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DELINEATING THE SUBSURFACE MEGA-STRUCTURE OF LONG VALLEY CALDERA; REGIONAL GRAVITY AND MAGNETOTELLURIC CONSTRAINTS

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ABSTRACT

One of the principal tectonic elements in the Long Valley volcanic complex is the presence of a deep basin-like caldera bounded by steeply dipping normal faults having characteristic offsets of at least several kms. This paper reports a magnetotelluric interpretation which delineates the subsurface structure of this feature. As a preliminary step we have reinterpreted regional gravity data in terms of a simple 3-D model employing the inverse algorithm of Cordell and Henderson (1968). Our gravity model clearly defines the major subsurface features of the caldera walls. In addition, the basin fill and major boundary faults impose a strong imprint on regional magnetotelluric (MT) data as well. A strong similarity is seen between gravity model and telluric thin sheet interpretations; this underscores the fact that both types of data are largely influenced by the same geologic features: the caldera fill, basement topography, and the major boundary faults. Moreover as in the earlier, preliminary MT interpretation of Hermance et al. (1984), we see a conductive zone beneath the southwest moat as well. In addition, however, we now have evidence for a resistive "topographic high" cutting across the main body of the caldera from the northwest to the southeast. We assume that this horst block is the same feature described as a central platform by Kane et al. (1976) from gravity studies and that it has been a major element in the structural evolution of the resurgent dome. Such a structural "high" is quite compatible with limited drilling data.

BACKGROUND

One of the principal tectonic elements in the Long Valley volcanic complex is the presence of a deep basin-like caldera bounded by steeply dipping normal faults having characteristic offsets of at least several kms (Pakiser, 1961). There is increased interest in delineating the subsurface structure of this feature for a number of reasons (Hill, 1976; Kane et al., 1976; Bailey, 1982, 1983; Hermance et al., 1984; Abers, 1985; Hill et al., 1985; Jachens and Roberts, 1985). First, characterizing the location and maximum offset of these faults will lead to clearer models for the tectonic style of the evolution of this system. Second, there is strong evidence that recent sequences of seismicity and volcanism are structurally constrained by such boundary faults; thus there is a valuable predictive component in knowing the precise geometry of these features. Thirdly, the caldera basin forms the major hydrologic element in the region (Sorey, 1985; Blackwell, 1985). Its highly porous fill provides the major aquifer, and superimposed faults provide the vertical conduits for allowing water to enter or to exit the hydrologic system. Thus the detailed characterization of the subsurface geometry of Long Valley caldera continues to be an important objective of current geophysical studies (Hill et al., 1985; Jachens and Roberts, 1985). This paper reports the interpretation of gravity and magnetotelluric data from this area.

GEOLOGICAL AND GEOPHYSICAL CONSTRAINTS

A simplified geologic map for Long Valley caldera is shown in Figure 1. It is well-known that values of Bouguer gravity typically show strong negative values over the interior of the caldera caused by its low density fill (Pakiser, 1961; Kane et al., 1976; Abers, 1985; Jachens and Roberts, 1985). Of course there is some ambiguity in determining actual depth to bedrock from gravity data alone unless the density contrast is well-known. For example, because the density contrast between the basin fill and the surrounding country-rock was underestimated, early gravity interpretations of Long Valley caldera (e.g. Pakiser, 1961) significantly overestimated depth to basement. The interpretation measurably improved when Abers (1985) combined the interpretation of gravity data with Hill's (1976) seismic refraction interpretation. However Abers used a 2-D model which, while useful for characterizing local fault structures, is limited for the kind of regional study we are describing here.

Thus following Kane et al. (1976) we have reinterpreted the regional gravity data in terms of a 3-D model employing the inverse algorithm of Cordell and Henderson (1968). In keeping with Abers' results, however, we have increased the mean density contrast from the value of $-450\ kg/m^3$ assumed by Kane et al. to a value of $-625\ kg/m^3$. The results of our interpretation in Figure 2 largely confirm the earlier analysis of Kane et al. We have revised the average depth of caldera fill to smaller values (approx. 2 km) because of the larger density contrast that we feel is required by the seismic data. In particular, our gravity model clearly defines the major subsurface features of the caldera walls. Moreover the evidence persists for a high central platform separating the two basinal lows remarked upon by Kane et al.

The basin fill and major boundary faults impose a strong imprint on regional magnetotelluric (MT) data as well. The MT data base described by Hermance et al. (1984) has been augmented with measurements at a number of additional sites throughout the caldera and the adjacent area (Figure 3). In acquiring these new data, we particularly sought sites outside the rim of the caldera in order to better characterize the basin margins.

A REGIONAL ELECTRICAL MODEL FOR LONG VALLEY CALDERA

The thin-sheet modelling algorithm of Hermance (1982) was modified to account for conductivities which varied smoothly in the lateral direction. Starting with a model based on the average telluric field amplitudes at each site (the square root of the telluric ellipse area), the results were perturbed by hand over various sub-regions of the model until a reasonable agreement was achieved between the theoretical model and the observed telluric fields (Figure 4). Machine generated contours for the resulting model showed many sharp small-scale discontinuities which were artifacts of the computer contouring, therefore the model values were numerically smoothed (low pass filtered at a cut-off wavelength of 6 km, equivalent to our mean station spacing), and are replotted in Figure 5. The similarity between the gravity model in Figure 2 and the telluric thin sheet model in Figure 5 clearly underscores the fact that both types of data are largely influenced by the same geologic features: the caldera fill, topography on the underlying basement, and the major boundary faults.

As in the earlier, preliminary interpretation of Hermance et al. (1984), the telluric field data shows that a zone of enhanced conductivity appears to be present beneath the southwest moat. In addition, however, we now have clear evidence for a resistive feature (the "topographic high" in Figure 5) cutting across the main body of the caldera from the northwest to the southeast. We tentatively assume that this is a horst block intimately associated with the structural evolution of the resurgent dome and is the same feature described as a central platform by Kane et al. (1976). The telluric data, however, show this feature to be much more continuous across the caldera than do the gravity data.

Such a structural "high" is quite compatible with the limited drilling data shown in Figure 6. In particular, the Mammoth-1 drillhole site on the south central flank of the resurgent dome encounters the metasedimentary basement at a much shallower depth than the two drillholes to the east (the granite porphyry encountered at the bottom of Clay Pit-1 is likely to be a post-caldera intrusive; see discussion in Hermance, 1983). Seismic refraction data (e.g. Hill et al., 1985) also suggest some sort of topographic relief beneath the resurgent dome, but have not yet been interpreted to reveal the kind of detail needed to confirm or to reject the intracaldera horst block shown in Figure 5.

ACKNOWLEDGEMENTS

This research was funded by the Department of Energy Office of Basic Energy Sciences through Contract No. DE-AC02-79ER10401 to Brown University.

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Figure Captions

Figure 1. Generalized geology of Long Valley caldera, after Bailey and Koeppen (1977).

Figure 2. A simple 3-D model for the depth of basin fill based on gravity data. We assume a mean density contrast of -625 kg/m^3 between the basin fill and the surrounding country rock.

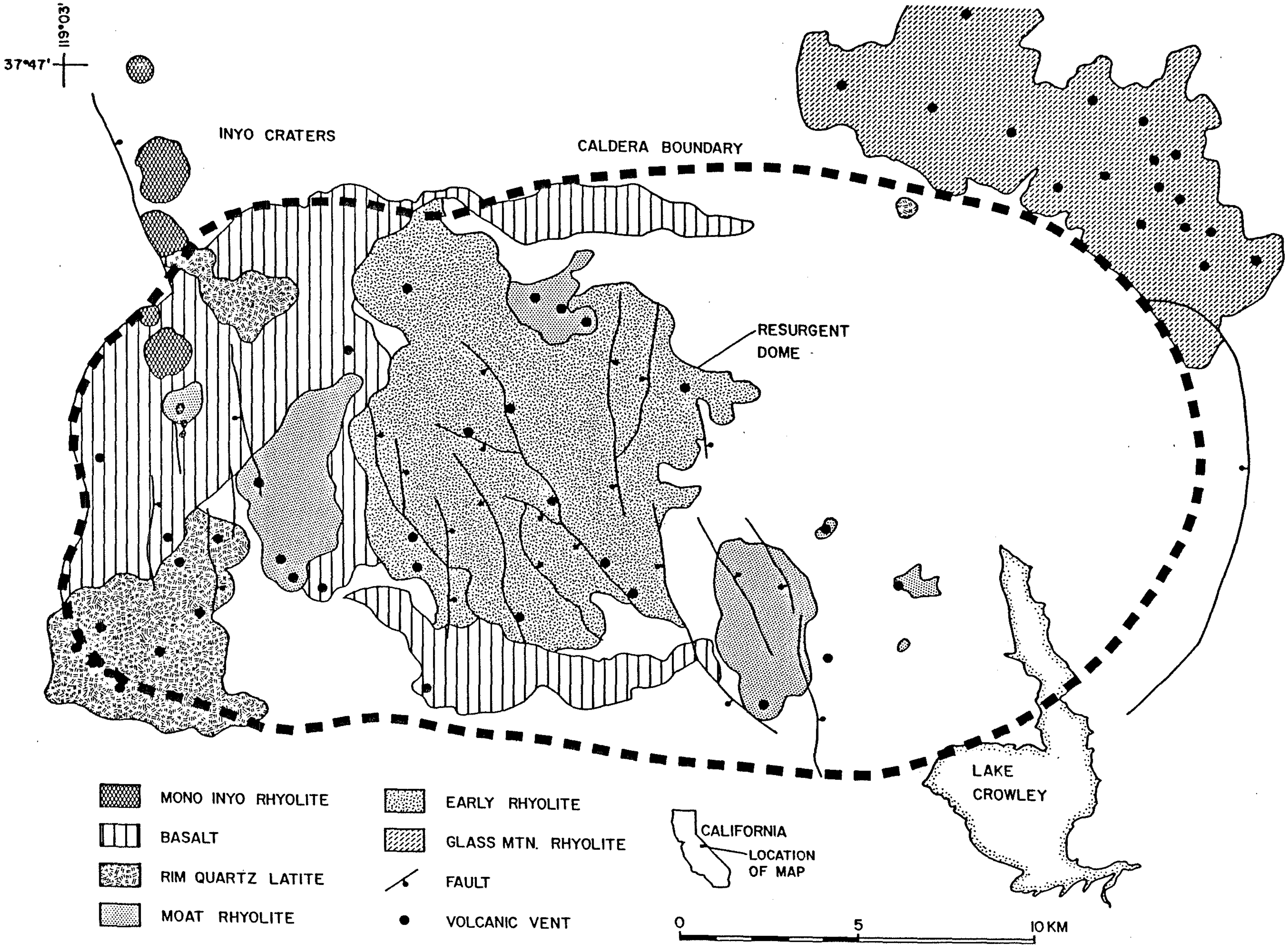
Figure 3. Present magnetotelluric data set from Long Valley caldera shown as normalized telluric ellipses referenced at infinity to the unit electric field shown. The dashed line is the caldera boundary from Bailey and Koeppen (1977).

Figure 4. Comparison of the telluric field response of our preferred theoretical model to the observed data at 20 sec period.

Figure 5. A smoothed version of our final thin sheet model. Contours are in terms of conductance (depth-integrated conductivity) relative to a unit value at infinity. The relative conductance of our preferred model was low pass filtered using a 2-D numerical filter having a cutoff wavelength of 6 km. Increasing conductance is plotted downward to correspond to topography on resistive basement.

Figure 6. Lithologies from deep boreholes in Long Valley caldera (modified from Abers, 1985, to show true altitudes relative to sea level). Mammoth-1 is on the south central flank of resurgent dome; Clay Pit-1 is at a lower altitude on the eastern flank; Republic 66-29 is in the eastern moat (note lake bed sediments at surface).

FIGURE 1


119°03'
37°47'
INYO CRATERS
CALDERA BOUNDARY
RESURGENT DOME
LAKE CROWLEY
MONO INYO RHYOLITE
BASALT
RIM QUARTZ LATITE
MOAT RHYOLITE
EARLY RHYOLITE
GLASS MTN. RHYOLITE
FAULT
VOLCANIC VENT
CALIFORNIA
LOCATION OF MAP
0
5
10 KM

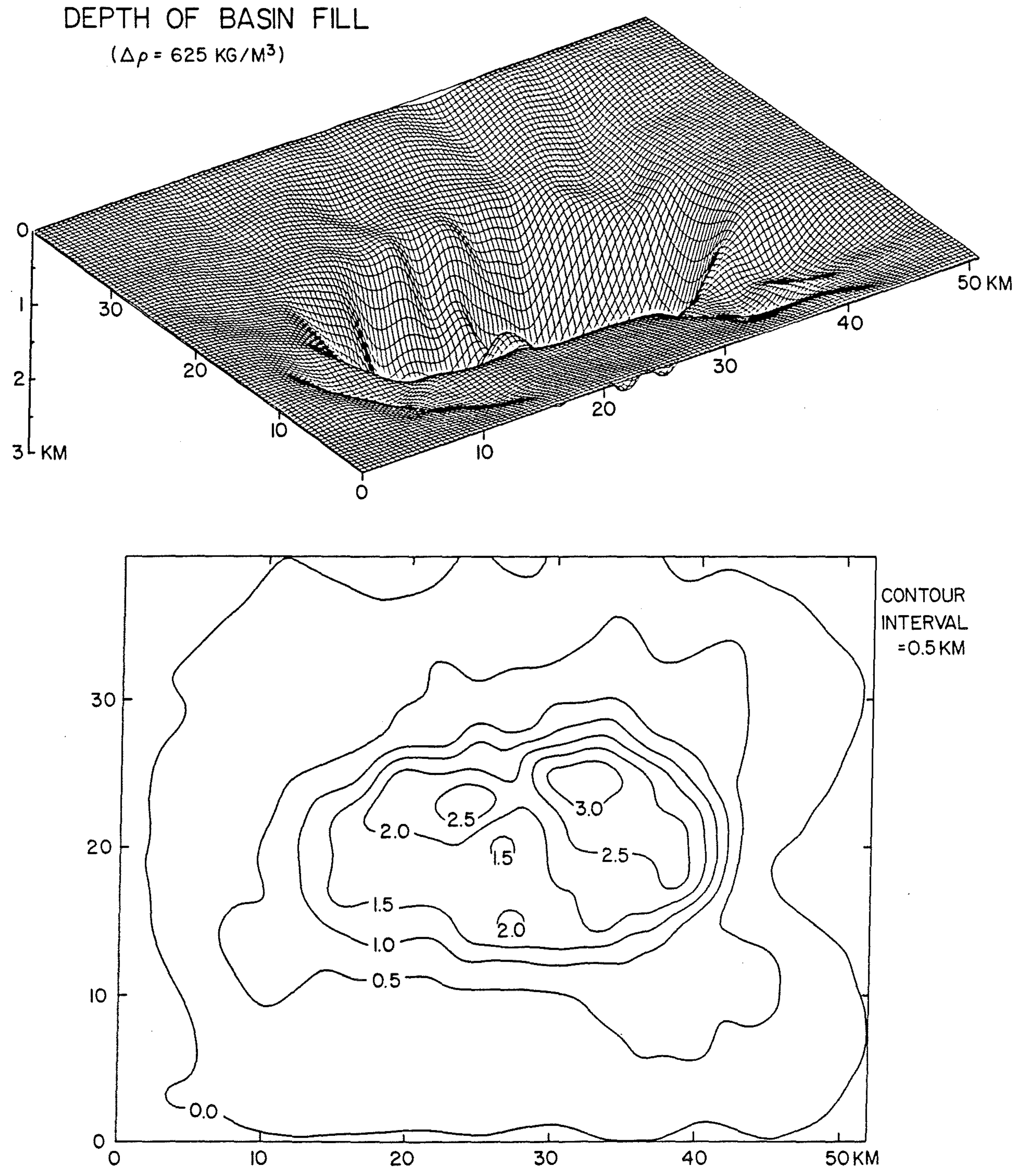

DEPTH OF BASIN FILL
($\Delta\rho$ = 625 KG/M^3)
0
1
2
3 KM
10
20
30
0
10
20
30
40
50 KM
CONTOUR INTERVAL =0.5 KM
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1.5
2.0
2.5
2.0
0
10
20
30
0
10
20
30
40
50 KM

FIGURE 2

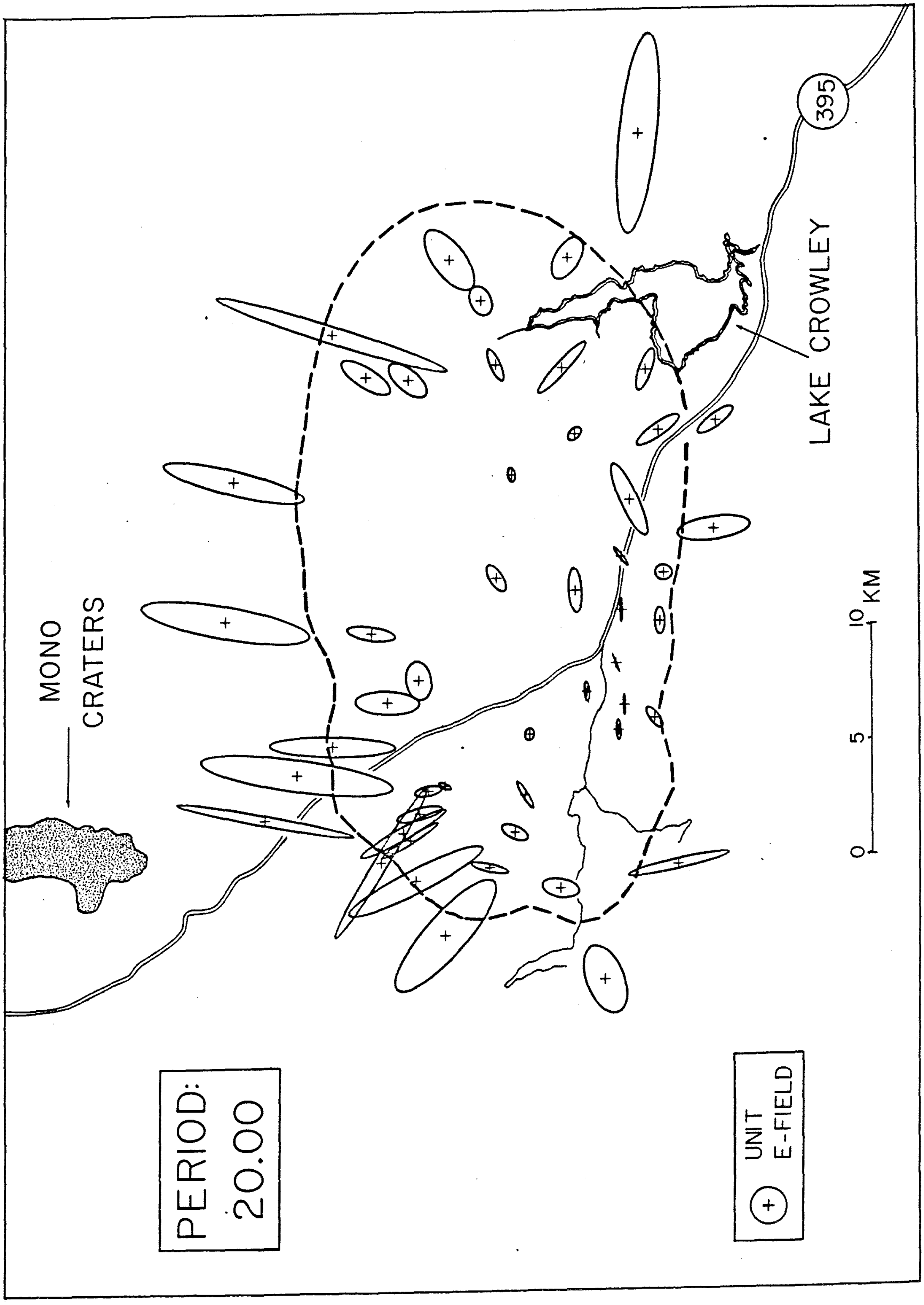

PERIOD:
20.00
MONO
CRATERS
LAKE CROWLEY
395
0
5
10
KM
UNIT
E-FIELD

FIGURE 3

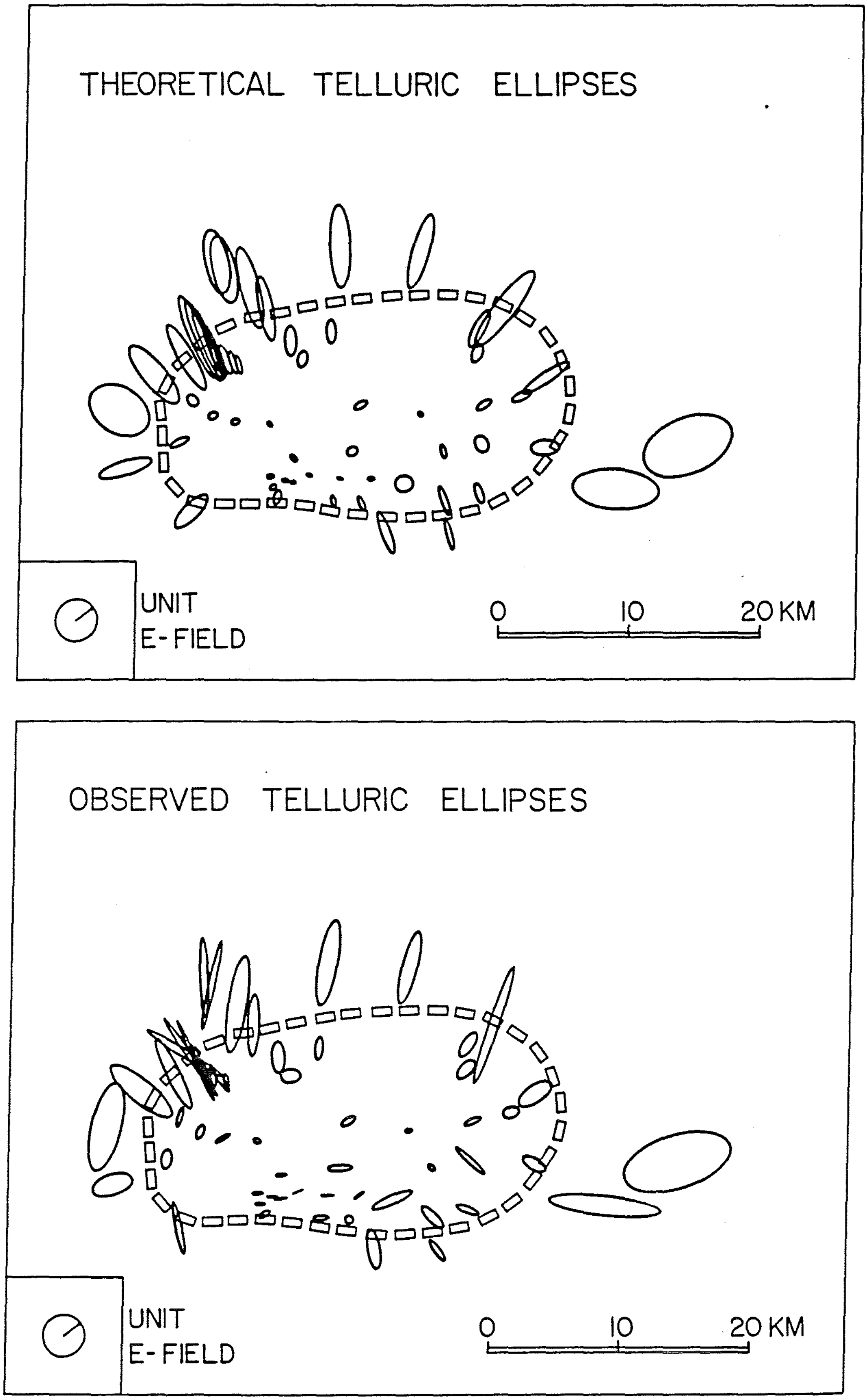

THEORETICAL TELLURIC ELLIPSES
UNIT
E-FIELD
0
10
20 KM
OBSERVED TELLURIC ELLIPSES
UNIT
E-FIELD
0
10
20 KM

FIGURE 4

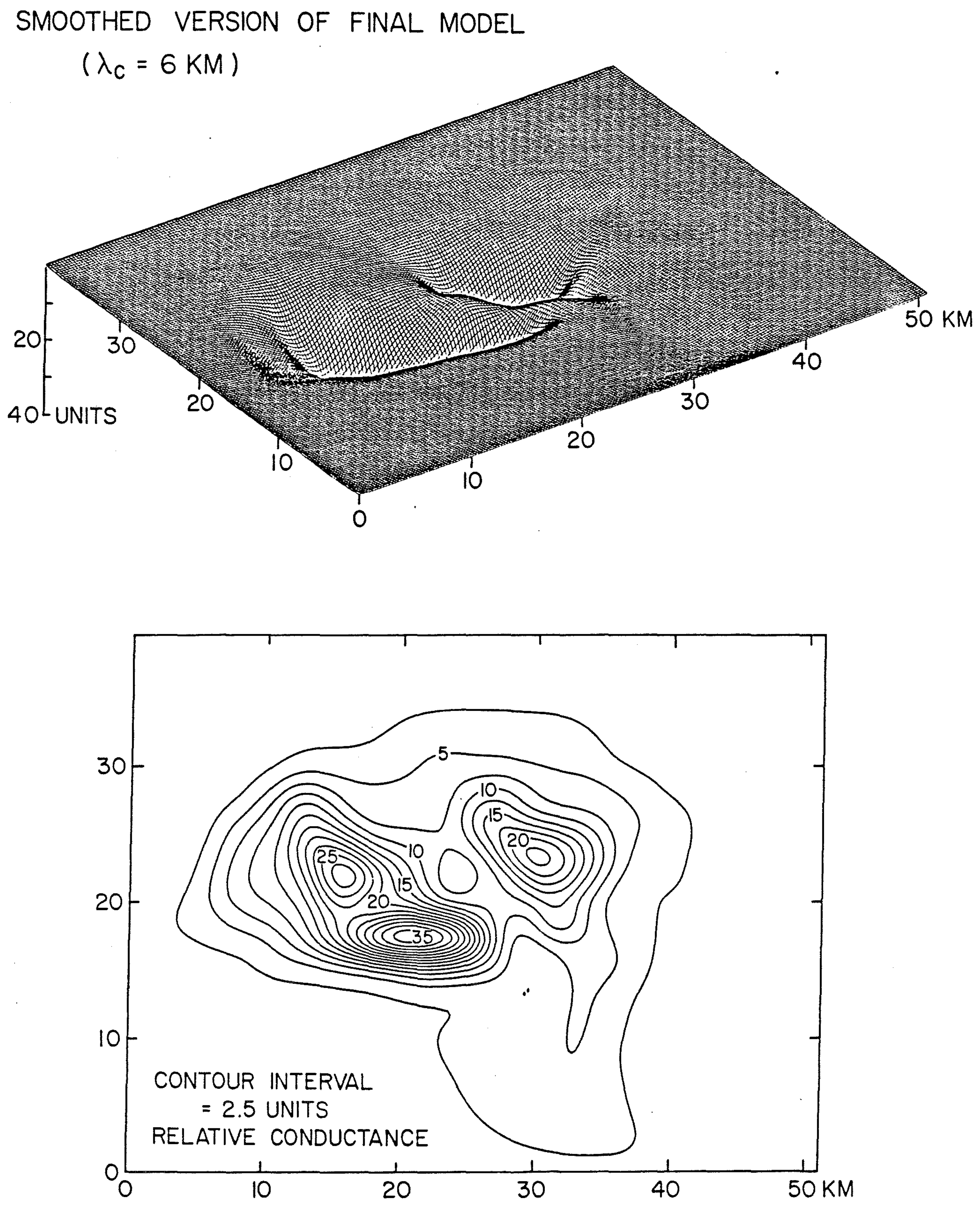
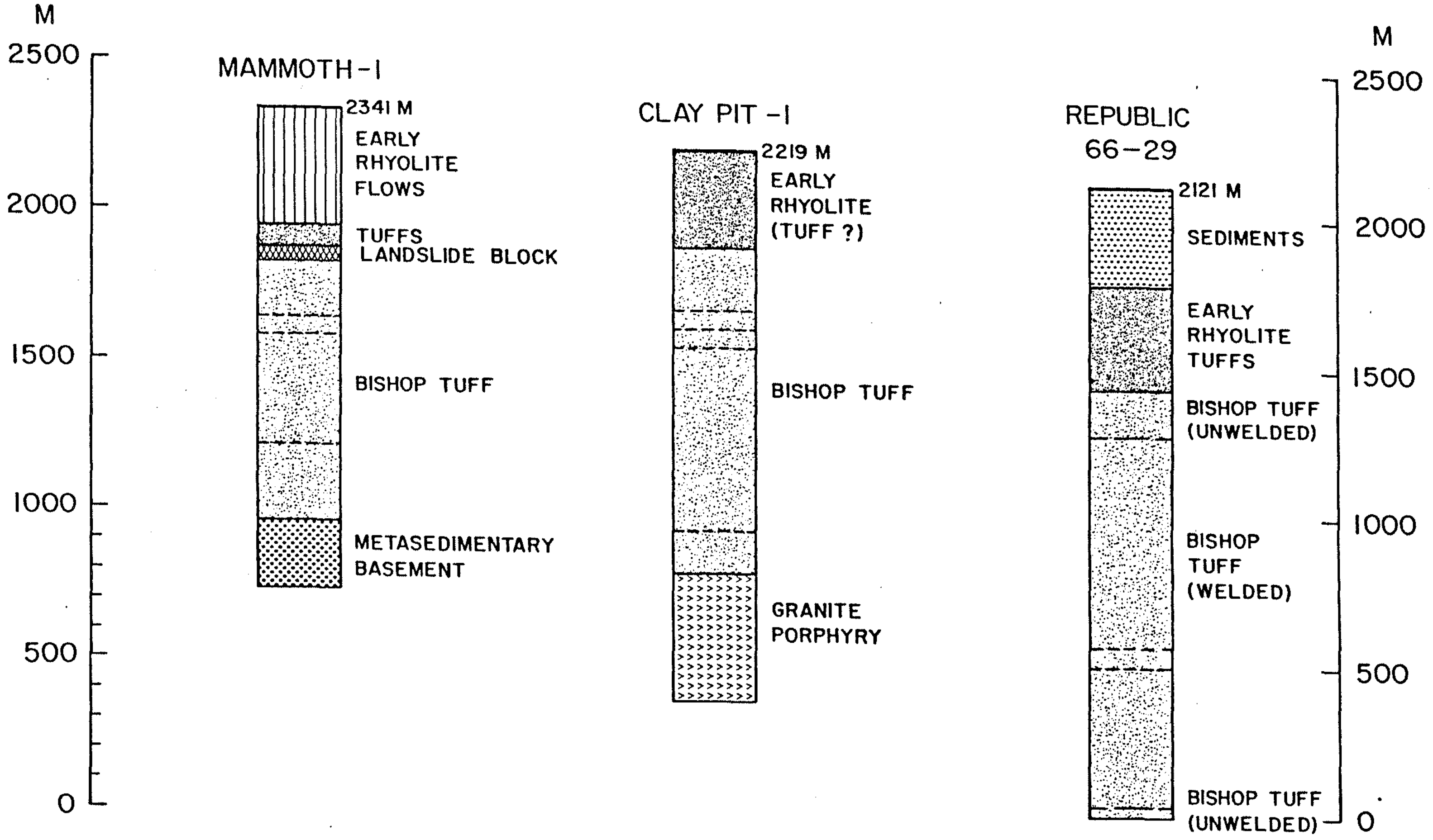

SMOOTHED VERSION OF FINAL MODEL
(λ_c = 6 KM)
20
40 UNITS
30
20
10
0
10
20
30
40
50 KM
5
10
15
20
25
10
15
20
35
30
20
10
0
0
10
20
30
40
50 KM
CONTOUR INTERVAL
= 2.5 UNITS
RELATIVE CONDUCTANCE

FIGURE 5

FIGURE 6


M
2500
2000
1500
1000
500
0
MAMMOTH-1
2341 M
EARLY RHYOLITE FLOWS
TUFFS
LANDSLIDE BLOCK
BISHOP TUFF
METASEDIMENTARY BASEMENT
CLAY PIT-1
2219 M
EARLY RHYOLITE (TUFF ?)
BISHOP TUFF
GRANITE PORPHYRY
REPUBLIC 66-29
2121 M
SEDIMENTS
EARLY RHYOLITE TUFFS
BISHOP TUFF (UNWELDED)
BISHOP TUFF (WELDED)
BISHOP TUFF (UNWELDED)
M
2500
2000
1500
1000
500
0