DISCUSSION

Dicussion on "Resistivity, self-potential, and induced-polarization surveys of a vapor-dominated geothermal system" by A. A. R. Zohdy, L. A. Anderson, and L. J. P. Muffler (GEOPHYSICS, December 1973, p. 1130–1144).

The paper deals chiefly with the quantitative interpretation, based on *horizontally layered models,* of sixteen vertical, electrical resistivity soundings (except for no. 11). If the section reproduced in Figure 2 is any indication, the requirement in such interpretation of the lateral continuity of layers does not seem to be even approximately satisfied. This is especially true over the central section involving the target area, where thirteen of these sixteen soundings with maximum spacings of the order of AB = 2000 ft are distributed over a linear distance of about 6000 ft.

There may be some difference of opinion as to what constitutes an acceptable lateral continuity for practical interpretation—whether the horizontal extension of the layers should be large compared to the depths of interfaces or compared to the spacings necessary to explore those depths. Ideally, it should be considerably larger than both, and even then lateral variations can come in only gradually. Whichever criterion an interpreter may choose to work with, Figure 2 seems to satisfy none, for the deeper portions in particular. VES 4 and VES 6, for instance, are separated by a distance of only about 300 to 400 ft, yet the two curves and their interpretations are entirely dissimilar. Indeed, Figure 2 places a near-vertical interface between the two locations for depths above 400 ft. The same remark applies to VES 3 and VES 15. In general, even though closely spaced, the sounding curves vary markedly in shape as a result of rapid lateral variations. While the close multiplicity of sounding points apparently anticipates the existence of such variations, the large spacings used for individual soundings assume their absence.

The surface layer resistivity has interpreted values of 490, 2000, 730, 9.3, 1700, 300, 20, 180, 13.5, 100, 230, 750, 160, 1400, and 1600 ohm-m. The corresponding thicknesses are 6.8, 11, 5, 27, 6.8, 3.6, 8.7, 8.5, 3.8, 4.5, 3.1, 5, 3.5, 3.1, and 3.1 ft, the highest value being about nine times the lowest. The authors recognize this acute inhomogeneity of the top layer but seem to ignore its effect on the measurements at larger spacings as the electrodes for any one sounding move from one type of top layer to another. This is quite apart from the fact, mentioned in the preceding paragraph, that the deeper layers are themselves horizontally inhomogeneous.

The paper contains no information on the orientation of the expanding electrode arrays. It seems rather likely that measurements at different azimuths at the same VES station would yield significantly different curves and interpretations (even near the control point, well Y-11).

Topography is another relevant aspect. Perhaps this is not unfavorable in the area of survey, although the ground would slope toward the river, we assume, gently. Many of the soundings, however, would have been affected by the river itself. It is also possible that the lateral continuity of formations is more restricted than that in Figure 2 in the riverward direction, that is, northeast.

In essence, we feel (1) that the soundings are far too many in number, (2) that the basic model and the emphasis on detail for their quantitative interpretation are incompatible with the geologic complexities, and (3) that the geophysical results are to be reckoned as qualitative.

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Reply to A. Roy by A. A. R. Zohdy

In the article discussed, Figure 2 is vertically exaggerated five times (as indicated on the figure), consequently the departure of the model from quasi-horizontal layers is also exaggerated five times. Furthermore, as stated in the article, the geoelectric section is divided into three segments: northwestern, middle, and southeastern. The lateral continuity *and* the successful correlation of the intermediate and deeper layers within each segment (especially in the target area) were demonstrated by the quantitative interpretations of the various soundings. Therefore, the assumption of horizontal layering is still an acceptable approximation except at the boundaries of the geothermal system. The lack of completely generalized two- or three-dimensional modeling techniques (except for oversimplified structures) prevented us from calculating an even more sophisticated model.

The multiplicity of sounding stations indeed was made in anticipation of lateral variation in the resistivity of the shallow layers, but contrary to what Dr. Roy states, the large electrode spacings

do not assume their absence. After all, the average thickness of the first layer of variable resistivity is about 2 m (7 ft); such lateral variation in the resistivity of the top layer may cause: (a) the formation of *minor* cusps on Schlumberger VES curves as the current electrodes are moved over them (a phenomenon which is frequently observed on practical VES curves), and (b) "displacements" on the curve segments that are not in agreement with those prescribed for horizontal layering (see p. 1136 of the article for a discussion of this subject). We are aware of both the direction and the permissible magnitude of discontinuities, as well as the magnitudes of the possible cusps (Deppermann, 1954; Zohdy et al, 1974); and in the article we have proposed a practical method for processing such VES curves.

We did not show the direction of expansion of the sounding arrays on Figure 2. We assumed, however, that (inasmuch as most of the sounding stations were placed on the road) it was apparent that the direction of expansion of the sounding arrays was parallel to or along the road. Furthermore, we are quite aware of the type of practical and theoretical results obtained by variable azimuth soundings near large lateral heterogeneities (Zohdy and Jackson, 1969; Zohdy, 1970). With the azimuth of the sounding expansions being almost at right angles, rather than parallel, to the strike of the major conductive lateral heterogeneities, the possibility for misinterpreting the effect of lateral variations in resistivity as vertical ones is minimized.

We agree with Dr. Roy that the topography (Dakhnov, 1953) of the area, the possible lateral restriction of some of the shallow formations in the riverward direction, and even the river itself may have had some effect on the shape of the sounding curves. We consider such effects to be minor in the area studied.

As to Dr. Roy's final remarks: (1) This is the first time, that we know of, for someone's work to be criticized because "the soundings are far too many in number." If anything, a seasoned interpreter often feels that he does not have enough soundings to interpret and that the sounding arrays were not expanded to sufficiently large electrode spacings (for a classical remark in this regard, read Van Zijl, 1969). (2) We feel that the basic model is indeed compatible with the known and assumed geology of the geothermal system studied. (3) The sounding interpretations are to be reckoned as quantitative or semiquantitative [in view of the principle of equivalence, Zohdy (1974)] but not as qualitative (as evidenced by the excellent fitting of the theoretical models to the practical sounding observations).

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