BS

Reconnaissance geophysics of a known geothermal resource area, Weiser, Idaho and Vale, Oregon

C. L. Long* and H. E. Kaufmann*

Audio-magnetotelluric (AMT) and telluric current soundings were made in a study of the geothermal potential of the area between Weiser, Idaho and Vale, Oregon, during the spring and fall of 1974. The electrical surveys covered an area on the western edge of the Snake River plain of approximately 3500 km^2 with 89 AMT and 31 telluric current stations at approximately 6-km spacings.

The AMT method used the natural electromagnetic (EM) field from 7.5 Hz to 6.7 kHz (10 frequencies) with two VLF radio sources at 10.2 and 18.6 kHz, while the telluric method utilized geomagnetic micropulsations, band-limited from 0.02 to 0.1 Hz. Maps were compiled using both methods to outline major high- and low-resistivity features.

Major high-resistivity zones appear to trend northwest on the AMT apparent resistivity maps. These zones parallel structural trends between Vale and Weiser. The lowest apparent resistivities are associated with the known geothermal hot springs in the Vale and Weiser areas.

The telluric ratio map shows lowest values at the eastern side of the area, and a low trend extending through Vale and to the northeast.

INTRODUCTION

During a period of 14 days in the spring and 10 days in the fall of 1974, 89 audio-magnetotelluric (AMT) and 32 telluric current soundings at a station spacing of approximately 6 km were made in a study of the geothermal potential of the area between Weiser, Idaho and Vale, Oregon. Combining these two geoelectric methods improved data correlation and interpretation of the geophysical trends. The areas near Weiser, Idaho and Vale, Oregon have now been designated as Known Geothermal Resource Areas (KGRAs). The electrical surveys cover an area on the western edge of the Snake River plain of approximately 3500 km^2.

GEOLOGY

The geomorphic setting in this area is a terrain of alluvial terraces with low gentle slopes dissected by many drainage systems, as shown in the map of Figure 1 adapted from Newton and Corcoran (1963). The western Snake River plain is underlain by a thick section of principally nonmarine Cenozoic sediments and sedimentary rocks. The area covered by the electrical surveys, as shown on Figure 1, is mostly the Pliocene and Pleistocene Idaho group which contains gravel, sand, silt, clay, and ash. The Idaho group is at least 1.2 to 1.5 km thick in the center of the survey area; these depths were taken from logs of a number of petroleum exploration wells drilled in the basin. Older rocks outcrop around the edges of this region with the principal unit being the Miocene and Pliocene Columbia River basalt group. In Oregon the Deer Butte formation (Kittleman et al, 1965) and in Idaho its equivalent (the Poison Creek formation), both of the Idaho group, vary from place to place; however, in general each contains a section of fine-grained tuffaceous sediments with a few intercalated basalt flows in their lower part, grading upward into the sandstone layers and conglomerates. Vales Buttes and Mitchell Butte are formed by massive sandstones (Figure 1) in the Poison Creek formation. In the sur-

Manuscript received by the Editor December 3, 1976; revised manuscript received July 6, 1979.
*U.S. Geological Survey, M.S. 964, Box 25046, Denver Federal Center, Denver, CO 80225.
0016-8033/80/0201—312$03.00.

very area, structural trends are northwesterly, with a few exceptions which are north to south as shown in Figure 1.

AMT RESISTIVITY

For the AMT method the natural electromagnetic (EM) field from 7.5 Hz to 6.7 kHz (10 frequencies) with two VLF radio sources at 10.2 and 18.6 kHz was used. The AMT method is useful in searching for conductive bodies such as hot saline water concentrations because it is an inductive method. The method itself has been described by Strangway et al (1973) in relation to mineral exploration, and the reader is referred to this paper for more details and references. A description of a reconnaissance method similar to the one used in this study was given by Hoover and Long (1975). Three methods of AMT data presentation are given below, namely, resis-

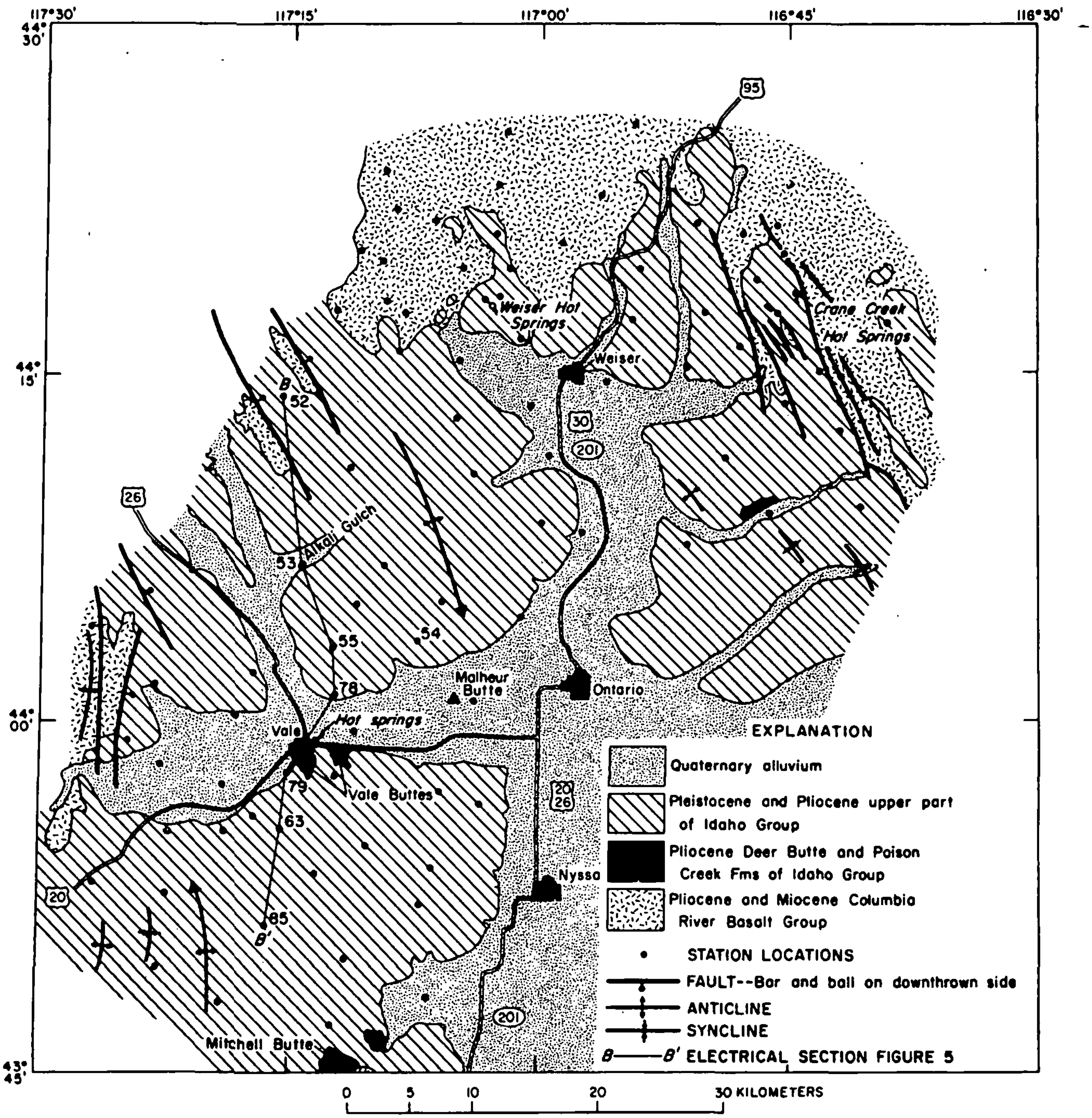

FIG. 1 Audio-magnetotelluric station location and general geology, Weiser, Idaho to Vale, Oregon.

tivity maps, resistivity soundings, and theoretical one-dimensional (1-D) models.

Figure 2 is a 7.5-Hz AMT apparent resistivity map of the Vale-Weiser area. The apparent resistivity values on this map are computed from the logarithmic average of the north-south and east-west scalar impedances. Averaging of values for the two sounding directions is necessitated by a fairly high degree of scatter in the scalar impedances and as a means of summarizing the data at 7.5 Hz. The maximum penetration depth, in meters, of the survey is given approximately by "skin depth" = $503\sqrt{\rho_a/f}$, where ρ_a is apparent resistivity and f is the frequency. Due to the low resistivities in the basin, at 7.5 Hz the maximum penetration depth was approximately 200–300 m, which in most cases is much less than the thickness of the sediments. The map (Figure 2) shows the highest resistivities in the northern part of the area. The large resistivity gradients are related to thinning of conductive sediments and to the

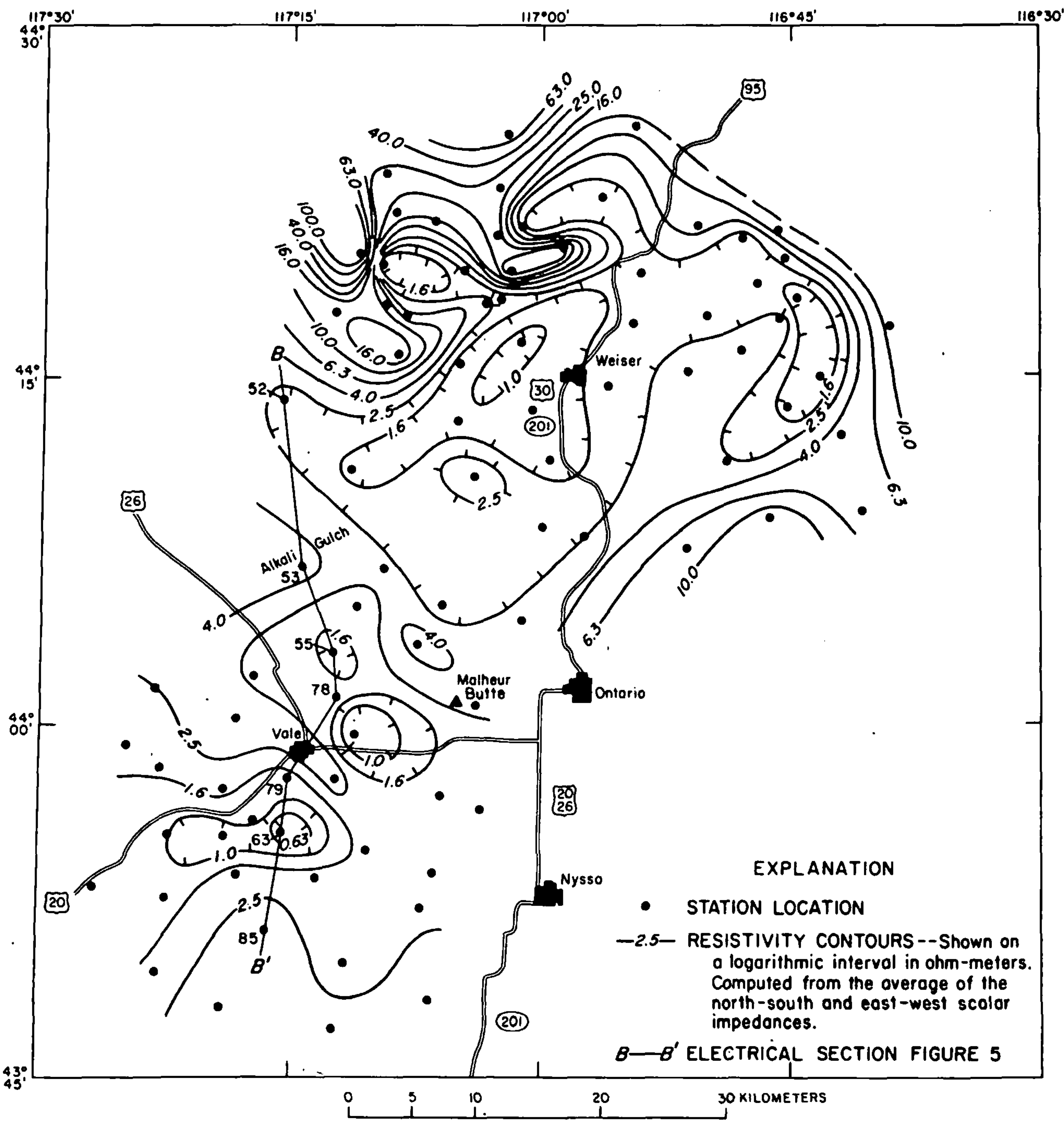

FIG. 2. Audio-magnetotelluric (7.5-Hz) apparent resistivity map, Weiser, Idaho to Vale, Oregon.

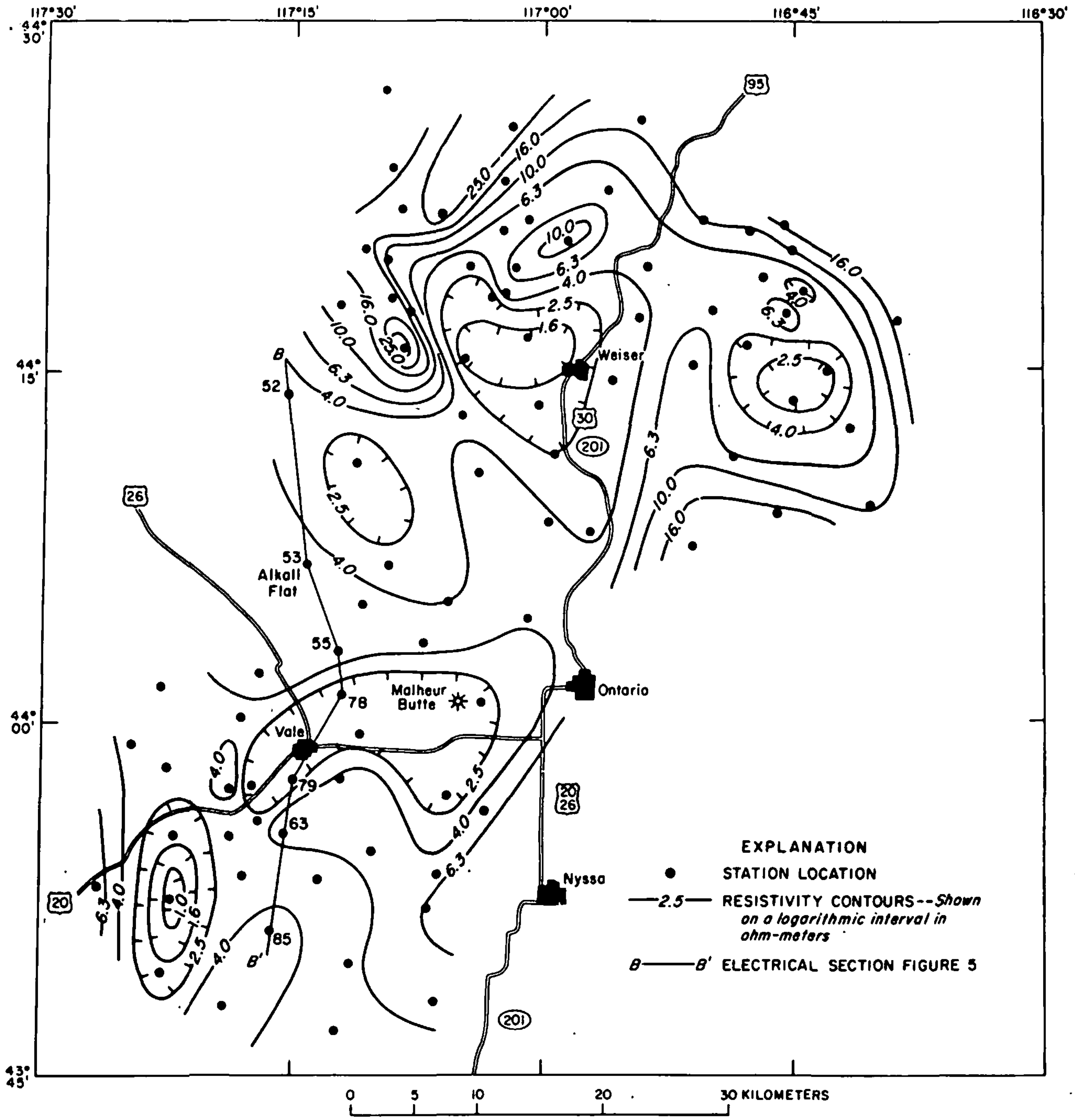

FIG. 3a. North-south telluric line (27-Hz) and audio-magnetotelluric apparent resistivity map, Weiser, Idaho to Vale, Oregon.

presence of near-surface Columbia River basalts and intrusives. Within the basin there is a general trend of low resistivities from south of Vale, Oregon extending to the Crane Creek area in Idaho. Small highs finger into this low and have a northwesterly orientation similar to the structural trend on the geologic map. Despite the low station density, the trends are very descriptive of the local features. The station density is not adequate to define all the lows, and the details of the contouring would be different with more stations.

Comparing the two AMT 27-Hz apparent resistivity maps in Figure 3, one sees that the low-resistivity trend covers the same areas as were shown on the 7.5-Hz AMT map (Figure 2). On the 27-Hz east-west telluric line orientation (Figure 3b), we can see some of the nearer surface lateral effects described by Strangway et al (1973). The best example of this effect is a localized 16 Ω-m high, which is an expression of the higher-resistivity material comprising Malheur Butte. The volcanic material of Malheur Butte may be structurally related to a dike in Alkali Flat to the northwest; there is a general high-resistivity trend in that direction as can be seen on both 27-Hz maps as well as the 7.5-Hz map (Figure 2). At 27 Hz, the skin depth is about 120 m in the basin areas and increases to a maximum of about 2–3 km near the northern edge of the project area.

Figure 4 illustrates three bidirectional AMT soundings taken, respectively, at stations 53, 54, and 69; the station locations are shown on Figure 1. These soundings are representative of the AMT data of this survey. On Figure 4a, station 69 shows the similarity in apparent resistivity at the lower frequencies

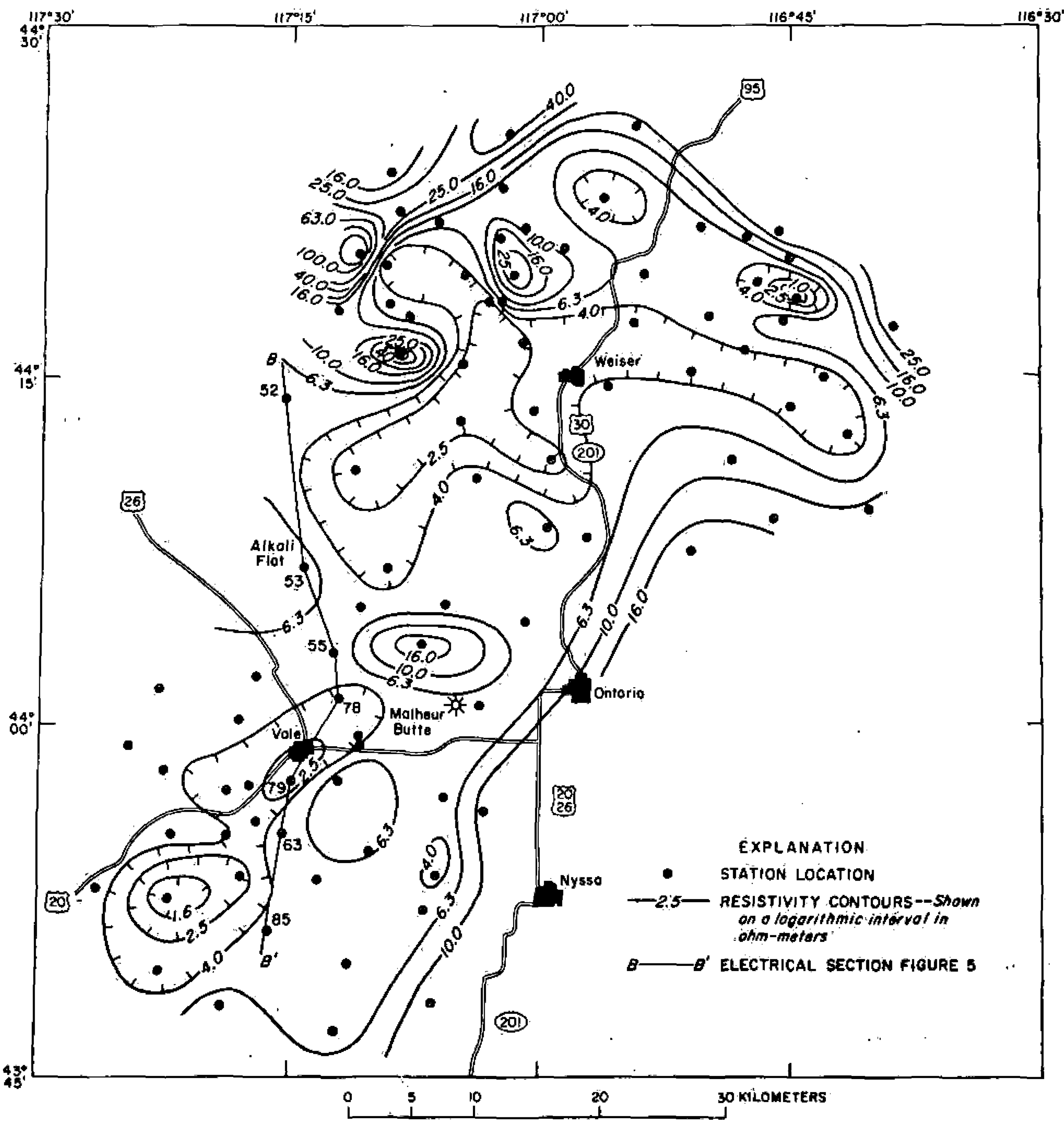

FIG. 3b. East-west telluric line (27-Hz) and audio-magnetotelluric apparent resistivity map, Weiser, Idaho to Vale, Oregon.

of the two sounding orientations (north-south, east-west). There is little evidence of lateral effects, and the variation between soundings is not much greater than the standard deviation (described in Hoover and Long, 1975) shown by the vertical bars.

The sounding curves for station 53 (Figure 4b) show almost no separation, but there is a definite break in the trend of the curves, perhaps due to a vertical dike located a few hundred meters from the station. The strike of the dike is at a 45-degree angle to both telluric lines, affecting the two telluric directional measurements equally.

In Figure 4c (station 54), we see evidence of a lateral effect which is almost constant at the lower frequencies, due to the inhomogeneity near Malheur Butte. The dip in the east-west sounding curve at 76 Hz is due to changing polarization of the incident field over inhomogeneous media. The separation

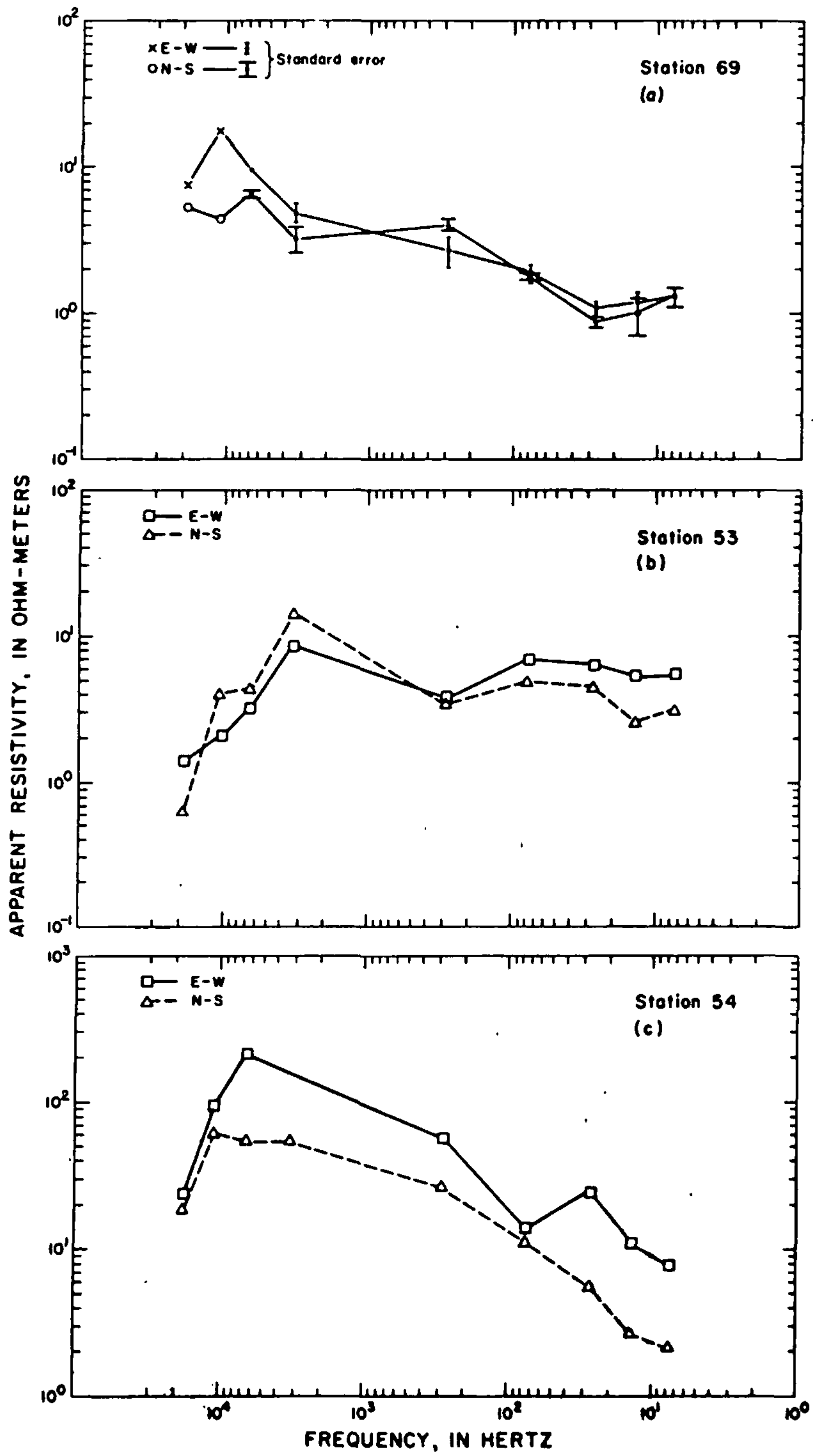

FIG. 4. Three bidirectional AMT soundings.

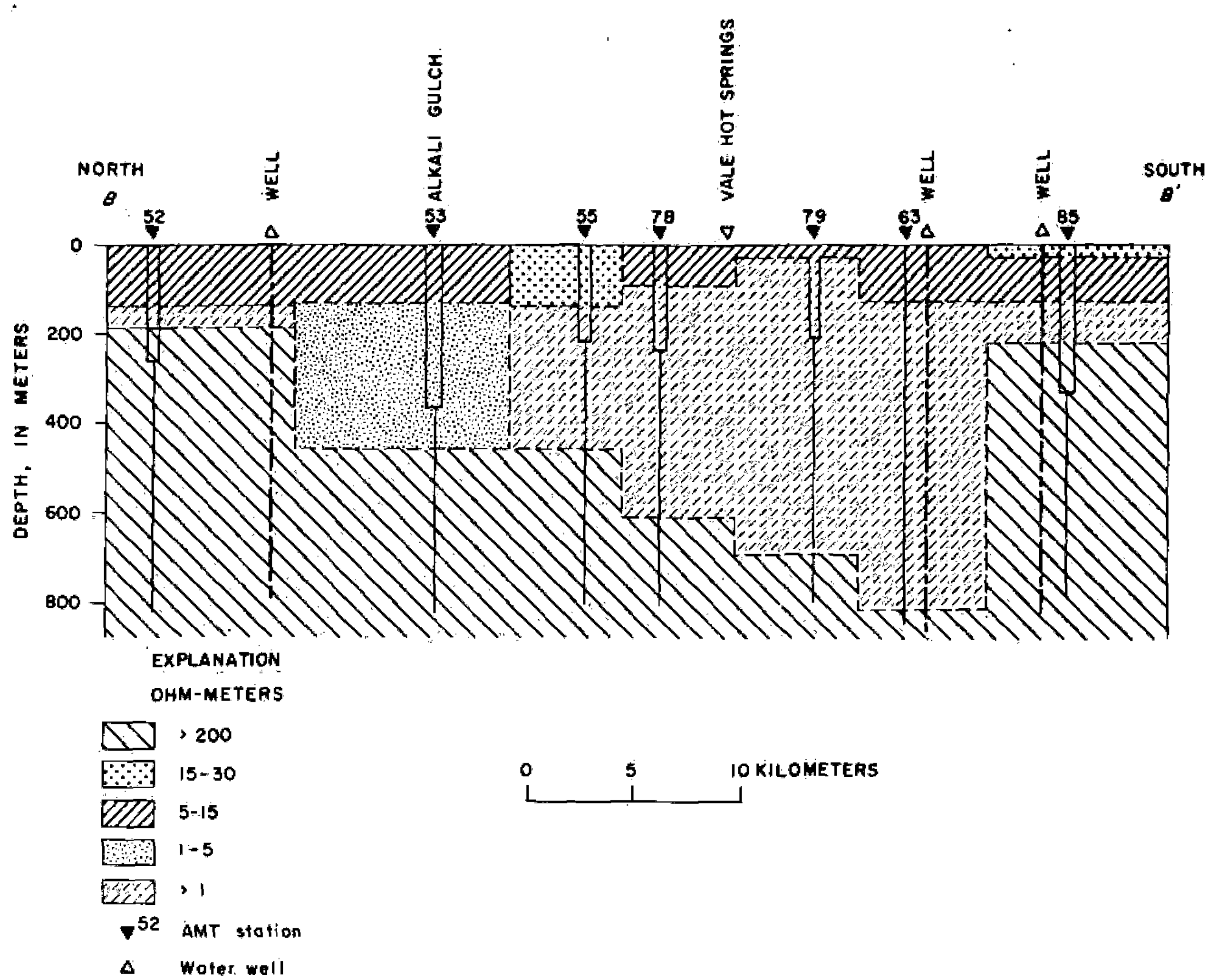

FIG. 5. Electrical cross-section.

between the curves is less at 10.2 and 18.6 kHz, indicating minimal lateral effects in the near-surface.

Assuming a 1-D model, we inverted data along profile B-B′ (Figure 1) by computer (Smith, 1975) to obtain an electrical cross-section (Figure 5). Well logs along the profile provided information on rock depth and types. The rectangular area below each AMT station is the skin depth at 7.5 Hz plotted to scale vertically and horizontally to show roughly the maximum area sampled by the AMT method. The vertical scale exaggeration is about 60 to 1. The basement, indicated by the material of resistivity greater than 200 Ω-m, is a basaltic layer which was identified from well logs. With the depth to the basalt fixed from various well logs and for an assumed resistivity of greater than 200 Ω-m for the basalt, the other layer thicknesses and resistivities were allowed to vary until a good fit to each sounding curve was found. A qualitative comparison of AMT and telluric current data (Figure 8) was used for additional guidance in preparing this resistivity section. In most cases, a four-layer model was required; however, for station 52, a three-layer model fit was adequate. In general the AMT method was unable to penetrate the low-resistivity layer of sediments shown by less than 1 Ω-m material on the section (Figure 5), except at station 85 where basement of resistivity greater than 200 Ω-m was detected. Model fits to most of the sounding curves were very good, except at station 53 near the dike. The dike seemed to influence the model as evidenced by the zone of 1–5 Ω-m material.

TELLURIC CURRENT RESULTS

The telluric current method utilized micropulsation data, band-limited from .02 to .1 Hz and recorded using x-y plotters (Yungul, 1966). A contoured telluric current map of J values is shown in Figure 6. The J values were obtained by taking a ratio of rover to base station (fixed position) ellipse areas (Yungul, 1968). As seen in Figure 6, the J values of less than 10 indicate an area of lower resistivity relative to the base. The lowest resistivities are found in the east-central part of the area, near Ontario, and extend west across the map and just north of Vale. The most outstanding anomaly on Figure 6 is a ridge of higher resistivity trending to the north and west from Vale. This trend follows the basic grain of the geologic structures and reflects basement topography, but does not agree with the overall trends displayed by the 7.5-Hz AMT map (Figure 2). The low surface resistivities (shown by AMT data) do influence the telluric current data, but the deeper part of the section has enough influence on the telluric current results to change the trend of the contours.

In Figure 7 we show the normalized ellipses for 31 telluric stations in the Vale-Weiser area. At each

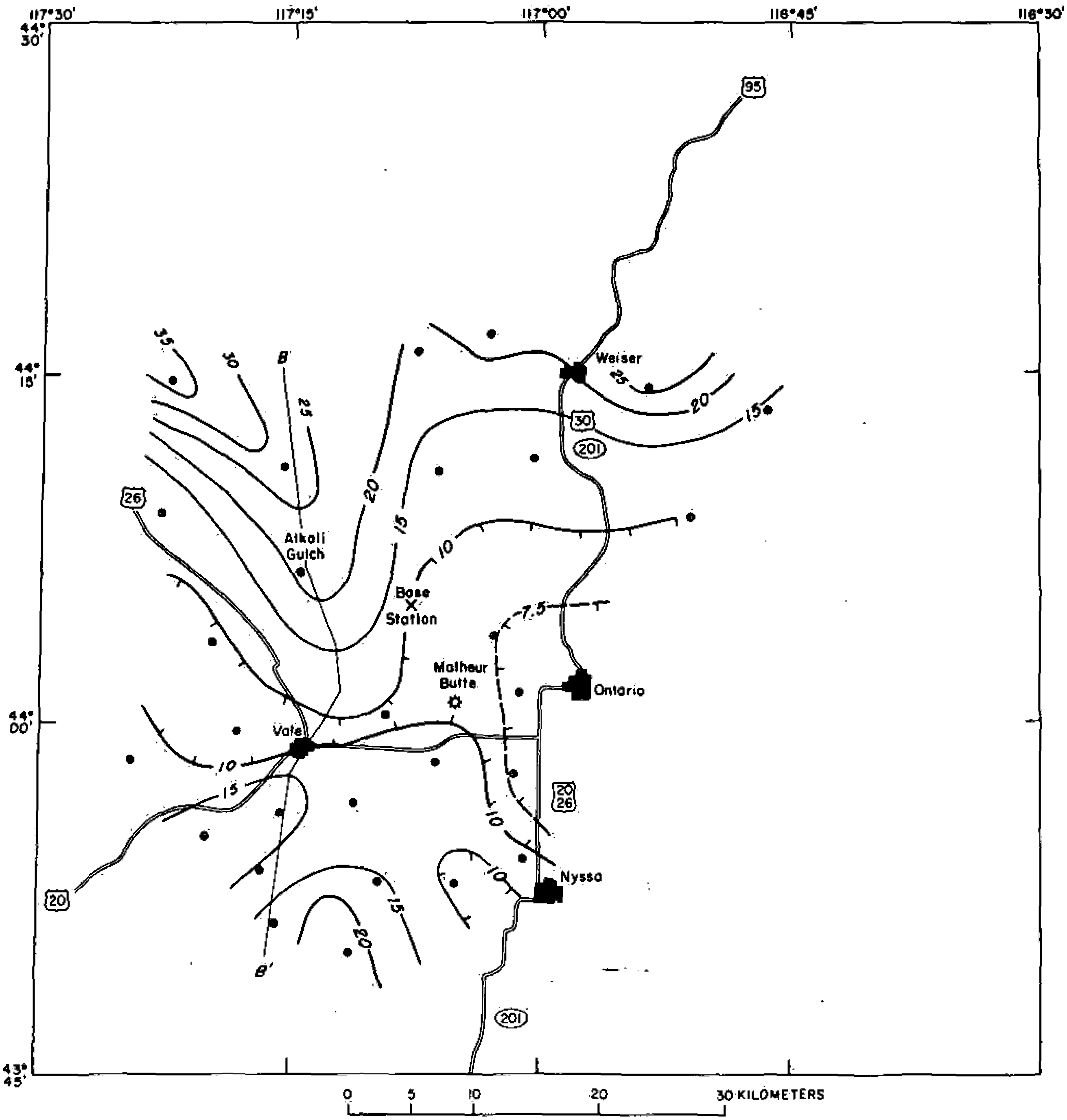

FIG. 6. Telluric anomaly map at 20–30 sec period. Contour interval in J values varies from 2.5 to 5, Weiser, Idaho to Vale, Oregon.

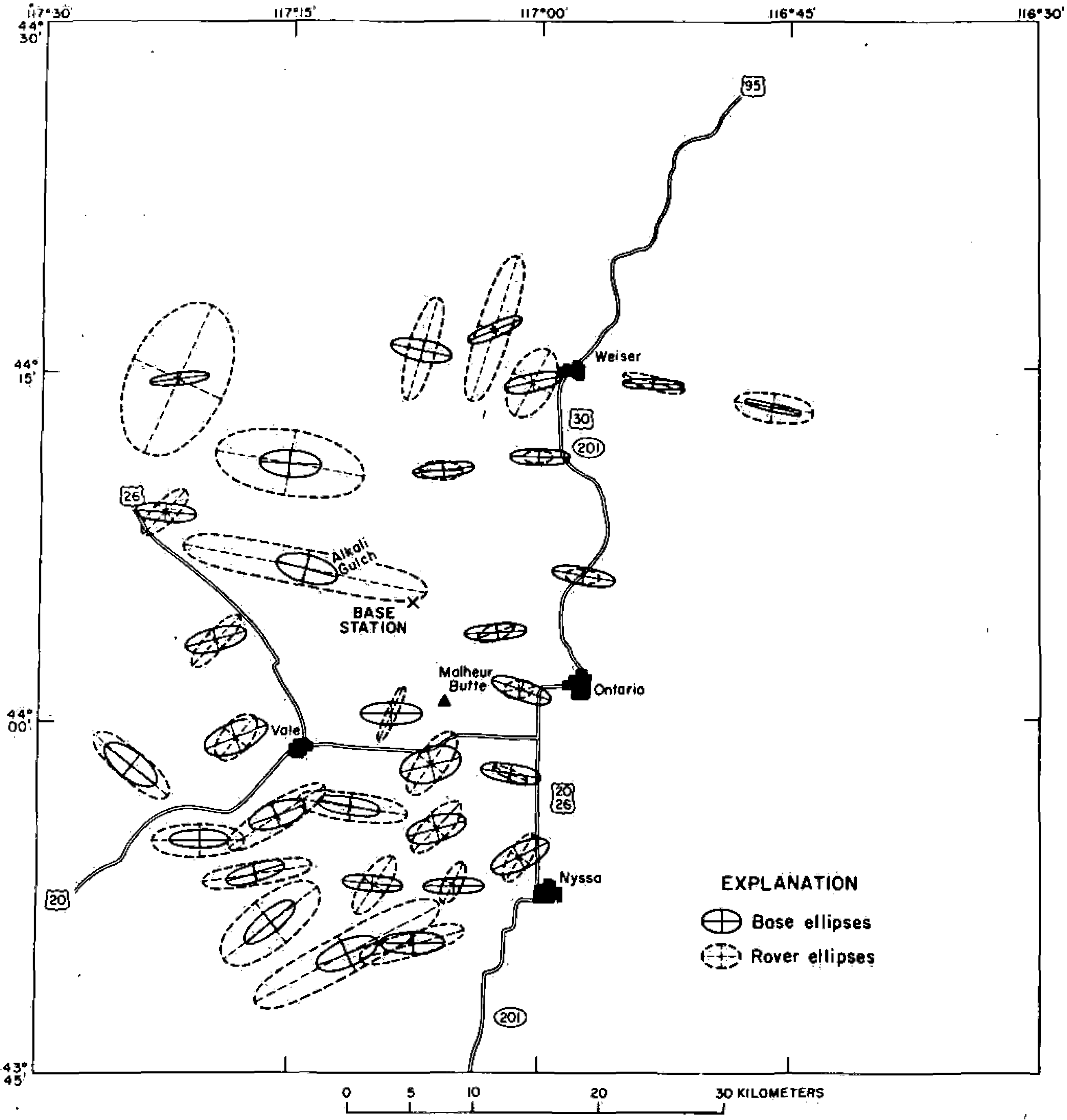

FIG. 7. Correlations of rover-to-base orientations and current amplitudes, Weiser, Idaho to Vale, Oregon.

rover station, the relative area and estimated orientation of base and rover ellipses are indicated. The rover ellipse outline is dashed, and the base ellipse outline is solid. At three stations west of Weiser, the axis of the rover ellipse is shifted almost 90 degrees with respect to that of the base ellipse, and larger amplitudes are indicated by the larger size of the form. This implies a major structure to the north, changing direction of telluric current, and also a decreasing distance to basement. The three large rover ellipses in the northwest corner reveal very large changes in electric field current with respect to the base station. The three stations along highway 26 show a significant shift of the electrical axis from Vale to the northwest. This may be indicative of local features related to the northwest-trending resistivity high seen on Figure 2 between Malheur Butte and Alkali Gulch. The rover ellipse with the small amplitude and large electrical axis shift with respect to the base, seen near Malheur Butte northeast of

Vale, is another good example of a local effect of high-resistivity material. South and east of Vale, we see numerous changes in orientations and amplitudes. While most of the changes are smaller than the ones described to the north, they help illustrate the complexity of the local area.

Figure 8 illustrates a qualitative comparison of the AMT and telluric current data along the same profile as the AMT 1-D section. The apparent resistivity profile was computed from the AMT horizontally layered model for a frequency of .04 Hz. The telluric profile was obtained directly from the contoured telluric current J value map (Figure 6). The telluric current and AMT data correlate well on this profile, despite the lateral variation in the electrical section at depths greater than those probed by the AMT method.

CONCLUSIONS

Highly conductive sediments restricted the exploration depth of the AMT method to a few hundred meters over much of the area. Nevertheless, high-conductivity anomalies were mapped with the method in an area near prominent hot springs. The limited extent of these anomalies suggests that near-surface thermal waters are restricted to a few narrow fault zones in the immediate vicinity of the hot springs. Scattered dikes and volcanic rocks which cut through the sediments and are exposed at the surface locally cause large differences between the north-south and east-west scalar resistivities.

The telluric current data are strongly influenced by the highly conductive near-surface layers which affect the AMT results, but the telluric current results do reflect the presence of deeper structures and basement

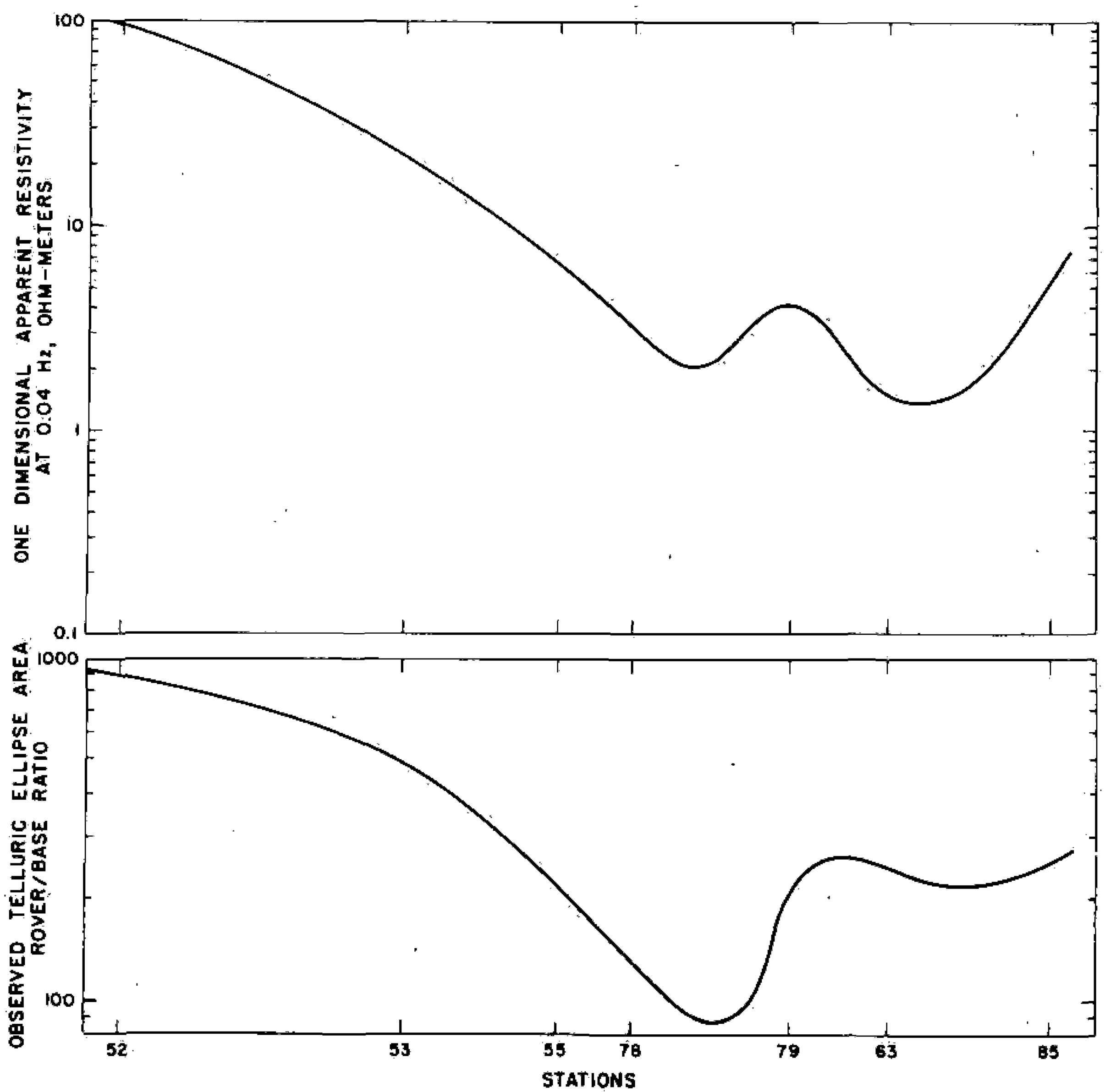

FIG. 8. Qualitative comparison of AMT and telluric current data.

topography, at least in the northwest part of the area.

The station density for both methods was too sparse to locate and define accurately all of the small anomalies which exist in the area. In particular, additional measurements are needed in the Crane Creek, Weiser, and Vale Hot Springs areas to delineate more closely the low-resistivity anomalies associated with those "hot spots." Despite the need for some additional work, the AMT and telluric current methods were effective in covering a large area rapidly and at low cost.

REFERENCES

Hoover, D. B., and Long, C. L., 1975, Audio-magnetotelluric methods in reconnaissance geothermal exploration: U.S.G.S. open file rep. 75–362.

Kittleman, L. R., Green, A. R., Hagood, A. R., Johnson, A. M., McMurray, J. M., Russell, R. G., Weeden, D. A., 1965, Cenozoic stratigraphy of the Owryhee region, southeastern Oregon: Univ. of Oregon Mus. Nat. Hist. Bull., no. 1.

Newton, V. C., and Corcoran, R. E., 1963, Petroleum geology of the western Snake River basin, Oregon, Idaho: Oil and Gas Investigations no. 1, State of Oregon, Dept. of Geol. and Mineral Ind.

Smith, B. D., 1975, Computer program: U.S.G.S., unpublished.

Strangway, D. W., Swift, C. M., Jr., and Holmer, R. C., 1973, The application of audio-frequency magnetotellurics (AMT) to mineral explorations: Geophysics, v. 38, p. 1159–1175.

Yungul, S. H., 1966, A magnetotelluric method without magnetic measurements: Geophysics, v. 31, p. 185–191.

——— 1968, Measurements of telluric relative ellipse area by means of vectograms: Geophysics, v. 33, p. 127–131.