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THE LONG VALLEY/MONO BASIN VOLCANIC COMPLEX: A PRELIMINARY MAGNETOTELLURIC AND MAGNETIC VARIATION INTERPRETATION

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Abstract. The Long Valley/Mono Basin volcanic complex in eastern California is one of the few major silicic caldera systems in western North America which have exhibited volcanic activity so recently that they may still be potentially active. Whereas, in principle, magnetotelluric measurements offer a significant opportunity to study such systems through mapping subsurface electrical features associated with hydrothermal and magmatic processes in the crust, our studies in this area indicate that such techniques are profoundly affected by the highly three-dimensional structures associated with these complicated volcanic terranes. We argue that while simple plane-layered (one-dimensional) interpretations are likely to be misleading in such a complicated three-dimensional environment, magnetotelluric observations can delineate important physical features associated with caldera structures; in particular, the method can closely determine the location and magnitude of major boundary faults. Because of the high resistivity contrast between basin fill and crystalline basement, these techniques are very useful for characterizing the subsurface hydrologic regime as well. In addition, sites have been occupied in the southwest moat of Long Valley caldera, an area that is currently exhibiting a variety of tectonic activity. Both the telluric field and magnetic induction arrows imply the presence of a structurally controlled east-west electric current system at relatively shallow depth in the crust. This elongated east-west zone is aligned along the belt of recent seismic activity in the southwest moat, a zone of seismic shear wave attenuation, and a zone of known hydrothermal alteration at the surface. Finally, we summarize observations from the vicinity of Pumice Valley (adjacent to Mono Craters) which has been thought to be an active incipient caldera. Since our present data do not indicate an observable decrease in resistivity at shallow depths beneath the valley, we are led to conclude that the parent magma body feeding Mono Craters (and perhaps Inyo domes) is either too thin or too deep to be resolved or is significantly displaced from a position beneath the center of the inferred ring fractures.

Introduction

The Long Valley volcanic system is one of several young volcanic centers along the western margin of the Great Basin adjacent to the eastern front of the Sierra Nevada (Figure 1). Other such centers include Mono Craters and Mono Basin to the north and the Coso volcanic complex (not shown) to the south. All occur along a particularly active marginal segment of the Basin and Range province where seismic activity, high heat flow, and recent faulting indicate that relatively rapid east-west crustal extension dominates the tectonic regime.

This paper reviews the status of our current magnetotelluric investigations in the Long Valley/Mono Basin volcanic complex, specifically emphasizing the influence of surface features on the observed natural electromagnetic fields.

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The Tectono-Magmatic Character of the Long Valley/Mono Basin Volcanic Complex

Geological Setting

Bailey [1980] has suggested that the volcanism responsible for forming Long Valley caldera has probably evolved through five stages: (1) early basalt to quartz latite effusion; (2) precaldera rhyolite ring fracture extrusion, (3) voluminous ash flow eruption and caldera collapse, (4) post caldera structural and magmatic resurgence, and (5) extrusion of intracaldera rhyolite and quartz latite. Long Valley at present should be in a stage of development similar to the Valles caldera [Smith and Bailey, 1968; Smith, 1980], although recent volcanism in Inyo Craters, as well as an increasing amount of geophysical evidence, suggests that this system is possibly being reactivated.

Long Valley caldera is the southernmost and oldest member of three progressively younger volcanic complexes, each in different stages of evolution [Bailey, 1980]. These are, in decreasing age, Long Valley (3.0-0.05 Ma), Mono Craters (40-1 ka), and the centers in Mono Lake (<2000 years).

The youngest volcanic features associated with Long Valley caldera are the Inyo domes which lie on a linear trend extending north from the northwest sector of the caldera, across the caldera rim, to Mono Craters [Bailey et al., 1976]. The five Inyo domes are roughly rhyolitic in composition, and the three largest are less than 720 ± 90 years old [Wood, 1975]. Not shown in Figure 1 are the Inyo Craters: three phreatic explosion pits on the south flank of Deer Mountain which have been dated at 650 ± 200 years [Rinehart and Huber, 1965]. Early studies indicated that Inyo domes are chemically heterogeneous, which suggests that they may be a product of mixing magmas from the Long Valley chamber and a possible chamber beneath Mono Craters to the north [Bailey et al., 1976]. Recently, however, R. A. Bailey (personal communication, 1982) found evidence that the Inyo volcanoes may have derived from a single source associated with the Mono Craters.

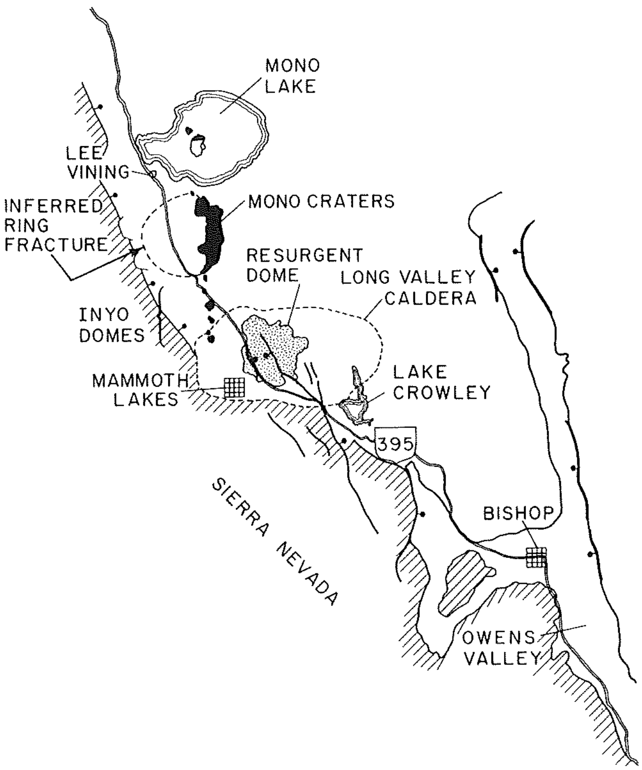

Fig. 1. Generalized map of the Long Valley/Mono Basin volcanic complex showing its position relative to the Sierra Nevadas to the west and the Basin and Range province to the east [after Bailey et al., 1976]. The darkly shaded portions of the map (Inyo domes, Mono craters, and the volcanic craters in Mono Lake) represent recent (Holocene) volcanism. The Inyo domes are five quaternary eruptive centers extending north from the northwestern sector of Long Valley caldera to Mono Craters.

Present geological evidence therefore suggests the possibility that an extensive magma reservoir, or system of reservoirs, may exist beneath the northwestern section of Long Valley caldera and extend 30-35 km north to Mono Lake.

Present Tectono-Magmatic Activity

A number of workers have recently stressed the possibility of renewed volcanism in Long Valley caldera [Savage and Clark, 1982; A. Ryall and F. Ryall, 1983; Miller et al., 1982]. Beginning in October of 1978, a sequence of moderate earthquakes occurred northwest of Bishop, culminating in May 1980 with what is now called the Mammoth Lakes earthquake sequence, of which eleven events had magnitudes close to 5 or larger and four had magnitudes between 6 and 6.3. The epicentral locations of the four major earthquakes [after Archuleta et al., 1982] are shown in Figure 2, along with their general fault plane solutions determined by Cramer and Toppozada [1980].

The unusual seismic activity which followed the Bishop earthquake on October 4, 1978, and which has continued to the present time, is described by A. Ryall and F. Ryall [1980, 1983], and Savage and Clark [1982]. Local events were used by F. Ryall and A. Ryall [1981] to infer the presence of an anomalous zone of seismic shear wave attenuation beneath the southern part of the resurgent dome (see Figure 2). Following the main shocks in May 1980, intensive swarms of small earthquakes occurred in a small area beneath the southwest moat of the caldera [A. Ryall and F. Ryall, 1983]. Typical swarms lasted several hours and had the appearance of spasmodic tremor. Nine such swarms have been reported, all within a 3-km radius circle centered on 37.63°N, 118.94°W, just to the east of the town of Mammoth Lakes (Figure 2).

Savage and Clark [1982] reported geodetic leveling data that suggested a dramatic doming of as much as 25 cm of the central part of Long Valley caldera, which apparently occurred between surveys in 1975 and 1980. This they felt could be due to magmatic intrusion at depth beneath the resurgent dome. The inferred uplift predicted theoretically by Savage and Clark's magma injection model is shown in Figure 2 as dashed contours centered on the Long Valley resurgent dome. Also shown as dashed arrows are the theoretical horizontal displacements predicted by this model, along with those actually observed shown as solid arrows.

Renewal of fumarolic activity at Casa Diablo hot springs was reported in January 1982 (for location, see Figure 5 below). This, along with the localization of spasmodic tremor, which A. Ryall and F. Ryall [1983] argued is usually associated elsewhere with volcanic activity, and the domal uplift reported by Savage and Clark [1982], led many workers to become apprehensive about a possible volcanic eruption in this area. A volcanic hazards notice was issued by the U.S. Geological Survey on May 25, 1982 [Miller et al., 1982].

Recent Magnetotelluric Studies in Long Valley/Mono Basin

Description of Experiment

In October 1981, Brown University initiated a regional magnetotelluric survey in east central California in an effort to study the relationship of the active volcanic centers along the eastern front of the Sierra Nevadas to regional extension in the Great Basin. The locations of representative sites in this area are shown in Figure 3. Originally, our field system was deployed during the early winter in Mono Basin and in the Owens Valley region. In April-May 1982, sites were occupied in the Long Valley volcanic complex including 10 sites in the southwest moat of the caldera straddling the location of the most recent seismic swarm as reported by A. Ryall (personal communication, 1982). Useful data were obtained at nine of these sites.

Our five-component magnetotelluric field system employed a three-axis SQUID magnetometer and two orthogonal electric lines each with a center ground. A PDP 11-23 minicomputer data acquisition system digitally recorded and processed data on line. Magnetotelluric parameters and data quality were displayed on a

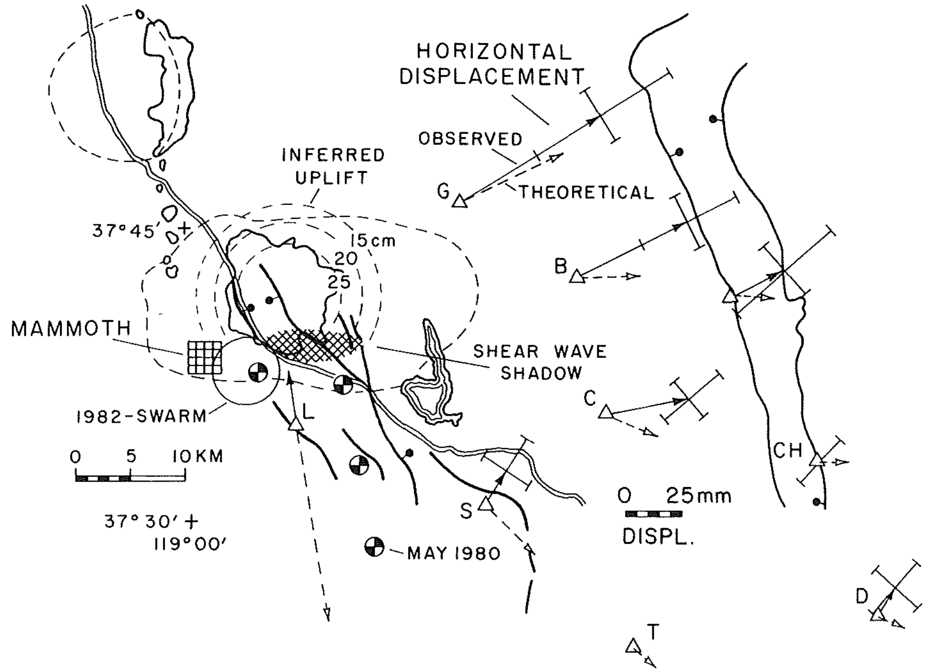

Fig. 2. Composite diagrams showing the interrelationships of various types of recent tectonic activity in the region of the Long Valley/Mono Basin volcanic complex. Long Valley caldera and the incipient Pumice Valley "caldera" are indicated by dashed lines. Mono Craters and the Long Valley resurgent dome are indicated by solid lines. Owens Valley is shown to the east, and major faults are shown by heavy lines. This figure illustrates horizontal displacements, the locations and general fault plane solutions for the major earthquake sequence in May 1980, the shear wave shadow zone, and the theoretical contours of the uplift inferred from recent releveling. The circle to the east of Mammoth village outlines the area of 1982 earthquake activity [after Hermance, 1983a].

video monitor, while recorded signals were plotted on a strip chart recorder after digital to analog conversion. Data during this experiment were normally acquired within four overlapping frequency bands in the range from 10 hz to 300 s. After frequency conversion using a fast Fourier transform, auto and cross powers were band averaged with a selectivity of 0.2 at six periods per decade. Tensor impedance elements were rotated to principal axes, and errors were estimated following the procedure of Hermance and Pedersen [1980].

Preliminary Results

As is indicated by the magnitude of the telluric ellipses at selected sites in this region (Figure 3), Long Valley caldera exhibits anomalously low apparent resistivities at long periods, more than an order of magnitude less than the highly resistive region (Pumice Valley) to the north or Owens Valley south of Bishop (see also Table 1).

In the Long Valley/Mono Basin complex (Figure 4), the telluric ellipses and induction arrows show a striking interplay between the effects of regional current systems (as indicated by a general north-south orientation of the major axes of the telluric ellipses) and the effects of local conductivity anomalies (as evidenced by the sharp differences in polarization and magnitude between closely spaced telluric sites). Within the Long Valley caldera, over the resurgent dome and within the area of recent seismic activity in the southwest moat, a greatly reduced telluric field reflects low resistivities associated with the caldera fill and/or features in the basement.

In the southwest moat of Long Valley caldera (Figure 5), there is a high coherency between the orientation and magnitude of the telluric ellipses at these sites as well as an orthogonal orientation of magnetic "induction arrows" relative to the major axes of the telluric ellipses. Both the telluric field and the induction arrows imply an east-west electric strike for this area reflecting a structurally controlled east-west current system at relatively shallow depth in the crust. This elongated east-west zone is aligned along the belt of seismic activity in the southwest moat, the zone of seismic shear wave attenuation (Figure 2), and a zone of known hydrothermal alteration.

The results summarized in Figure 6 and Table 1 compare the mean maximum principal resistivities for each subregion at periods of 20, 70, and 300 s. The resistivity in each subregion is offset from that at the others by a multiplicative constant (along with a close similarity among the phases at the same periods). This suggests the presence of a "static" offset due to telluric distortion from near-surface lateral heterogeneities

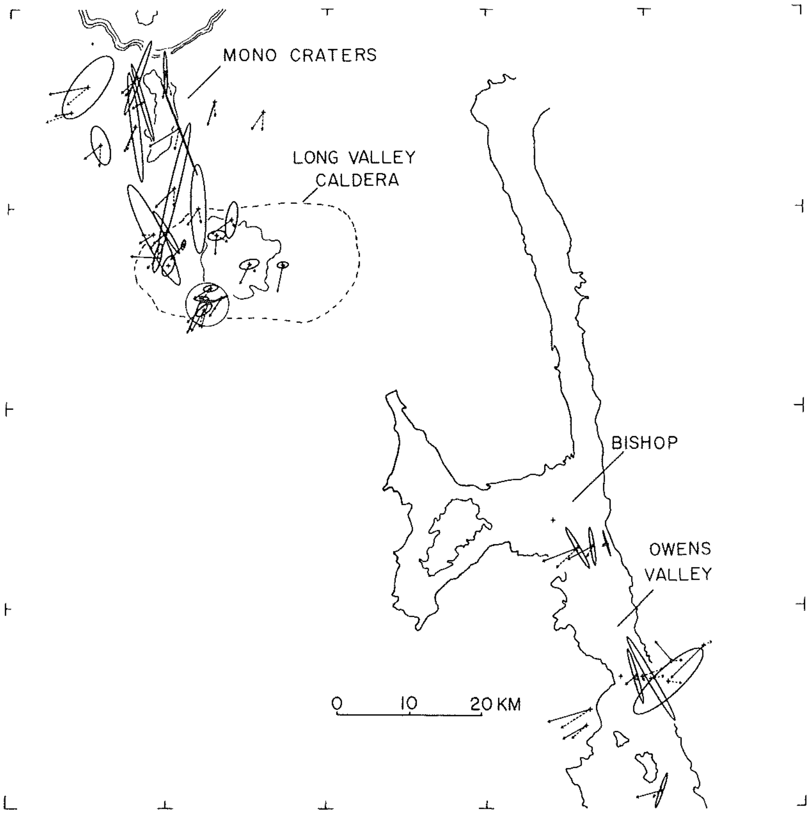

Fig. 3. Observed compensated telluric ellipses and magnetic induction arrows at 20 s for the region of Owens Valley, Long Valley, and Mono craters.

[Berdichevskiy and Dmitriev, 1976]. These results imply that modeling certain characteristics of the magnetotelluric fields in this region at periods of 20 s and longer may be appropriate using dc telluric models.

Modeling

A simple three-dimensional model. The static effects of surficial lateral heterogeneities can be simulated at periods from tens to hundreds of seconds by invoking the dc or galvanic approximation [e.g., Berdichevskiy and Dmitriev, 1976]. This approach has been recently exploited by Hermance [1982, 1983b] to simulate the long-period behavior of magnetotelluric fields in the vicinity of three-dimensional features. The thin sheet conduction algorithm of Hermance [1982] has been applied to a model which simulates the effects of regional geologic features in the Long Valley/Mono Basin area on local magnetotelluric field observations

TABLE 1. Subregional Mean Apparent Resistivities for the Maximum Principal Resistivity Estimates

Subregion	No. of Sites in Average	Period			
		0.12 s	20 s	70 s	300 s
Mono Basin	10-12	210* (42°)	340 (47°)	220 (57°)	190 (52°)
NW caldera rim	2-3	570 (43°)	850 (55°)	580 (59°)	380 (54°)
Resurgent dome	8	28 (39°)	37 (59°)	23 (66°)	18 (59°)
Southwest moat	7-9	29 (36°)	21 (66°)	13 (71°)	9 (59°)
Owens Valley	5-7	25 (42°)	250 (51°)	130 (55°)	98 (57°)

*Values are in ohm meters.
Typical expected range for apparent resistivity in each subregion is ±50%; for phase it is ±5°.

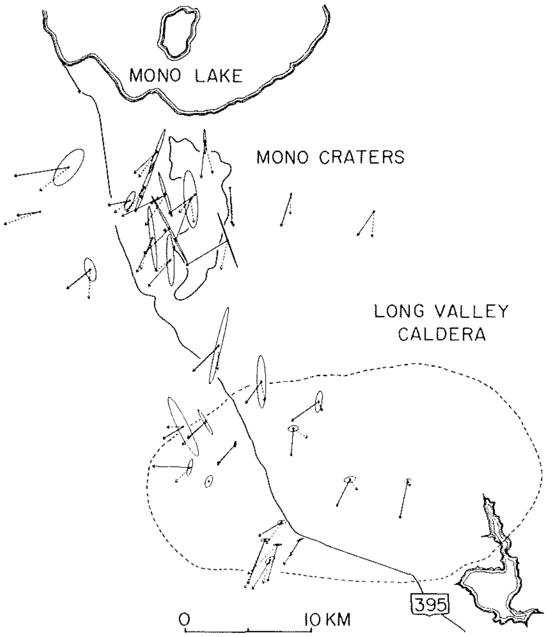

Fig. 4. Telluric ellipses and induction arrows computed from data in the Long Valley/Mono Basin volcanic complex.

(Figure 7). The algorithm has been extended to calculate the magnetic field as well as the telluric field anomalies.

In the model used here, a 3-km layer of heterogeneous resistivity overlies an insulating basement; resistivities in the surface layer are representative of the contrasts between "known" electrical features in the regional geology. We represented the granitic batholiths of the Sierra Nevada range to the west and the White Mountains to the east with a resistivity of 500 ohm m. This would correspond to a thin weathered surface layer.

A somewhat lower resistivity, 200 ohm m, was assigned to the Pleistocene volcanic rhyolite and pyroclastic rocks, with occasional outcrops of granite, which span the region between Owens Valley in the east and Pumice Valley/Mono Basin in the west. We took this value as representative of the north rim of Long Valley caldera as well.

Within the basins and the interior of the caldera, guided by the results of Hoover et al. [1976] and Stanley et al. [1976], we assigned a value of 100 ohm m to the somewhat variable alluvial fill and tuff. Effects of the known hydrothermal zone associated with the southern portion of the resurgent dome in Long Valley caldera were represented by an arc wrapped around the southern part of the dome having a value of 40 ohm m (following Hoover et al. [1976]). These values represent resistivities that were depth integrated to basement, which we assumed had infinite resistivity for the purposes of this model. Details of the modeling algorithm are given in the work of Hermance [1982].

The overall dimensions of our model was 200 km on a side and mesh spacing was 3 km minimum. The portion of the model shown in

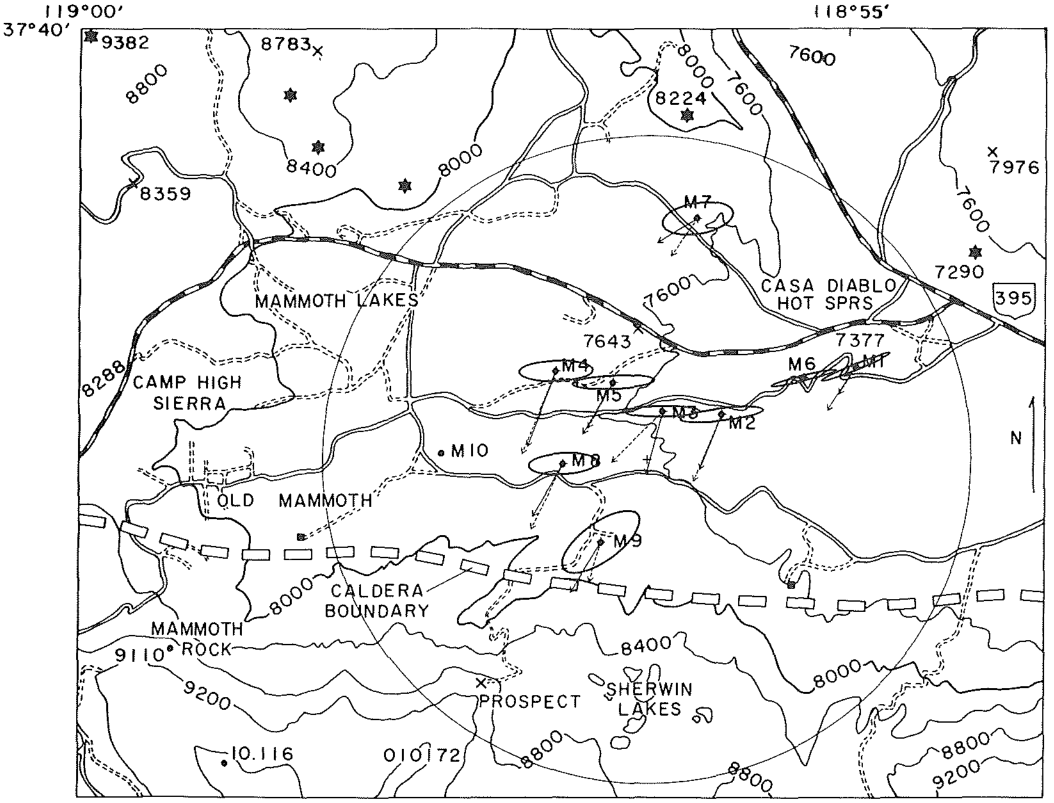

Fig. 5. Telluric ellipses and induction arrows computed from data collected in the southwest moat in Long Valley caldera.

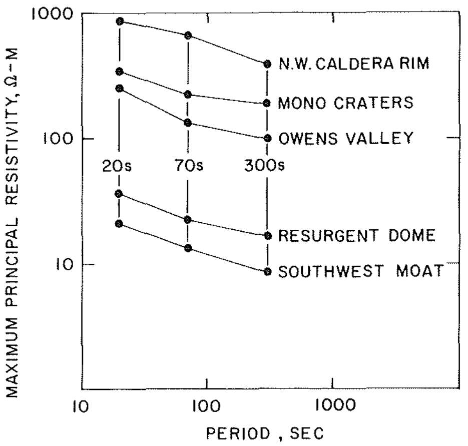

Fig. 6. The average maximum principal resistivity at 20 s, 70 s, and 300 s for various subregions of our survey areas. Note the apparent static offset between curves.

Figure 7 extends 40 km east-west and 70 km north-south. The width of Owens Valley, for example, is 7 km. We feel our results are representative of periods of 20 s or greater; this is when the skin depth is large in relation to the thickness of surface heterogeneities.

Modeling Results. Although the model can be driven by a variety of "source" fields, for purposes of illustration we have generated the electric and the magnetic field components, respectively, for the case of a unit amplitude, circularly polarized, purely horizontal field at "infinity" (Figure 8 and 9). The H, D, and Z fields can be combined into "induction arrows" (following Schmucker [1970]), which are shown in Figure 8. By convention, these arrows tend to be orthogonal to the direction of electric current flow and point away from good conductors.

The orientation of the telluric ellipses follows the line of the Sierra Nevada batholith on the west as currents are channeled north-

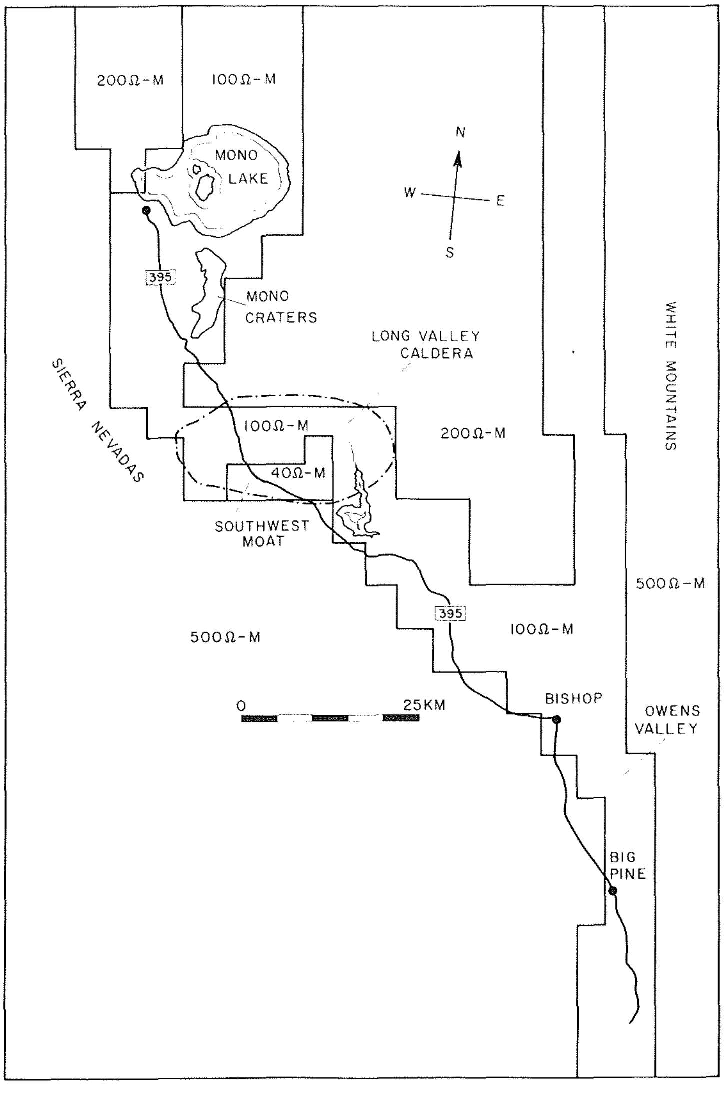

Fig. 7. Plan view of thin sheet electrical model of Owens Valley and the Long Valley/Mono Basin volcanic complex.

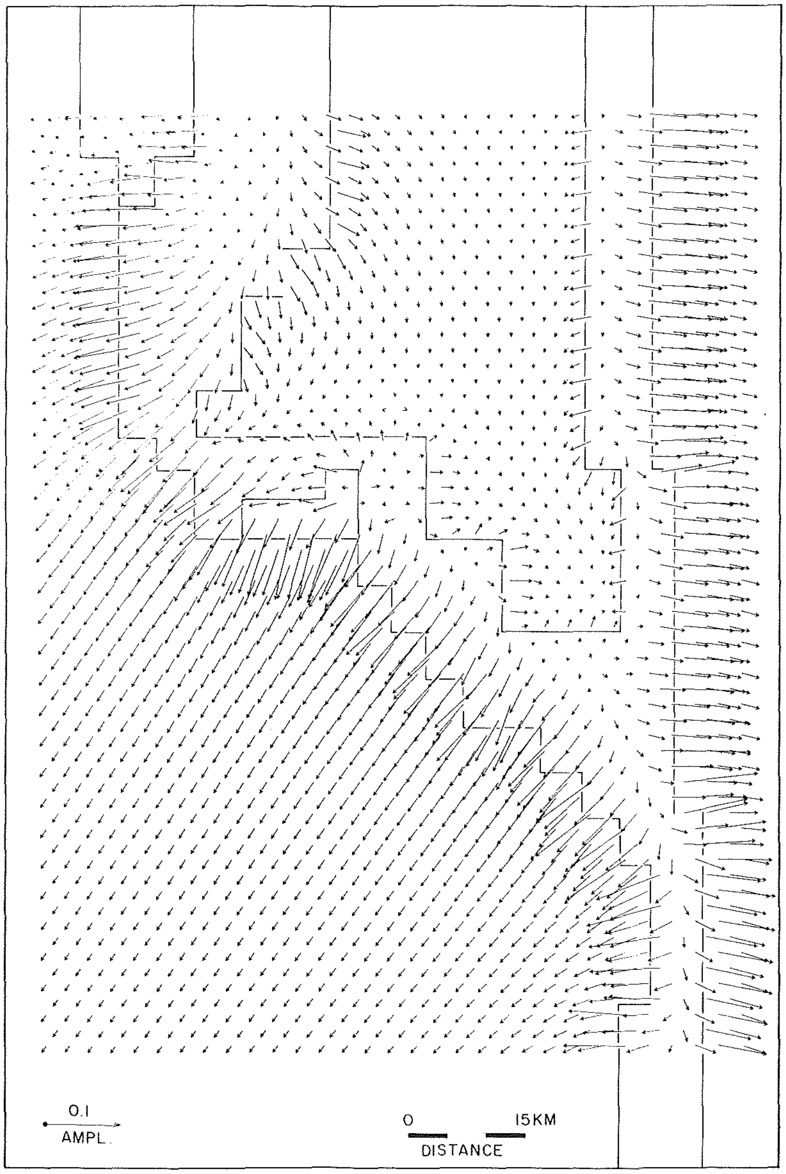

Fig. 8. Theoretical induction arrows for the model in Figure 7.

south along the sedimentary basins (Figure 9). On the east they follow the contours of Owens Valley in a general north-south direction. Within the more conductive region of the Long Valley caldera, especially through the arc of lowest resistivity corresponding to the hydrothermal zone, there is an overall east-west distortion of the telluric field. The induction arrows shown in Figure 8 indicate a similar pattern, emphasizing the complementary character of magnetic field and telluric field measurements.

Comparison of Thin Sheet Modeling Results to Observed Data

The modelled magnetic induction arrows and telluric ellipses shown in Figures 8 and 9 bear a marked resemblance to our field observations (Figures 3-5). On a regional scale a dominant north-south trend exists for the telluric ellipses adjacent to Mono Craters in the north and in Owens Valley to the south. The large amplitude of the major axes reflects the highly resistive crust beneath these two regions.

The area of Long Valley is characterized by lower telluric field amplitudes both in the field data (Figure 4) and the model results (Figure 9). Even some of the detail in the field data from the southwest moat of Long Valley caldera (Figures 4 and 5) is embodied in the modeling results for both the induction arrows (Figure 8) and the telluric ellipses (Figure 9). In addition, there is some suggestion of the effects on the magnetic field of an east-west current system in Mono Basin which is indicated both in the model results (Figure 8) and in the field data (Figure 4).

While some improvement could be made with modest fine tuning of our model, the results might be misleading considering the gross assumptions underlying the numerical algorithm we are using [see Hermance, 1982].

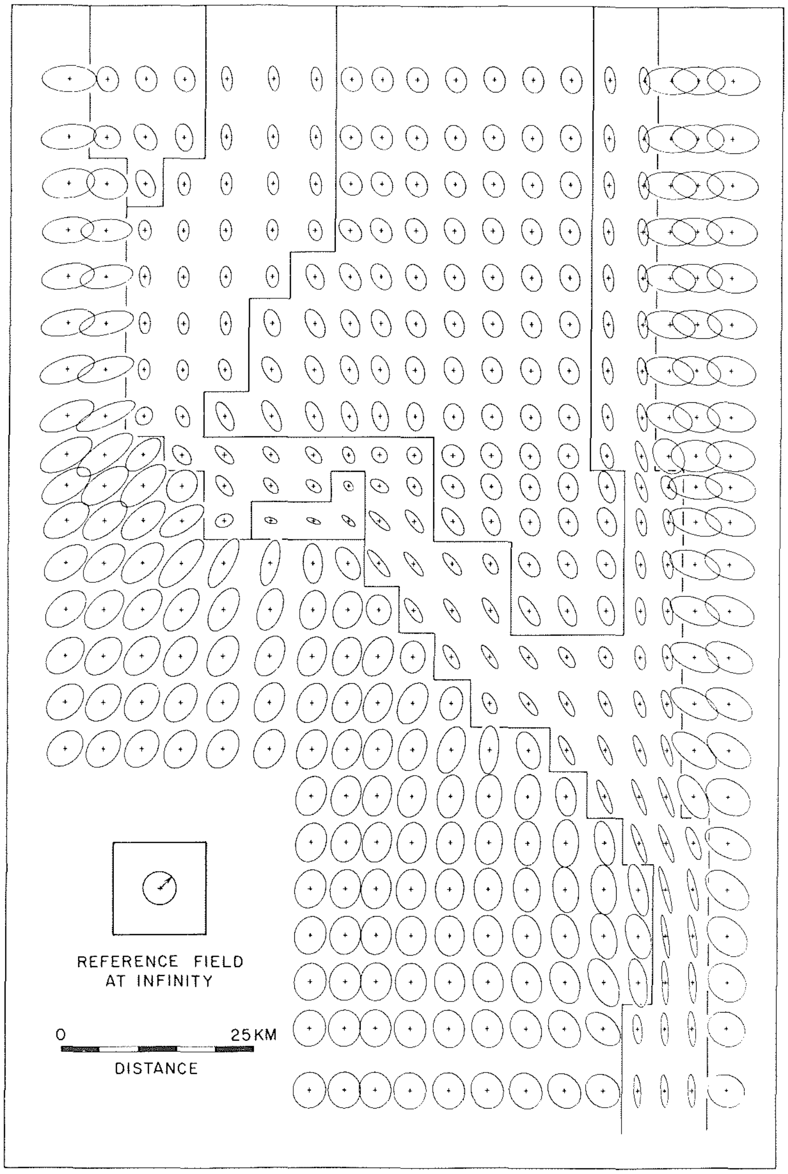

Fig. 9. Theoretical telluric ellipses for the thin sheet model in Figure 7.

Constraints on the Depth to a Conductor Beneath the Southwest Moat

Both the thin sheet study (Figure 9) and the field data (Figure 5) indicate that the local electrical and geological strike is east-west in the southwest moat of Long Valley caldera. In addition, for a strictly two-dimensional situation, the E polarization mode would be associated with the maximum principal resistivity in this area. If such were the case, then one could use the data in Table 1 and Figure 6 to estimate depth to the conducting material causing the decrease of apparent resistivity with increasing period. If the apparent resistivity decreased as a function of period with a slope of -1 in Figure 6, this would indicate a highly conducting layer at depth $h = (\rho_a/\omega\mu)^{1/2}$, where h is in meters, ρ_a is in ohm meters ω is the radian frequency, and μ is the permeability ($4\pi \times 10^{-7}$ h/m). Each observed value of ρ_a at a given T in Table 1 could be used to estimate such a depth, leading to the values for h summarized in the third column of Table 2. If the structure is approximately two-dimensional, then the actual resistivity would be less than 21 ohm m at 7 km, 13 ohm m at 11 km, and 9 ohm m at 18 km. Therefore in a preliminary way, there is some indication of a systematic decrease of resistivity with depth.

On the other hand, the thin sheet model results (Figure 9) warn us about taking these results too seriously. The maximum telluric field amplitudes in the south moat of Long Valley are reduced to about two-thirds of their normal value (i.e., relative to the "reference" field at infinity). This suggests that local three-dimensional effects might easily bias our estimates of h to lower values. Hence the values of h in Table 2 might need to be revised upward by a factor of 1.5 (the inverse of 2/3),

TABLE 2. Depth h to an Equivalent Conductor Beneath the Southwest Moat of Long Valley Caldera

Period, s	Apparent Resistivity, ohm- m	Depth h for Simple 1-D or 2-D Case, km	Depth Compensated for 3-D Effects, km
20	21	7	10
70	13	11	16
300	9	18	27

One dimensional, 1-D; two dimensional, 2-D; three dimensional, 3-D.

which is done in the fourth column of Table 2.

We emphasize again that one should not take these numbers too literally; we are essentially extracting a one-dimensional estimate from a highly three-dimensional situation. However, these preliminary results suggest that there is little evidence for a large-scale distributed conductor at shallow depth outside of that associated with the basin fill itself. The deep conductor appears to be at a depth of 7 km or greater.

Delineating Major Boundary Faults in Long Valley Caldera

A careful comparison of the field data in the vicinity of the northwest rim of Long Valley caldera (Figure 4) and the thin sheet model results (Figure 9) shows that the actual telluric fields are much more discontinuous than allowed for by our model. As we approach Long Valley caldera from the north, the field data indicate a sharp discontinuity in the telluric field amplitude between sites outside the caldera and those within (Figure 4). This is associated with a sharp vertical offset due to normal faulting along the major boundary faults. A vertical throw in the basement of 3 km or more is indicated in both gravity and seismic refraction interpretations (Figure 10, after Kane et al. [1976]; Hill [1976]), although the actual location of the fault is known somewhat less than satisfactorily (a discrepancy exists between the gravity and seismic interpretations of up to 3 km; see Figure 10).

We have been able to locate this fault with somewhat greater precision (0.5 km) because of the close spacing of magnetotelluric sites in this region and have accounted for the discontinuity in the telluric field amplitudes using the simple three-dimensional azimuthally symmetric model of Hermance [1983b]. The caldera has been modeled as a 3-km-deep basin having a fixed resistivity contrast with respect to the surrounding host medium. Recognizing that Long Valley caldera is elliptical in plan, whereas our model was required to be azimuthally symmetric, we have used the local radius of curvature of the caldera (R = 6.5 km) as the radius of the basin in our circular model. In Figure 11 we compare telluric ellipse areas from actual field measurements with results from our model for various resistivity contrasts between the basin fill and the surrounding medium. Surprisingly, we can determine the range of possible resistivity contrasts quite well, considering the simplicity of our model. It seems clear that refined surveys in the future

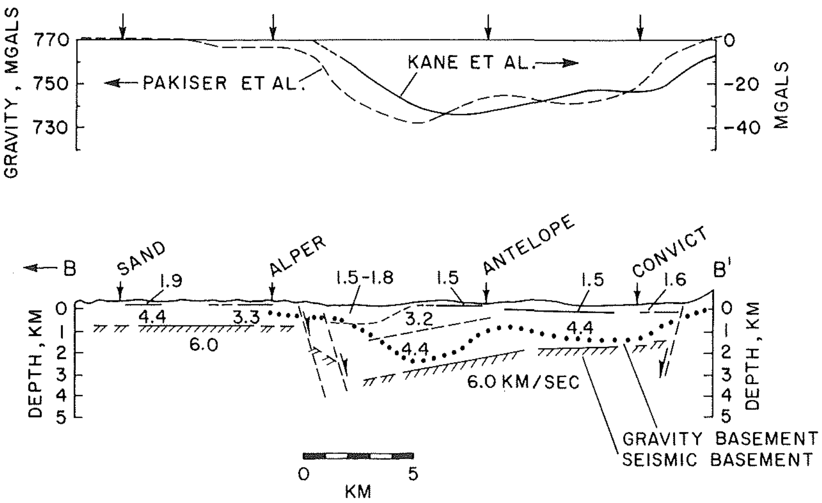

Fig. 10. Gravity and seismic refraction interpretations along a profile across the northwest rim of the Long Valley caldera [after Pakiser et al., 1964; Kane et al., 1976; Hill, 1976].

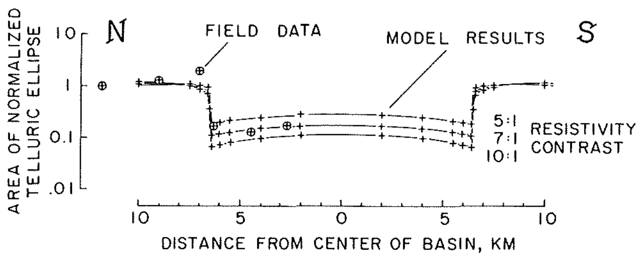

Fig. 11. Comparison of telluric ellipse area across the caldera rim calculated from field data with various results from our azimuthally symmetric three-dimensional model for the caldera basin. The basin has a radius of 6.5 km and is 3 km deep. The curves differ in the resistivity contrast assigned between the basin fill and the surrounding medium.

are promising for detailed studies of caldera structures, in particular for characterizing features associated with major boundary faults. The high resistivity contrast between crystalline basement and basin fill is very favorable for telluric and magnetotelluric mapping experiments.

Magnetotelluric Results From Mono Craters and Mono Basin

Mono Craters and Mono Basin are the northernmost and youngest (1 ka) members of a succession of three progressively younger volcanic complexes, each in different stages of evolution. According to Bailey [1980], Mono Craters may have evolved through stages 1 and 2 described for Long Valley above, and the centers in Mono Lake form the smallest and youngest complex and seem to be in stage 1. Mono Craters are chemically homogeneous which, along with their recent age and frequency of eruption, suggests that they were extruded from a single magma chamber, largely molten and perhaps still rising to the surface [Bailey, 1980].

Little is known concerning the subsurface structure of Mono Craters. Present-day volcanism at the surface is, to a marked degree, structurally controlled. Bailey et al. [1976] and Bailey [1980] have argued that the inferred ring fracture (Figure 1) outlines what may be an incipient magma chamber in the crust. The depth to such a magma body, if it exists, is not clear; however, Bailey has drawn on Carmichael's [1967] petrologic study of samples from Inyo domes to the south to suggest a source depth of less than 22 km. Temperatures at the time of extrusion averaged 825°C [Carmichael, 1967].

Little geophysics has been reported from the area of Mono Craters. Regional gravity studies do not indicate the type of strong anomaly patterns that are associated with low-density basin fill beneath Long Valley caldera and Mono Basin proper (i.e., in the vicinity of Mono Lake). Seismic refraction studies show that the overburden in Pumice Valley is quite thin [Pakiser et al, 1960; Pakiser, 1976]. The surface geology confirms this with crystalline basement outcropping in several places over the floor of the valley. Hence although the setting is ideal for using gravity to detect a shallow low-density magma body, the data do not indicate that one is present.

Lachenbruch [1982] noted that a preliminary heat flow estimate of 2.2 HFU from within the inferred Mono ring fracture is not atypical for the Basin and Range province and argued that there may be no detectable heat flow anomaly over this feature. He concluded that if the background heat flow is, in fact, typical of the Basin and Range, then any magma body must be deeper than 10 km if older than 0.7-1 Ma, 8 km if older than 3 x 10^5 years and 6 km if less than 1.5 x 10^5 years. On the other hand, he pointed out that if the background heat flow is more characteristic of the Sierra Nevada province (which is about 1.2 HFU), then the observed heat flow is anomalous by approximately 1 HFU. This could be caused by a magma chamber at 8 km emplaced 5 x 10^5 years ago or a chamber at 6 km emplaced 2 x 10^5 years ago. If such a magma body were present, it should be readily detected using magnetotelluric methods.

Constraints on the regional electrical structure have been provided by the studies of Lienert and Bennett [1977] and Lienert [1979], who inferred low resistivities within the crust from a large-scale controlled source experiment. Their data are compatible with a relatively resistive upper crust ($d < 10$ km), but the resistivity drops to values of the order of 30 ohm m at depths of 15 km or so. Whether this crustal feature is able to explain the long-period geomagnetic variation anomalies of Schmucker [1970], who inferred that the conductor is at much greater depth ($d \geq 40$ km), is not known at present.

Referring again to the map in Figure 4 and the data in Table 1 and Figure 6, we see little evidence from the area of the inferred ring fracture of Mono Craters to suggest the presence of a major magma body at shallow depth in the crust. Telluric field amplitudes have generally the same amplitude and are polarized in more or less the same sense to the east and to the south of Mono Craters. In addition the magnetic induction arrows do not suggest a unique anomaly associated with the Mono Craters ring fracture. We conclude that if an anomaly were present, it must represent less than 20% of the background telluric field pattern. Any possible magma body is either too thin to be resolved in our data or too deep.

Using the three-dimensional azimuthally symmetric model of Hermance [1983b], we have attempted to identify the limits on resolving a conductive magma body (having a nominal resistivity of 1 ohm m) in a fairly resistive crust (Figure 12). To be compatible with a variety of telluric, magnetotelluric, and active dc resistivity experiments in this region, we assume an average resistivity of 350 ohm m. The maximum anomaly in the telluric field is defined as the total electric field over the center of the body minus the field which would be observed if the magma body were absent, this difference being divided by the normal reference field at infinity. For example, if the maximum anomaly is required to be less than 20% (consistent with observed data), the magma body must be less than 500 m thick if it is less than 8 km deep; or if it is very thick, it must be deeper than 10 km (Figure 12).

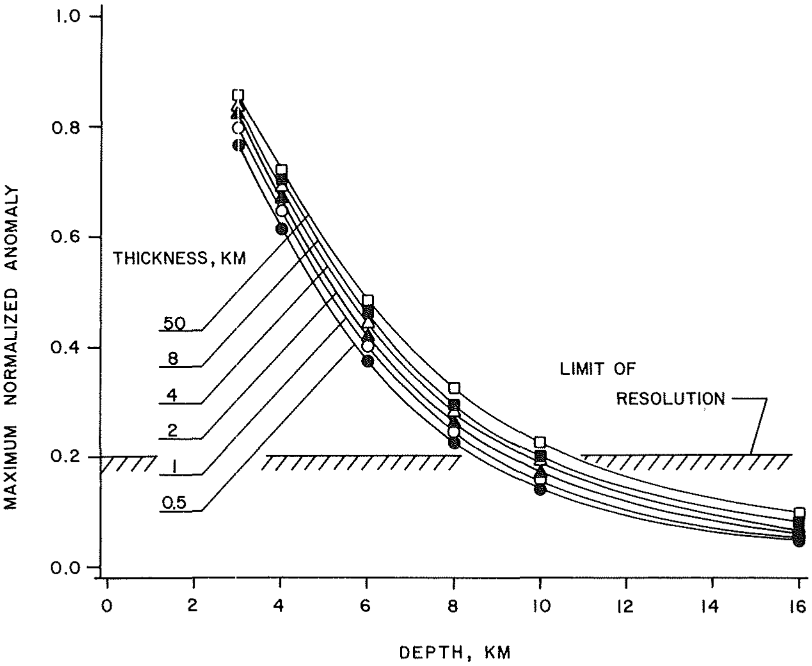

Fig. 12. The maximum normalized telluric field anomaly over the center of an imbedded three-dimensional azimuthally symmetric magma body as a function of depth for various thicknesses (0.5, 1, 2, 4, 8, and 50 (or ∞) km). Its radius is 6.5 km. The magma is assumed to have a nominal resistivity of 1 ohm m; and the resistive crust, a resistivity of 350 ohm m.

Conclusions

Quantitative interpretation of the observed magnetotelluric data in terms of a one-dimensional plane-layered model is not appropriate for many sites in the region of the Long Valley/Mono Basin volcanic complex and may be misleading. Nevertheless, several substantive points can be emphasized:

1. A strong influence is exerted by the Long Valley caldera boundary on the direction and magnitude of the local telluric fields. This suggests that telluric field measurements may be an effective tool to map structural relief in basement topography, particularly sharp offsets associated with major normal boundary faults.
2. Magnetic induction arrows are useful indicators of regional current systems; in some cases their interpretation is less ambiguous than if the telluric field alone were used. This suggests that in such a complex area as that described here, magnetic variation measurements offer an effective reconnaissance tool for rapidly identifying the spatial behavior of large scale electric current systems in the lithosphere. Having thus constrained broad features of the conducting structures, more refined magnetotelluric and broadband magnetic variation measurements can then be employed to quantitatively evaluate the electrical structure in detail.
3. The southwest moat of Long Valley caldera and a significant portion of the resurgent dome and western caldera are underlain by low resistivity material.
4. Telluric fields in the southwest moat show a strong preferential east-west direction, contrasted with the regionally dominant north-south pattern elsewhere along the Sierran front. This can be explained in part by current channeling through a surface hydrothermal zone, although the feature may well extend to appreciable depth. In addition this elongated (east-west) zone is aligned along the belt of present seismic activity in the southwest moat and the zone of seismic shear wave attenuation.
5. While the three-dimensional effects of surficial geology make it difficult (and highly questionable) to put precise limits on the depth to the conductive feature beneath the southwest moat of Long Valley caldera, simple model considerations suggest that such a conductor might be present at depths greater than 7 km, and perhaps more like 10 km.
6. Magnetotelluric measurements in the area of the Mono Craters ring fracture, thought to be an active incipient caldera, do not indicate an observable decrease in resistivity at shallow depth beneath Pumice Valley. The parent magma body feeding Mono Craters (and perhaps Inyo domes) is either too thin or too deep to be resolved or is significantly displaced from a position beneath the center of the inferred ring fractures.

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