INTERPRETATION OF MAGNETOTELLURIC SOUNDINGS FOR HOT DRY ROCK PROSPECTING

George R. Jiracek
Department of Geological Sciences
San Diego State University
San Diego, CA 92182

Electrically conductive intracrustal zones have been detected by magnetotelluric (MT) soundings in tectonically active areas as well as in stable crustal environments throughout the world. Many researchers are convinced that the layers are due to crustal magma, particularly in active regions. If this association is valid, the detection of such layers at shallow depths would signal a source of heat that could produce a viable hot dry rock target. The successful analysis of magnetotelluric soundings in hot dry rock exploration must, however, consider other possible sources of conductive zones in the earth's crust. For example, pore water and thermally activated electronic solid-state semiconduction enhanced by crystal-charged defects, impurities, volatiles, metamorphism, and ductile flow mechanisms may be important. Also, purely geometrical effects can be mistaken for conductive layers at depth.

Two-dimensional modeling of recent magnetotelluric soundings in the central Rio Grande rift (Jiracek et al., 1982) has confirmed the existence of conductive zones at depths of 10 km or less. Some soundings are located over a region where contemporaneous magma bodies are well-defined at shallow and intermediate crustal levels by seismic observations. Surprisingly, however, the crust is more conductive by at least an order of magnitude where the magma is not detected compared to where it has been confirmed. To explain this result, it is first suggested that a conductive horizon occurs in the crust where an impermeable, ductile cap traps pore fluids beneath. This concept of the crust follows the geologic model presented by Eaton (1980) for the Basin and Range province, therefore, it may have wide applicability in the western United States. Fig. A-8 summarizes the model.

Ductile flow mechanisms are thermally activated processes, which involve charged defects, lattice dislocations, or atomic diffusion, all of which enhance solid-state electrical conduction. The hypothesized ductile layer

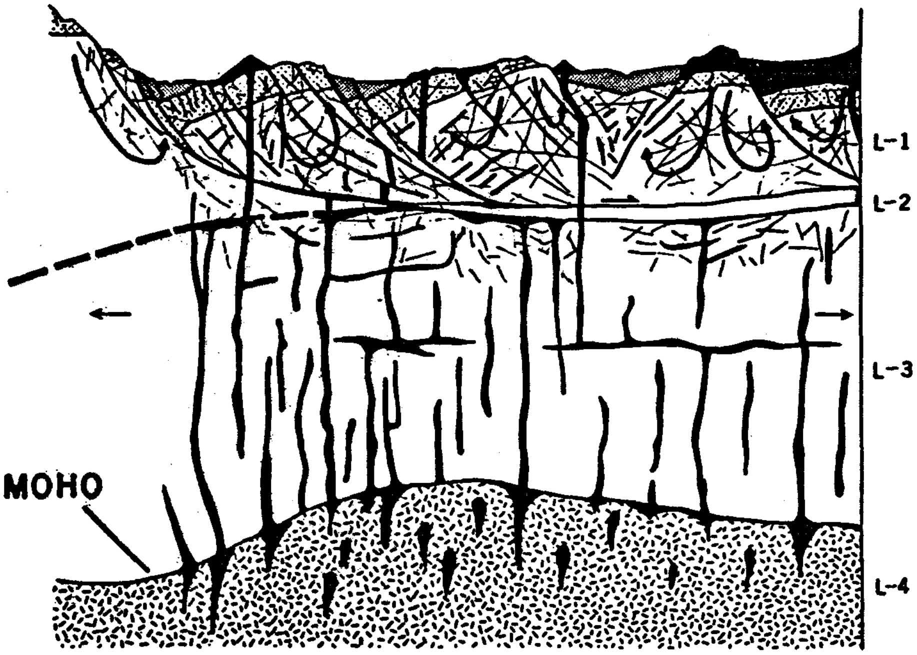

Fig. A-8.
Interpretive model of possible basin and range (or rift) structure (simplified, schematic, and not to scale). Crust is composed of three layers. L-1 is brittle, fault-fragmented surface layer 8-15 km thick. Base of L-1 generally marks the maximum depth of earthquake foci. L-2 is ductile intermediate layer, 0-3 km thick. L-3 is the lower crust, 10-20 km thick, composed of basement rocks on top, grading downward from granitic to mafic in composition. The uppermost part of L-3 may contain high-pressure, high-temperature pore fluids in a system capped by impermeable layer, L-2. L-4 is the lithospheric mantle, ultramafic in composition. Bleb-like bodies of rising magma in L-4 intrude the crustal layers as dikes and sills (indicated by solid black). Ductile crustal layer, L-2, may mark the top of an electrically conductive zone, which extends into layer L-3 when highly conductive pore fluids are trapped. Magma intrusion through the ductile cap may release these pore fluids thus reducing the overall conductivity of the sequence. Schematic diagram after Eaton, 1980.

(L-2, Fig. A-8) would, therefore, be perhaps an order of magnitude more conductive (~100's ohm-m) than the dry, brittle crust above it (L-1, Fig. A-8). A zone of trapped pore fluids (top of L-3, Fig. A-8) would be even more conductive by about another order of magnitude (~10 ohm-m). Mineral dehydration at greater depth due to an enhanced thermal gradient or magma injection could provide such fluids.

If active magma injection destroyed the integrity of the ductile cap, trapped fluids would escape resulting in an overall decrease in conductivity.

The final electrical signature with such a dynamic concept would depend on the thermal gradient, the relative impermeability of the cap, the extent of pore fluids beneath, and the amount (and frequency) of magma intrusion. The temporal and spatial distribution of earthquake foci in the western United States supports the existence of a ductile layer at 5 to 15-km depth and the hypothesis of magma injection.

The aforementioned considerations result in a more resistive crust despite the presence of magma bodies; these bodies would have to be a minor constituent of the crust, otherwise the effects of a highly conductive magma would dominate.

The depth at which a ductile zone would form in the crust is dependent on pressure, temperature, composition and tectonic stress. Since temperature would likely be the major variable in a given geologic province, the depth of a conductive layer caused by ductility would provide a measure of the thermal gradient. So, even if crustal conductive zones are reflecting the depth of ductility rather than crustal melt, they may still provide a very useful geothermal indicator. As previously mentioned, the ductile layer would not be as conductive as a zone of high-pressure pore fluids or of a significant concentration of magma. These latter two possibilities would not be separable by magnetotelluric data alone; however, MT results combined with active and passive seismic reflection measurements such as those performed in the central Rio Grande rift (Brown et al., 1980) should be diagnostic.

References

Brown, L.D., Chapin, C.E., Sanford, A.R., Kaufman, S. and Oliver, J., 1980. Deep structure of the Rio Grande rift from seismic reflection profiling. J. Geophys. Res., 85:4773-4800.

Eaton, G.P., 1980. Geophysical and geological characteristics of the crust of the Basin and Range province. In: Studies in Geophysics-Continental Tectonics, Nat. Acad. Sci., Washington D.C., pp 96-113.

Jiracek, G.R., Gustafson, E.P. and Mitchell, P.S., 1982. Enhanced conductivity in continental rift zones and magnetotelluric grounds for ductile origin in the Rio Grande rift. Submitted to: Proceedings of the Conference on Planetary Rifting, Tectonophysics.