TEC-1

PRELIMINARY INTERPRETATION OF TUSCARORA MAGNETOTELLURIC MODELS

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Abstract

Magnetotelluric modelling at Tuscarora to date reveals an updomed electrically-resistive region having its crest under Hot Sulphur Creek (Figure 6). The arch is capped by an extensive low resistivity medium near-surface, and merges into a low (5Ωm) resistivity mass extending from 2 to more than 10km depth. The resistive arch corresponds geologically to Paleozoic strata, penetrated in two places by intrusives that map as vertical bodies of still higher resistivity. The cap material, better resolved in the dipole-dipole models, follows the volcanic sediments, which become conductive through a combination of alteration and hot water. This conductor deepens toward Independence Valley.

The conductive mass underlying the arched Paleozoics is best explained as an altered zone and hot-water reservoir in the region between 2 and 7km depth. From measured <u>conductive</u> temperature gradients temperatures greater than 200°C are reasonable for this region. Curie-point temperature can be expected about 5km and below, while the solidus of wet granite could be encountered below 7km. These thermal properties permit the interpretation of a zone of partial melt overlain by a liquid-dominated geothermal reservoir.

The present program of cautious step-out drilling is a reasonable approach toward tapping the upper aquifer at a favorable isotherm: these isotherms are determined by the deep heat source. If the configuration of the deep reservoir can be confirmed by a non-electrical method, it ultimately would be desirable to tap it at its culmination under Hot Creek. Although gravity and magnetic modelling could prove supportive of the heat source deduced from MT, the delineation of a region of partial melt (magma chamber) is best accomplished by high resolution mapping of P- and S-wave delays and attenuations.

Introduction

Portions of 2 MT lines at Tuscarora have been modelled by Howard Ross and Claron Mackelprang of UURI, as reported in my earlier memo of 12 February. Additional modelling is underway; meanwhile, I have recontoured the MT pseudosections to conform to our standard powers-of-two scale and had them colored accordingly. In addition, the models have been colored.

Layout

Figure 1 displays the lines and stations along which the modelling was performed. The E/W line (A-A') corresponds to that depicted in a 1D inversion in the 1:24,000 folio, and approximates the dipole-dipole Line 9. Line C-C' corresponds to Terraphysics' Line C-C', but is rotated (around an axis near the drillhole 66-5) relative to the diagonal lines in the folio (E-E', MT and Line 16 of the dipole-dipole survey). Furthermore, the 3 supplementary MT stations run during 1980 were overlooked by the modellers, and hence not incorporated.

Pseudosections

Pseudosections of the T_m mode appear in Figures 2 and 3. In any modelling attempt, one's confidence in the model is determined by the coincidence between the observed data and that generated by the model. In Figure 2 (E/W) this agreement is very good. In Figure 3, only the region at depth beneath stations M1, B1, M10 could not be reconciled using the 2D program. Probably 3-dimensionality of the model is responsible for this difficulty.

Model, Line A-A'

A geologic section compiled by H.D. Pilkington overlies the model, wherein Well 66-5 approximates MT site M1 and 51-9, M10. The upper half-kilometer in this region, corresponding to volcanics and volcanic sediments (Ttb and Tts) falls within the 5 to 15Ωm range. Alteration and/or a warm aquifer may be producing the high conductivities, that occupy the region between the projected 100° isotherm and the surface. Below 1/2km, a more resistive regime is encountered, as seem in the well logs. In the model this region, shown as Paleozoic, is represented by a 35Ωm block under DH66-5. Adjacent to the well on the east a 500Ω m "dike" corresponds to the Tla plug deduced by Pilkington. Below 2km, a more conductive material bounds the plug both to the east and west. A 5 m mass appears to pervade a large region below 3km, including the base of plugs Tla and Tlg within a mapped fault block of Hot Creek. Mineralization, alteration and graphite zones might account for portions of this conductive mass; however, its great vertical, as well as horizontal, extent argues for a reservoir of hot fluids at intermediate depth and associated heat source of partial melt in the deepest regions modelled.

Eastward, the deep conductor merges into the upper conductive zone without an intervening resistive unit, suggesting possible communication of fluids or lithology in the eastern graben region. This matter should be clarified when the continuation of the modelling in this direction is received.

Westward, the upper conductor plunges to a depth of 2km in the vicinity of the very faulted rocks near the Owyhee River. The underlying resistive blocks could be expressing Pilkington's (and Sivitt's) 37 million-year-old intrusive (No MT stations overlie it) or the Paleozoics seen in DH66-5. If either of the deduced intrusive bodies possesses broad bases as drawn in the geologic section, reheating below about 5km has evidently rendered them conductive.

Is this "reservoir/heat source" the conductor that appears to underlie a broad area of Line A perhaps only a lateral projection of valley sediments from the south which the MT and the modeller view as lying at depth? An examination of the model of Line C-C' suggests that this is not the case.

Model, Line C-C'

In this line, running approximately NNW/SSE, the upper near-surface conductor steps down into the 5Ωm region of the upper end of the Independence Valley. The yellow 25Ωm zone corresponds to Sivitt's downfaulted region. Probably the 3km-depth of fill shown in the model is excessive. Between the valley and Hot Creek, intervenes a resistive mass (300 m) separating a deep conductive zone from the upper. The resistive zone that arches across from south to north, appears to correspond to Pilkington's intrusives of Line A-A', and probably Paleozoics as well. In any event, we see that the deep conductor is bounded by this mass to the south and north, whereas in the E/W section it enjoyed considerably greater breadth. Under B1 (C-C') it is modelled as reaching to only 4km of the surface, rather than the 2km of A-A'. Here I would favor the E/W model, because of its excellent pseudosection agreement. There is evidence that the deeper conductive region extends northward beneath the resistive blocks, suggesting a broad zone of heat.

Justification of Interpretation

In order to demonstrate that the interpretations of the deep conductive zone are reasonable, I have computed temperatures at depth from the reliable temperature gradient information available for the area of interest; namely, logs of DH51-9, at M-10, which sustained a conductive gradient to its bottom. A conservative gradient of 100°C/km is adopted from the well log. Projecting the gradient downward, we find that reservoir temperatures of 200° can be expected at about 2km depth, which is the crest of the 5Ωm conductive body on Line A-A' (Figure 6). Of course fluids would have to be present in order to lower the resistivity to this value. Projecting further on a purely conductive basis, we expect the Curie isotherm at 5km or 500°, which is the depth at which the modeller truncated the resistive blocks. Actually, in the presence of an adjacent convective reservoir, I would expect the Curie point to lie somewhat deeper, unless the temperature gradients increased in degree of alteration and heating. The Curie isotherm would express itself magnetically as an absence of magnetization below that depth; however, it alone would not be expected to lower resistivities to 5Ωm (from 35 to 500 m) in the Paleozoics and intrusives.

It is, of course, venturesome and perhaps unwarranted to translate electrical boundaries at such depths into isotherms; but the fact that a continuously conductive mass to 10km had to be introduced to fit the psuedosections demands that we relate the low resistivities to thermal effects. In the region of 5-10km depth (cf. Figure 7) 9%-H_2O granite begins to melt around 700°, or, in our case, 7km. Basalt and 2%-H_2O granite start to melt around 850°. Thus, a region of partial melt is not an extravagant deduction at Tuscarora.

Referring to Figure 8, from Parkhomenko (1967), we see that the resistivity of dry granite drops sharply above 650° and 1000 bars (below about 4km): to 5 m at about 700°. More mafic rocks become conductive at higher temperatures, while rocks of higher moisture content become conductive at lower temperatures. The sharp decrease in resistivity seems to relate to the solidus. A generalized plot of resistivity vs. depth in Figure 9 (MADDEN, ET AL., 1977), shows a decrease of resistivity by 1000 times with partial melting. These properties of hot rocks permit us to ascribe a partial melt mechanism (i.e., a magma chamber) to the region of low resistivity below about 7km.

Conclusions and recommendations

An upper conductive zone, seen both in the MT and dipole-dipole surveys covers the upper half-kilometer of volcanics and volcanic fill. It dips down to the east, west and south where it merges with the Tertiary valley material. An arched resistive zone having its keystone underneath Hot Creek characterizes the Paleozoic strata and mapped intrusives in both directions. Beneath it lies a deep conductive zone topping at 4 to 2km (probably more like 2 1/2 to 3km), which to the east merges electrically with the upper conductor. In the top of this body we may be seeing hot fluids or simply alteration and mineralization, but its evident great extent below 3km is most likely occupied by hot fluids. At depths below about 8km, the conductor increases its extent to the north and west, and very likely is associated with elevated temperatures and possibly melt.

In light of the problems encountered in DH66-5, any deep drilling attempted should be done only after establishing favorable conductive gradients in intermediate depth holes and the assurance that the upper aquifer can be sealed off from communication with the deeper portions of the hole. The present strategy of mapping the isotherms by stepout wells is a cautious and reasonable one.

Regardless of the possibility that some other electrical method might detect and map the conductor below 2km, it is preferable to attempt to confirm the deductions of reservoir and heat source by other means. Since rock densities are reduced upon heating and melting, careful gravity modelling may be helpful for recognizing the heat source. Likewise, magnetic modelling may reveal the Curie-point level. The most convincing expression of partial melt, however, appears in measurements of P- and S-wave delays and attenuations of energy from teleseisms. Iyer (1980) and others have mapped numerous magma chambers by this method. The use of 3-component seismometers and magnetic tape recording would be required to adequately resolve the seismic variations.

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Figure 1. Location of MT stations and profiles.

Figure 2.

Captions not needed. (Pseudosections)

Figure 3.

Figure 4.

(Models)

Figure 5.

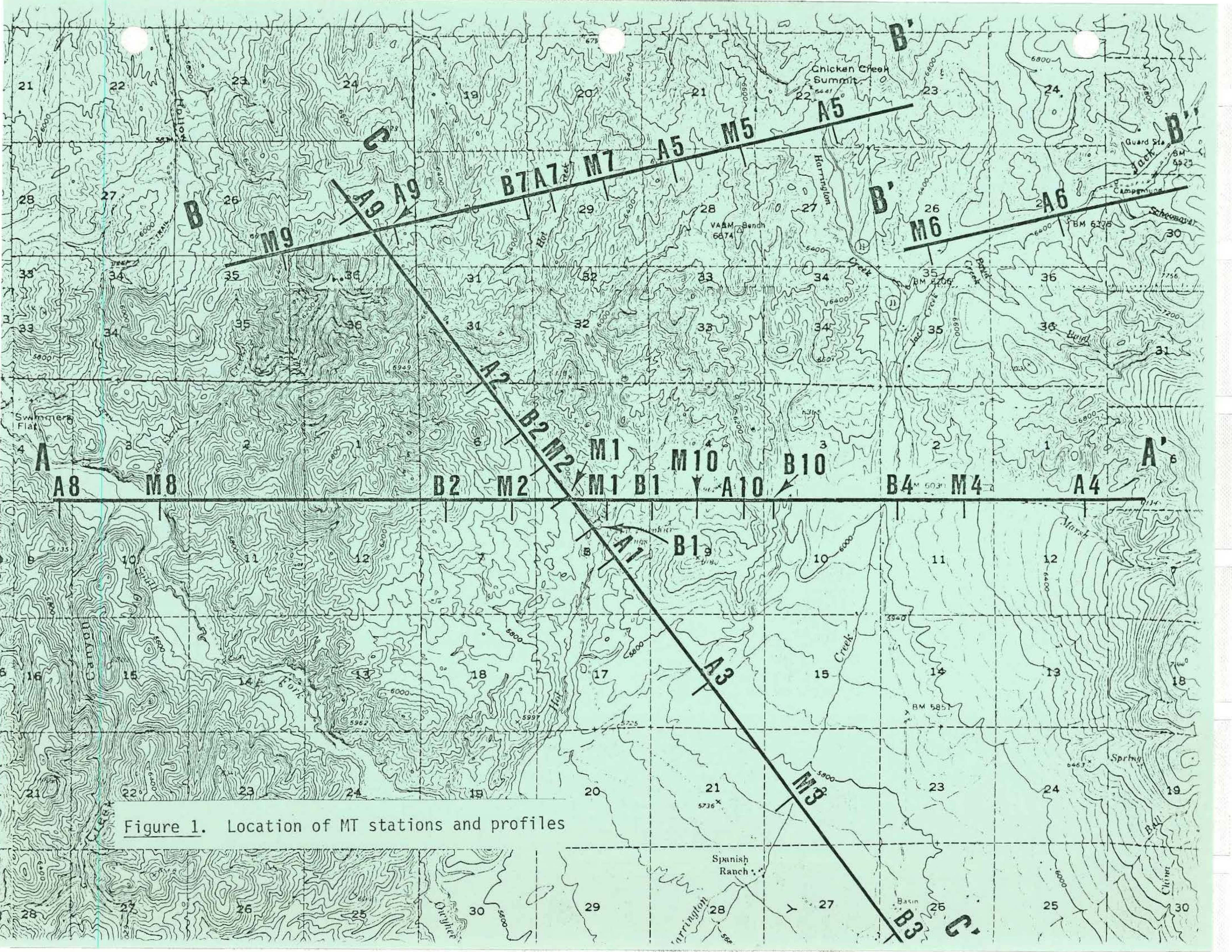
Figure 6. Perspective view of interpretation of MT models, showing deduced reservoir, heat source, and particular isotherms: 200°, Curie point, and wet-granite solidus.

Figure 7. Typical eastern, and western geothermal gradients, and the Tuscarora conductive gradient from DH51-9. At depths where these gradients intercept the melting curves, molten or partially molten material can be expected (TUTTLE & BOWEN (1958).

Figure 8. Resistivity and conductivity of granite during heating to 1500°C at various pressures (from PARKHAMENKO, 1967).

Figure 9. Hypothetical resistivity/depth profile, taking into account temperature and pressure effects on pore fluid resistivity and rock matrix resistivity for different temperature gradients (from MADDEN, ET AL., 1977).

FIGURES



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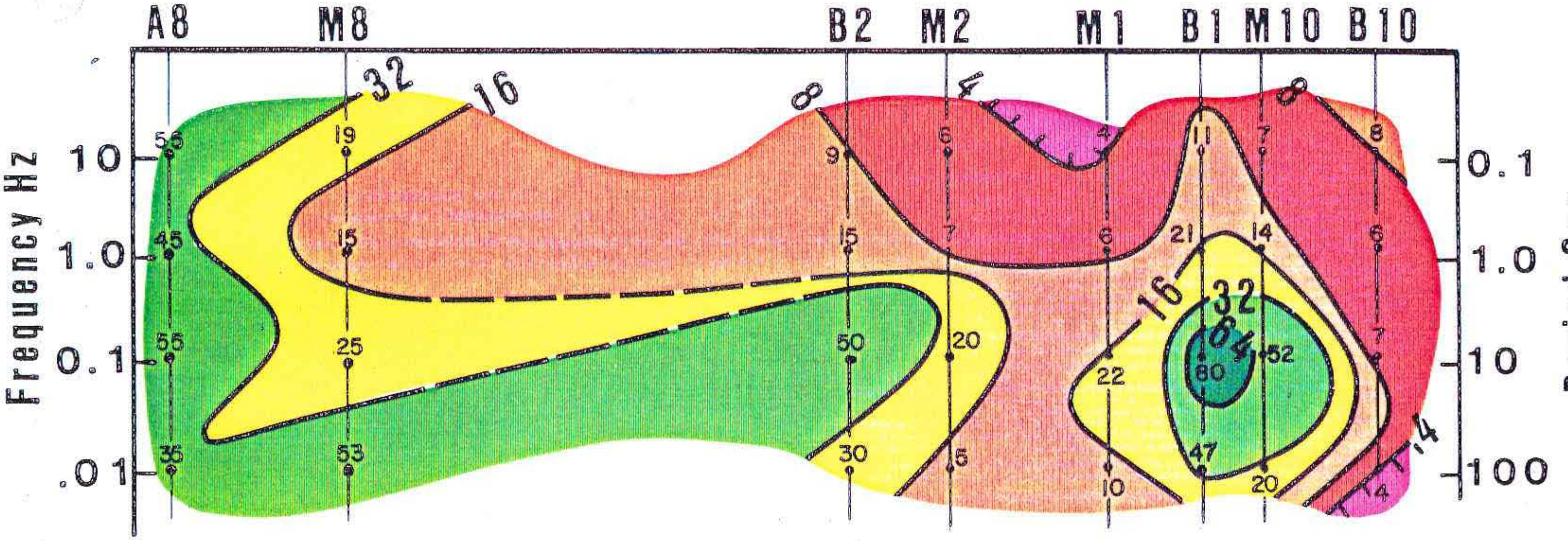

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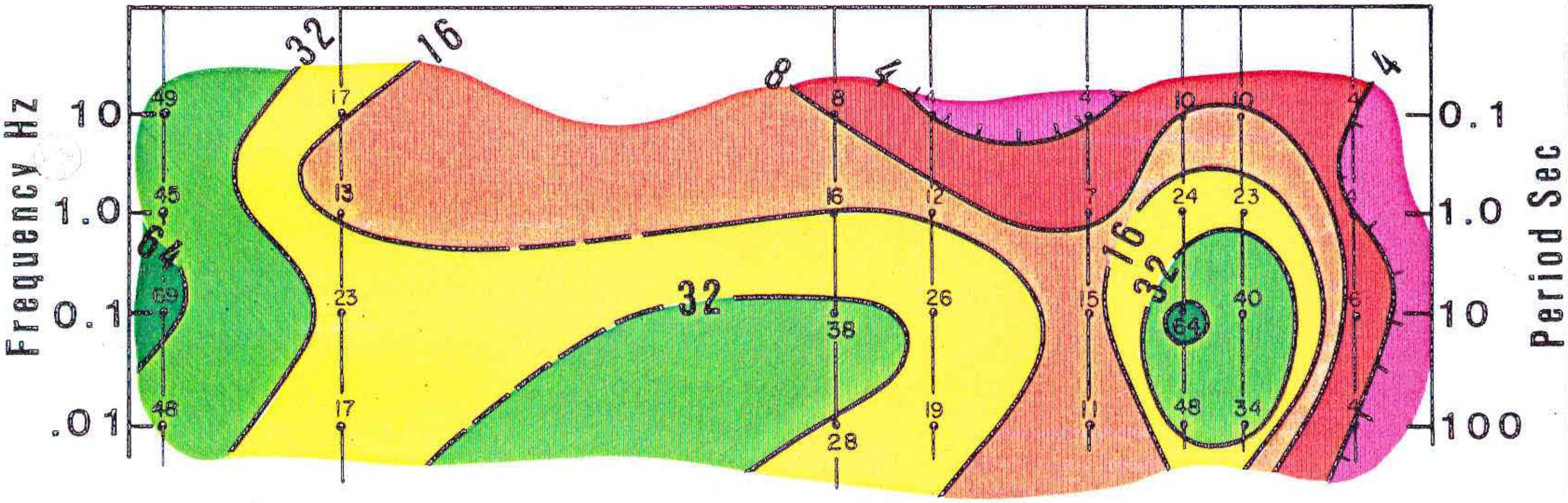
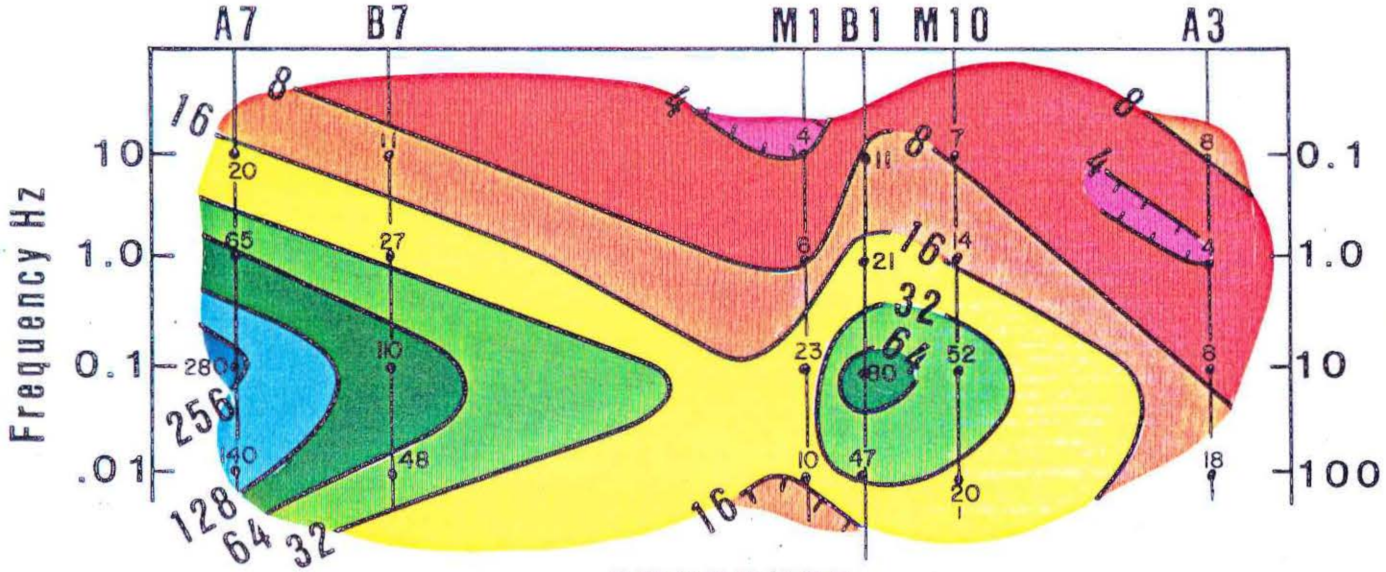


CALCULATED

LINE A–A′
MT PSEUDOSECTION
APPARENT RESISTIVITY Tm MODE
(OHM–METERS)

Figure 2.



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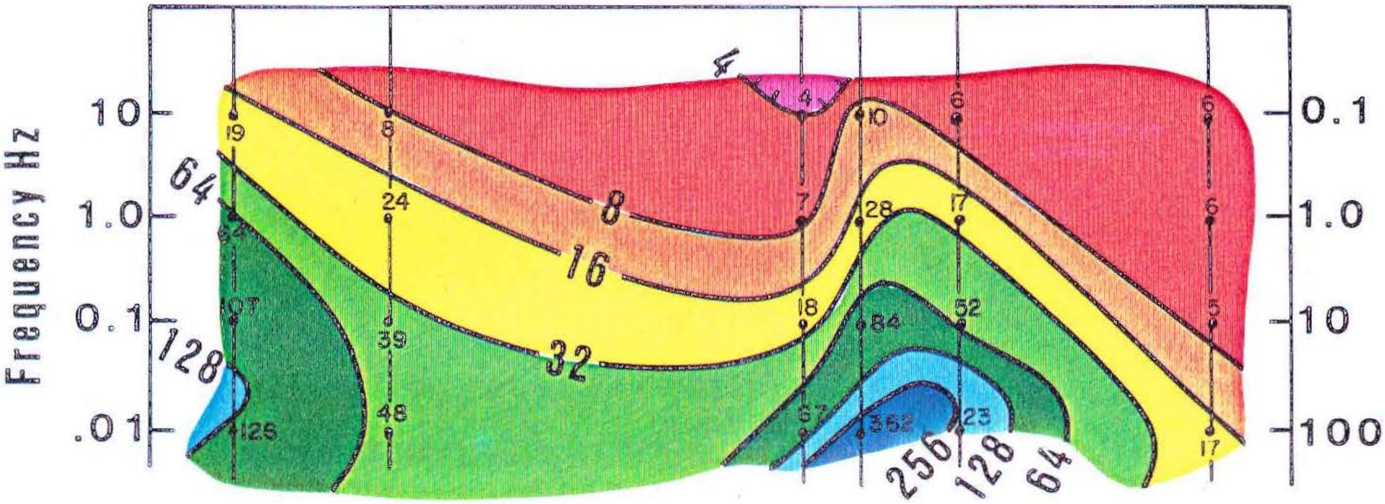


CALCULATED

LINE C–C′
MT PSEUDOSECTION
APPARENT RESISTIVITY Tm MODE
(OHM–METERS)

Figure 3.

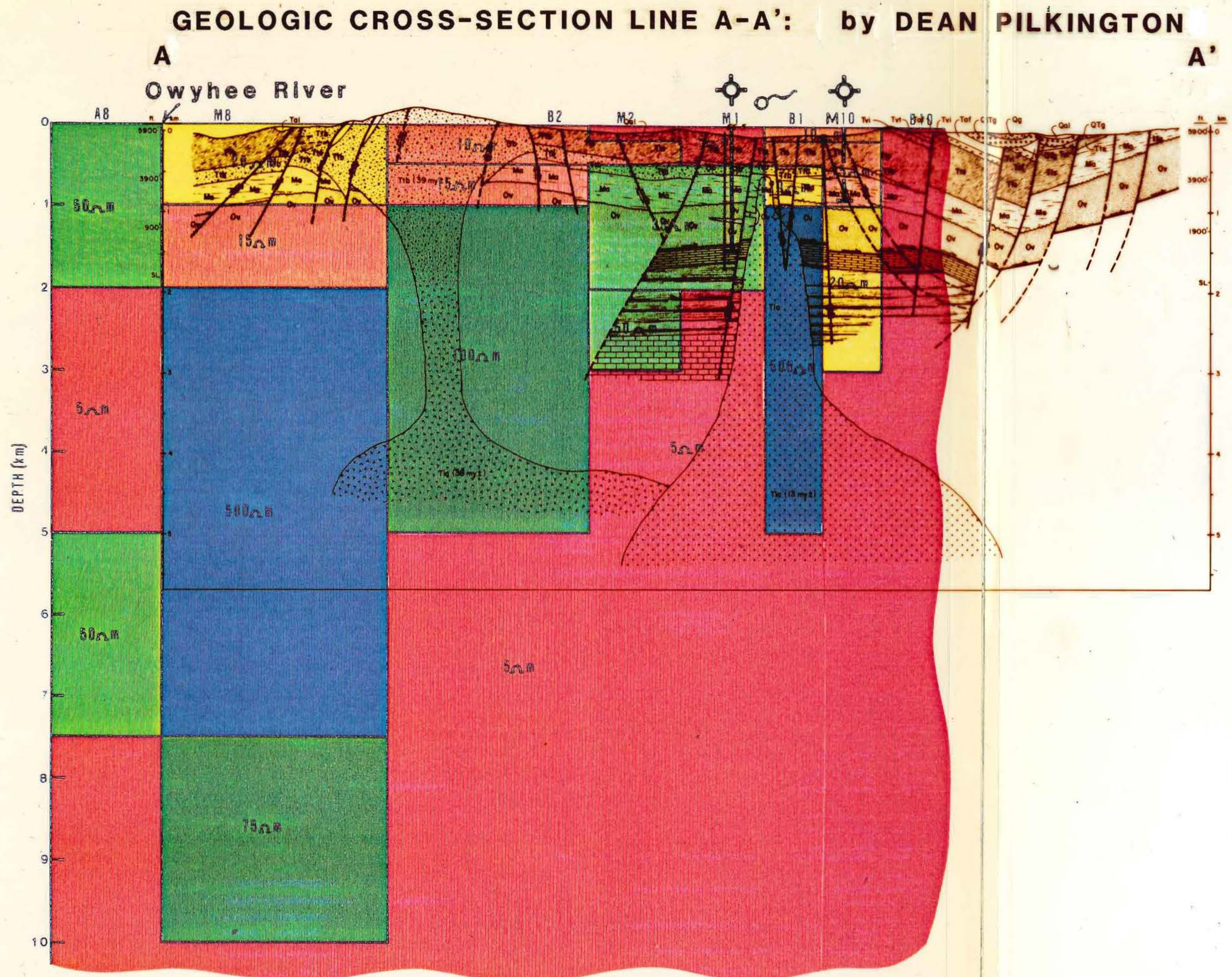


Figure 4.

LINE A-A'

MT-2D MODEL

Tm MODE

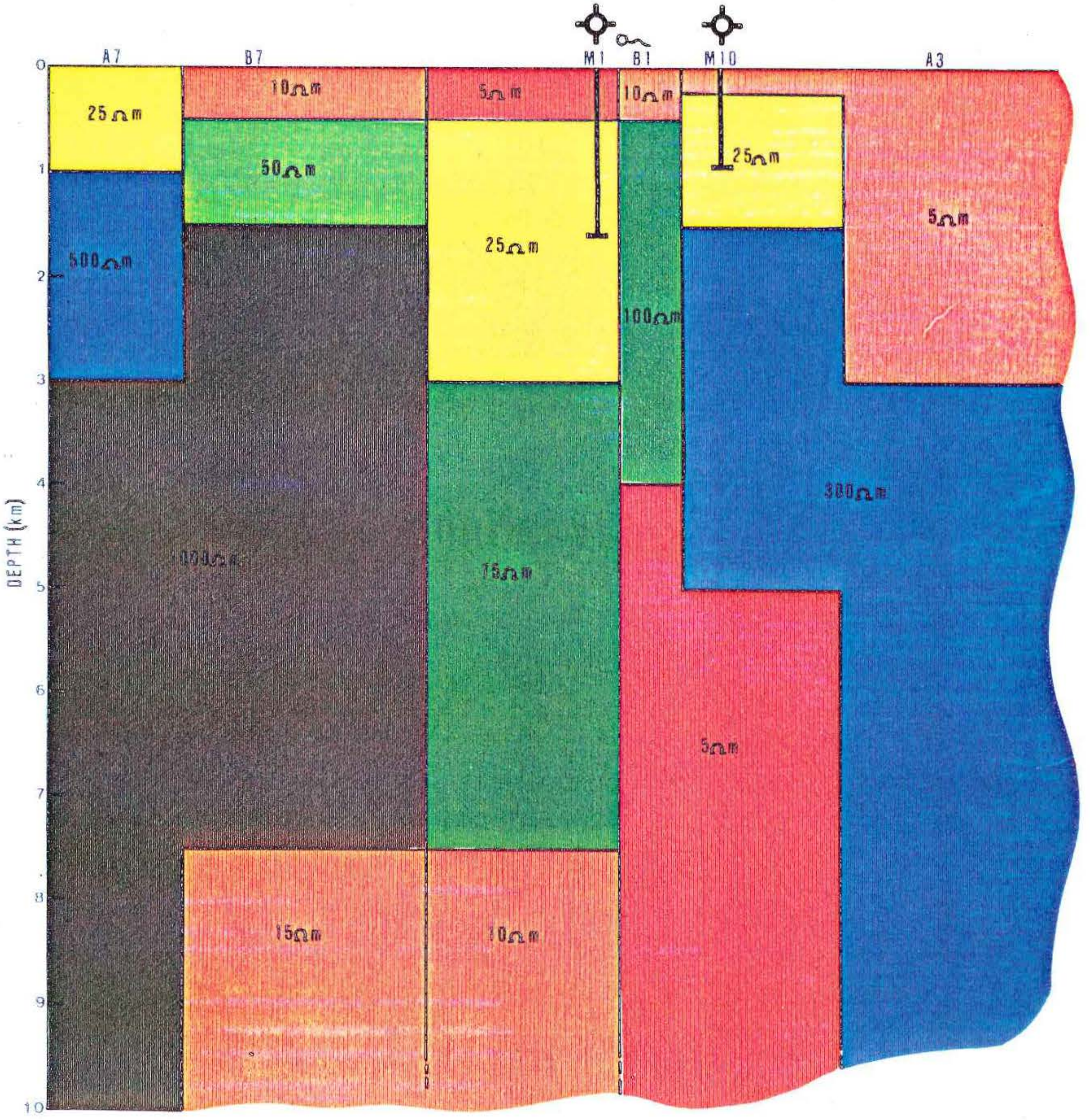
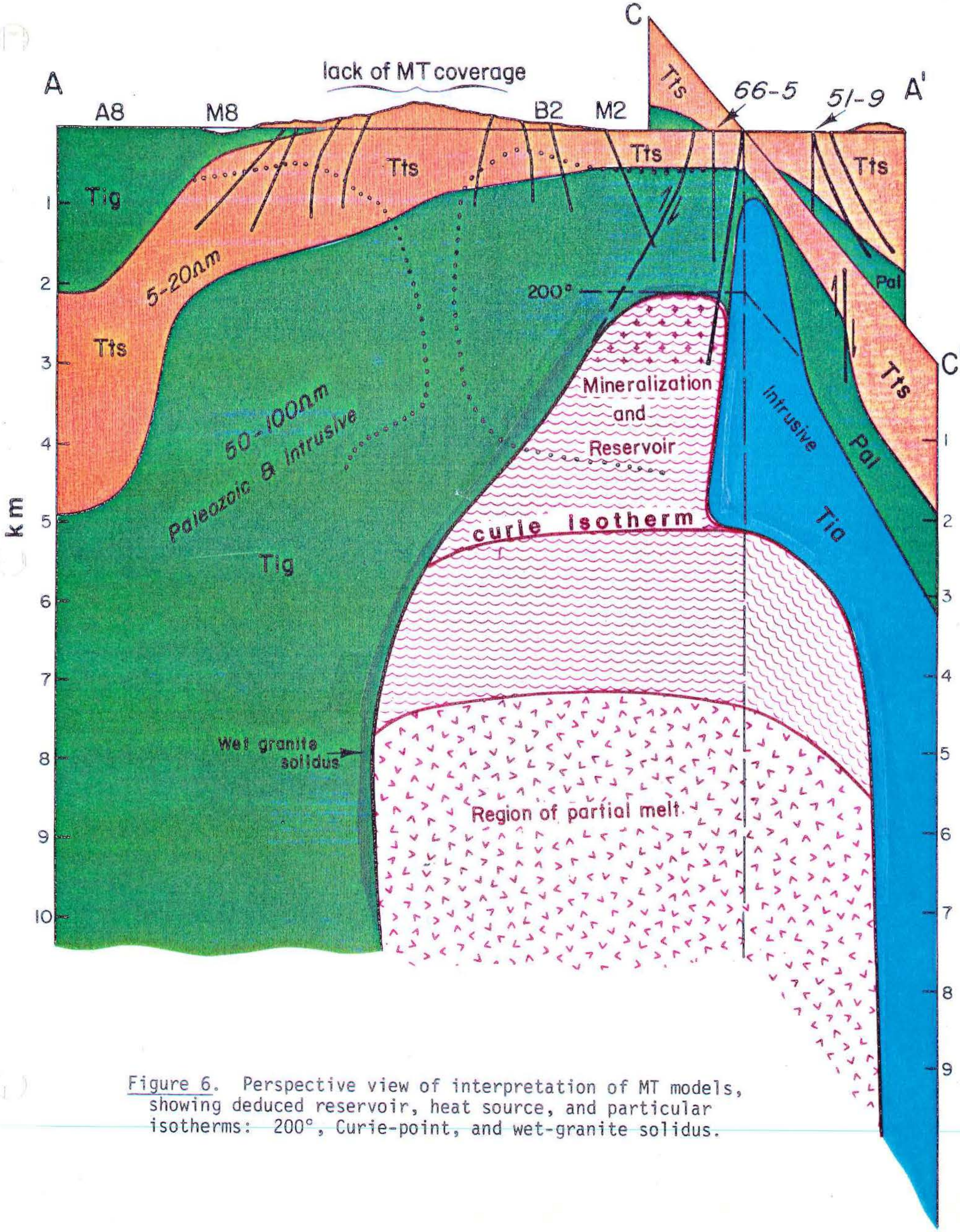


Figure 5.

LINE C–C′

MT–2D MODEL

Tm MODE



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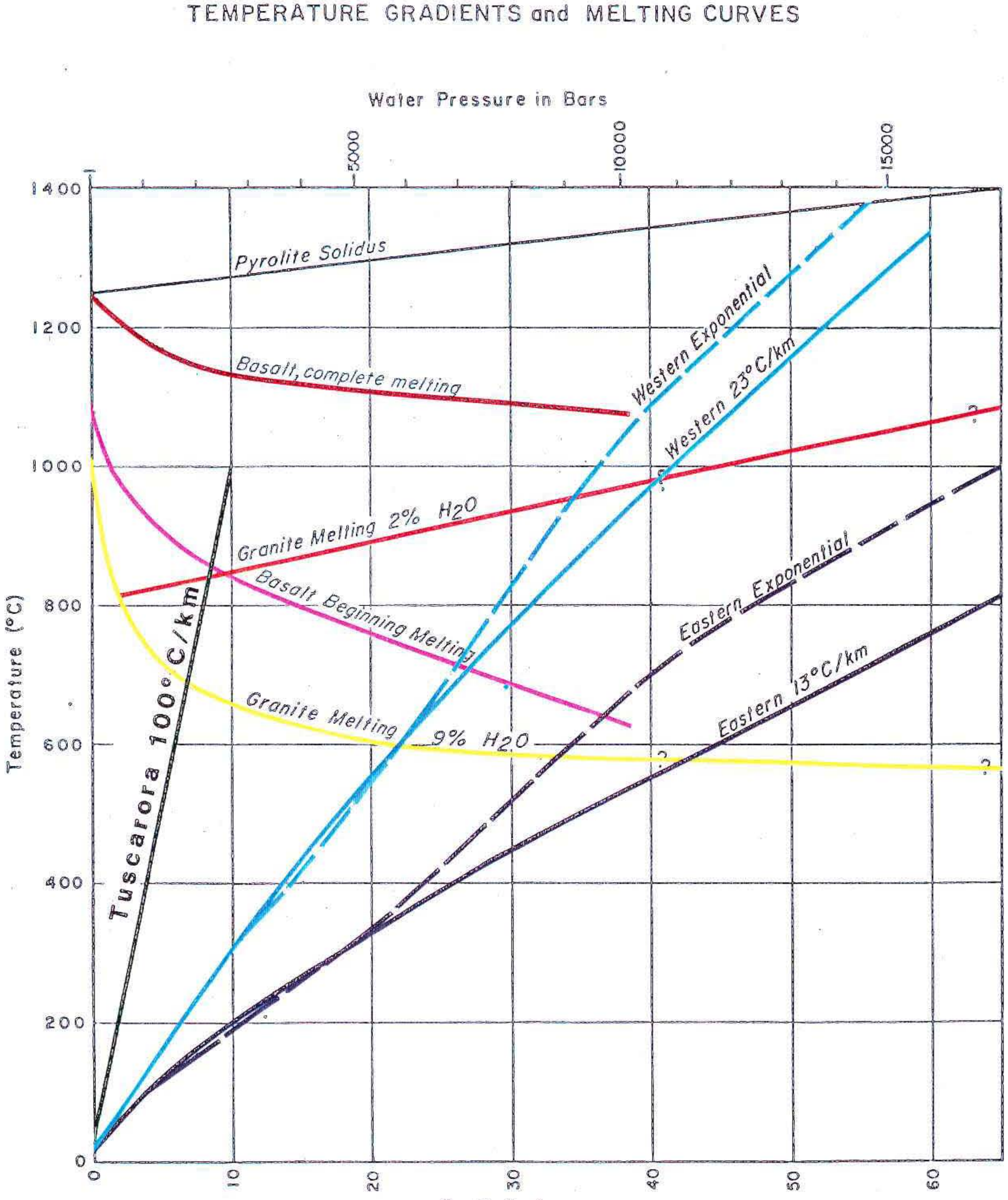

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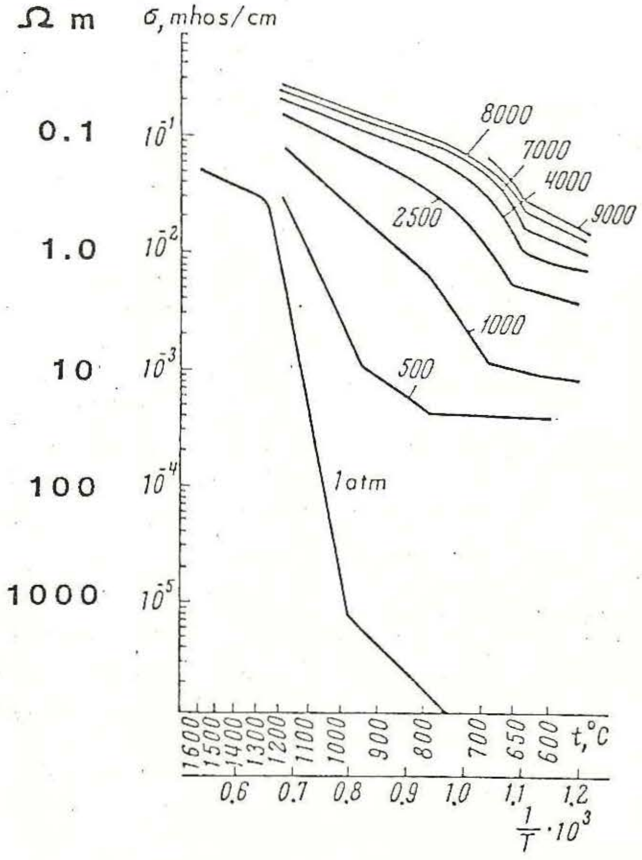
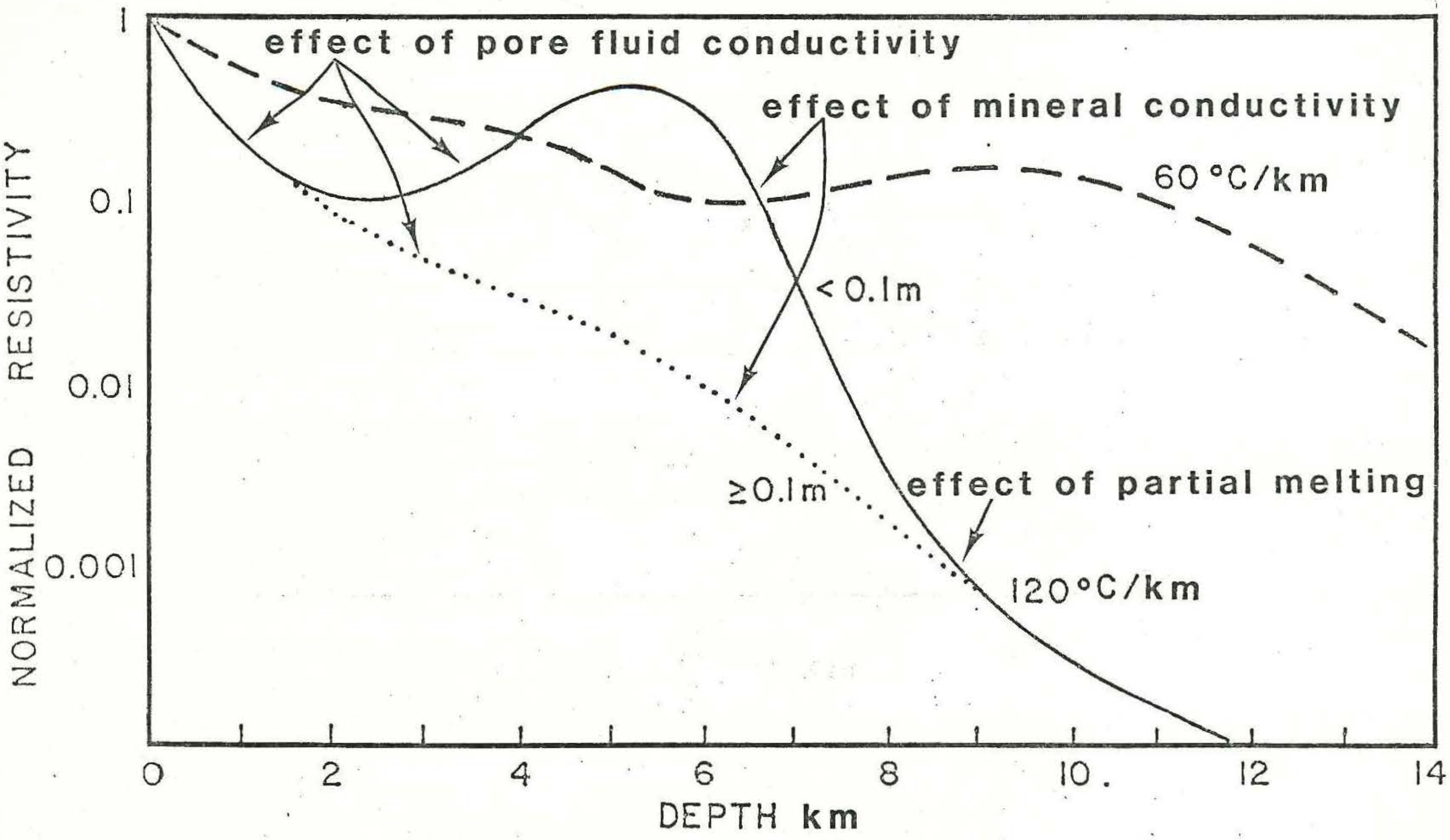
ELECTRICAL RESISTIVITY OF ROCKS



Conductivity of granite during
heating to 1500°C at various pressures.

Figure 8. Resistivity and conductivity of granite during heating to 1500°C at various pressures (from PARKHAMENKO, 1967).



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