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December 23, 1985

MEMORANDUM

TO: Marshall Reed
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FROM: Howard Ross
ESL/UURI

SUBJECT: Preliminary evaluation of electrical resistivity data base, Soufriere geothermal area, St. Lucia, Caribbean Sea

Introduction

The initial electrical resistivity survey on St. Lucia was completed by geophysicists from the Institute of Geological Sciences (IGS), Great Britain, in 1974. The survey included 13 lines of dipole-dipole resistivity using a standard electrode separation (a) of 200 m. The distribution of survey lines and geothermal test wells is shown in Figure 1. The survey is described in detail by Greenwood and Lee (1976). A review of this report, the detailed topographic map and the numerical data for each line (which you provided to us), suggest that the survey was completed in a competent manner. The survey lines were selected to provide reasonable coverage of the thermal area and much of the caldera while making good use of existing access and minimizing topographic effects. Resistivity values were recorded for separations (n) of 2 to 10 by the IGS terminology (corresponds to n=1 to 9 in the SEG terminology).

Although these data appear to be quite reliable, the pseudosection plots are somewhat misleading as they are presented in terms of depth instead of

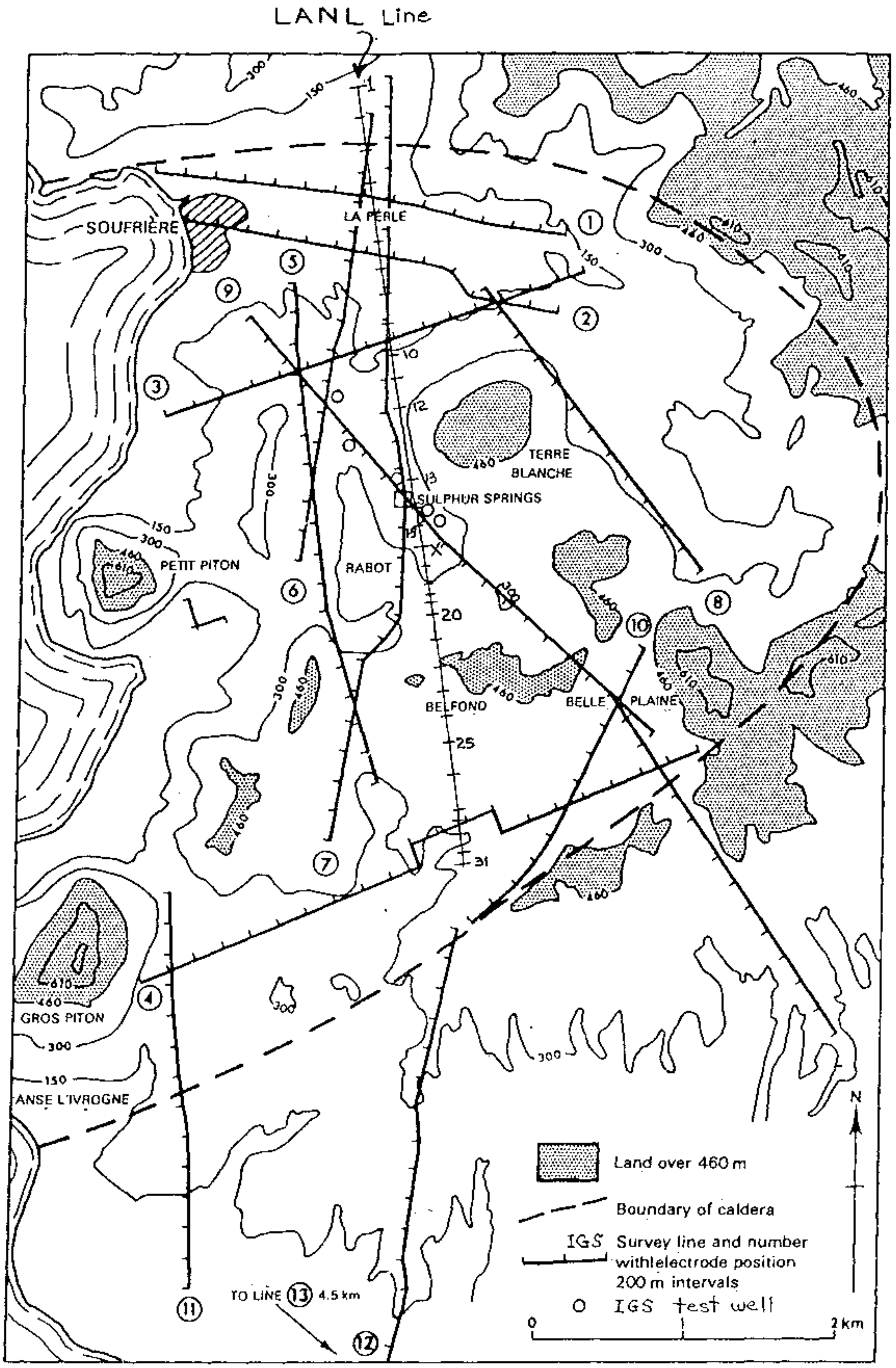

Fig. 1 Soufrière area, St Lucia showing geophysical survey lines

electrode separation (i.e. Figure 2c). The suggested depth equivalence (n=2=200 m, 3=300 m, 4=400 m, etc.) is not generally accepted or considered valid. The maximum reliable depths of resistivity mapping, assuming two-dimensional resistivity distribution perpendicular to the survey line with n=2-8 (IGS), and numerical modeling of the data has been shown to be approximately 2a to 2.5a.

In the case of the IGS data considered here this would correspond to depths of 400-500 m instead of the 800-1000 m indicated by depth scales on the pseudosections. Although the data were recorded to greater separations (n=2-10, IGS) the lateral effects associated with three-dimensional resistivity distributions and topography, and the lack of even two-dimensional numerical modeling, preclude an accurate mapping of resistivities for depths exceeding 400 m. The geologic interpretation of the data, excepting the depth considerations, seem reasonable and well considered.

Numerical Modeling, Line 9

Subsequent to reporting the field surveys, the IGS contracted to Geotronics Corp (U.S.A.) for a number of forward numerical model calculations simulating the resistivity distribution of the northern half of line 9 (dipoles 4-15) which crosses the Sulphur Springs area (Lee and Greenwood, 1976). Although none of the six models presented achieve a good fit to the observed data, model 6 (shown as Figure 2a, 2b) provides a fair indication of the near surface (0-200 m) resistivity distribution, and indicates the large scale resistivity distribution to depths of about 400 m. The models allow Lee and Greenwood to infer three deeper resistivity units of approximately 15 $\Omega\cdot$m, 30 $\Omega\cdot$m, and 5 $\Omega\cdot$m. The numerical model results lead the authors to the generally accepted resistivity depth-of-resolution values noted above, i.e. 2a-2.5a. The authors also correctly cautioned that three-dimensional subsurface and topographic effects, and the strong influence of near surface resistivities on the data set, severely limited interpretation for depths exceeding about 400 m. Numerical model 6 shows a good correlation with near surface geology. High temperature wells 3, 4 and 5 are sited in low (2-5 $\Omega\cdot$m) near surface resistivity bodies.

The resistivity modeling program used by Geotronics Corp. (RESCAL) was an early modeling algorithm and several important improvements have been incor-

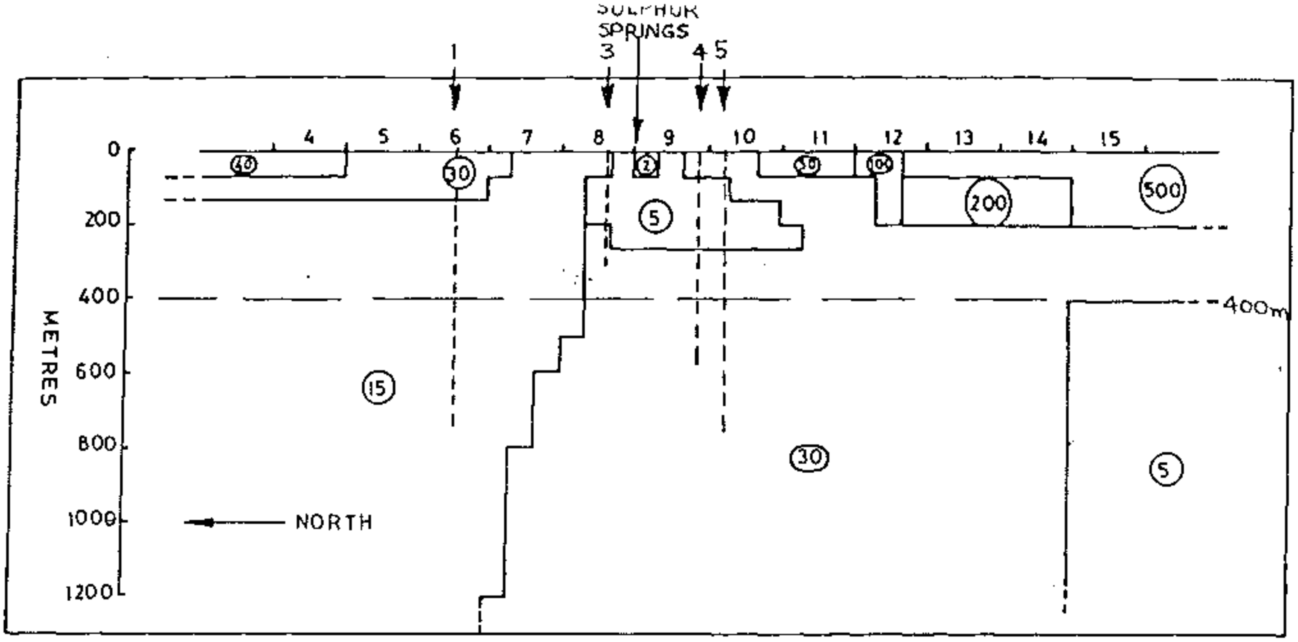

Fig. 2a Line 9 - true resistivity model 6

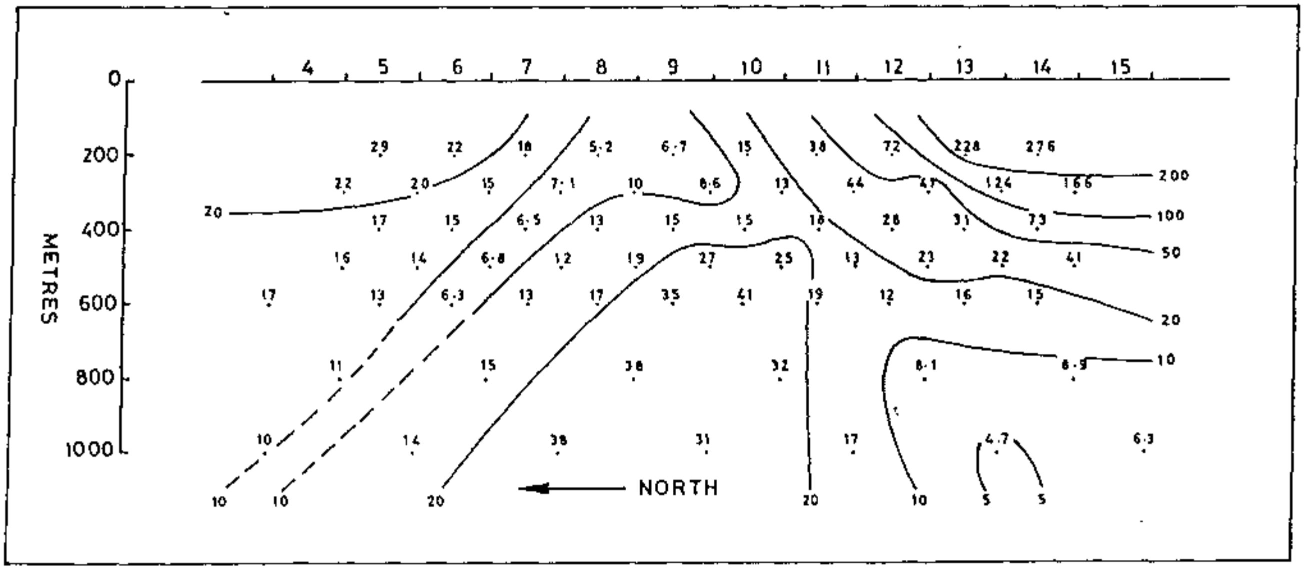

Fig. 2b Line 9 - computer generated section due to model 6

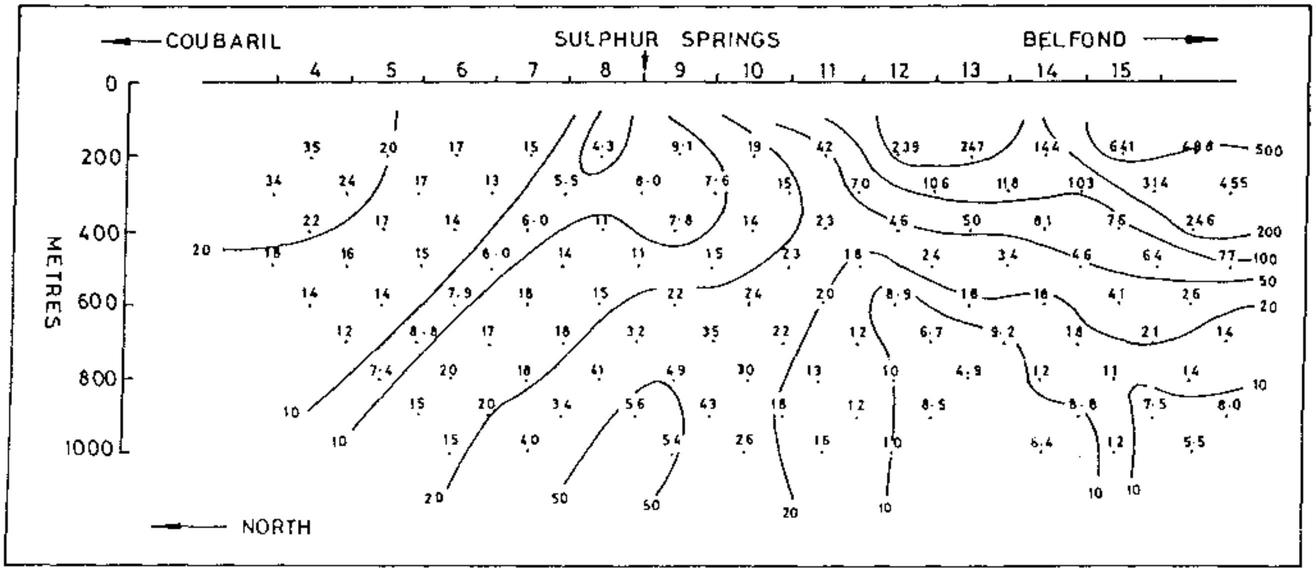

Fig. 2c Line 9 - apparent resistivity cross-section - observed

porated in later programs, such as RIP2 developed by ESL/UURI. The RIP2 algorithm is more efficient and permits a greater subdivision of the model (higher geometric resolution), calculation for separations n=2, 3, 4, 5, 6, 7 (as compared to n=2, 3, 4, 5, 6), and allows for modeling (2-D) topographic effects. As a result substantially more accurate interpretations, to depths of 2a-2.5a, are possible at present.

LANL Resistivity Profile

In January 1984, Los Alamos National Laboratory (LANL) completed one additional resistivity profile of total length 5.2 km (Ander et al., 1984). As shown in Figure 1, the northern half of the line is almost a complete duplication of the earlier IGS lines 6 and 7. The line location and electrode separation were chosen after evaluating the existing data of Greenwood and Lee (1976). The LANL survey profile attempted to achieve resistivity data to a depth of 2 km and simultaneously maintain a high spatial resolution consistent with 200 m dipoles. In an attempt to achieve these conflicting goals, they read voltages to separations as great as n=24 and 25. In order to read the small voltages which result from short transmitting and receiving dipoles, they developed their own 35-KW trailer-mounted DC transmitter driven by a 60-KW diesel generator.

The current flow path is primarily a function of the three-dimensional resistivity distribution and the separation of the current electrodes (i.e. the transmitting dipole length), and the use of short dipoles (200 m to less than 100 m) constrained most of the current flow to a near surface hemispherical volume with $r \leq 2a$ as shown schematically in Figure 3. Inherent to recording such extremely large transmitter-receiver separations as $n > 10$ are noisy data resulting from low induced voltages, which are then multiplied by large geometric factors. In addition, the current is not constrained to a simple flow path between transmitting and receiving dipoles, but is distributed inversely with resistivity for current paths lateral to the survey profile. As Lee and Greenwood (1976) and Greenwood and Lee (1976) reported earlier, the resistivity distribution in the subject area is certainly three-dimensional and topographic variations are also large. The Caribbean Sea is a low resistivity body only 1-2 km west of the survey profile. Thus the interpretation of these data to depths greater than 400 m to 500 m is very specu-

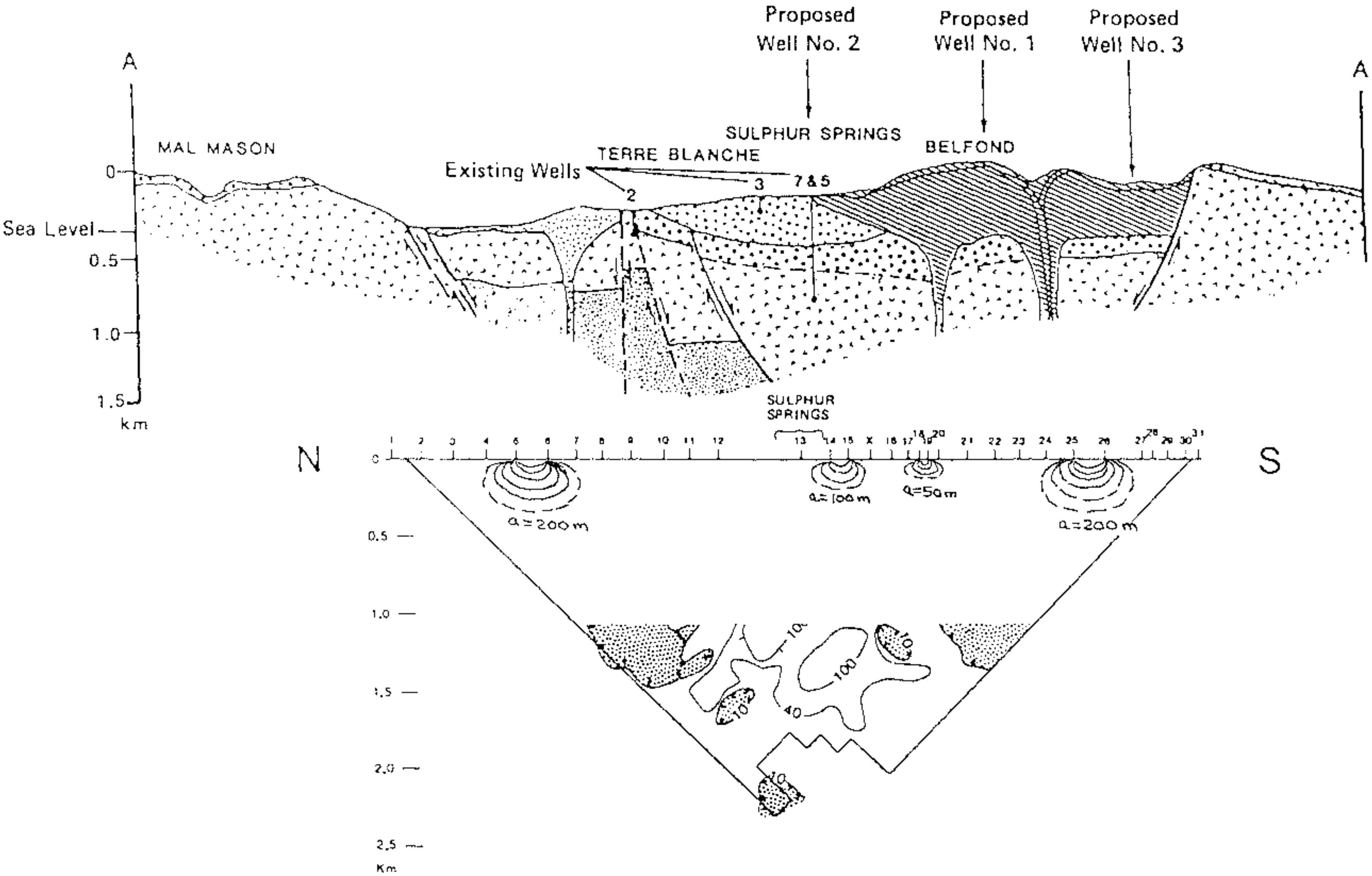

Figure 3. Schematic illustration of current distribution as a function of transmitting dipole length, for the LANL line.

lative.

The southern half of the LANL line does not duplicate earlier IGS coverage but is a real mix of different dipole lengths, from 200 m to less than 100 m (Figure 4), and hence of variable current depth penetration. A major data gap (or single 500 m dipole?) which occurs in the pseudosection (stations 12-13) is contoured as data comparable to the rest of the line. As a general rule the resistivity data could be interpreted through numerical modeling to determine the vertical resistivity distribution to depths of 400 m at most; less where the dipole length was 150 m or less.

Anders et al. (1984) present a very limited discussion of the LANL resistivity data, reproduced here as Figure 4. They note that "the upper 700 m of the pseudosection shows similar characteristics to the British dipole-dipole data" with 40 Ω•m resistivities common north of Sulphur Springs. They also note high apparent resistivities beneath the Belfond area and interpret a zone of very low resistivity, less than 1 ohm-m, underlying the Etangs area. They interpret a zone of higher apparent resistivity (40-150 Ω•m) starting at a depth of 600 m beneath the Sulphur Springs area. The remainder of the interpretation is a correlation with surface and geologic features. Based on the interpretation of the "deep" resistivity data they suggest three geothermal well locations 1, 2, and 3 (see Figure 4) where they expect to encounter geothermal brines at depths of approximately 900 m, 1800 m, and 1000 m, respectively.

Our limited review of these data suggest that the LANL interpretation is simplistic, and quite probably incorrect. As noted earlier, the probable maximum depth of reliable resistivity interpretation is about 400 m. Inspection of Figure 4, now annotated with the plotting diagonals, shows that the (apparent) deep low resistivity zones beneath Sulphur Springs and Belfond are more likely primarily due to reinforcement at the intersection of diagonals from low resistivity surface areas 1-5 and 26-27, and 13-15 and 26-31, respectively. There are no data to suggest the continuation of low resistivities near proposed Well No. 3 (electrodes 26-31) to depths below 200 m. It is uncertain from our reading of the LANL report if data were taken for the 12-13 dipole, or if this represents two large data gaps in the pseudosection. In addition, there is no numerical modeling to support an interpretation of the LANL data. In any case, we would never rely on one deep

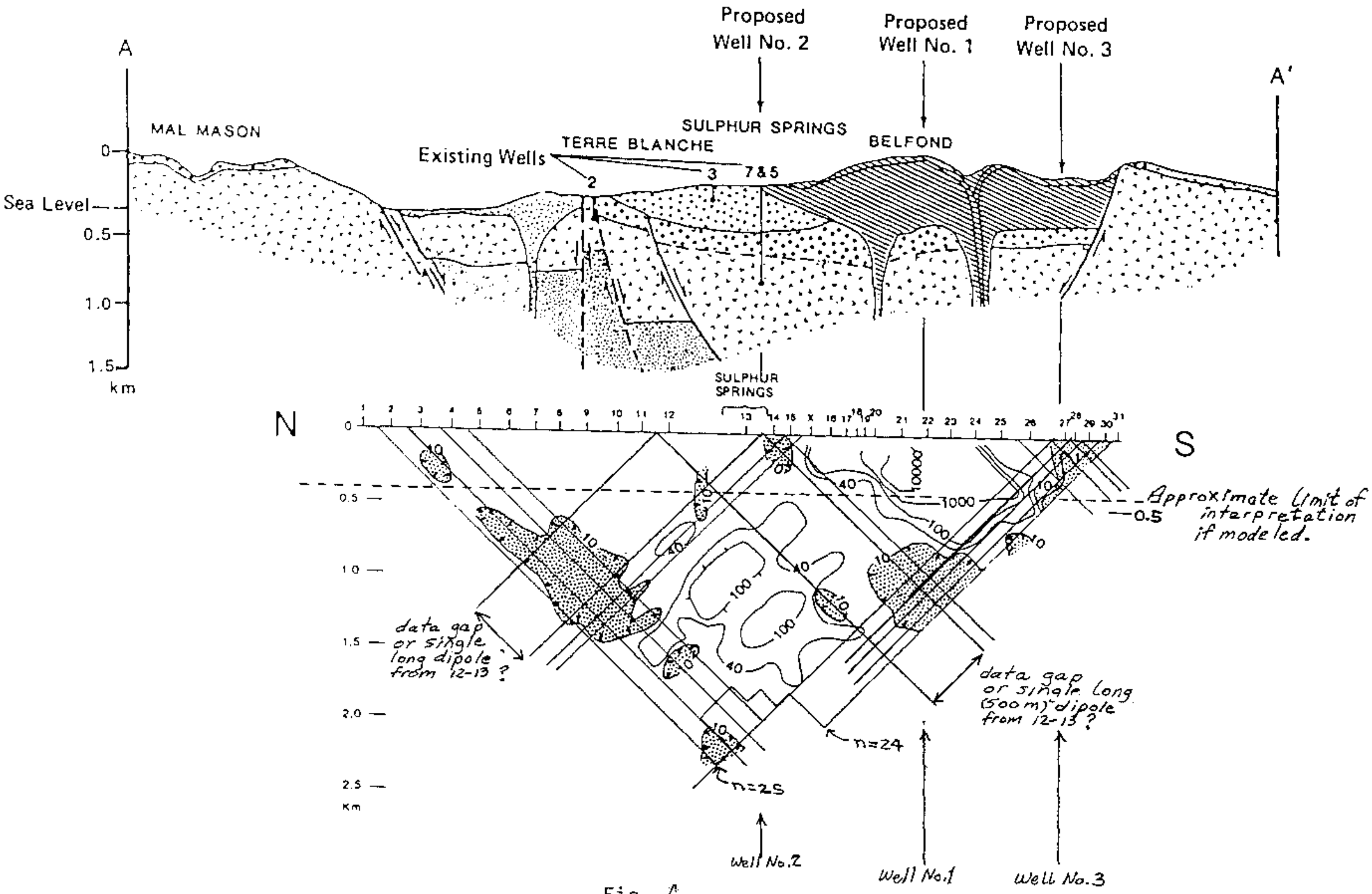

Fig. 4

Apparent resistivity data from the dipole-dipole survey plotted as a function of depth. Resistivity values are in ohm-m and are shown beneath the appropriate geologic cross section. Shaded areas depict resistivity contours of 10 ohm-m or less.

resistivity line since effects from beneath a single resistivity line cannot be separated from effects originating off to the side. There is thus no assurance at all that the low resistivity portions of the LANL profile indicate actual low earth resistivity at the depths they indicate directly beneath the line. We therefore recommend that the resistivity data of this line be given little weight in selecting drill sites for future testing of the geothermal resource.

Recommendation

Numerical modeling of several lines of the IGS resistivity survey could provide substantial information on resistivity distributions and hence possible faults, lithologic changes, and geothermal fluids, to depths of 400-500 m. Resistivity lines pertinent to siting of future drill holes include lines 4, 5, 6, 7, 8, 9, and 10. Topographic variations could be modeled, if severe enough to warrant the additional time and expense. Although the resistivity interpretation would not be valid for depths below 500 m, the structure from 0-500 m depths, when correlated with geologic data, would provide the best indication of deeper features, and hence the best basis on which to site future drill holes.

References

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