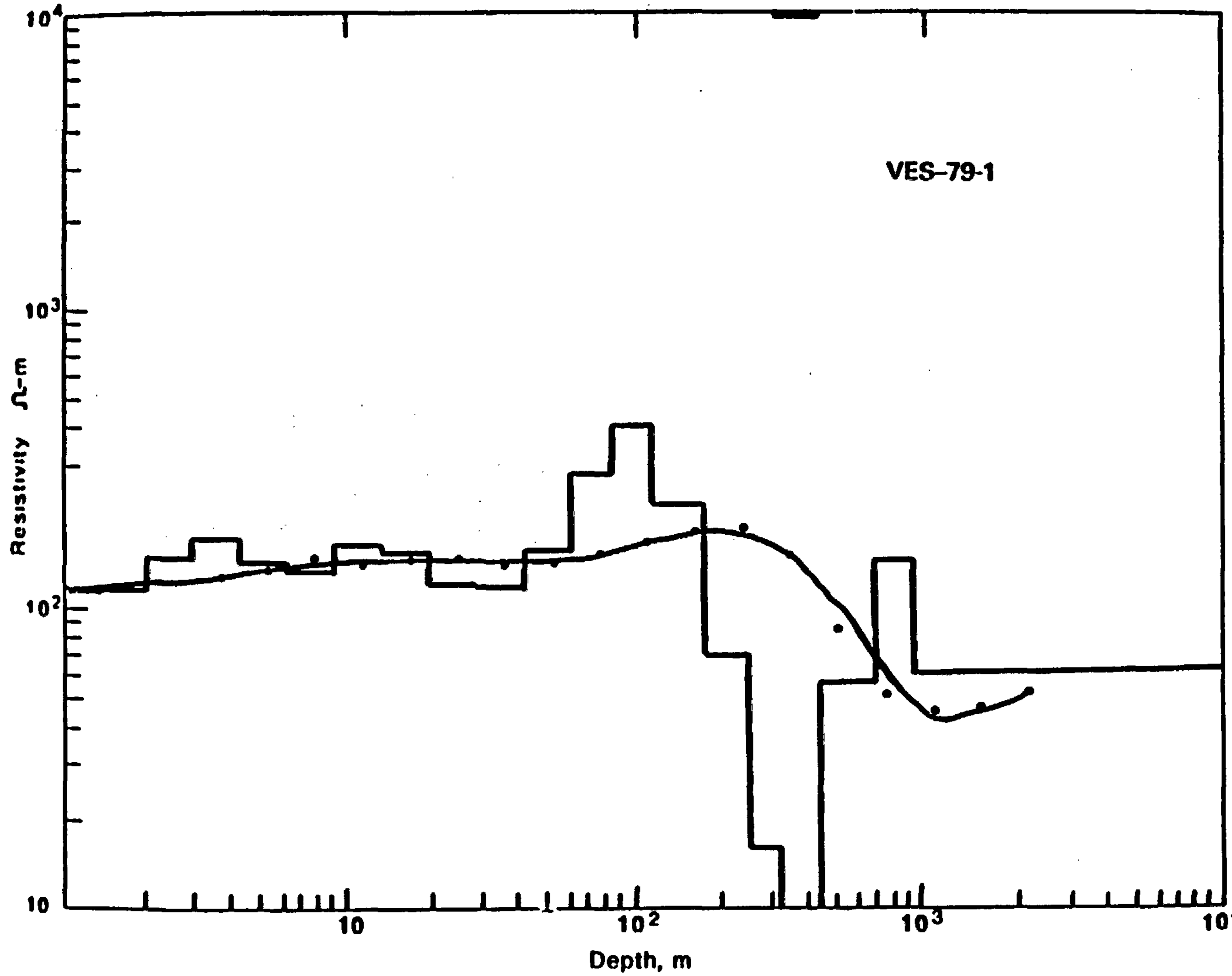


10³
10²
10
Resistivity, Ω·m
VES 23
1
10
10²
10³
Depth, m

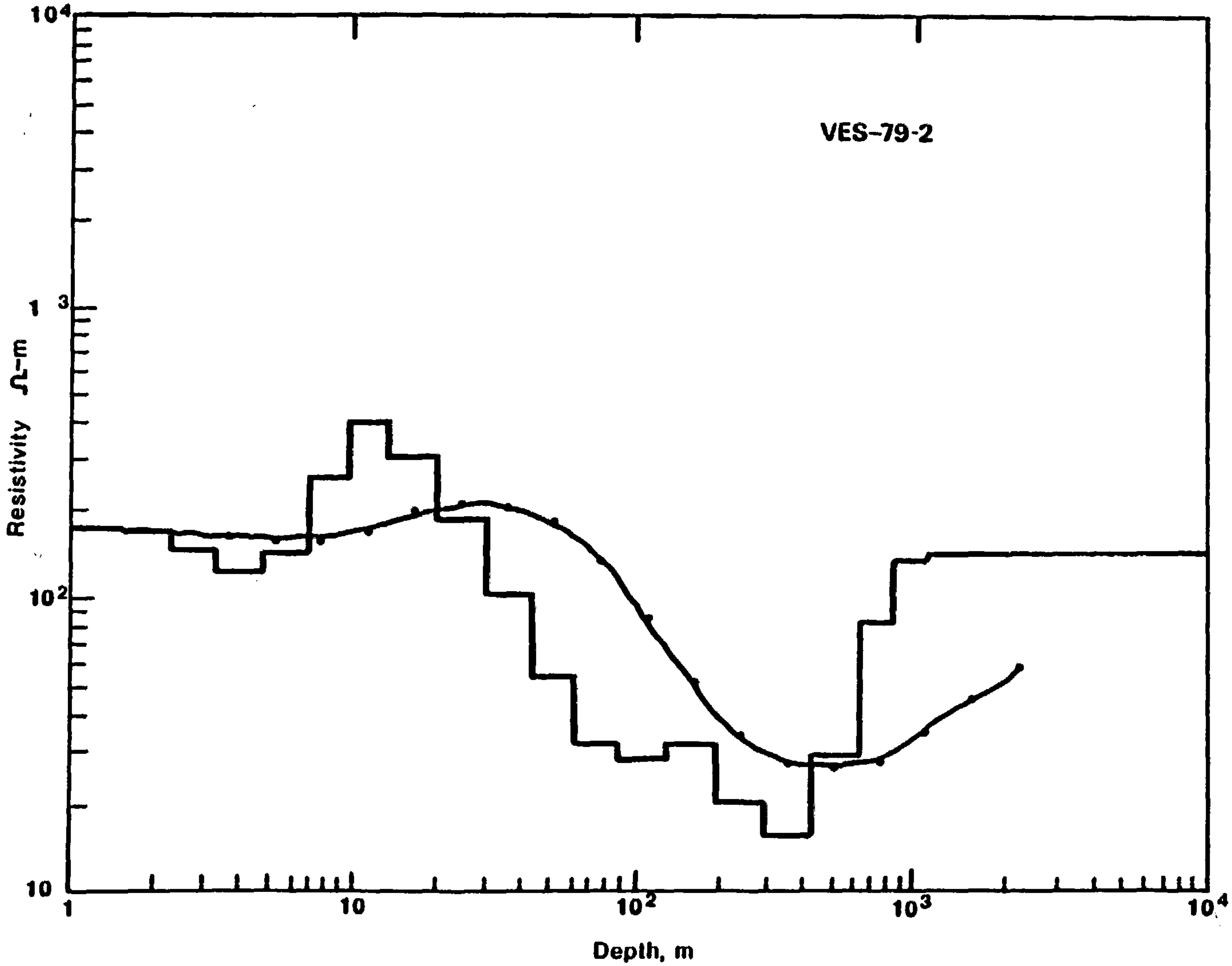


VES 26
Resistivity, Ω·m
Depth, m
10⁴
10³
10²
10
1
10
10²
10³

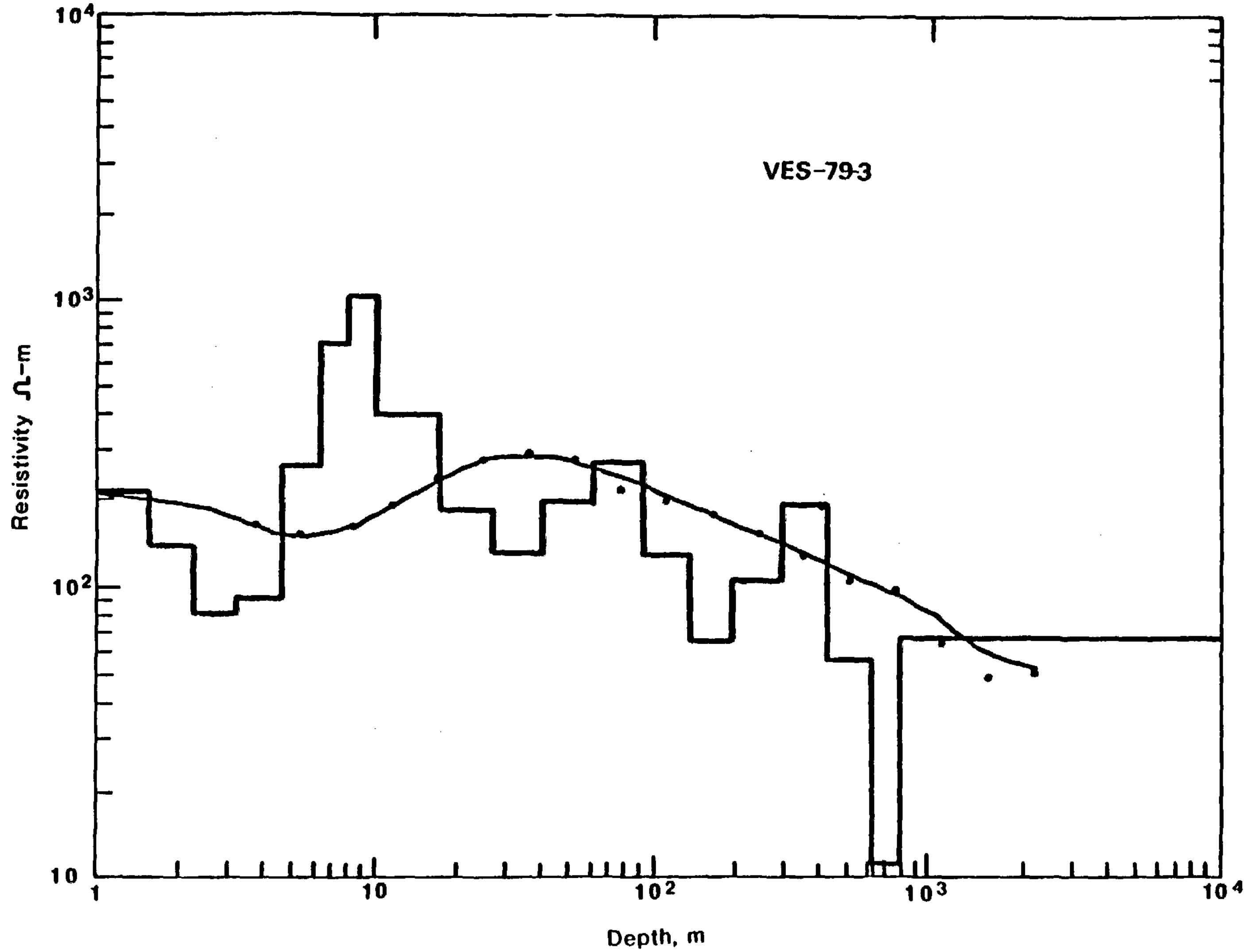

10³
10²
10
Resistivity, Ω·m
1
10
10²
10³
Depth, m
VES 28



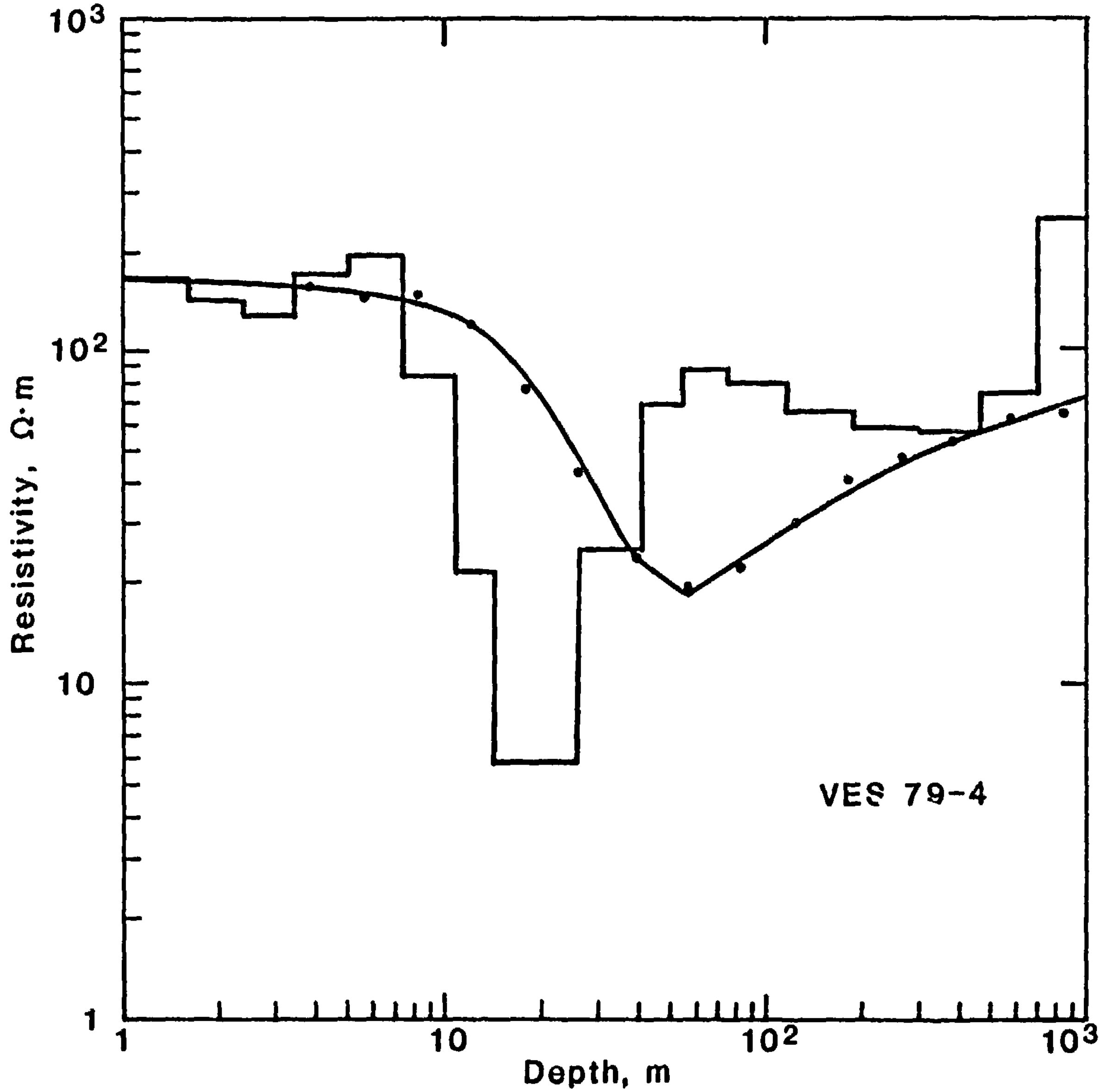
VES-79-1
Resistivity Ω-m
Depth, m
10
10²
10³
10⁴



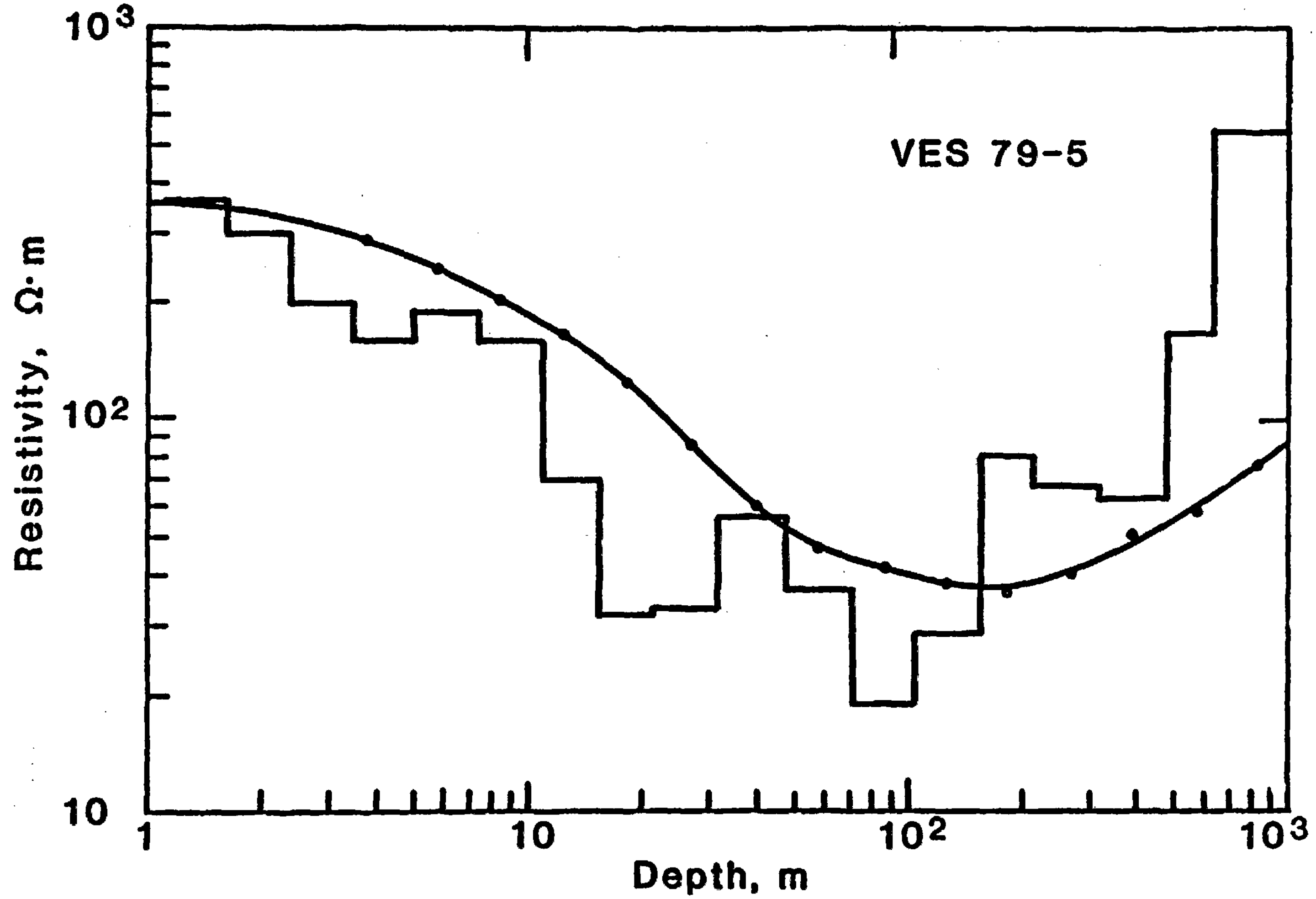
VES-79-2
Resistivity Ω-m
10^4
10^3
10^2
10
1
10
10^2
10^3
10^4
Depth, m



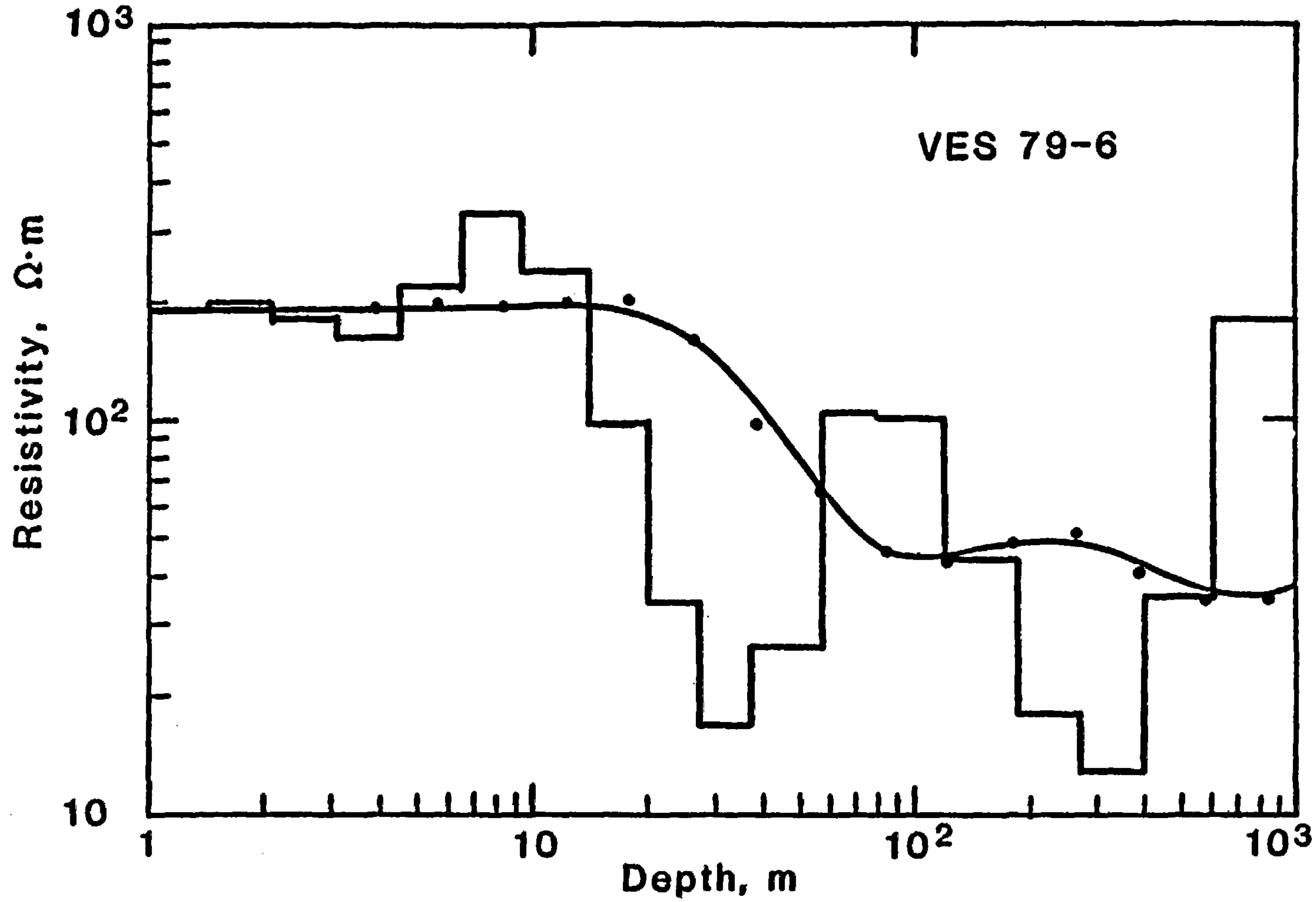
VES-79-3
Resistivity Ω-m
Depth, m
10⁴
10³
10²
10
1
10
10²
10³
10⁴

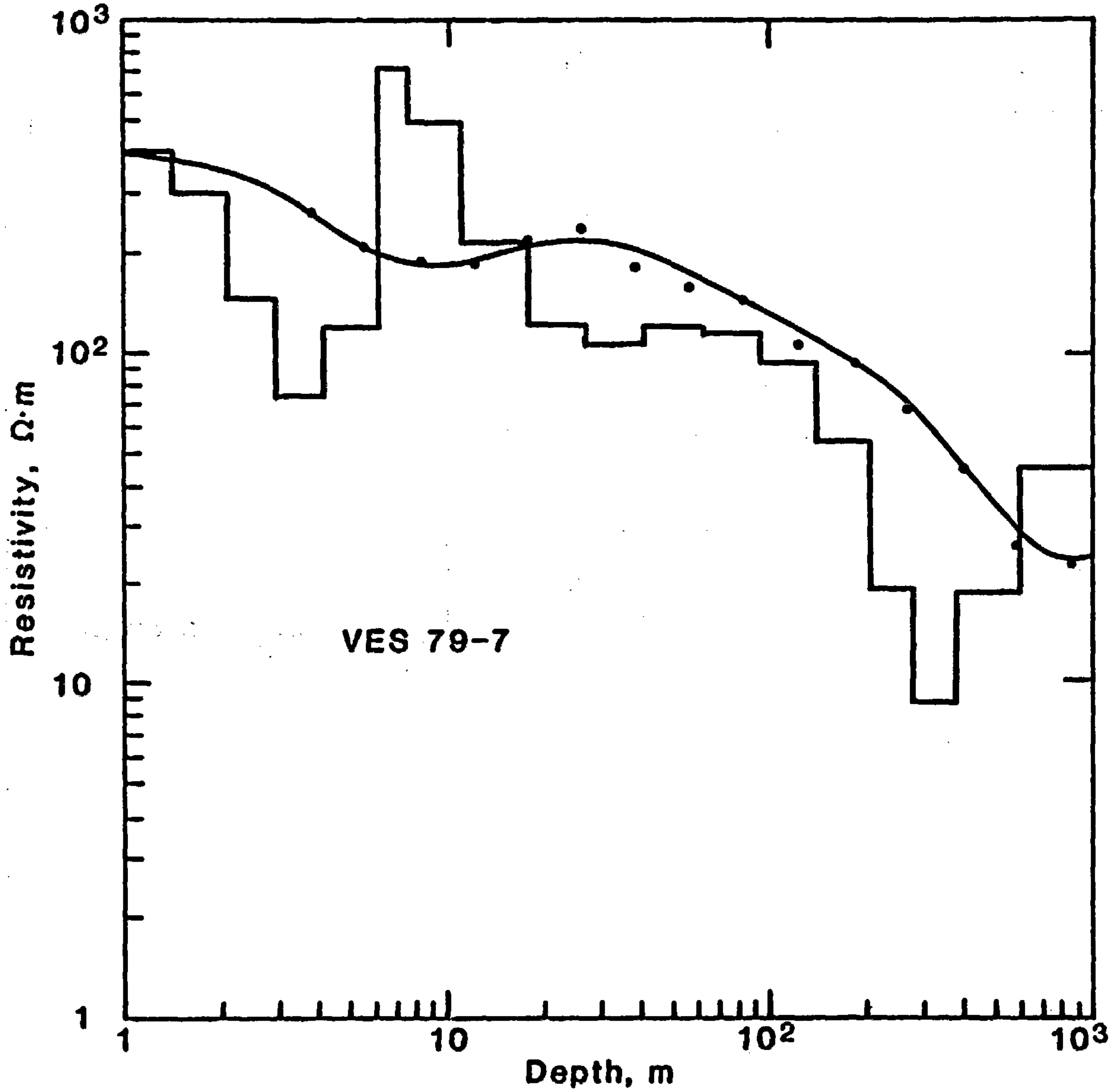


10³
10²
10
1
Resistivity, Ω·m
1
10
10²
10³
Depth, m
VES 79-4

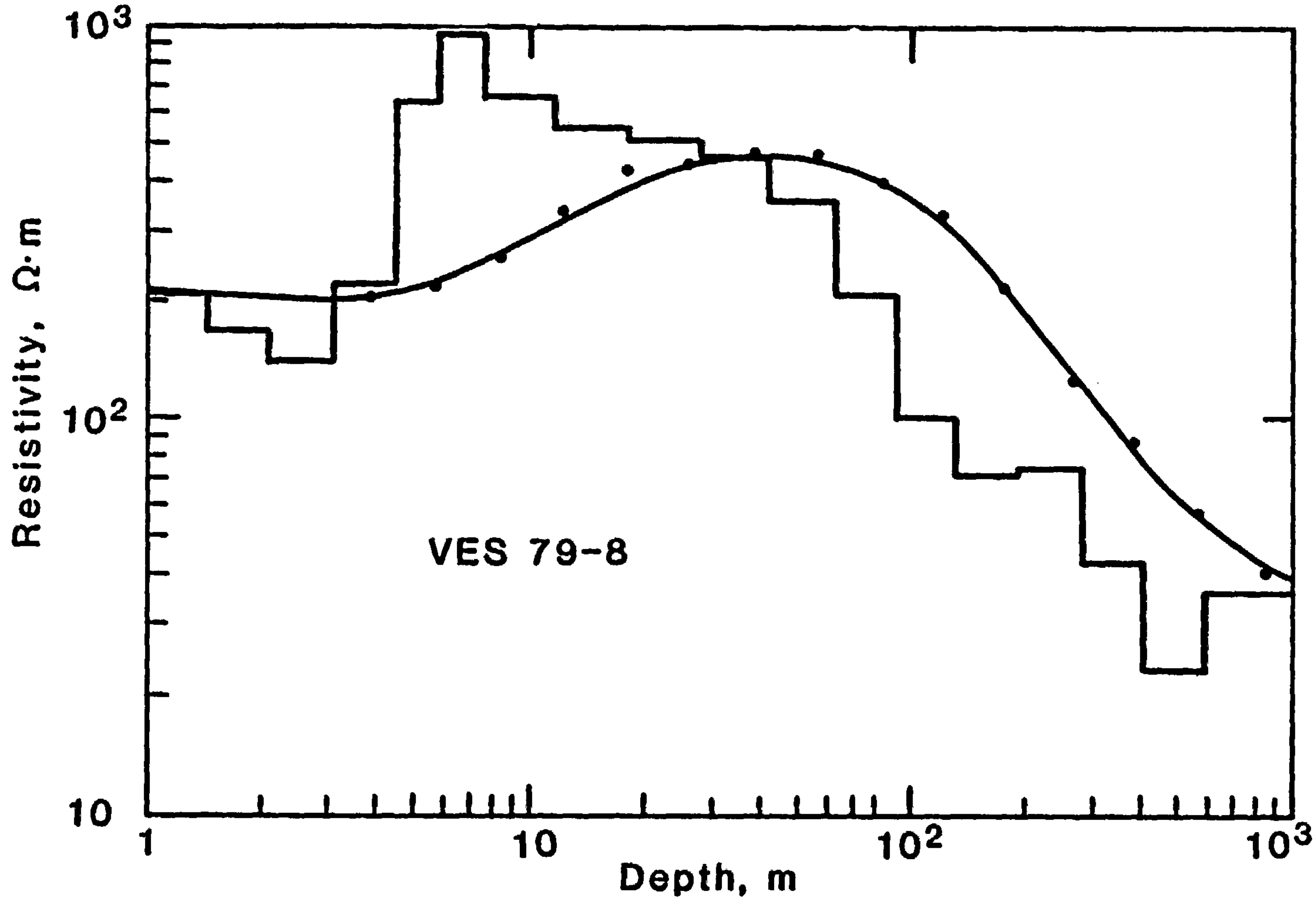


VES 79-5
Resistivity, Ω·m
10^3
10^2
10
1
10
10^2
10^3
Depth, m

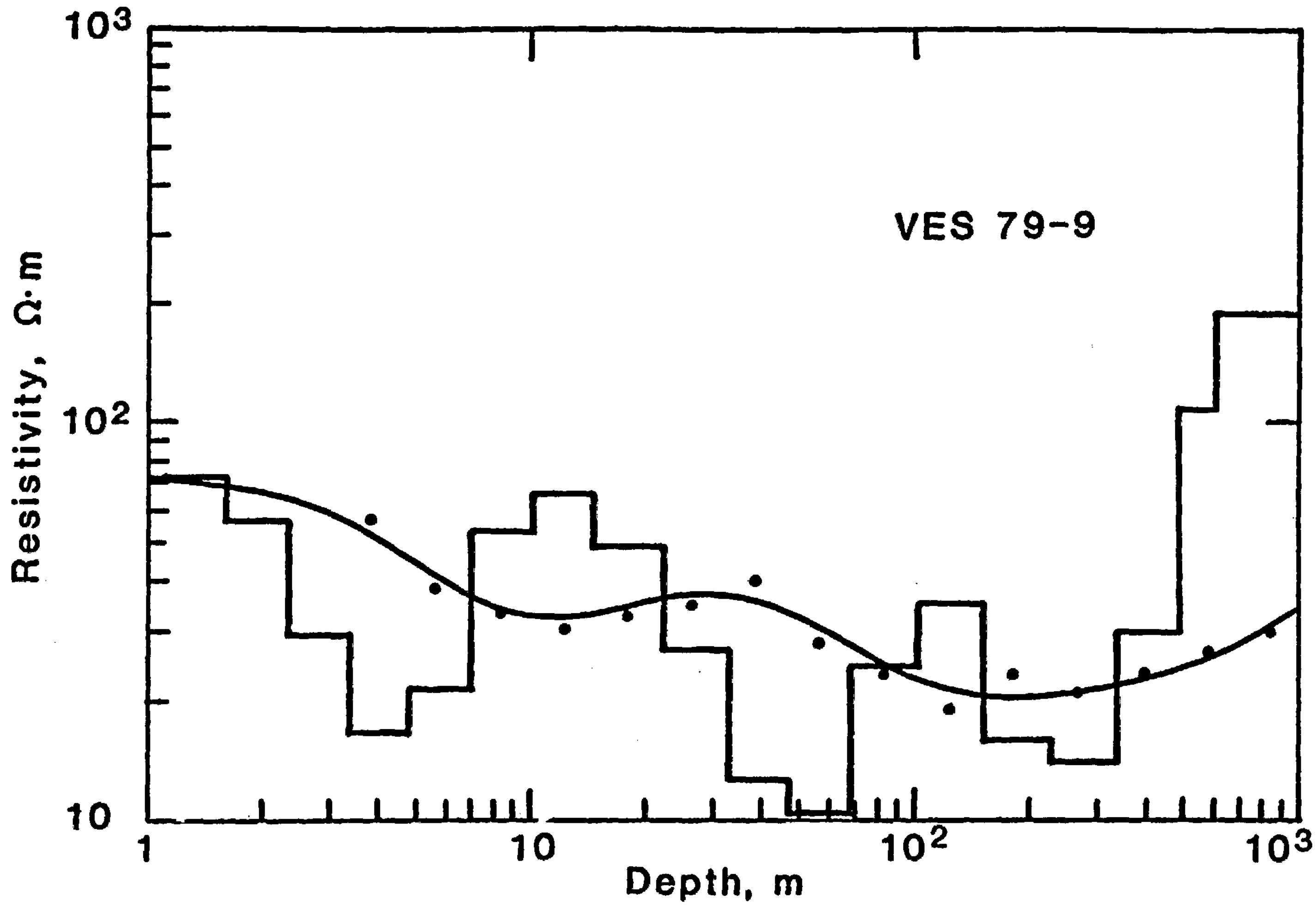

VES 79-6
Resistivity, Ω·m
10³
10²
10
1
10
10²
10³
Depth, m



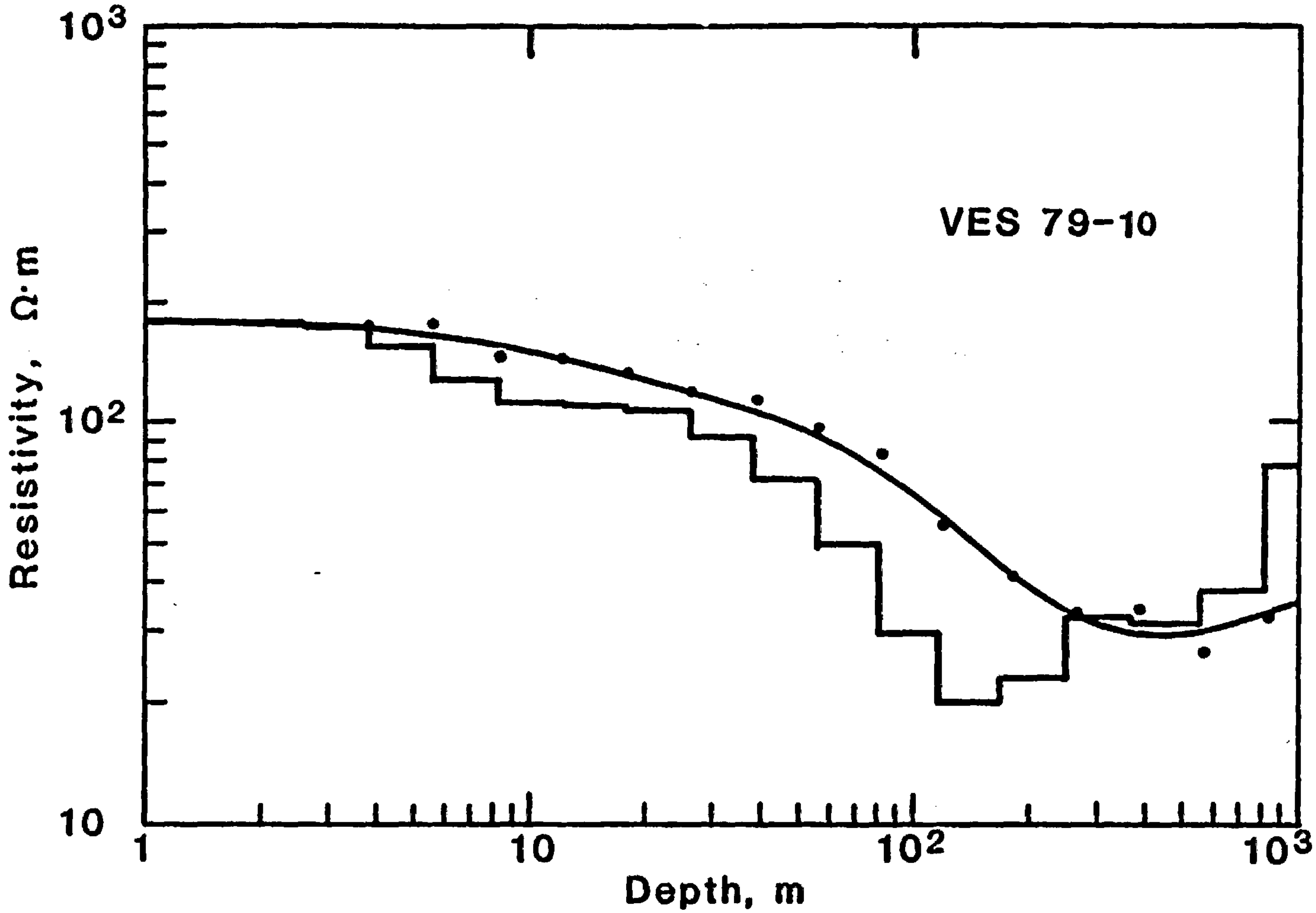
10³
10²
10
1
Resistivity, Ω·m
VES 79-7
1
10
10²
10³
Depth, m



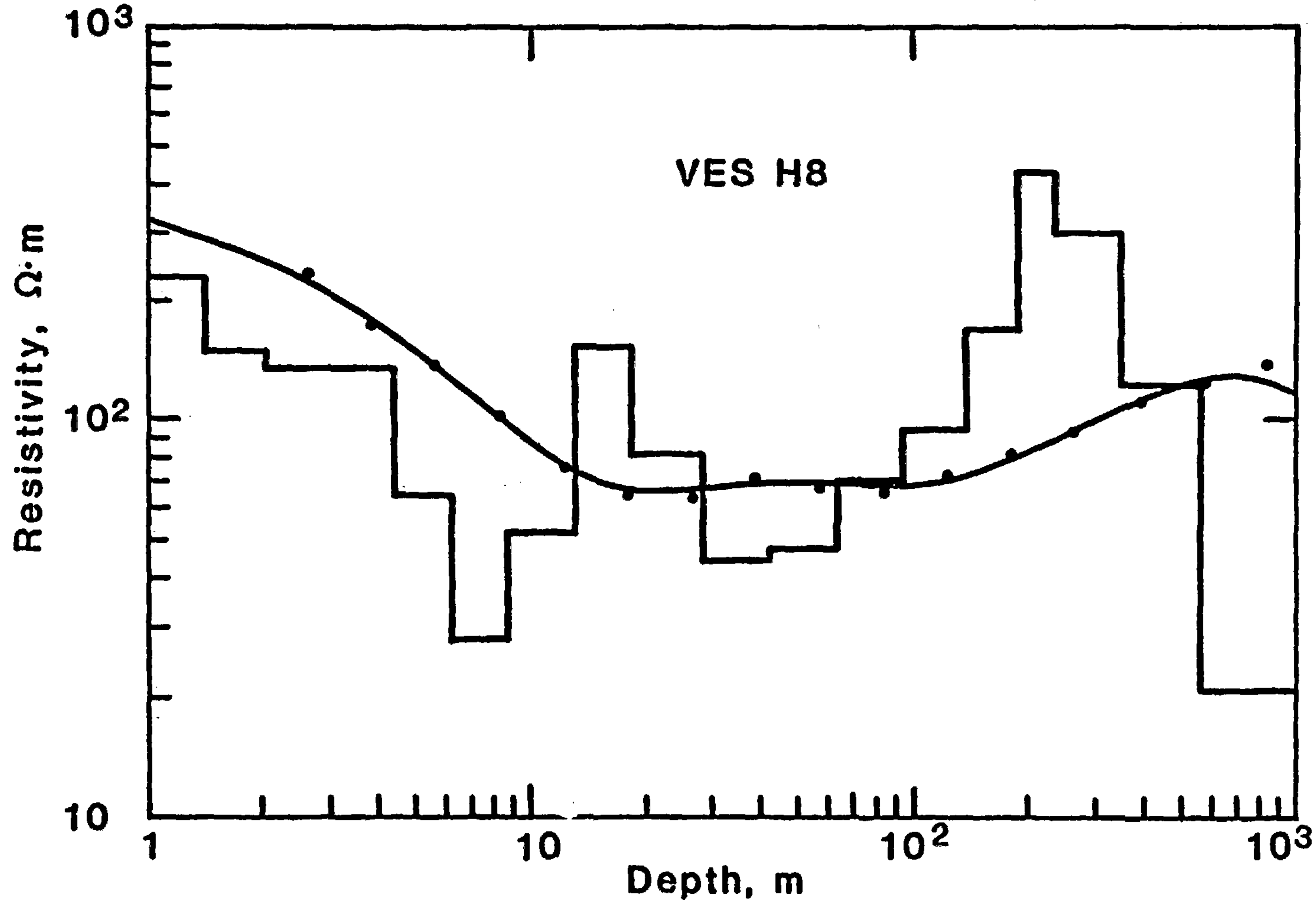
Resistivity, Ω·m
Depth, m
VES 79-8
10³
10²
10
1
10
10²
10³



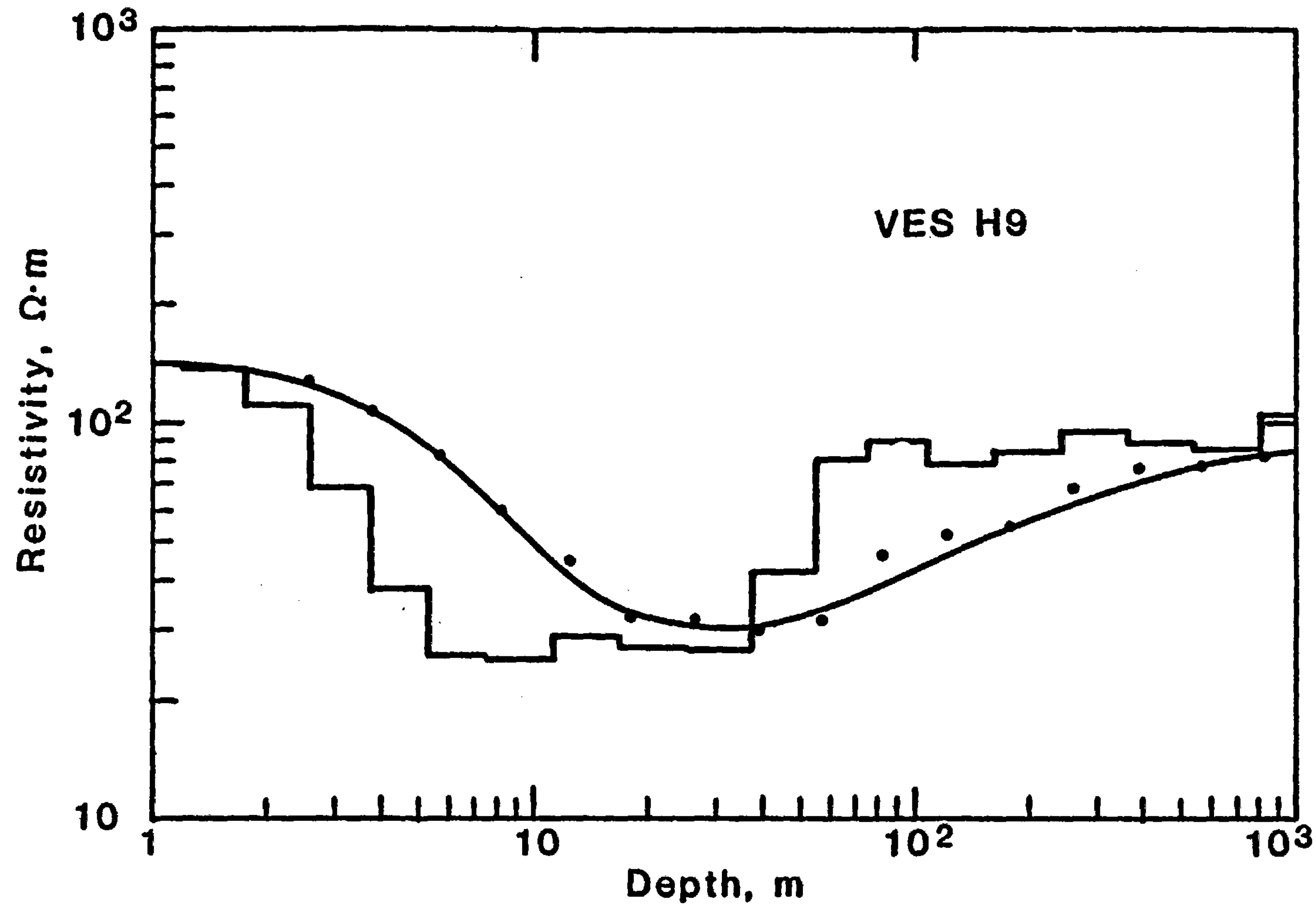
VES 79-9
Resistivity, Ω·m
Depth, m
10³
10²
10
1
10
10²
10³

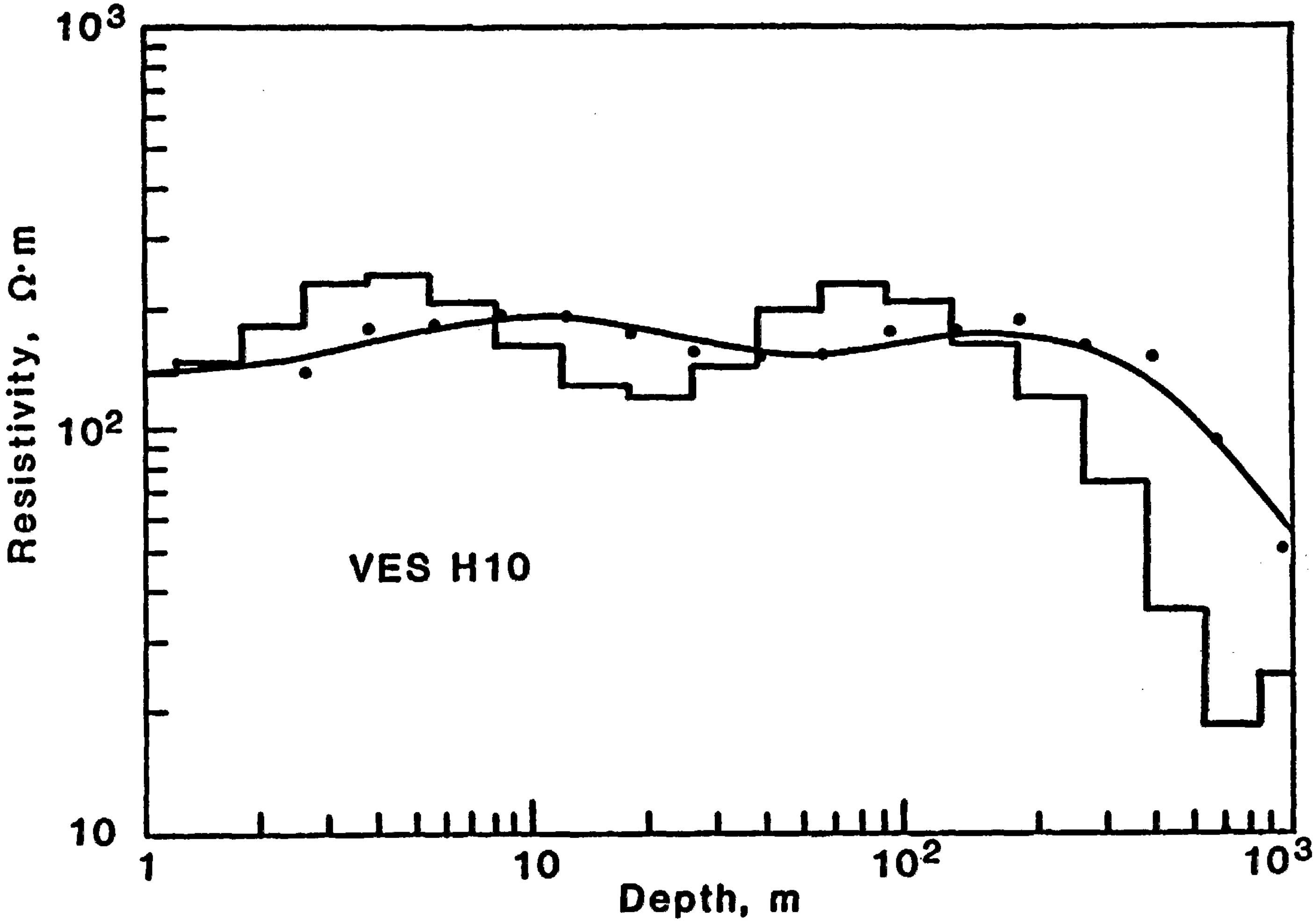


VES 79-10
Resistivity, Ω·m
Depth, m
10
10^2
10^3
1



VES H8
Resistivity, Ω·m
Depth, m
10³
10²
10
1
10
10²
10³

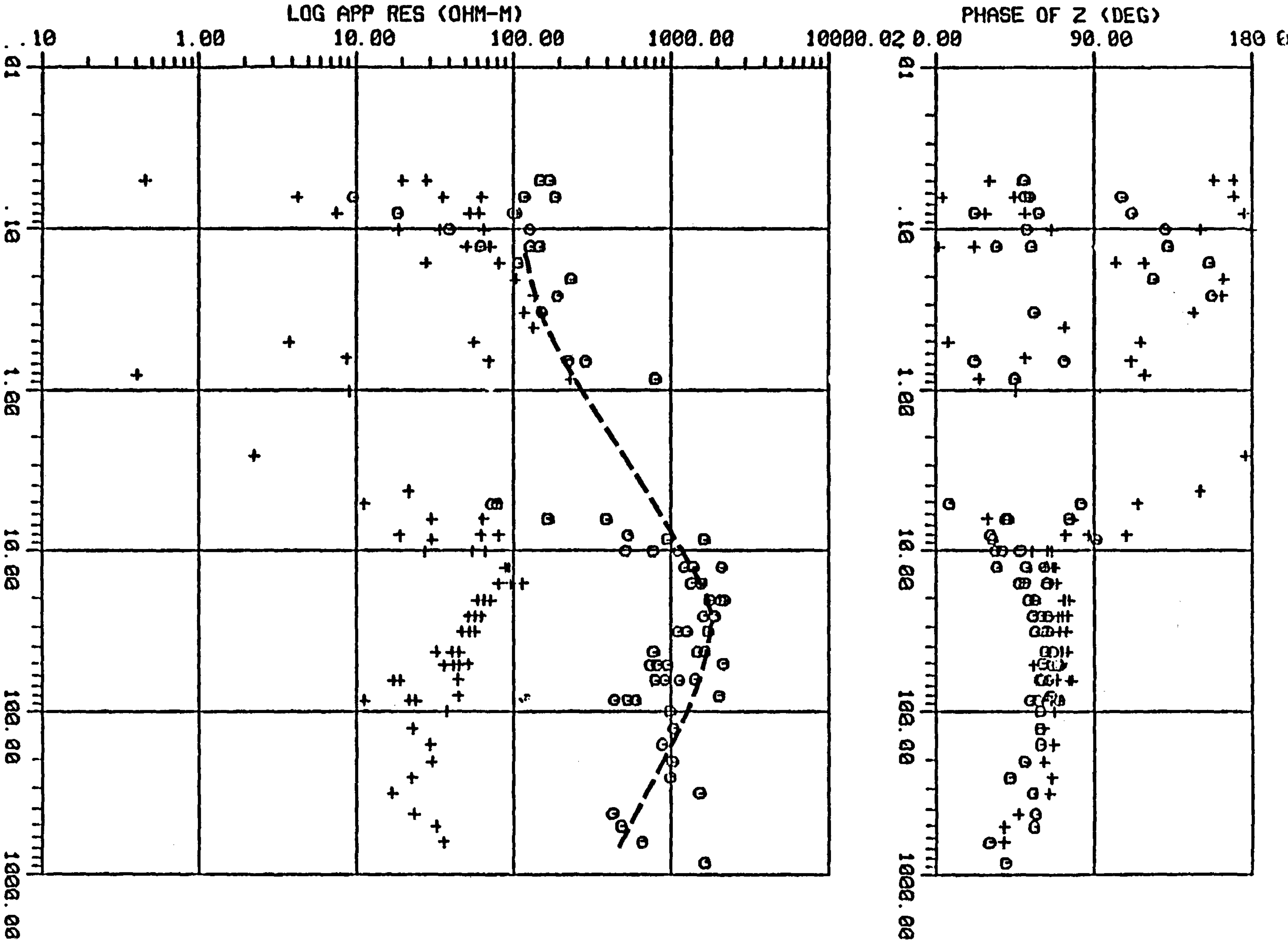

VES H9
Resistivity, Ω·m
Depth, m
10
10^2
10^3
1
10
10^2
10^3



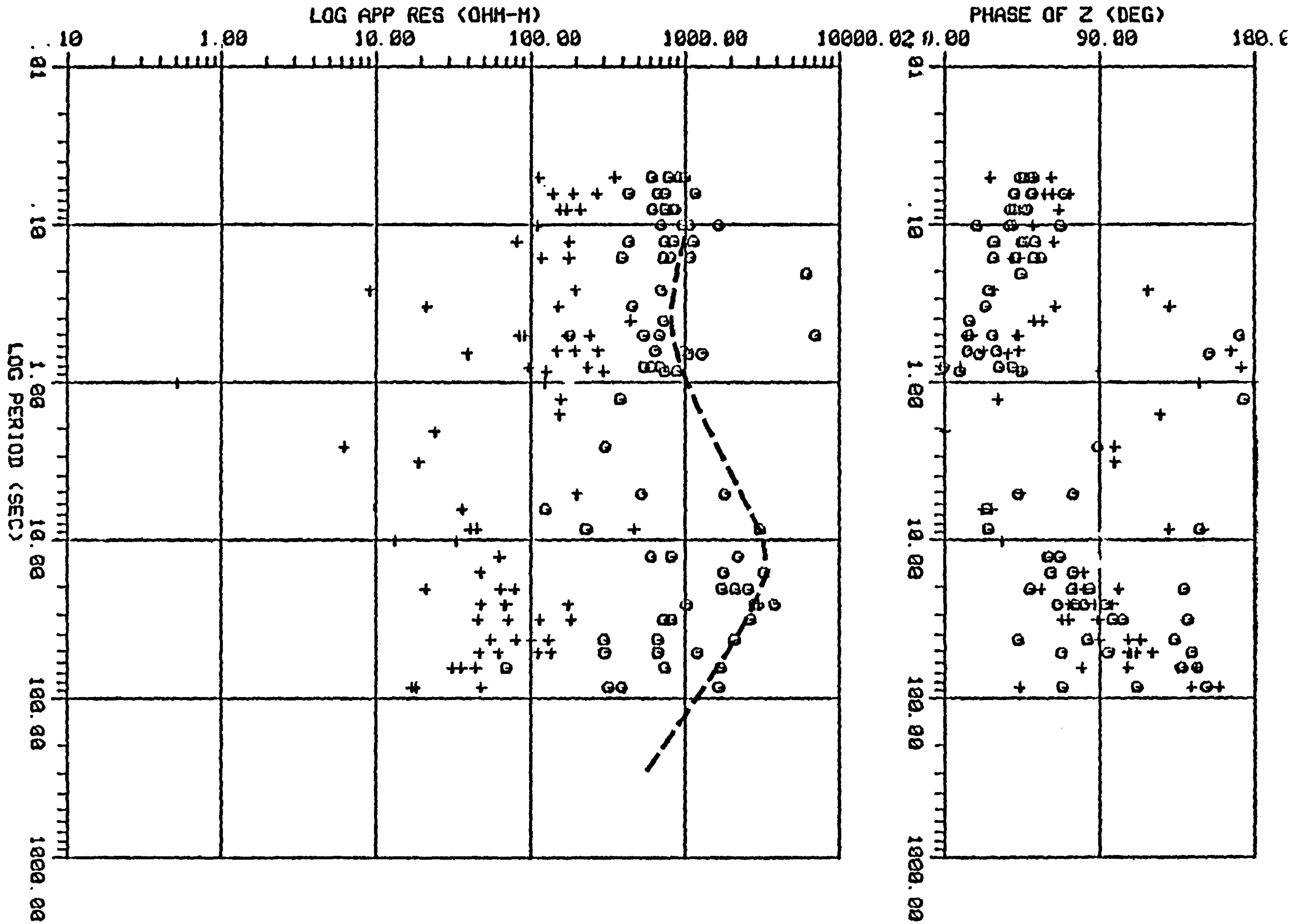
10³
10²
10
Resistivity, Ω·m
VES H10
1
10
10²
10³
Depth, m

Appendix 2

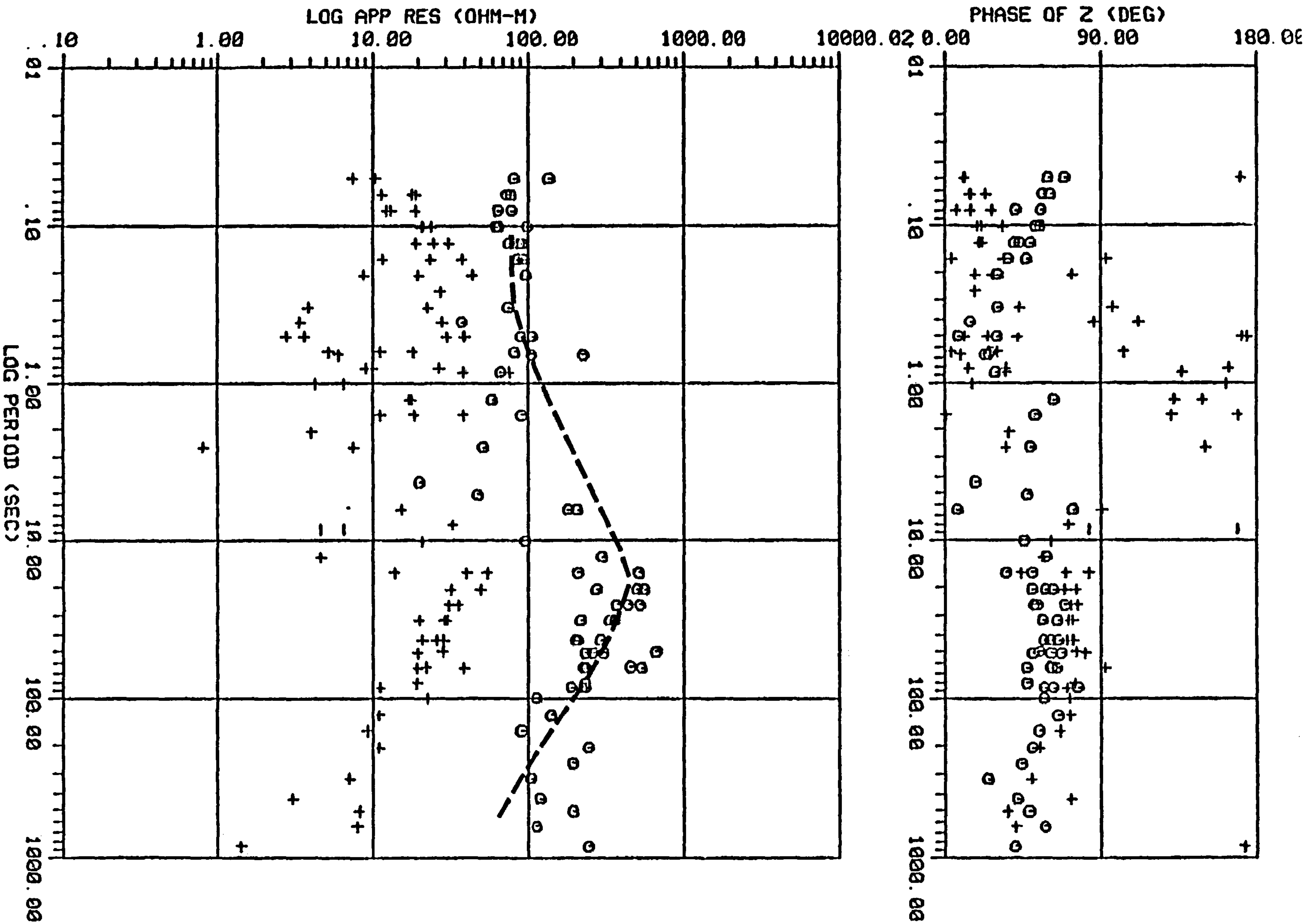
The following figures are the processed magnetotelluric data provided by Williston-McNeil Inc. and which was used by them to provide the one-dimensional inversions of fig. 22. The figures show the amplitude and phase of the major and minor axis of the resistivity tensor as well as rotation angle, skew, and tipper angle.

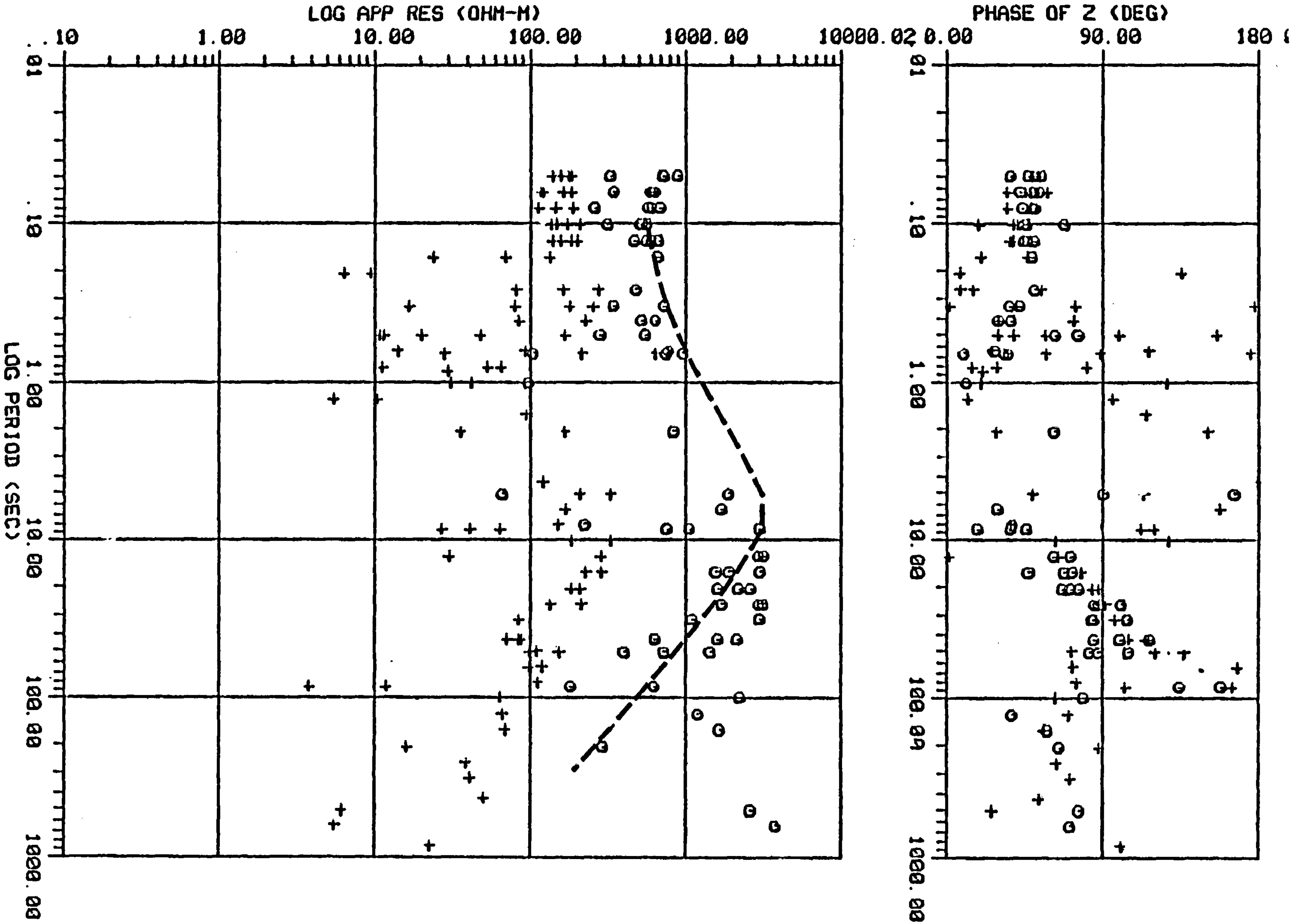


LOG APP RES (OHM-M)
.10
1.00
10.00
100.00
1000.00
10000.02
PHASE OF Z (DEG)
0.00
90.00
180 0
LOG PERIOD (SEC)
.01
.10
1.00
10.00
100.00
1000.00

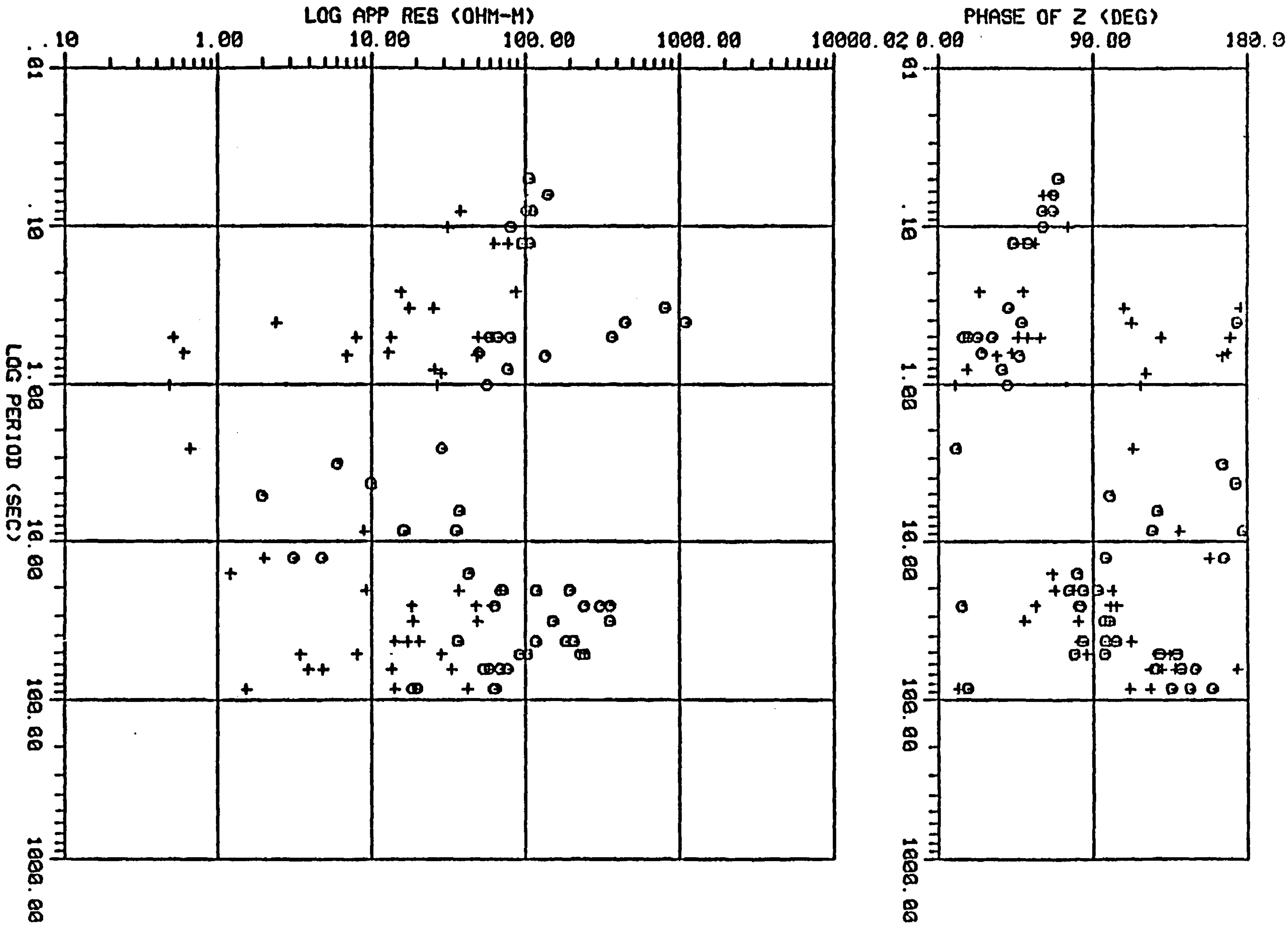


LOG APP RES (OHM-M)
.10
1.00
10.00
100.00
1000.00
10000.0
PHASE OF Z (DEG)
0.00
90.00
180.0
LOG PERIOD (SEC)
.01
.10
1.00
10.00
100.00
1000.00


LOG APP RES (OHM-M)
.10
1.00
10.00
100.00
1000.00
10000.0
PHASE OF Z (DEG)
0.00
90.00
180.00
LOG PERIOD (SEC)
.01
.10
1.00
10.00
100.00
1000.00



LOG APP RES (OHM-M)
.10
1.00
10.00
100.00
1000.00
10000.0
PHASE OF Z (DEG)
0.00
90.00
180
LOG PERIOD (SEC)
.01
.10
1.00
10.00
100.00
1000.00



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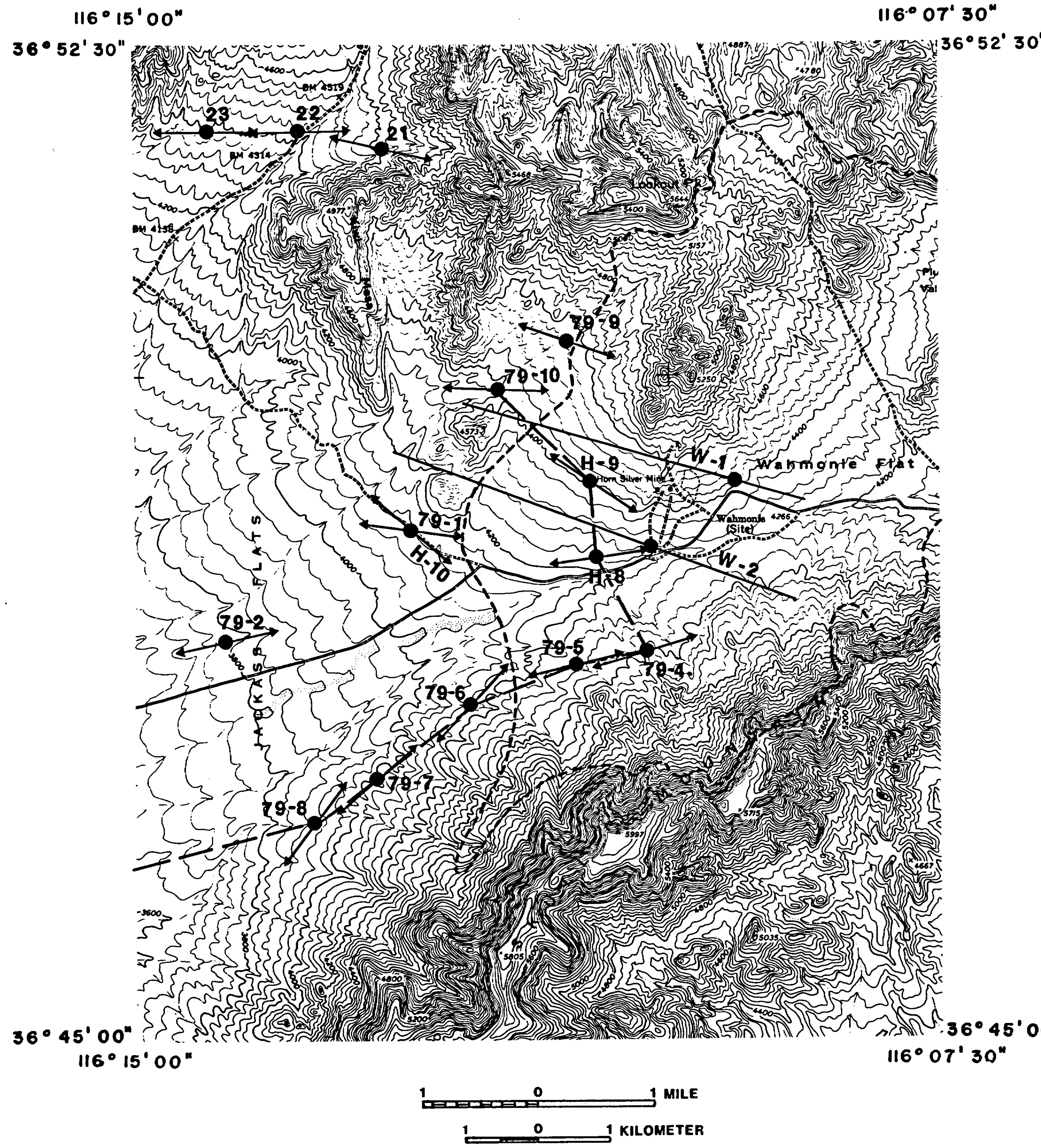

Figure 3. Map of the Wahmonie site showing location of Schlumberger VES and IP lines.

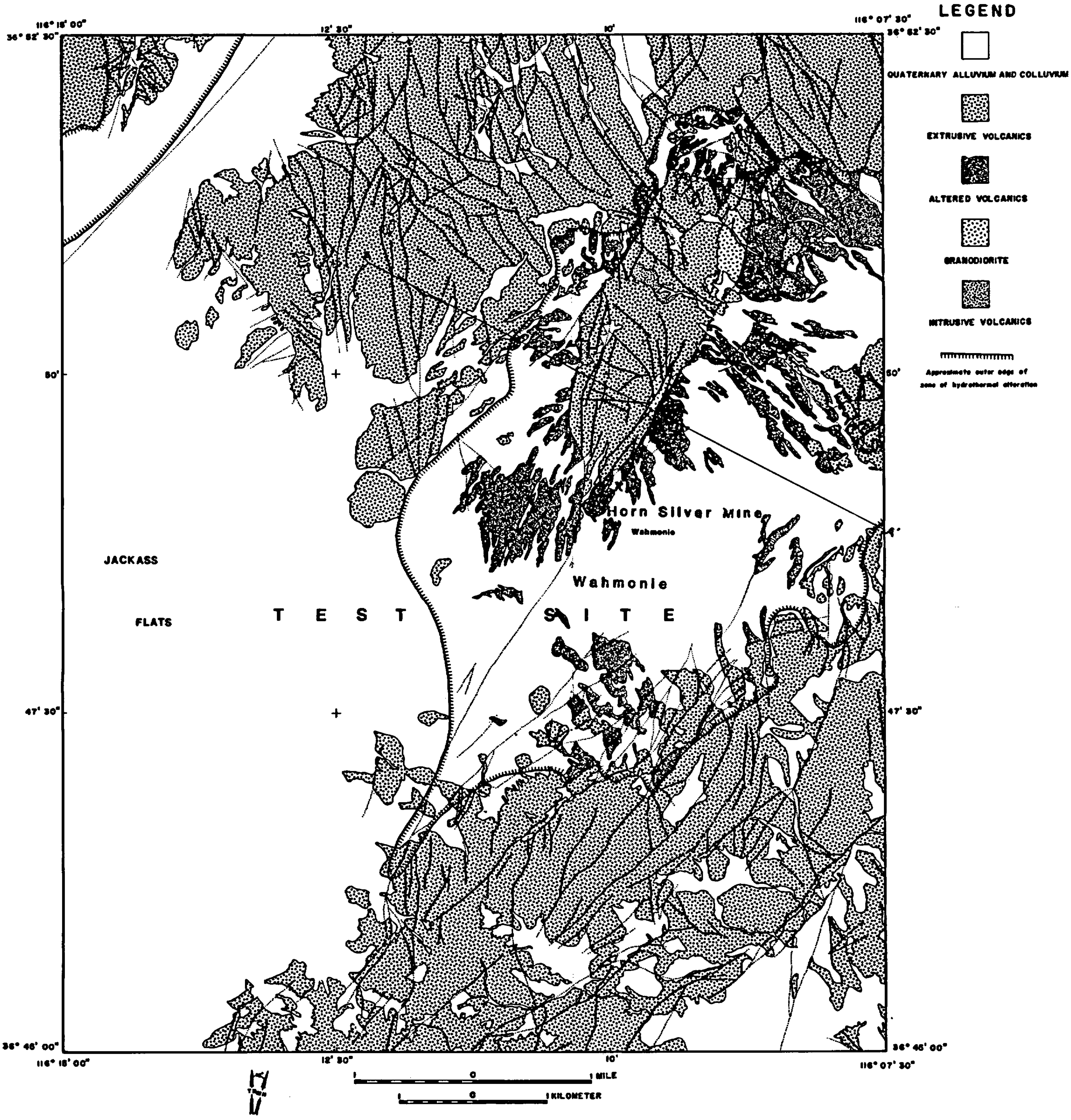

Figure 2. Generalized geology of the Wahmonie area, Nevada Test Site, Nevada adapted from Ekren and Sargent (1965).

All the igneous rock are of Tertiary age.

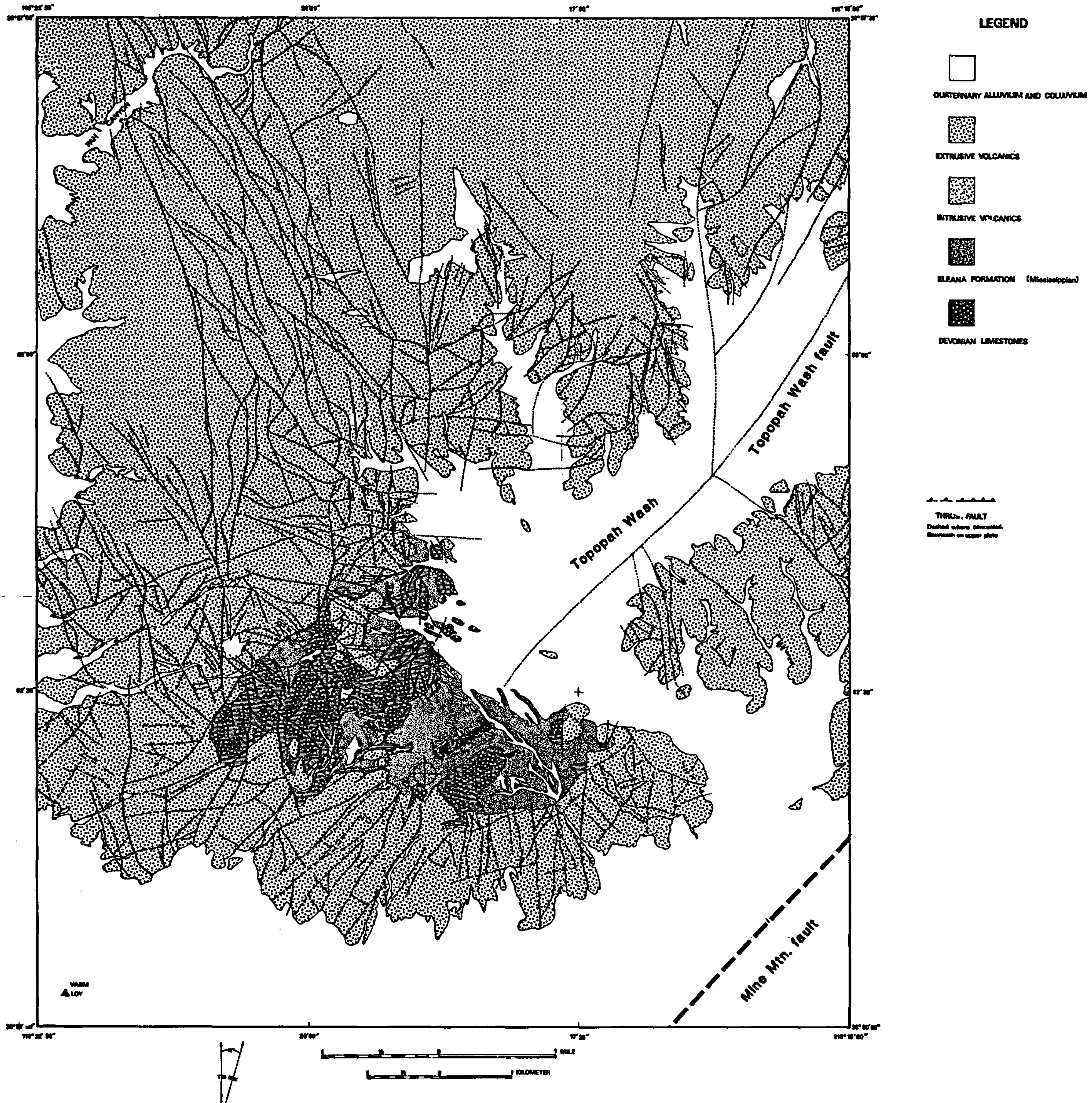

Figure 8. Map showing generalized geology of the Calico Hills site and Topopah Wash adapted from McKay and Williams (1964), and Orkild and O'Conner (1970). All the igneous rock are of Tertiary age.

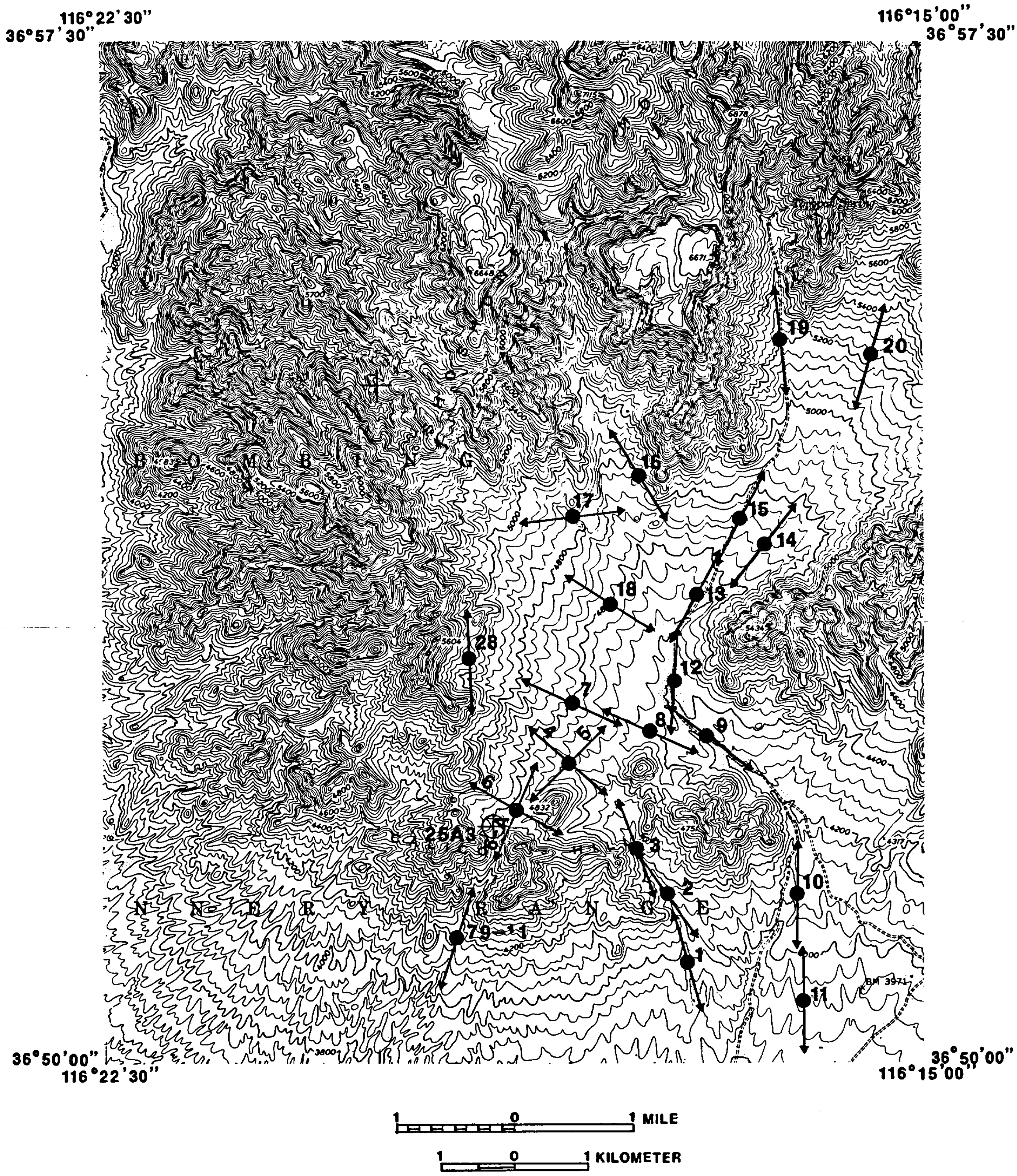

Figure 9. Map showing location of Calico Hills VES and drill hole UE 25A-3.

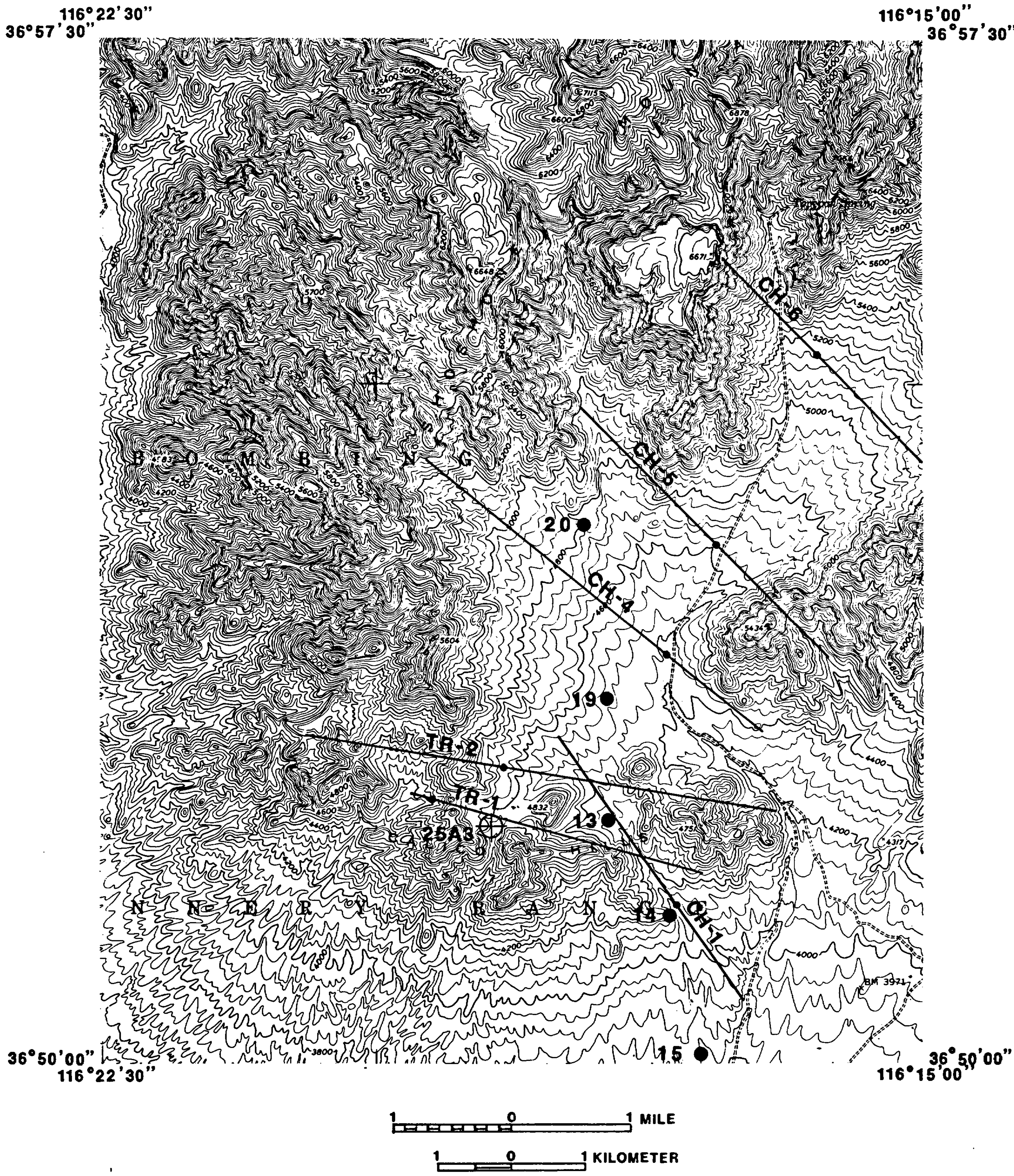

Figure 12. Map showing location of IP lines and MT soundings at Calico Hills.