# Geophysical studies of breccia pipe locations on the Hualapai Indian Reservation, Arizona

by

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Open-File Report 85-400

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## Introduction

The Hualapai Indian Reservation study is an integrated investigation combining geophysical and geological studies by the U.S. Geological Survey (USGS). Funding for the study was provided by the USGS under an agreement with the U.S. Bureau of Indian Affairs to compile and summarize geophysical and geological information to assess potential mineral resources in the area. This report presents and evaluates the results of these geophysical studies made on the Reservation.

The Hualapai Indian Reservation is located in northwest Arizona along the south rim of the Grand Canyon of the Colorado River, about 40 miles east of Kingman, Arizona, and 75 miles west of Flagstaff, Arizona (fig. 1). It is bounded on the north by Grand Canyon National Park and Lake Mead recreation area. Road access into the reservation is by U.S. Highway 66. The survey areas are reached by several paved and unimproved roads within the reservation.

Geologically, the area of study is located at the southern extent of the Colorado Plateau with the stratigraphic section ranging from the Mississippian Redwall Limestone to the Triassic Chinle Formation. Breccia pipes that occur within the area are the result of a solution collapse within the Redwall Limestone and stoping of the overlying strata, and are not associated with volcanic rocks (Wenrich, USGS, mineralization of breccia pipes in northern Arizona, unpub. report). Karst development in the Redwall Limestone began in the Mississippian and either continued to the Triassic or was reactivated during that time. Mineralization apparently occurred shortly thereafter, sometime during the Mesozoic. This mineralization commonly occurred within nodules and concretions associated with pyrite and goethite, within a sandstone matrix, or along features. This report presents and evaluates the results of the geophysical studies without extensive interpretation.

## Geophysical Methods

This study uses a multi-method geophysical approach to determine the geophysical characteristics of breccia pipes that are most diagnostic as exploration tools, particularly on the Coconino Plateau where tree cover limits helicopter reconnaissance mapping. Variations of magnetite content and rock density were determined by magnetic and gravity field measurements. Several electromagnetic (EM) methods were used to measure the electrical characteristics of the breccia pipes and surrounding host rocks. Among the frequency-domain electromagnetic methods (FDEM) used were VLF (very low frequency), loop-loop (slingram) measurements, AMT (audio-magnetotellurics) soundings, and telluric electric field profiles. In addition to the FDEM methods, most exploration sites include a time-domain electromagnetic (TDEM) profile. A complete description of the VLF electromagnetic methods is found in Telford et al., 1976. The VLF method measures magnetic and electrical responses of a vertically polarized radio-wave transmitted at frequencies up to 24.0 KHz from one of a number of powerful radio communications stations located around the world. Conductivity of the earth at the measuring site, is one of several other factors affecting the propagation of the radio wave as it moves across the earth. Exploration depth of the VLF method ranges from a few meters to several tens of meters, depending on the local resistivity of the earth and the frequency of the transmitted radio-wave.

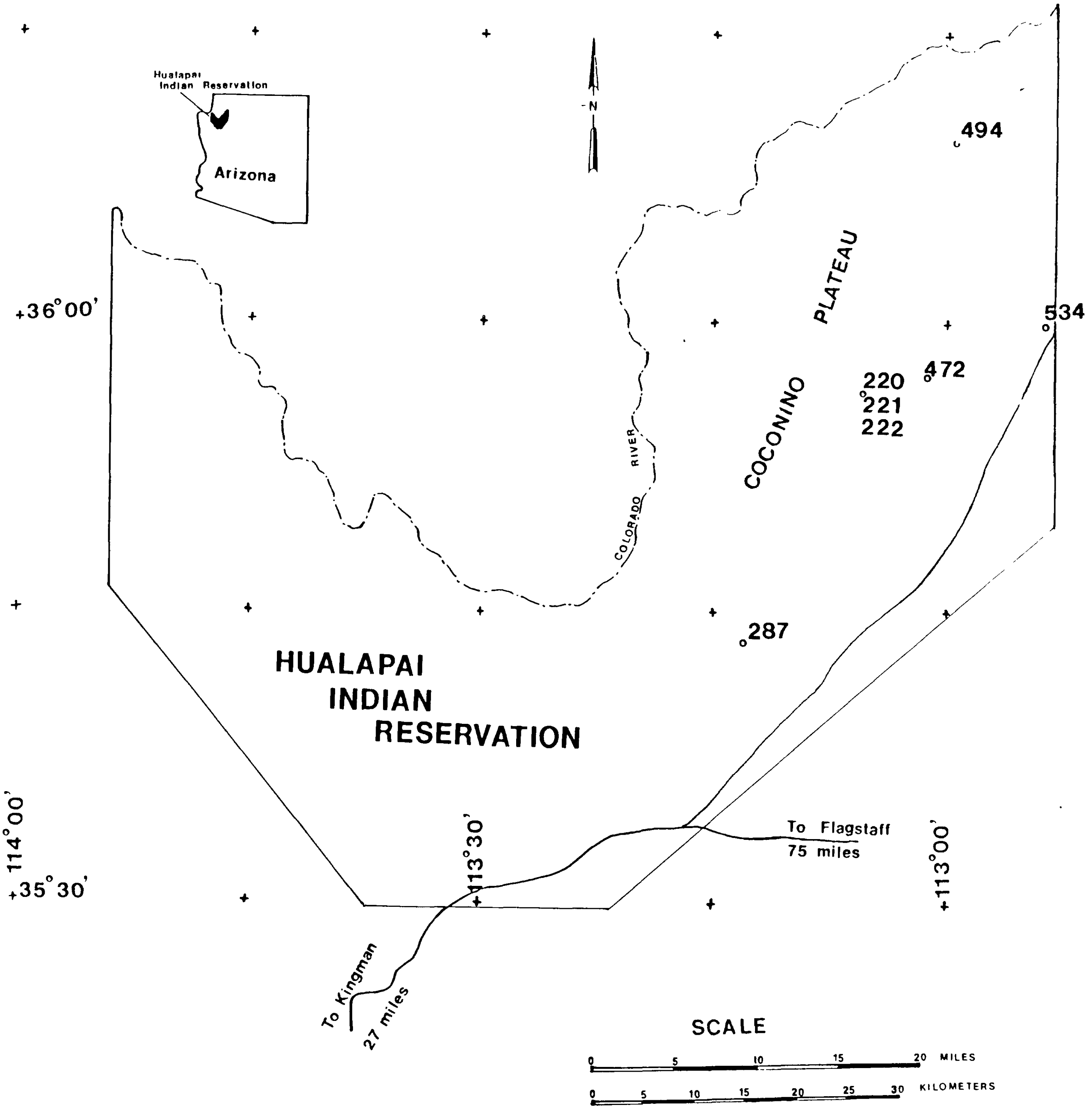



Figure 1 Location Map for Hualapai Indian Reservation showing locations of geophysical studies. (From McKee et al, 1977).

The theory of loop-loop electromagnetic methods (slingram) is described in detail by Keller and Frischknecht (1966) and Frischknecht (1967). EM fields are transmitted into the ground through a coil and components of the EM field are measured at several descrete frequencies at a fixed distance from the transmitter coil. In the present survey measurements were made at frequencies of 111, 220, 440, 888 and 1777 Hz; the separation between transmitter and receiver was 200 meters. Lateral changes of conductivity within 100 meters of the surface were mapped effectively by the method.

The theory of the Time Domain Electromagnetics (TDEM) method is described in Kuo and Cho, 1980. The TDEM system measures the fields of secondary induced current transients created in the ground by a transmitter loop. These eddy currents set up a secondary magnetic field which can be detected by a receiver loop. Since the eddy currents do not cease flowing instantly when the transmitted current is switched off but decay gradually, their presence is shown by the decaying or transient voltages that they induce in the receiver loop. The longer these transient voltages persist, the better the conductor. The TDEM system is sensitive to small conductivity contrasts and because of the relatively long time-periods involved the method allows a greater depth of exploration than VLF or slingram methods. Exploration depth is generally considered to be two or three times the loop diameter.

## Discussion of Results

Seven sites were selected for this geophysical study. Two sites (494 and 587) are thought to be classic examples of mineralized breccia pipes. Site 534 with its 700 to 800 meter depression was chosen for comparison because of a lack of surface mineral traces.

Sites 220, 221, 222 and 472 are generally thought to show stratabound copper mineralization. Circular drainage around these sites suggests that they may be collapse breccia pipes. Geophysical measurements were made along surveyed lines shown in figure 2.

Magnetic profiles were made at all sites. A magnetic survey at site 220 was recorded on a grid at 50-meter intervals along traverses oriented normal to the northeast baseline and 50 meters apart (fig. 3). The magnetic data were gridded and contoured (fig. 4) by use of a program by Webring, 1981, and Godson and Webring, 1982. The most significant feature of this magnetic contour map is a subcircular ring of magnetic highs and lows of about 20 gammas amplitude.

A gravity profile was run along the NE baseline of site 220 (fig. 5), and the profile shows a high of about 0.2 mgal located over the surface expression of the pipe but offset slightly northeast. Beneath the same area of alteration (between stations 400 and 600), the out-of-phase slingram profile data (fig. 6) show a conductive response at 1777 Hz, suggesting that a relatively shallow conductor is present. A VLF profile made along the NE baseline (fig. 7), although noisy, suggests a small (50 to 200 ohm-meter) low in apparent resistivity. The low is sharpest near station 600 on the SW-NE profile. Near-surface lateral variations of resistivity are a probable cause of scattered VLF apparent resistivity values along this profile; however, apparent-resistivity low at station 600 does correlate with the slingram data

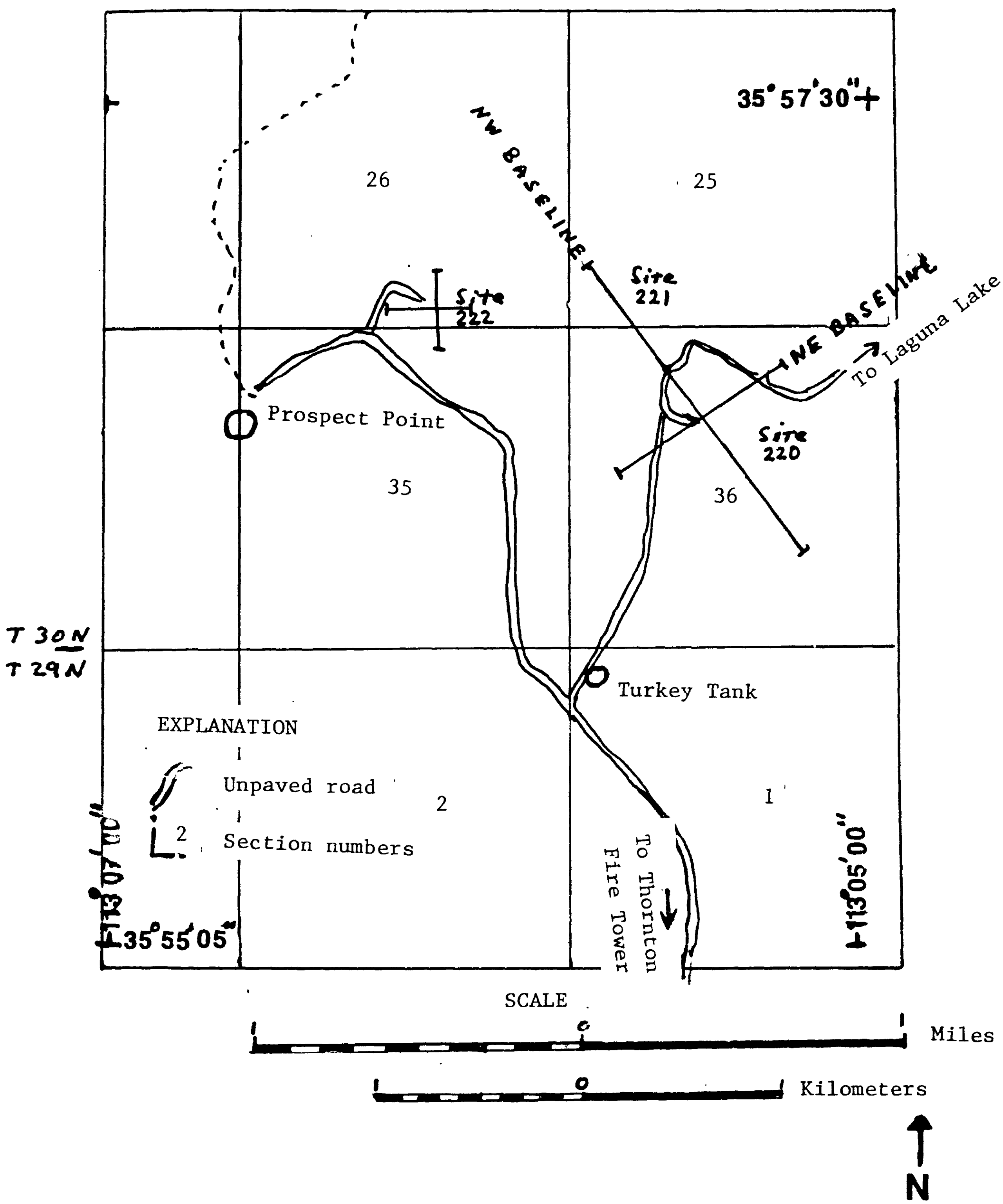



Figure 2 Location map for sites 220,221 and 222 showing traverses used for data acquisition.

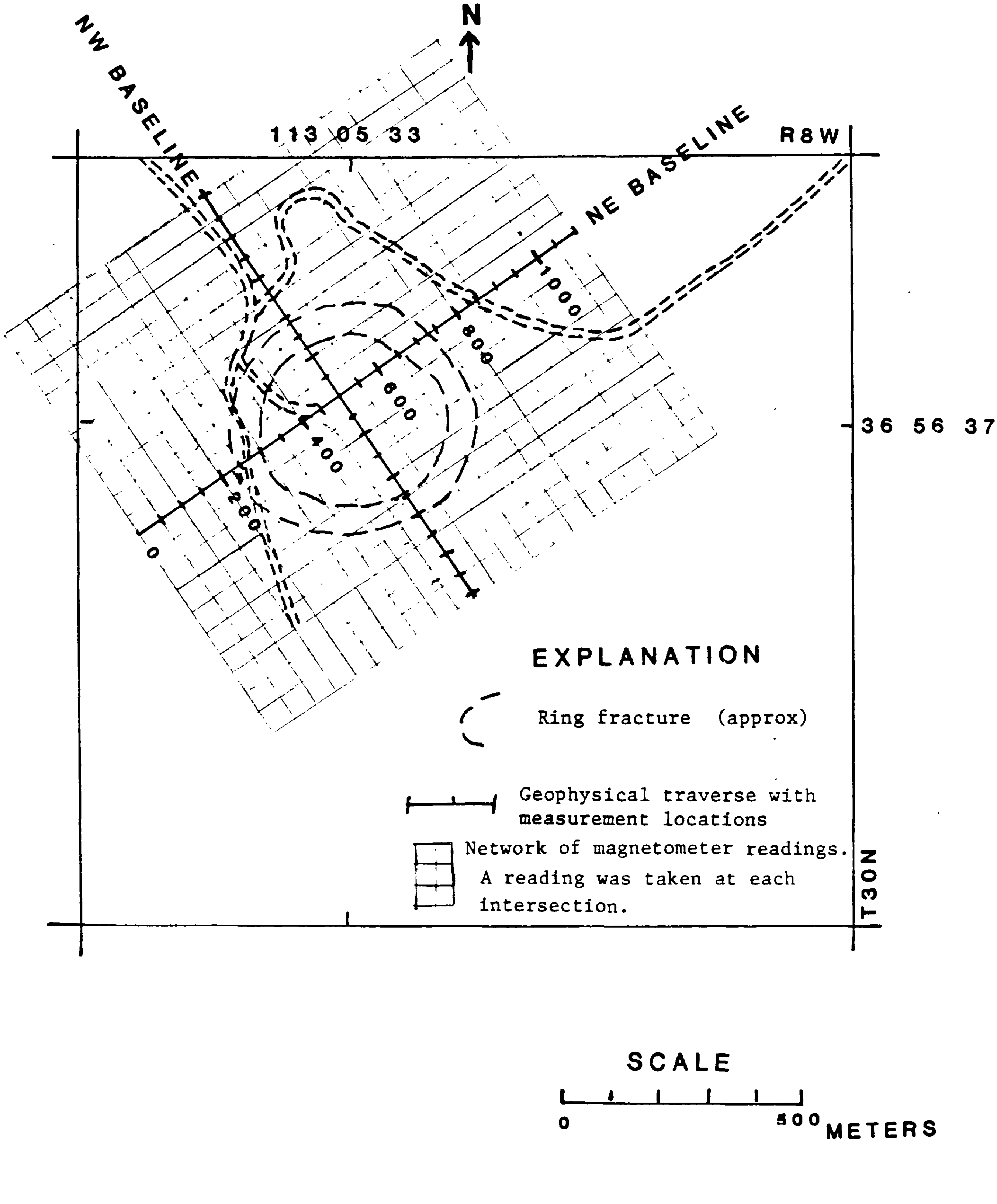



Figure 3 Site 220, Detailed sketch showing traverses used for data acquisition

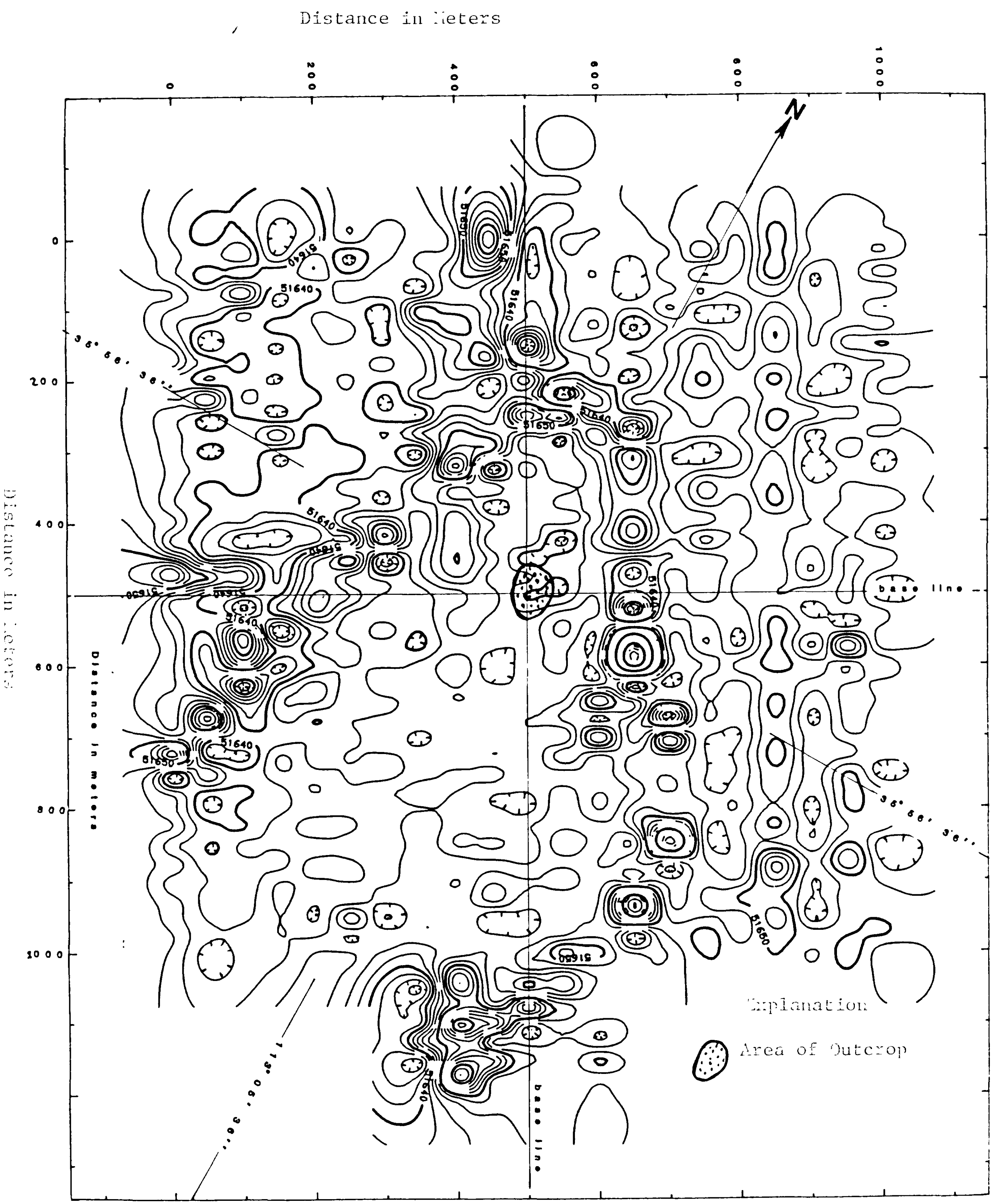



Figure 4 Magnetic Anomaly Map, Site 220

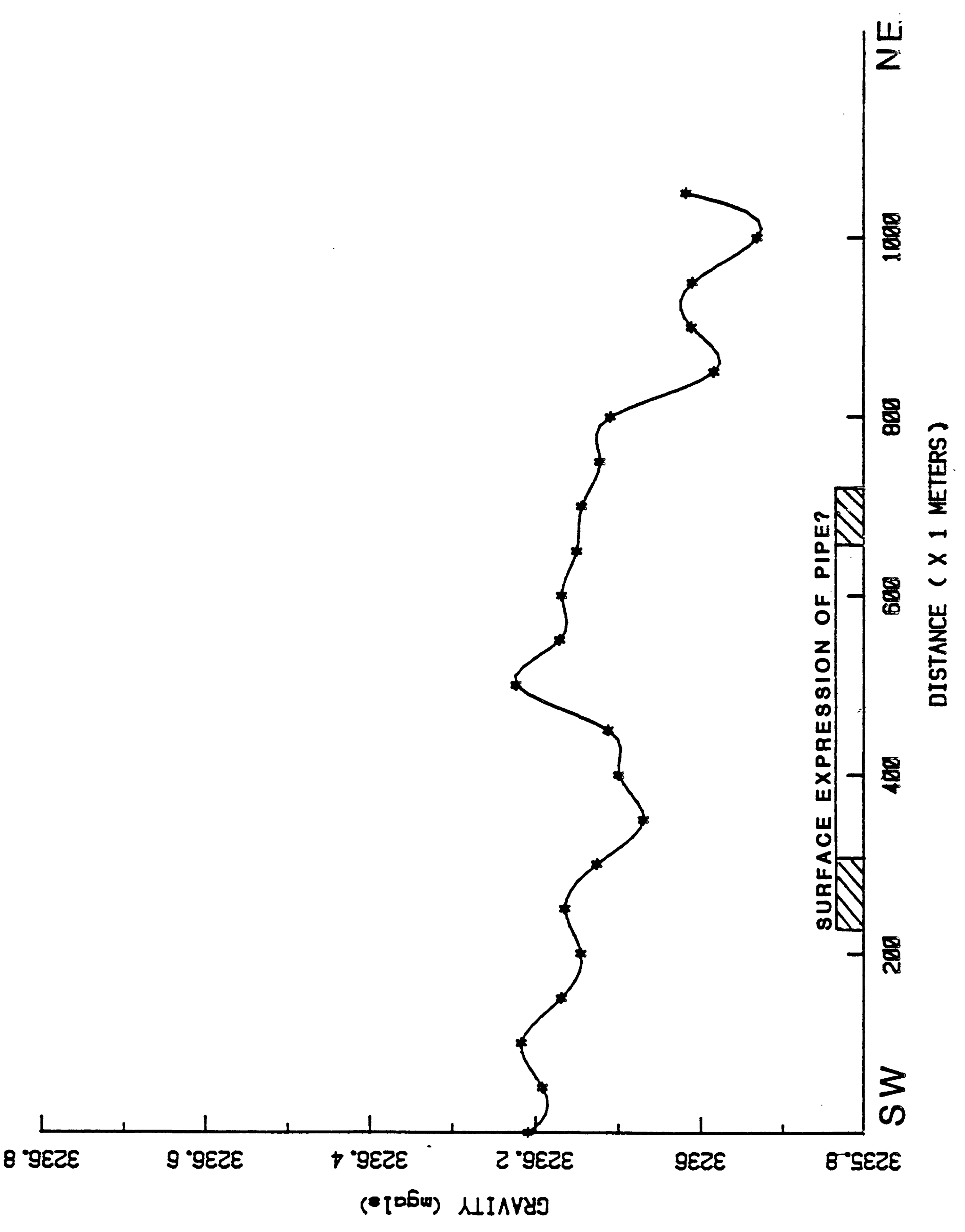



Figure 5 Gravity Profile, Site 220

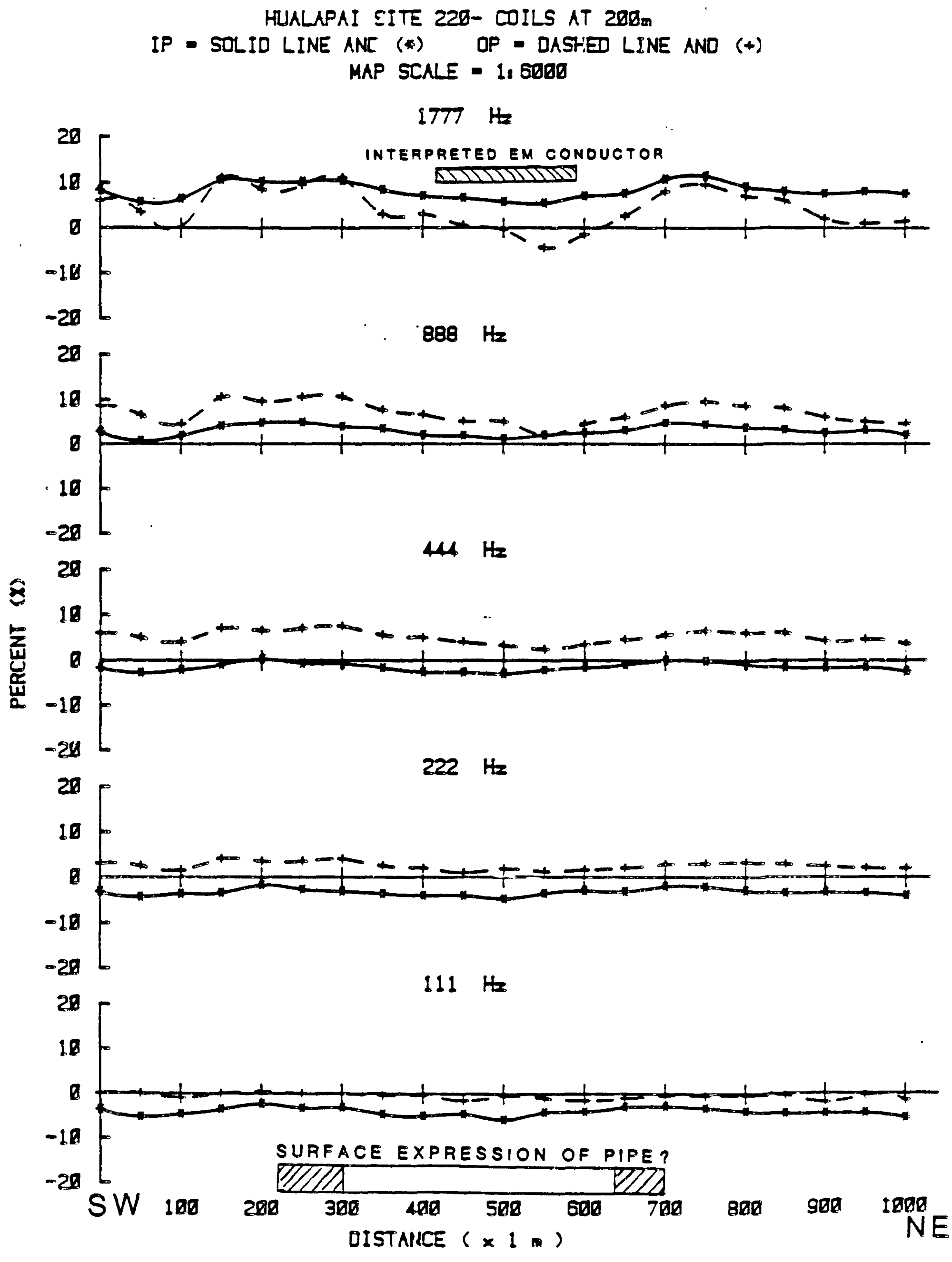



Figure 6 Slingram Data, Site 220

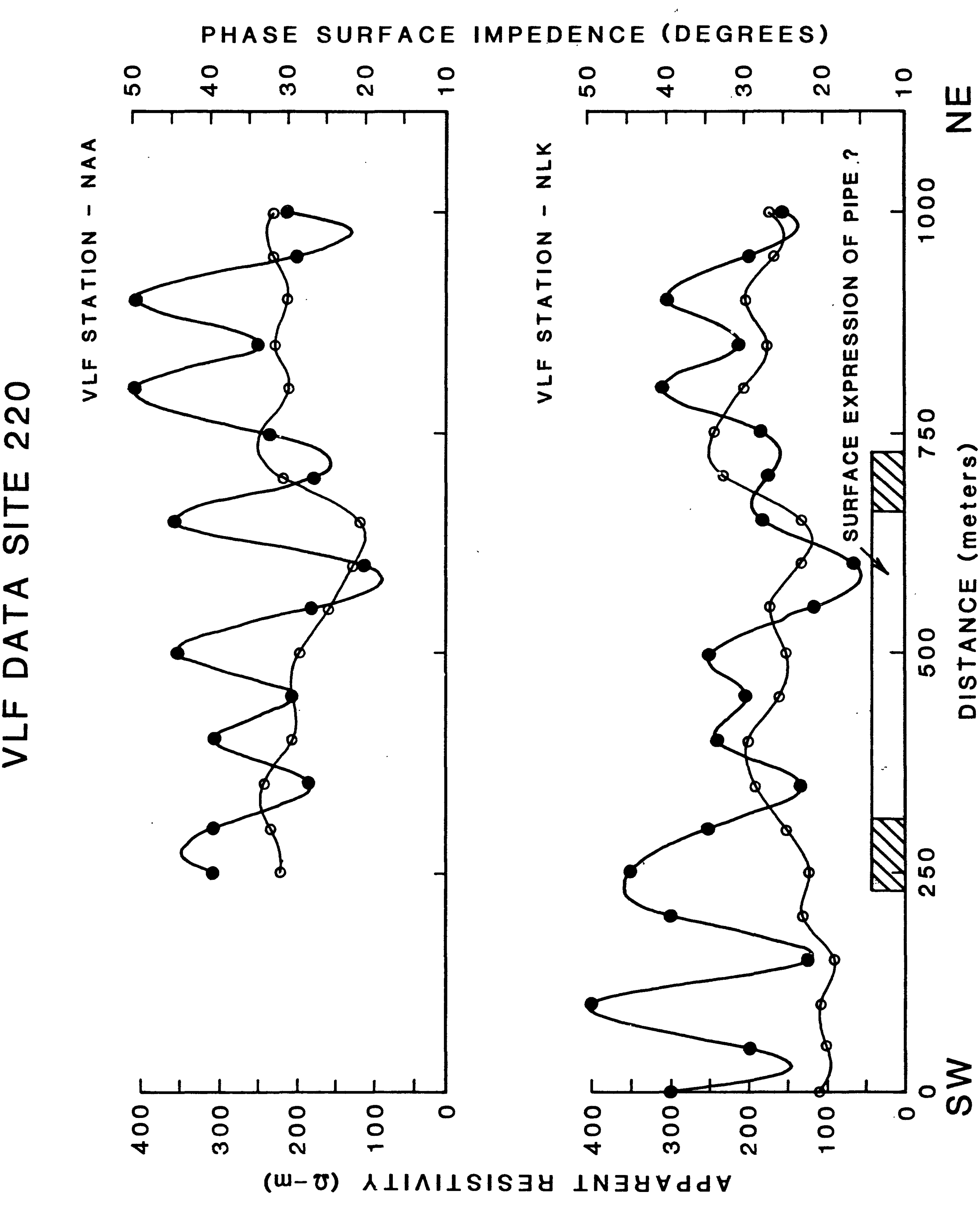



Figure 7 VLF Data, Site 220

and the gravity high. Abrupt changes in TDEM voltage readings from soundings taken along the NE baseline (fig. 8) also correlate with the magnetic and slingram data and the gravity high. An interpreted electric section based on TDEM data shows a distinct change in resistivity at a depth of about 290 meters (fig. 9). An apparent resistivity pseudosection based on TDEM data shows low near-surface resistivity between stations 400 and 600 (fig. 10).

Site 287 is located about eight miles northeast of the paved road from U.S. Highway 66 to the Hilltop parking lot (fig. 1). A more detailed location map is seen in figure 11. Previous exploration at site 287 included diamond core drilling. Casing left in some of the holes no doubt interfered with the results of the magnetic survey. The magnetic survey (fig. 12) was restricted to the immediate vicinity of the breccia pipe; thus, the regional magnetic contrast of mineralized to unmineralized rocks, if any, was not seen.

Site 472 is located near Lagoon Lake about three miles east of site 220 (fig. 13). Near-surface mineralization of copper is present in shallow pits and trenches in the area.

Site 494 is located at the edge of Mohawk Canyon, a major tributary to the Grand Canyon of the Colorado River (fig. 14). Topography due to the proximity of the Canyon causes severe problems in interpreting the electrical data. Magnetic and VLF profiles were made along the traverses shown in figure 15, with the magnetic profile (fig. 17) showing a low from two- to- four gammas between stations 0 to 100 on the SW-NE traverse. This magnetic low decreases slightly (about two gammas) along the traverse between stations 250 and 350. The VLF profile (fig. 16) shows consistency between the apparent resistivity values received from the two transmitting stations (NAA = Jim Creek Wa, NLK = Cutler, Me) with changes in apparent resistivity of 200 ohm-meters present between stations 200 and 250 on the SW-NE traverse. A magnetic profile made along the SW-NE traverse (fig. 17) probably reflects the topographic effect of the nearby Mohawk Canyon. The TDEM profile (fig. 18) shows a drop in voltage at 300 meters along the NS traverse. An apparent resistivity pseudosection (fig. 19) based on TDEM data shows fairly homogeneous lithology at the shallower depths.

Site 534 is located near the northeastern boundary of the Hualapai Reservation (fig. 20). Geophysical measurements were made along the profile shown in figure 21. Little surface mineralization is evident. Slingram data (fig. 22) suggest a shallow conductive zone that exists at the north and south edges of the topographic lows leading into a depression. A VLF profile shows increasing apparent resistivity at about 700 meters (fig. 23). A TDEM profile (fig. 24) shows decreasing voltage with depth at station 250 and 750 suggesting correlation with the shallow conductive zones interpreted from the slingram data. An interpreted electric section (fig. 25) shows a decrease in resistivities at depths of approximately 250 meters that could indicate the presence of a more conductive area at or below 250 meters.

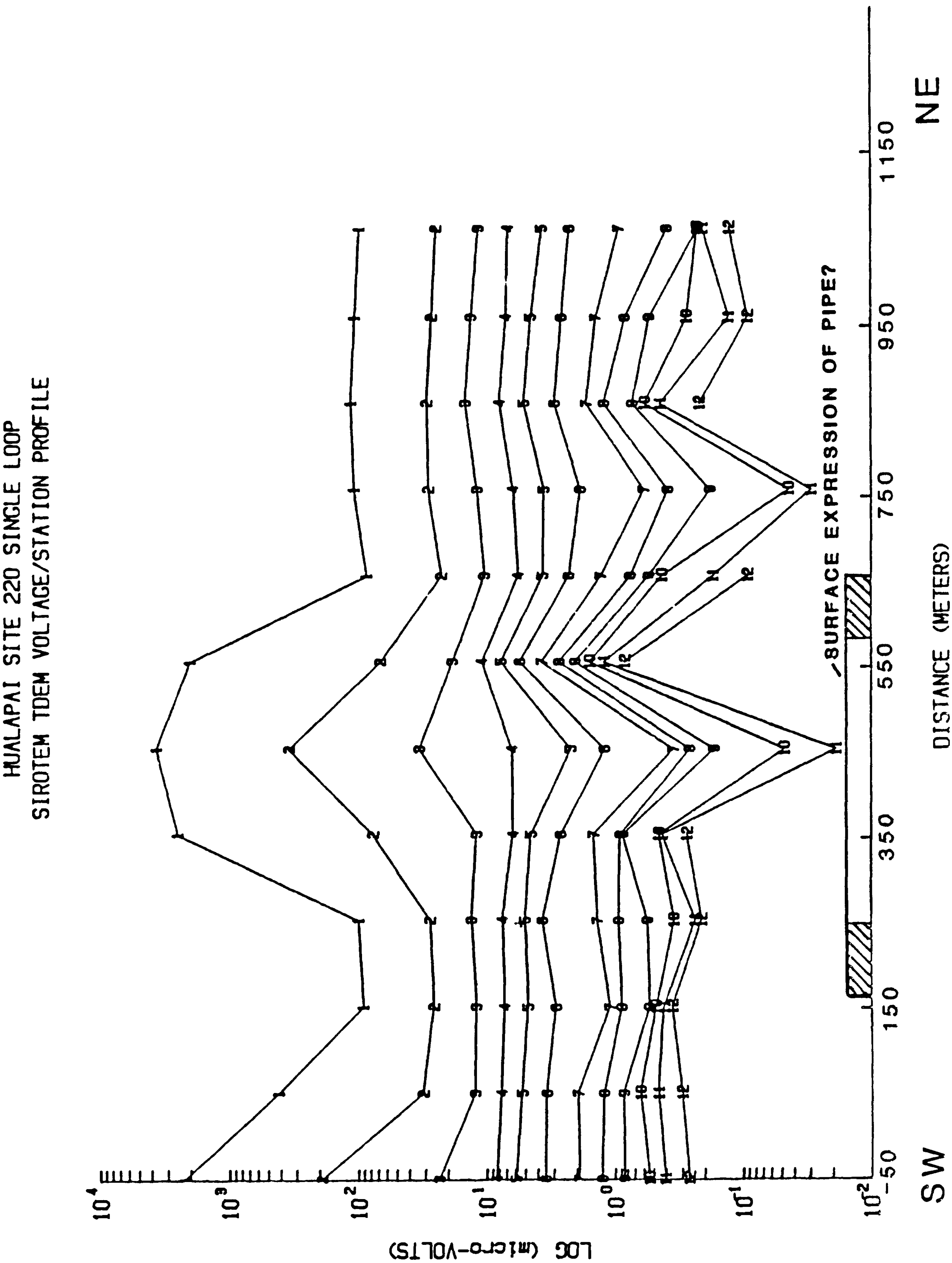



Figure 8 Sirotem TDEM voltage/station profile, site 220

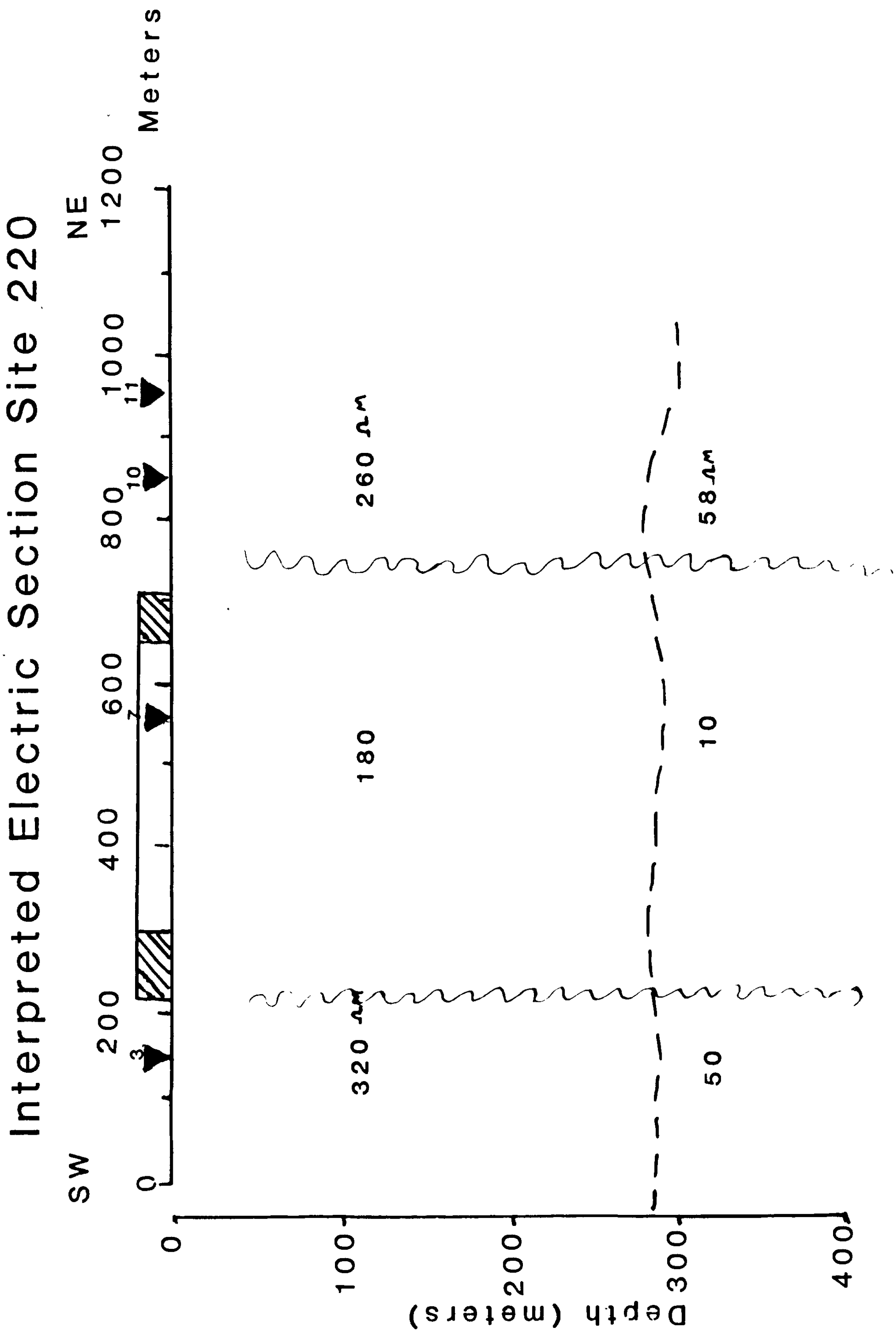



Figure [illegible] Interpreted Electric Section, Site 220

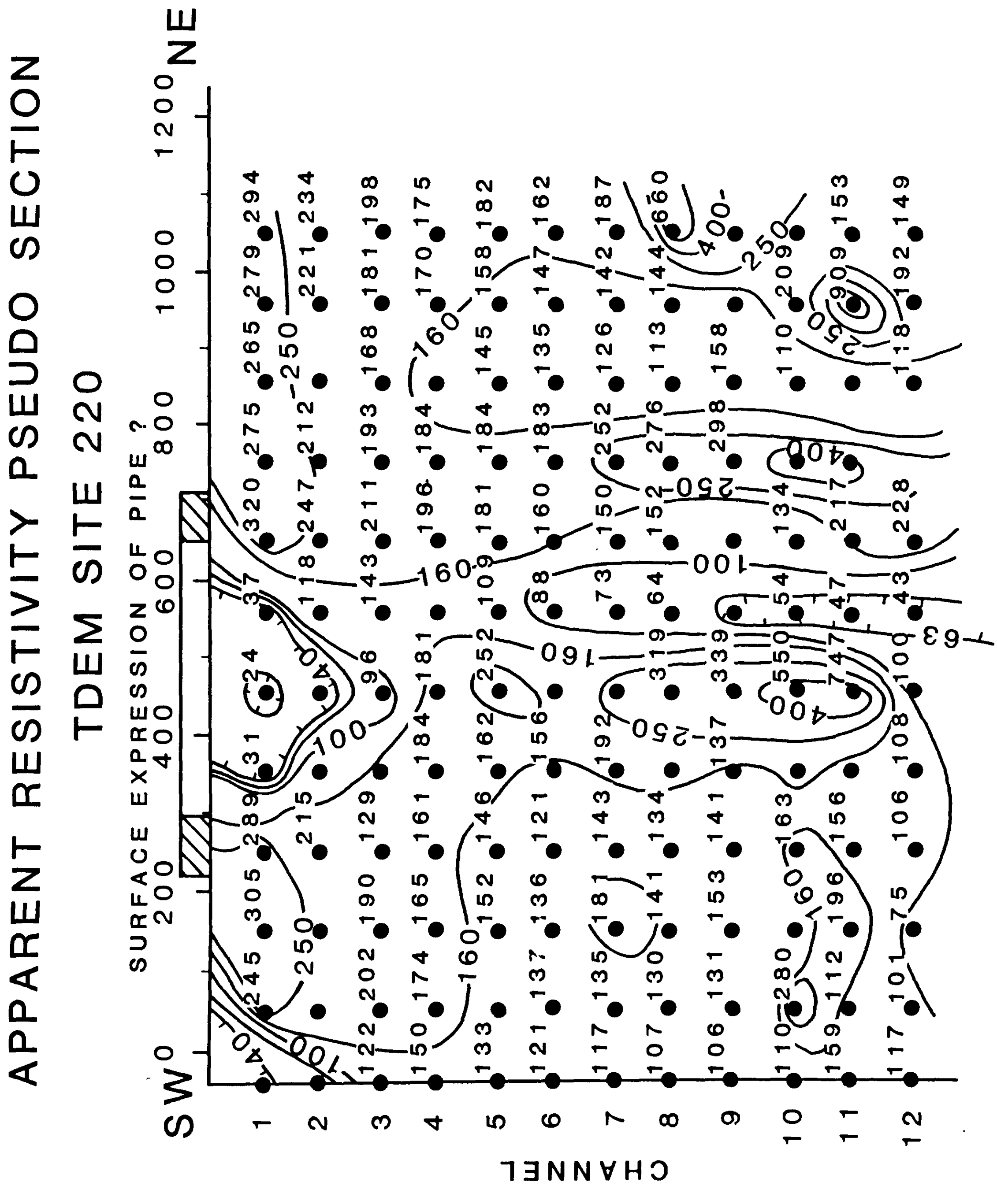



Figure 10 Apparent Resistivity Pseudosection, Site 220

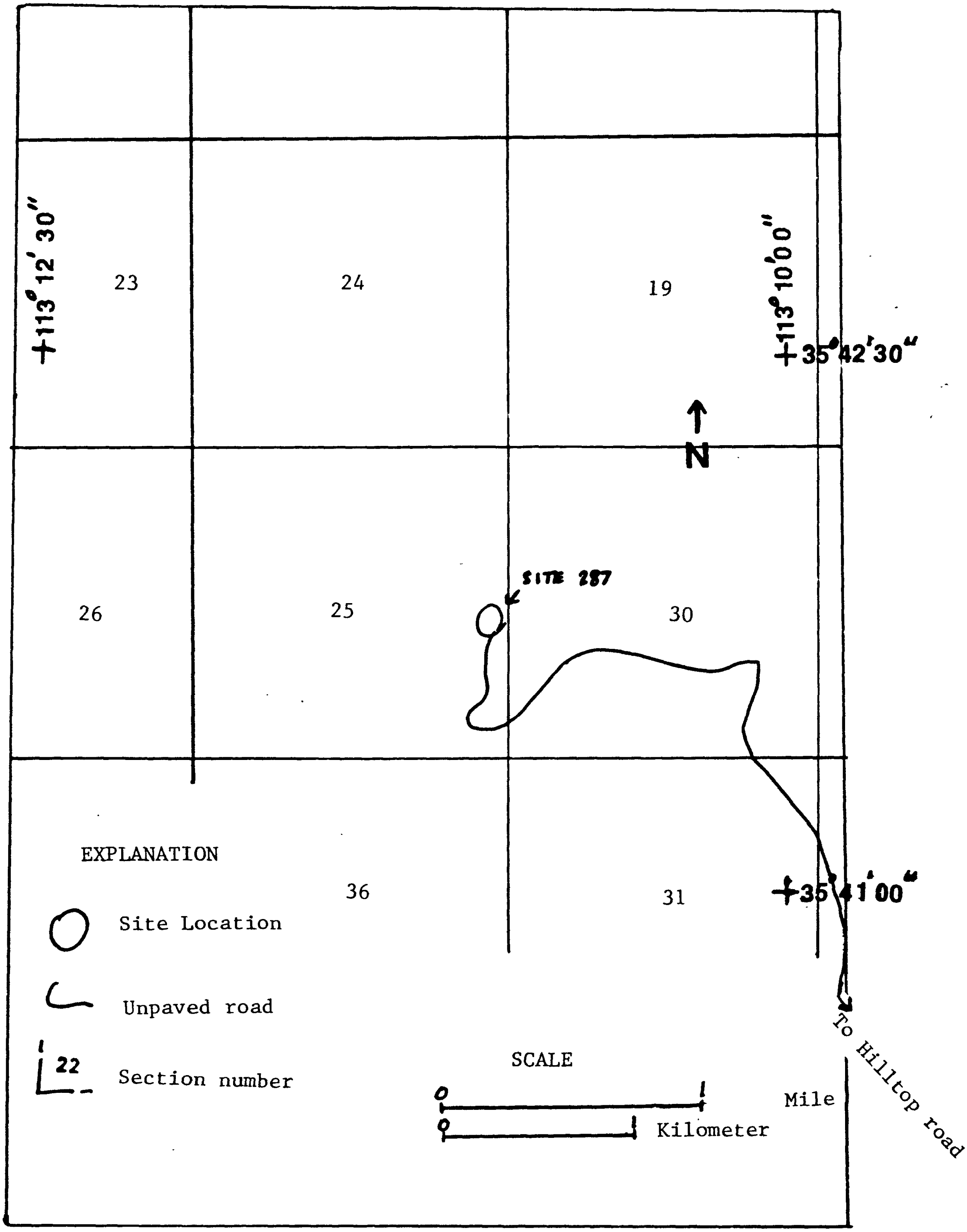
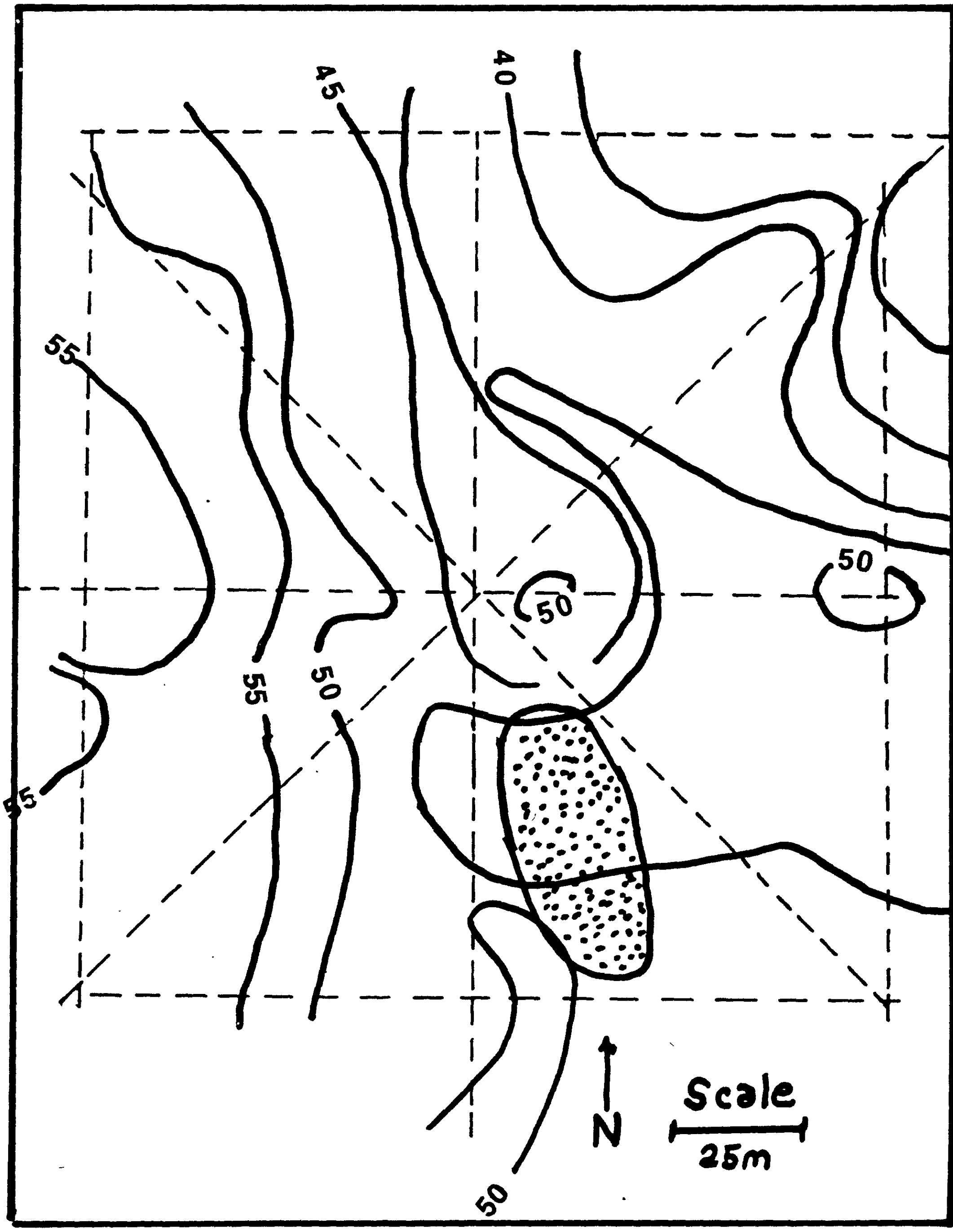



Figure 11 Location map for site 287




EXPLANATION

Traverse used for data acquisition

Contour lines for magnetic values (in gammas)

Area of outcrop

Figure 12 Magnetic Anomaly Map, Site 287

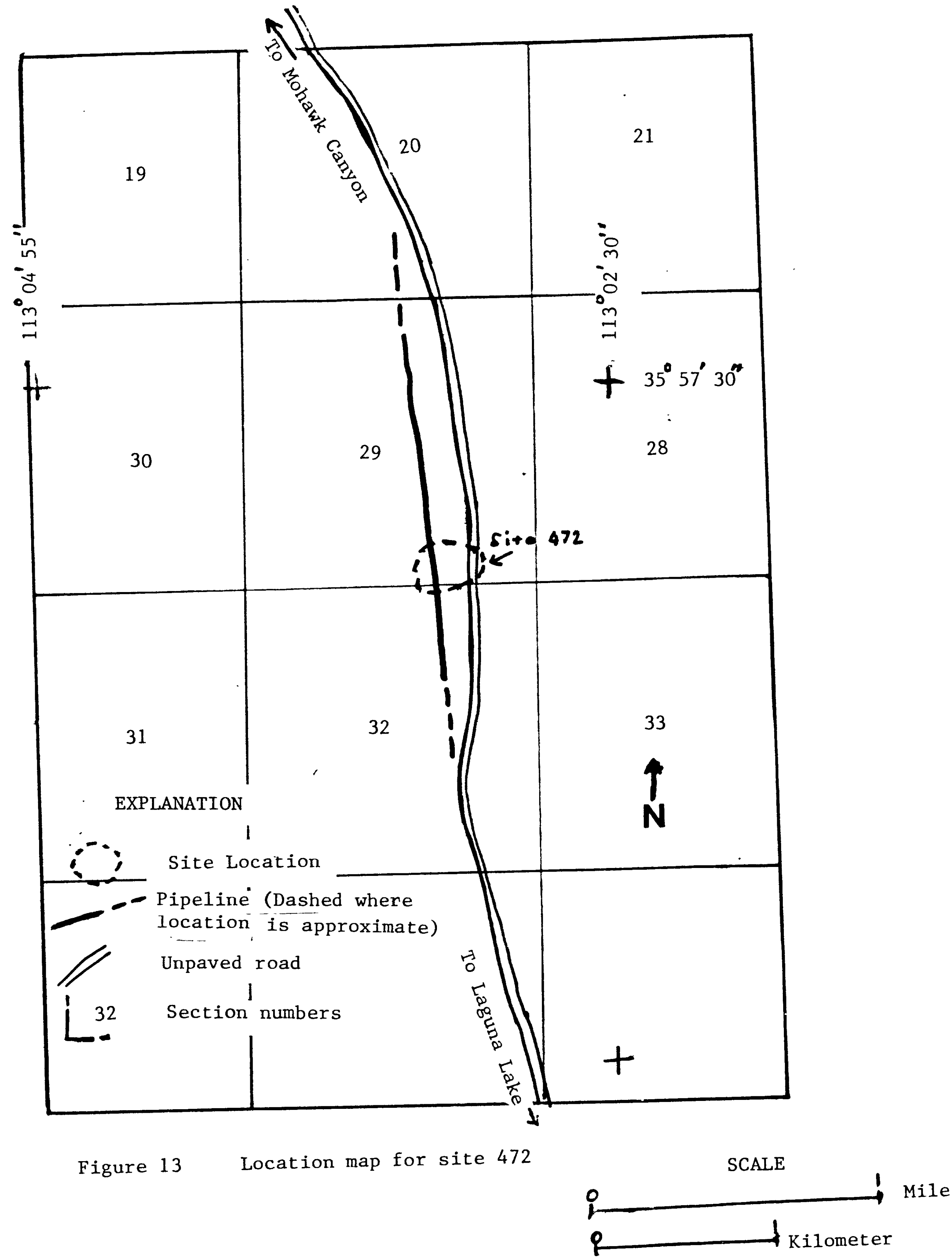



Figure 13 Location map for site 472

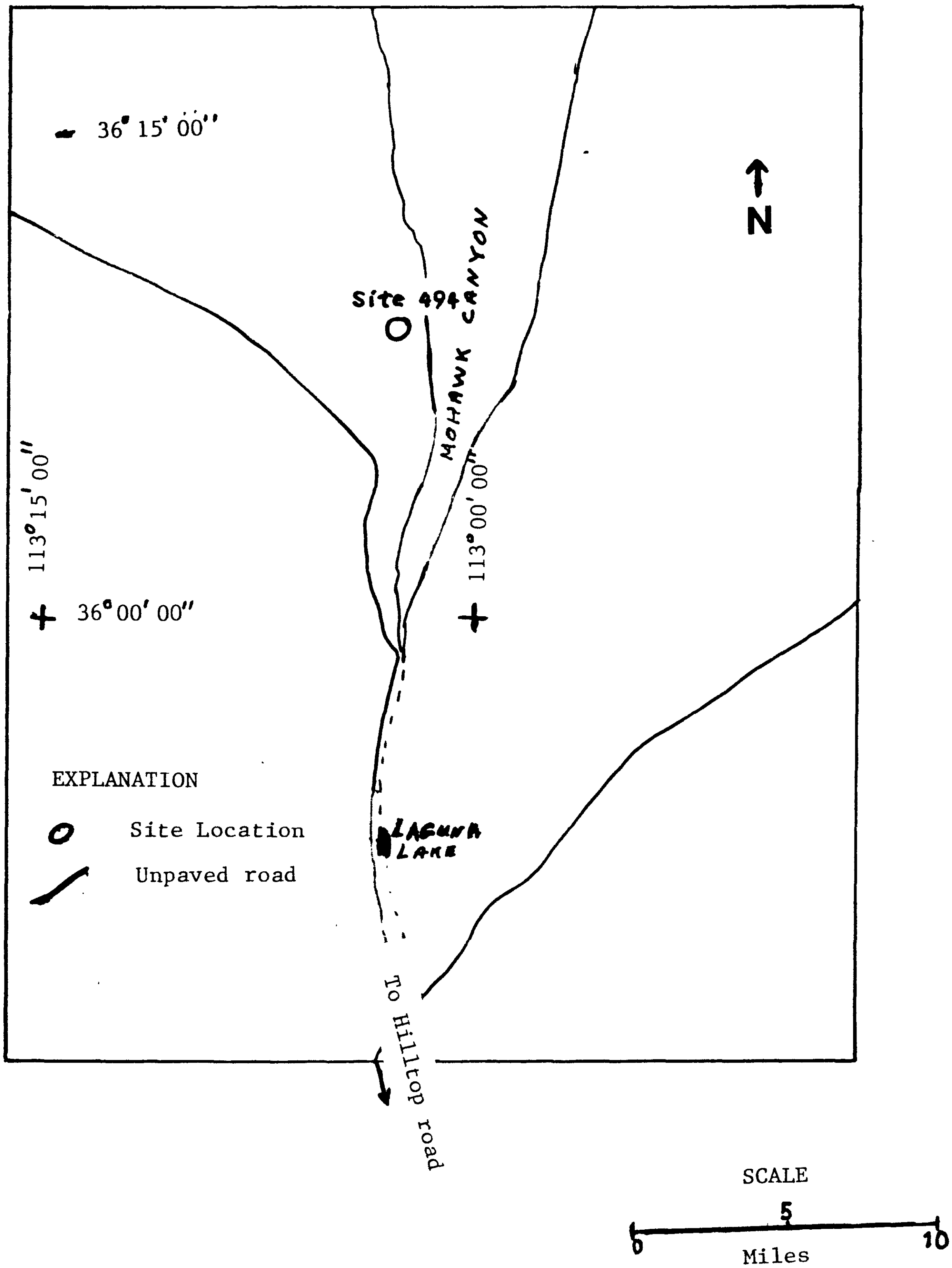



Figure 14 Location map for site 494

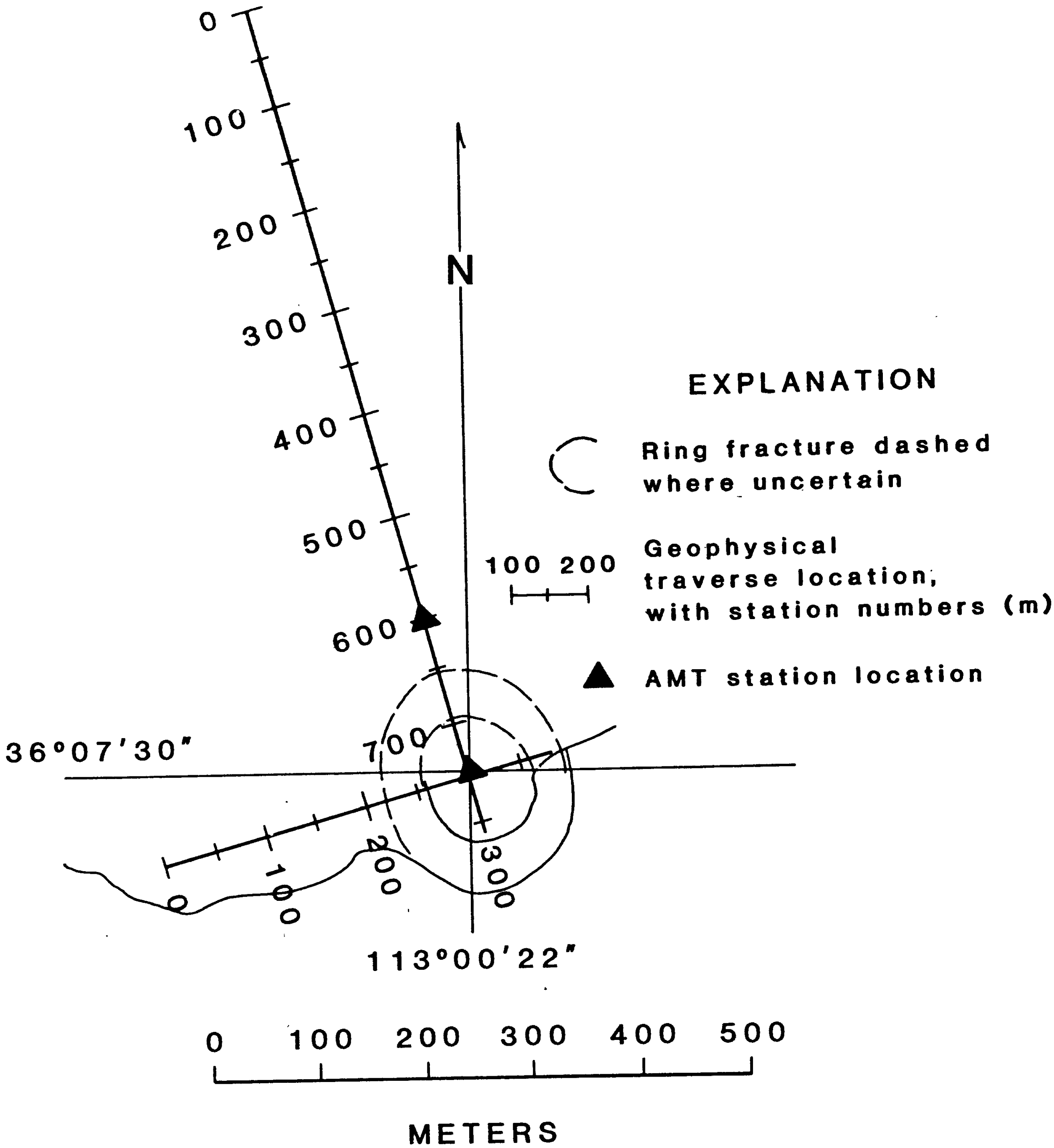



Figure 15 Site 494, Sketch showing traverses used for data acquisition.

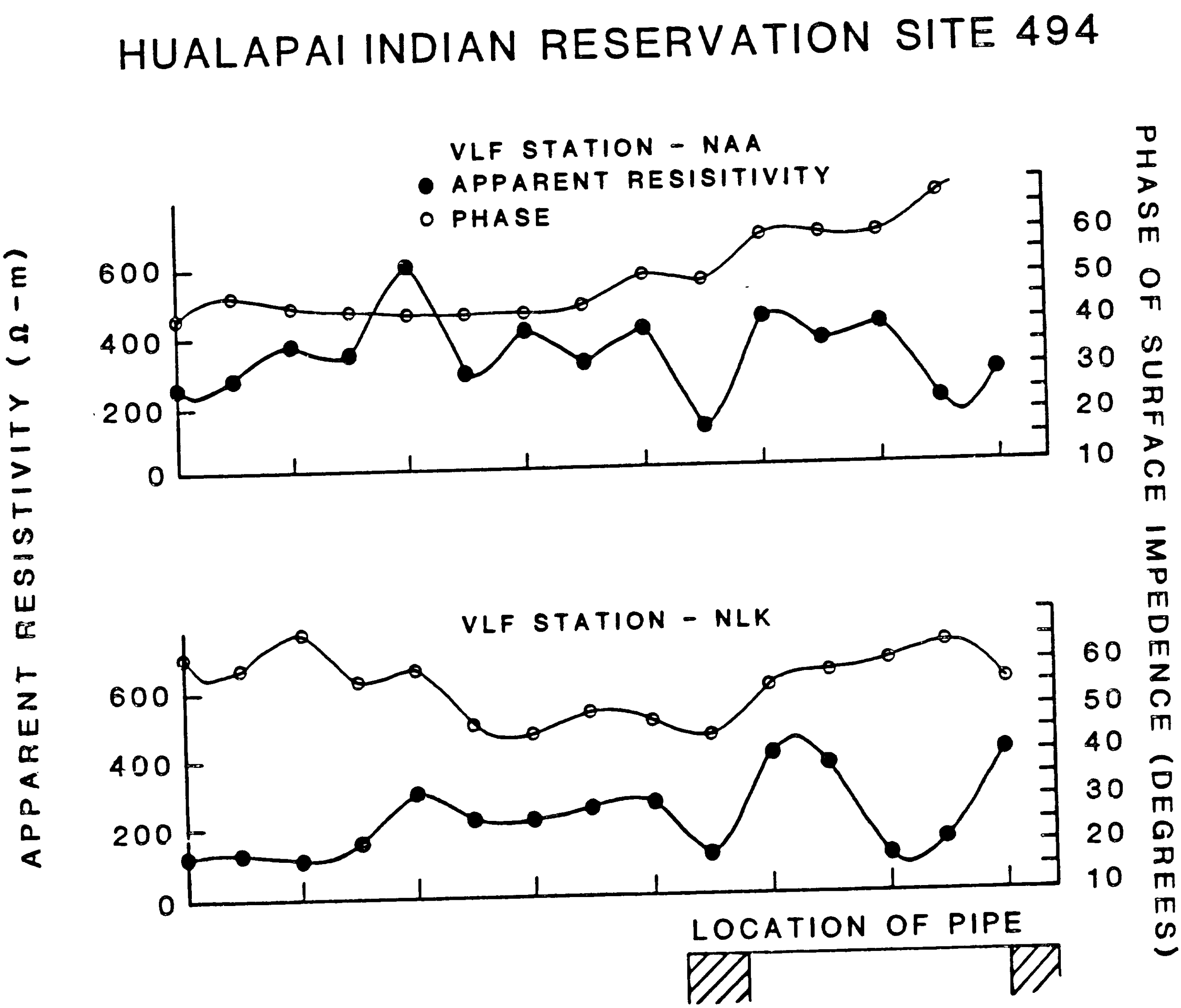



Figure 16 VLF Data, Site 494

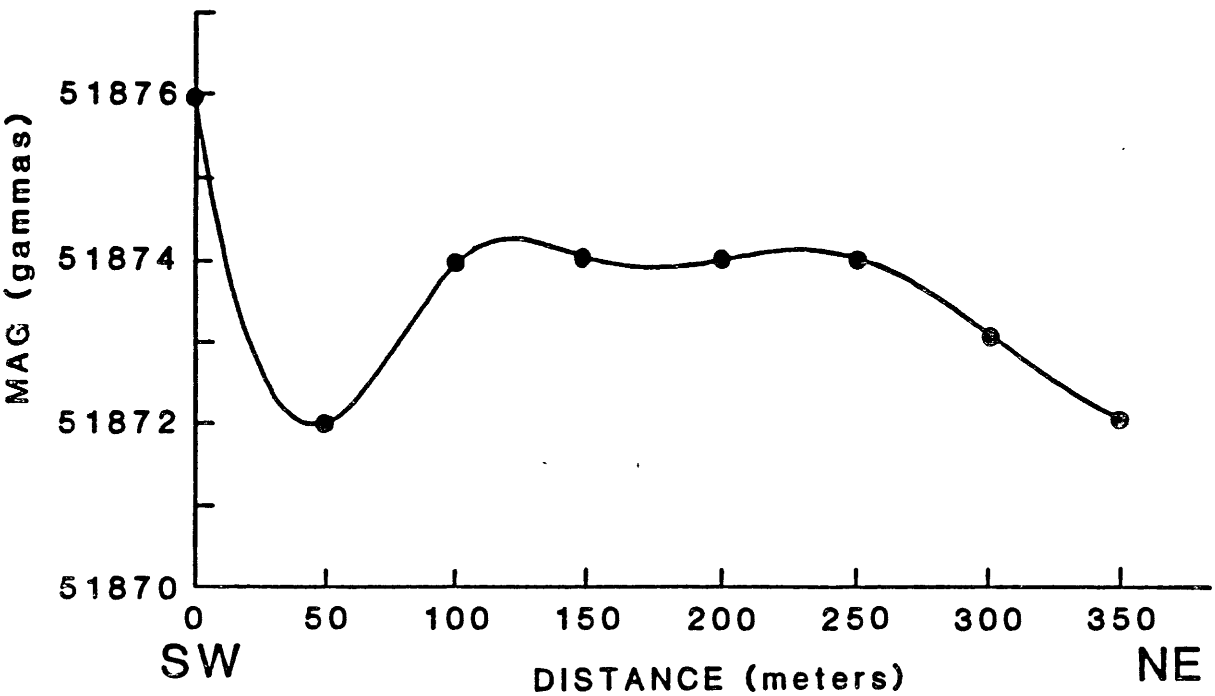



Figure 17 Magnetic Data, Site 494

HUALAPAI SITE 494 SINGLE LOOP
SIROTEM TDEM VOLTAGE/STATION PROFILE

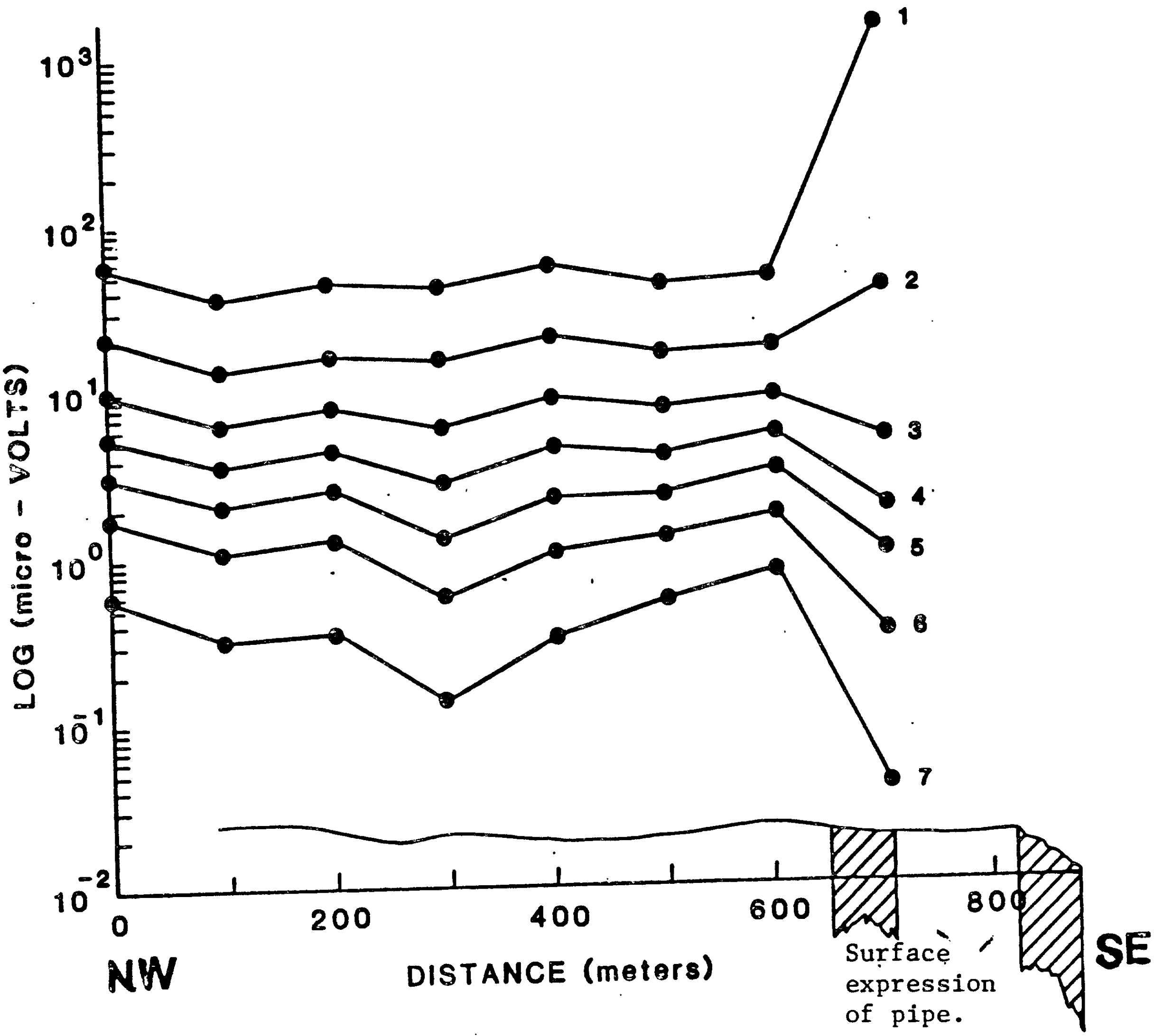



Figure 18 Sirotem TDEM voltage/station profile, Site 494

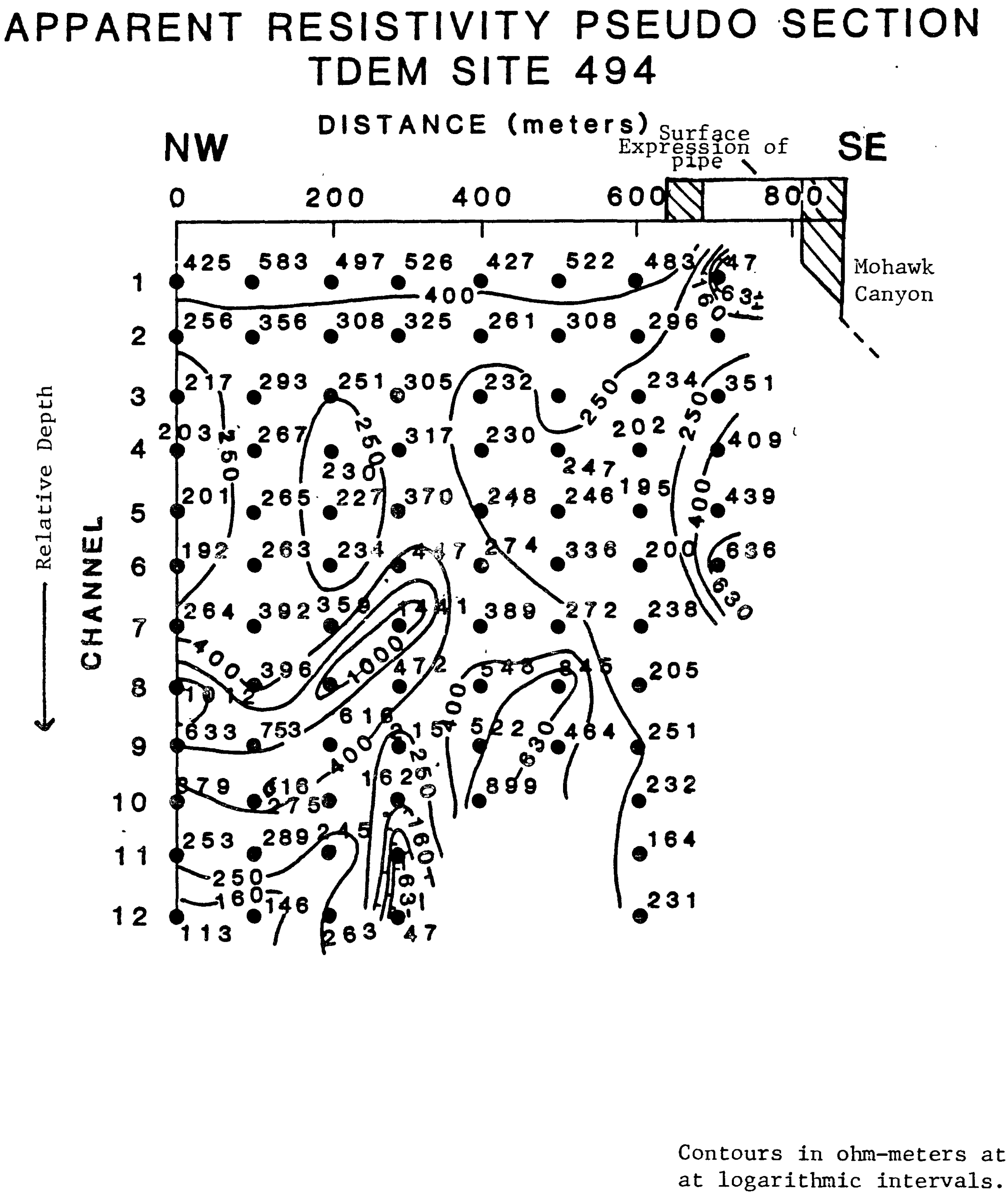



Figure 19 Apparent Resistivity Pseudosection, Site 494

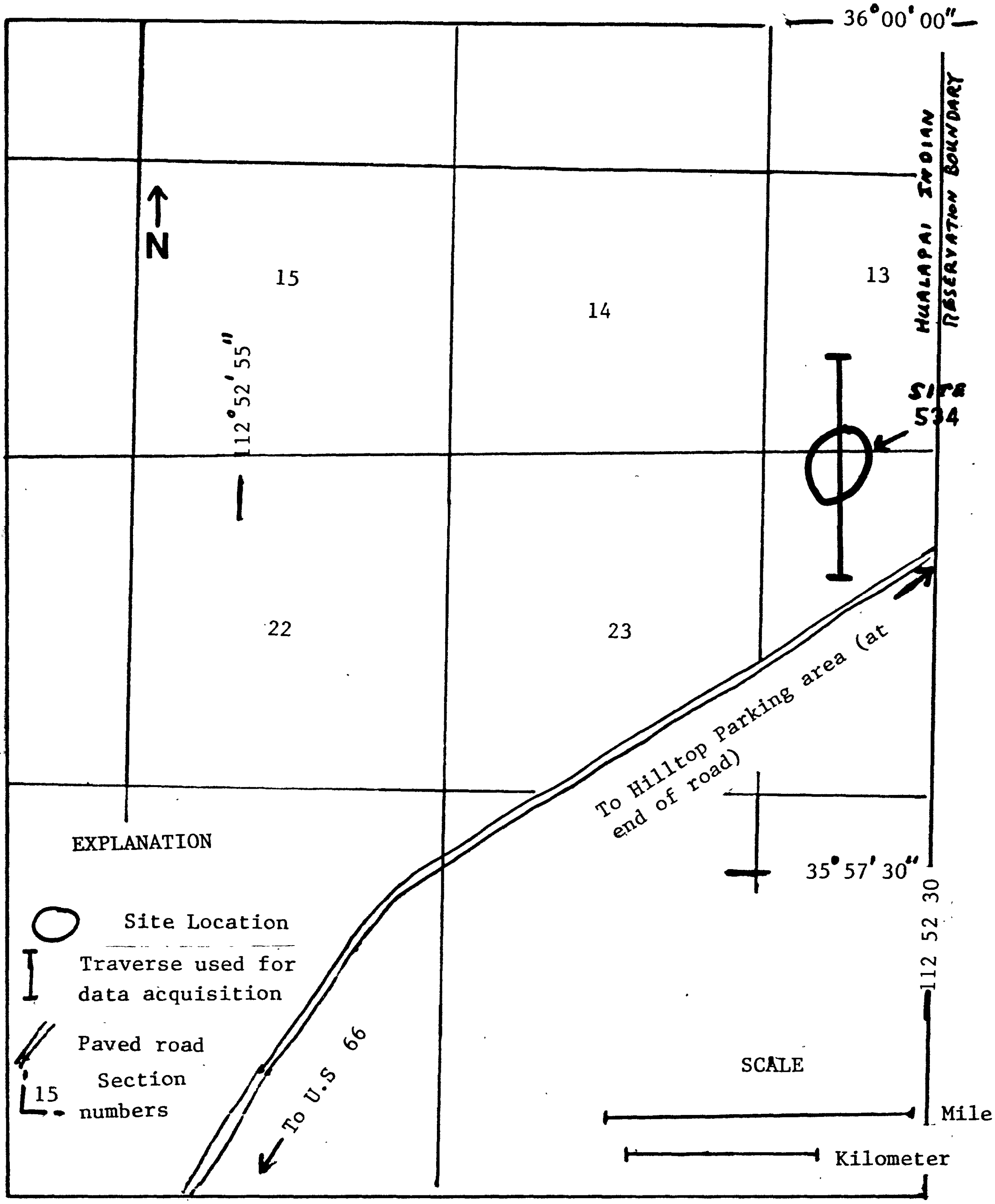



Figure 20 Location map for site 534, showing traverse used for data acquisition.

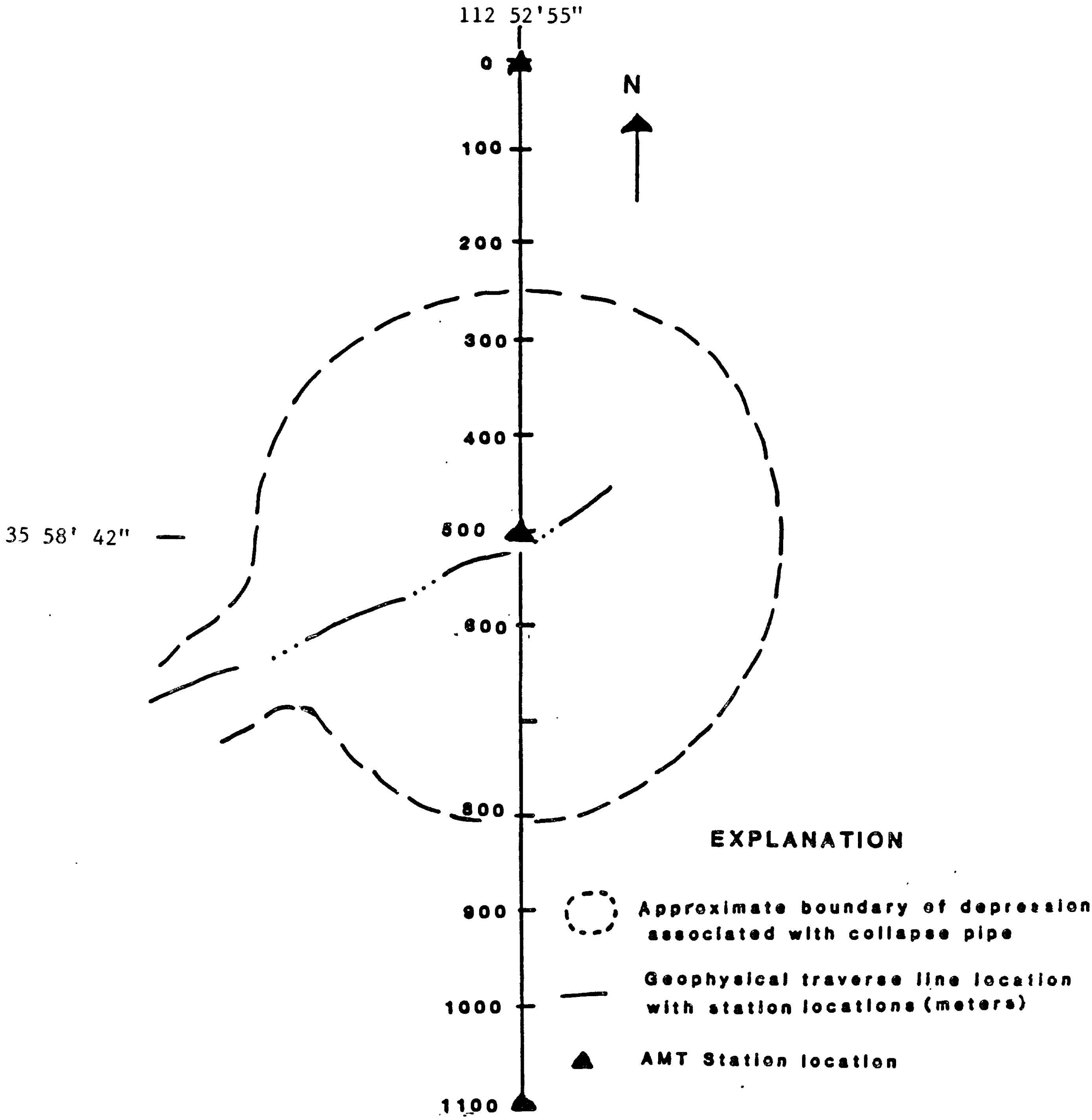



Figure 21 Sketch showing the location of geophysical traverse line location at Site 534 on the Hualapai Indian Reservation, AZ.

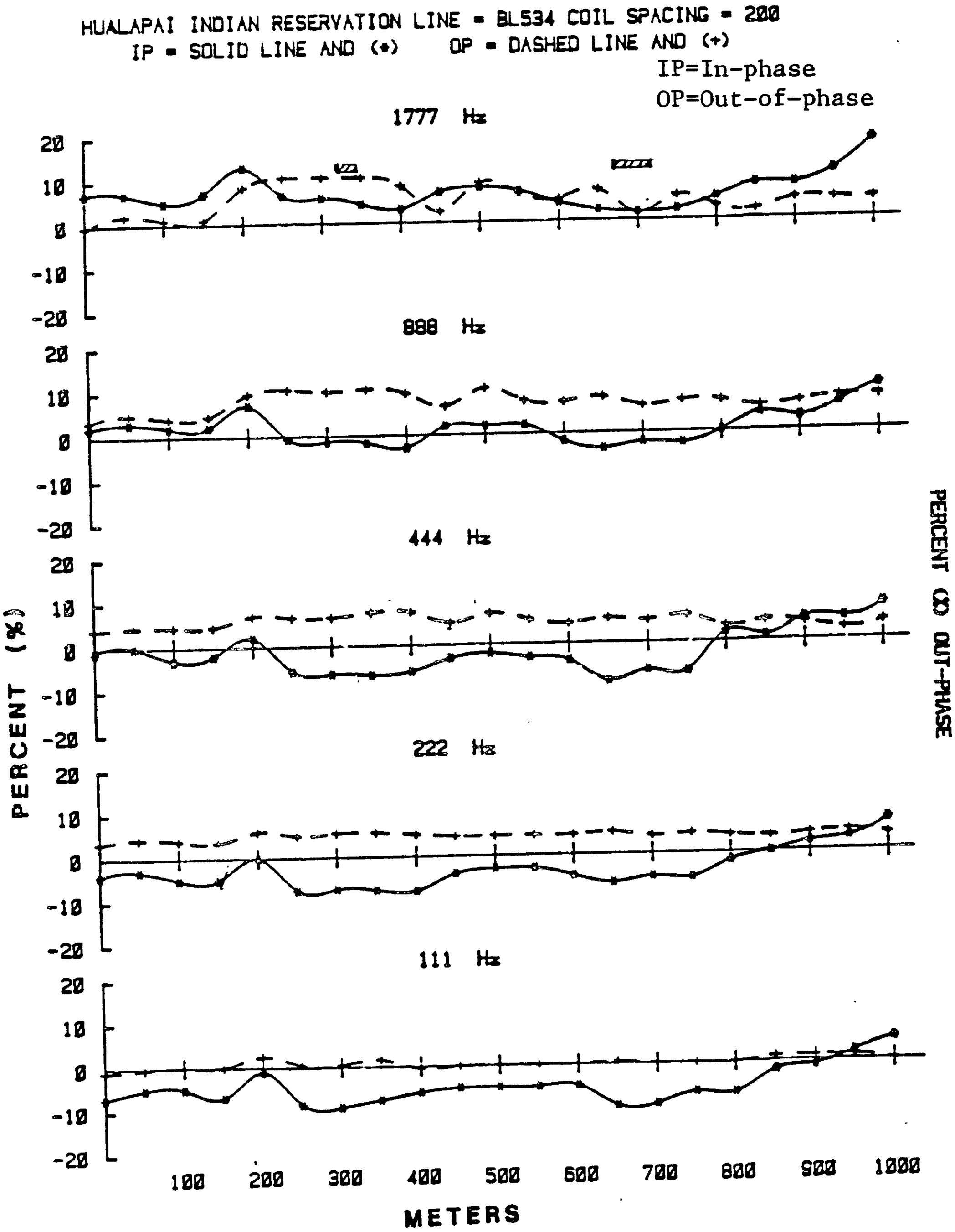



Figure 22 Slingram Data, Site 534

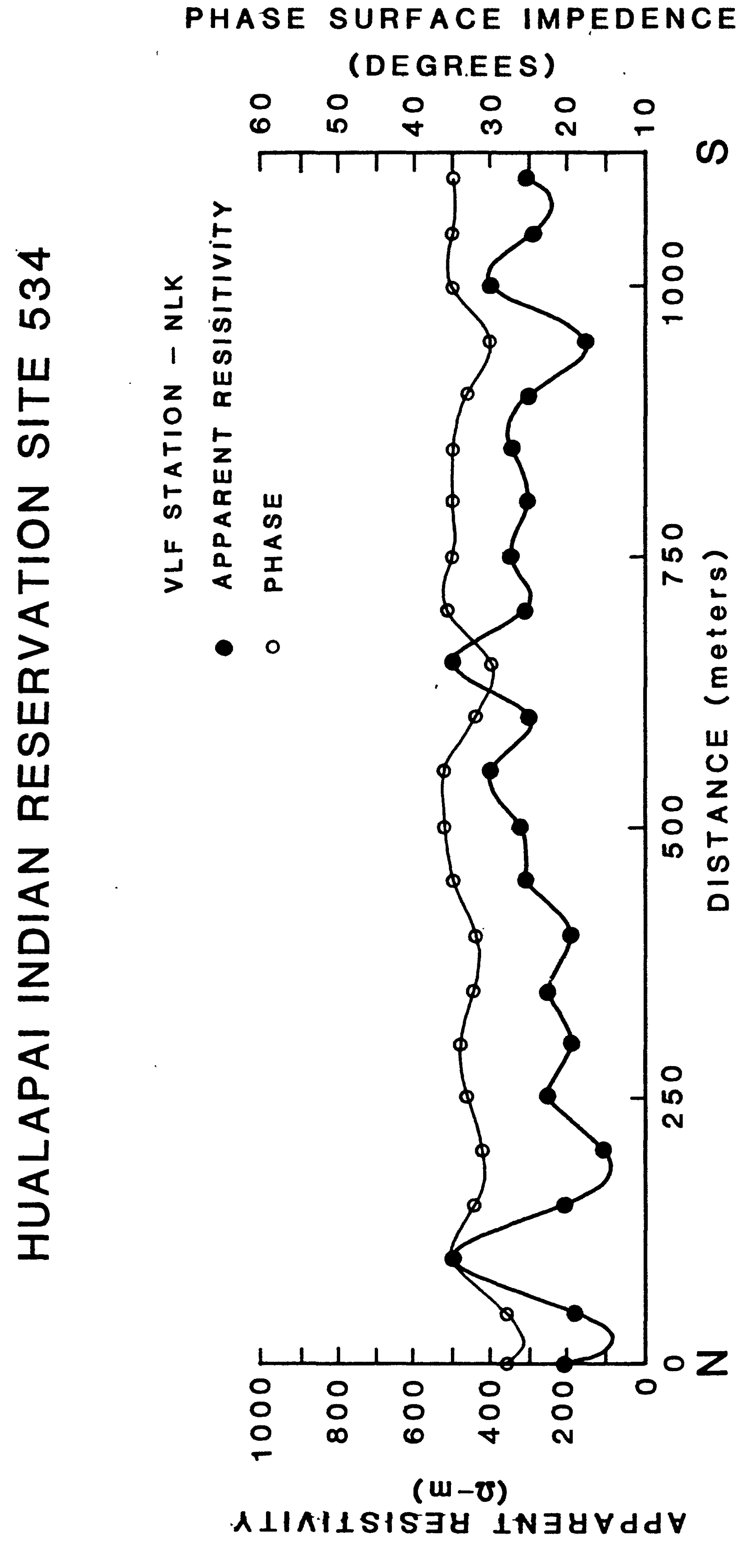



Figure 23   VLF Data, Site 534

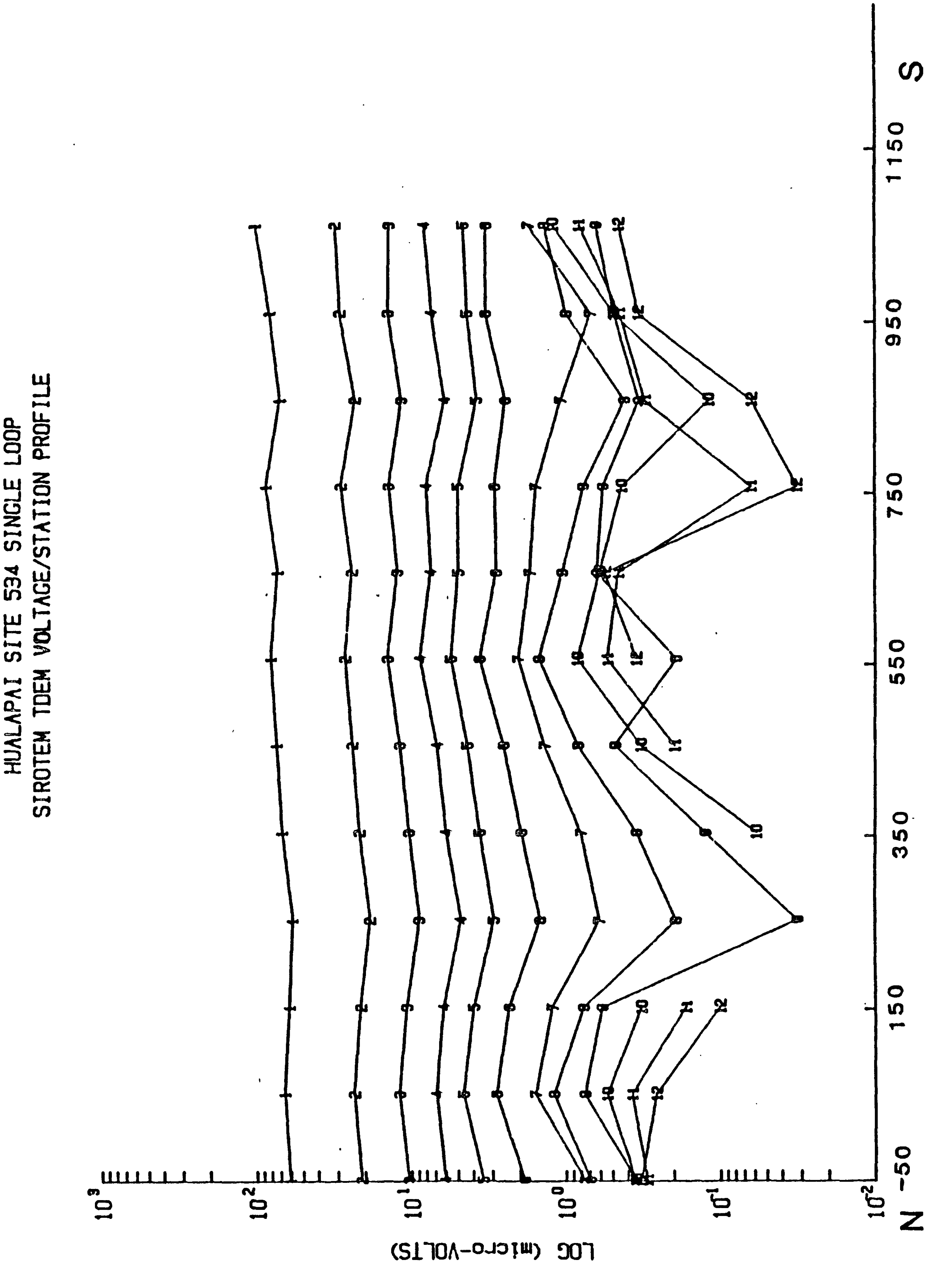



Figure 24 Sirotem TDEM voltage/station profile

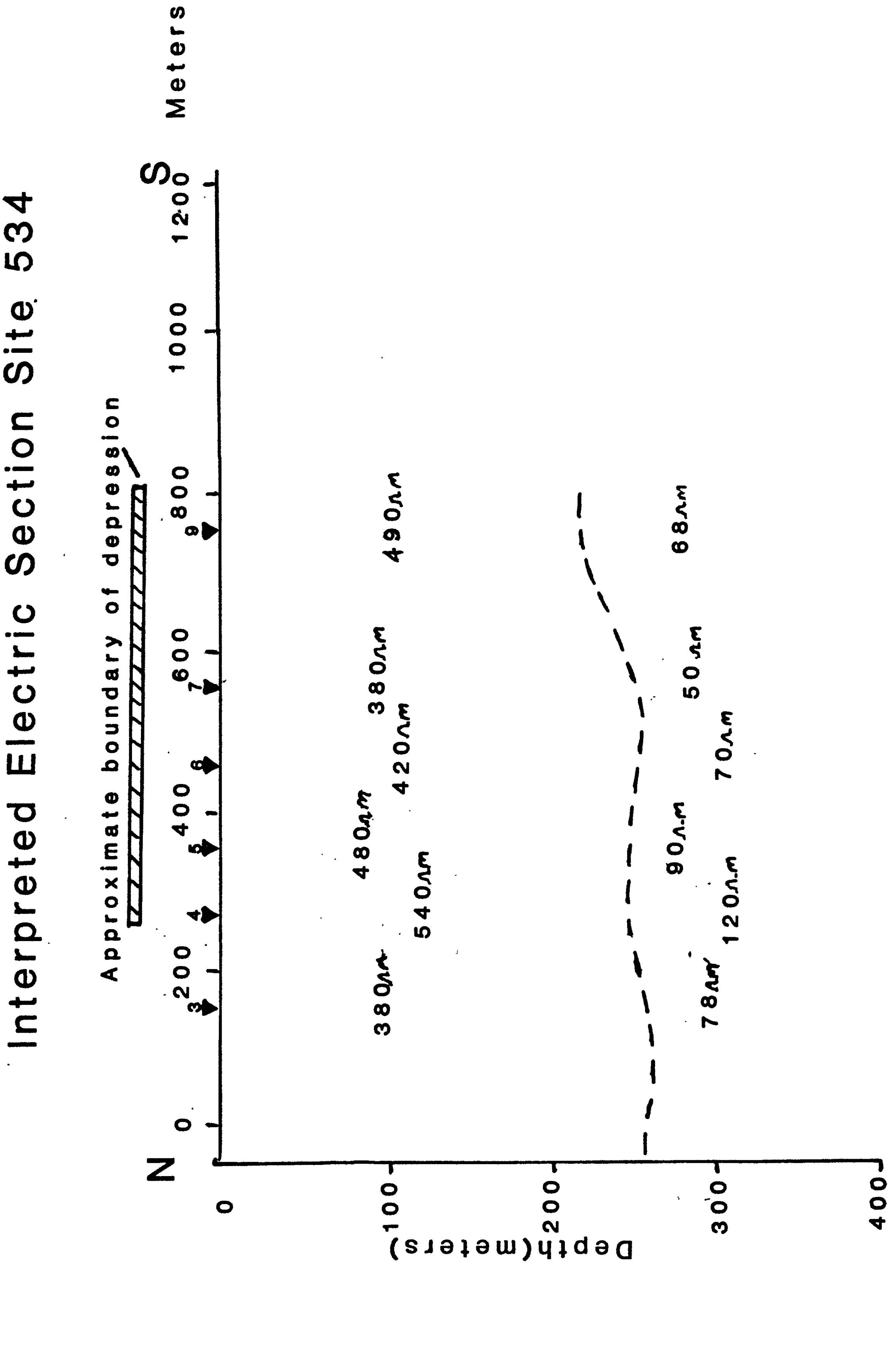



Figure 25 Interpreted Electric Section, Site 534

## Summary

Of the seven sites studied on the Hualapai Indian Reservation, three of them (287, 472, and 494) present topographic and cultural interference that render the geophysical data of limited use.

At site 534, although the magnetic profile did not indicate sufficient changes in magnetic character for interpretation, the TDEM profile suggests a conductive zone at and below a depth of about 250 meters (fig. 25). Along the same profile, a lack of response to VLF measurements indicates an absence of near-surface conductive features (fig. 23).

The most extensive and illuminating geophysical work was done in the area comprising sites 220, 221, and 222. This area included fairly gentle terrain with homogeneous geologic features and no cultural interference; hence, the geophysical techniques used accurately measure changes in density, magnetic character, and conductivity which could differentiate between possible breccia pipes and surrounding rock. The small magnetic anomalies at site 220 that surround the excavated area at the intersection of the baselines suggest magnetic sources that should be further investigated by drilling exploration. Shallow conductive zones are seen along the profile line between 400 and 600 meters in the Slingram profile (fig. 6) and along the apparent resistivity pseudosection derived from TDEM data. The Slingram profile, using 200-meter coil separation, suggests conductive rocks from the surface to a maximum of 100 meters depth, correlating with the high conductivity shown at shallow depths by the TDEM in figure 10.

The extensive geophysical picture at sites 220 and 221 suggest that geologic drilling would be most favorable at that area. Previous drilling has been done by Western Nuclear Corp., and assessing that data would help better define the present geophysical data.

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