GL03166 - 1048 GEOPHYSICAL RESEARCH LETTERS, VOL. 13, NO. 5, PAGES 479-482, MAY 1986

# THE MAJOR BOUNDARY FAULTS IN EASTERN LONG VALLEY CALDERA; MAGNETOTELLURIC AND GRAVITY CONSTRAINTS

John F. Hermance

Department of Geological Sciences, Brown University, Providence, RI 02912

Ragna Karlsdottir

Department of Natural Heat, National Energy Authority, Reykjavik, Iceland

Abstract. Geophysical studies of the major boundary fault(s) in eastern Long Valley caldera have led to significantly different models being proposed for the subsurface structure of this area. Pakiser originally interpreted gravity data to propose a steep vertical offset across the eastern boundary fault(s) which may be as great as 5 km. On the other hand, Hill employing seismic refraction data, and Abers, who reinterpreted the available gravity data in the light of the "hard" seismic constraints of Hill, suggested that the offset across this fault may be much more gentle. However, new magnetotelluric data may call for a revision of these models. Based on these recent MT results, offsets along the eastern boundary fault appear to be somewhat steeper than recent models would suggest. Our current thinking would favor a model more in keeping with the one originally envisaged by Pakiser, but with less throw (approximately 2 km) across the faults.

## Introduction

The character of the major boundary faults of Long Valley caldera (Figure 1) has been the subject of geophysical investigations for several decades. Early work was reported by Pakiser [1961], with the latest studies being described by Hermance et al. [1984], Abers [1985] and Hill et al. [1985]. Work along the eastern caldera margin is of particular interest because of significant differences in models which have been proposed for this area (Figure 2). Pakiser [1961] originally interpreted gravity data to propose that the vertical offset across the eastern boundary fault may be as great as 5 km. On the other hand, Hill's [1976] seismic refraction data suggested a more gentle offset. This latter model was supported by Abers [1985] who reinterpreted the available gravity data employing the "hard" seismic constraints of Hill [1976] in conjunction with limited borehole data from elsewhere in the caldera. On the other hand new magnetotelluric (MT) data may call for a revision of recent models. Based on results summarized below, offsets along the eastern boundary fault appear to be somewhat steeper than current models would suggest.

## Data Base

Magnetotelluric data at a period of 20 sec is shown for our survey area in the form of normalized telluric ellipses in Figure 3. We propose to interpret the MT data from the eastern section of Long Valley caldera in the light of the same gravity data employed by Abers [1985]. One practical problem that is often encountered in acquiring magnetotelluric data is the fact that access to high quality field sites may be limited either by rough topography, forests, land-owner restrictions and so forth. Thus, it is often difficult to find suitable field sites where one can deploy an orthogonal array of 100 m long electric wires to record natural telluric field variations. In order to minimize the impact of this problem on our present data set, we assume that both the telluric data and the gravity data are largely reflecting the effects of the caldera structure. Hence we seek a set of model solutions which satisfy both data sets simultaneously. This allows us to use the gravity data to interpolate our telluric field constraints between field sites.

We employ data from the three radial profiles in the eastern caldera shown in Figure 3. Gravity data are taken directly from contours transected by these profiles, and the telluric field data represent the projection onto this profile of the major axes of the telluric field ellipses determined at nearby sites. Unfortunately the telluric field sites were not deployed with such a refined analysis in mind, so that our data are somewhat sparse. Nevertheless one can obtain some preliminary idea of the information that the telluric field data contain, and perhaps identify some problems that future work might resolve. Ten percent error bars are attached to all the MT data points as being representative of the precision of data acquired throughout Long Valley caldera [Hermance et al., 1984]. This, of course, does not account for such errors as local geologic complexities which violate the simple model we employ to interpret these data.

The major axes of the telluric ellipses at 9 representative sites well inside the caldera boundary were arithmetically averaged to provide a mean intracaldera value. The value of the telluric field at infinity is approximated by the arithmetic average of the major and minor axes of the telluric ellipse at the first site outside the edge of the caldera along Profile C (Figure 3). The magnitude of the major axis of each telluric ellipse is then divided by the value at infinity and the resultant normalized value is then projected onto the corresponding radial profile.

## The Models

For the preliminary study described here, gravity values are calculated using the 2-D algorithm of Hubbert [1948]. Abers [1985] showed that 2-D gravity models are adequate to delineate the local

Copyright 1986 by the American Geophysical Union.

Paper number 6L6053.
0094-8276/86/006L-6053$03.00

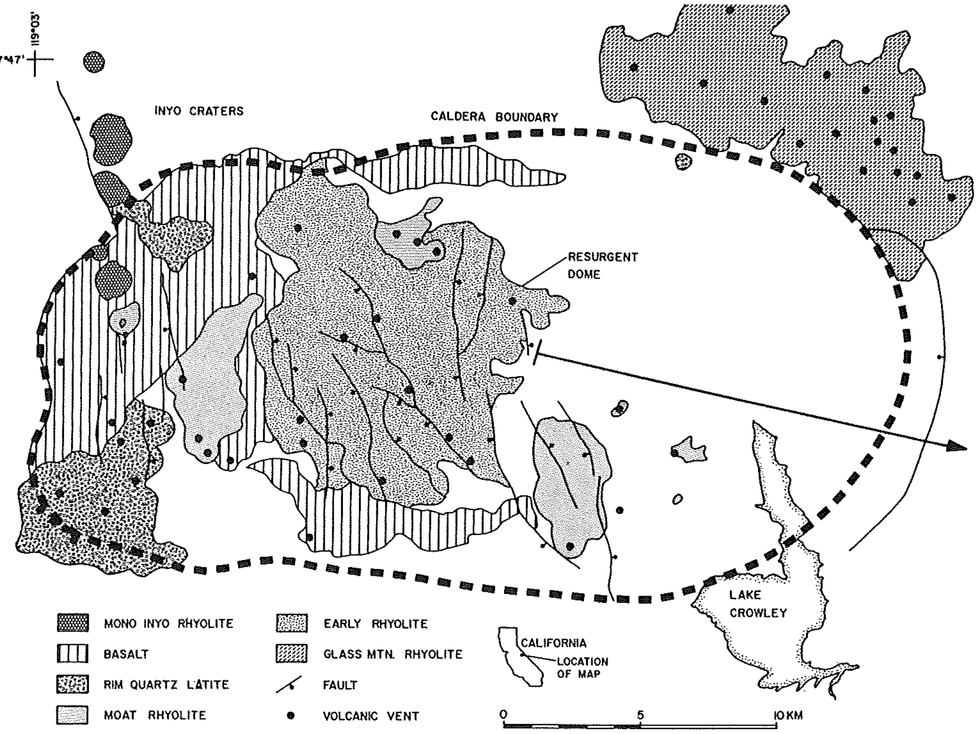


Fig. 1. Generalized geology of Long Valley caldera after Bailey and Koeppen [1977].

faulting at the caldera boundary along each profile. If anything, the 2-D assumption will tend to underestimate the magnitude of any inferred fault offset. The 2-D assumption, of course, would break down if one wanted to delineate basement structure over the interior of the basin at some distance away from the boundary faults. However, this is not our intent. We restrict our interest to the caldera "walls".

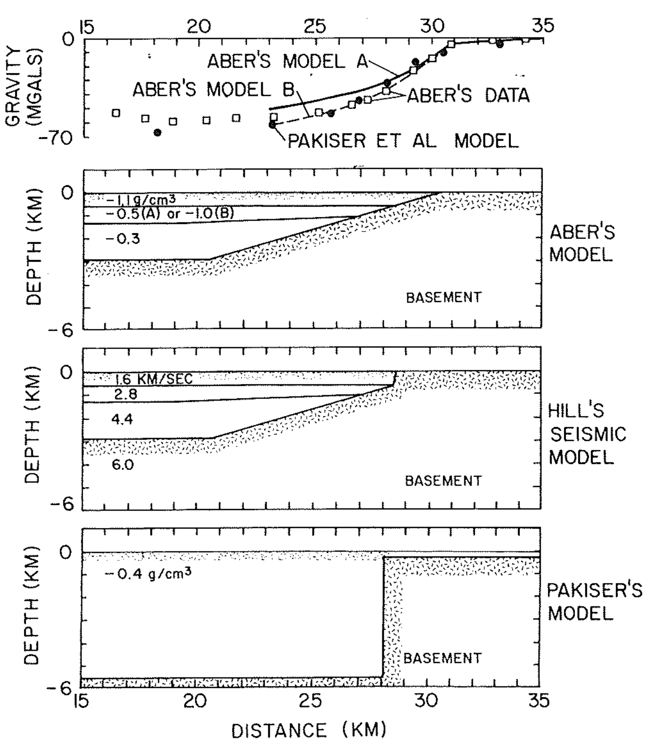


Fig. 2. Various proposed models for the subsurface structure beneath the eastern section of Long Valley caldera [after Pakiser, 1961; Hill, 1976; Abers,' 1985]. The location of these sections is shown by the profile line on the map in Figure 1.

A 2-D algorithm (Hermance, 1982) is also employed for interpreting the telluric field data. Whereas one must be cautious in employing such an approach when dealing with a structure which is clearly three-dimensional, our results should be adequate to interpret features close to the boundary fault(s). As in the gravity case, we would expect the 2-D approximation to underestimate, rather than overestimate, the maximum throw on the boundary faults. Similarly there will be a tendency to underestimate the resistivity contrast between the caldera fill and the surrounding country rock.

In order to emphasize which features of our resulting models(s) are most required by our data,

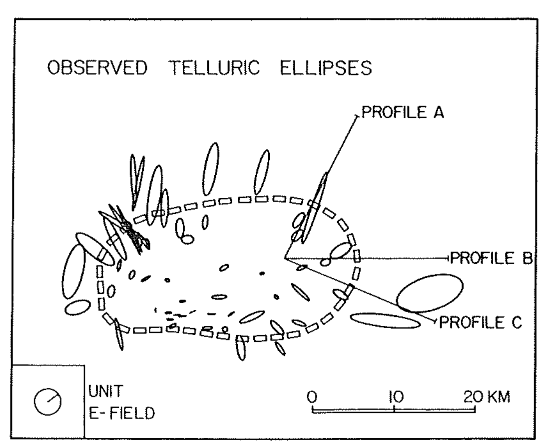


Fig. 3. MT data at a period of 20 sec. and the location of the profiles in eastern Long Valley caldera used in the present study.

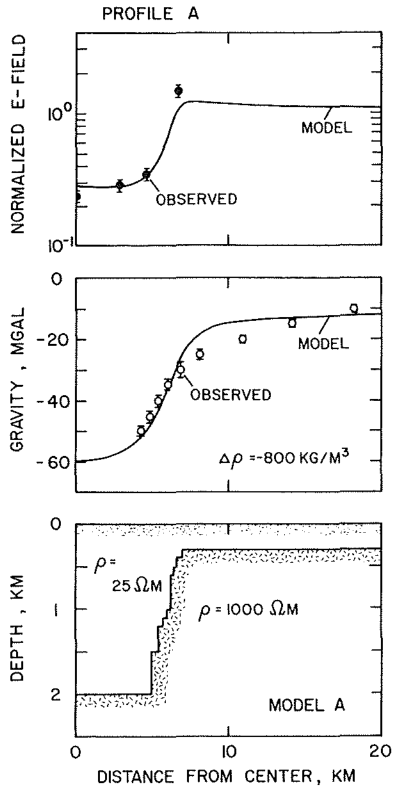


Fig. 4a. Comparison of 2-D electrical and density models to the observed telluric and gravity data along Profile A.

we use as few modelling parameters as possible. We assume a homogeneous basin fill and a homogeneous surrounding basement, each of which is characterized by an arbitrary resistivity and density. We then solve for the model geometry, the resistivity contrast, and the density contrast which best satisfies the telluric field and gravity data simultaneously.

## Profile A

Model A (Figure 4a) best-fits both the MT data and gravity data along Profile A. This model suggests an overburden of 350 meters, a rather steep boundary fault and a caldera basin about 2 km deep. The only constraint on the steepness of the boundary fault is the MT site close to or at the boundary. There is some discrepancy between the MT data and the gravity data, as the gravity measurements suggest a wider, less steep transition zone. But both data sets are fairly consistent in determining the location of the subsurface caldera wall. The resistivity contrast between the basin fill and basement is approximately 1:40 for this model, and the gravity suggests a density-contrast of -800 kg/m$^3$.

## Profile B

The gravity data and MT data along this profile (Figure 4b) could not be fit simultaneously by a model having a simple geometry. The model that best-fit the MT data (Model B1) needed to be displaced systematically to the left of the gravity model (Model B2) by approximately 1.5 km. The results for this profile suggest an overburden of 50 m, a boundary fault less steep than in Profile A, and a caldera basin 2 km deep according to the gravity model (B2). The only constraint on the displacement of 1.5 km for the MT-model is the MT site closest to the boundary. The resistivity contrast for this model is 1:20, and the density contrast is -750 kg/m$^3$.

## Profile C

The best-fitting model of Profile C is shown in Figure 4c. This profile is the only one that has MT sites both outside and inside the caldera. Model C is also the best fitting model to both the MT data and the gravity data of all three models (A, B and C). The model suggests an overburden of 100 meters outside the caldera boundary, a fault zone a little less steep than in Profile B, and a basin 2.2 km deep. The resistivity contrast for this model is 1:25 and the basin has a density contrast of -675 kg/m$^3$.

The difference in resistivity contrast between the basin fill and the surrounding basement for the three profiles (25-1000, 25-500, 20-500, respectively), as well as the difference in the density contrast for each profile (-800, -750, -675 km/m$^3$, respectively), suggest that lateral variations may be present either in the basin fill or in the surrounding country-rock. Refining our model, however, to account for such effects is beyond the scope of our present study.

### Sensitivity of Model Parameters to Data Constraints

Since the data and model-fit for Profile C is significantly better than the other two profiles, we choose this model as representative of the

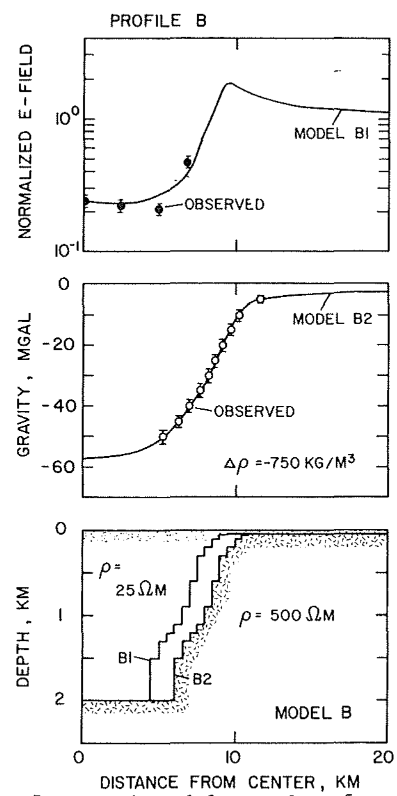


Fig. 4b. Data and model results for Profile B. Model B1 fits the telluric data best, whereas Model B2 fits the gravity data best.

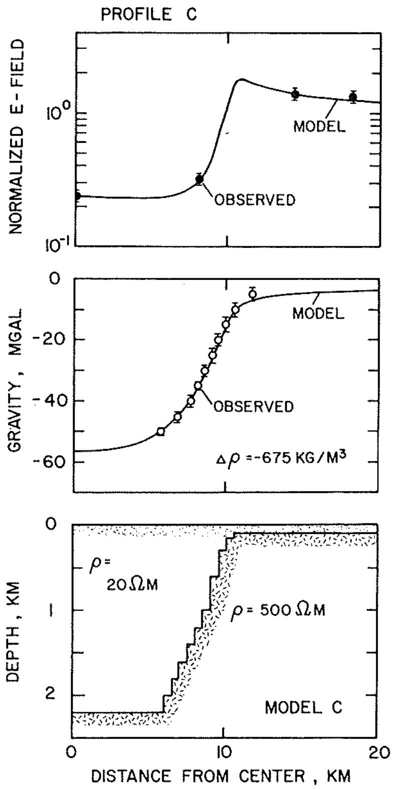


Fig. 4c. Data and model results for Profile C.

class of fault structures in the eastern caldera. We can now ask how sensitive are the parameters of our best-fitting model to the actual data constraints? We have explored this question through systematically varying each model parameter independently while keeping all other model parameters fixed, and comparing the results to the observed data.

To summarize the results of this exercise we have found that if all other parameters are held fixed then the resistivity contrast for Profile C may be constrained to within 25%, the density contrast to within 20%, the maximum vertical offset across the fault(s) to within 500 m (at a depth of 2000 m), the lateral position of the fault to within 500 m, and the depth to the top of the fault step to within 50 m (at a depth of 100 m).

## Discussion and Conclusions

This study underscores the synergism of using several types of geophysical data to study the same geologic structure. In a case where telluric field sites are too sparse to be used in more than a semi-quantitative way, the gravity data have allowed us to interpolate (and to extrapolate) structures with some degree of confidence. Our sensitivity analysis suggests that if all other parameters are well-known, then the maximum offset along the boundary fault is the least determined parameter of our study if one relies on telluric data alone and may be uncertain by 500 m or more. On the other hand the gravity data help significantly in resolving this parameter, providing a density contrast can be reasonably well-determined. If we accept a value of -675 kg/m$^3$ from Abers [1983], then the depth to basement appears to be about 2 km beneath the caldera's surface. A number of the parameters of our model are coupled, however, so that one might satisfy the data with a smaller (larger) maximum offset along the boundary faults if the resistivity contrast or the density contrast were higher (lower). On the other hand the location of the subsurface boundary fault (or fault zone) is relatively well determined by these data, particularly along Profile C, where the structure appears to be much steeper than recent seismic and gravity models seem to suggest [Hill, 1976; Abers, 1985]. Thus one is inclined to reconsider the steep bounding fault(s) model proposed some years ago by Pakiser [1961], but the analysis presented here suggests a vertical throw across this boundary of approximately 2 km, rather than the 5 km originally proposed by Pakiser.

Acknowledgments. We would like to thank Warren Slocum for his assistance in acquiring the MT data used here, and Greg Neumann and Hjalmar Eysteinsson for their help in the early stages of our analysis. One of the authors (R.K.) completed the analysis while on professional leave from the National Energy Authority of Iceland. This research was funded by the Department of Energy Office of Basic Energy Sciences through Contract No. DE-AC02-79ER10401 to Brown University.

## References

Abers, G., The subsurface structure of Long Valley caldera, Mono County, California: A preliminary synthesis of gravity, seismic, and drilling information, Jour. Geophys. Res., 90, 3627-3636, 1985.

Bailey, R.A. and R.P. Koeppen, Preliminary geologic map of Long Valley caldera, Mono County, California; USGS Open File Map 77-468, 1977.

Hermance, J.F., Refined finite-difference simulations using local integral forms: Application to telluric fields in two dimensions, Geophysics, 47, 825-831, 1982.

Hermance, J.F., W.M. Slocum and G.A. Neumann, The Long Valley/Mono Basin volcanic complex: A preliminary magnetotelluric and magnetic variation interpretation, Jour. Geophys. Res., 89, 8325-8337, 1984.

Hill, D.P., Structure of Long Valley caldera, California, from a seismic refraction experiment, Jour. Geophys. Res., 81, 745-753, 1976.

Hill, D.P., E. Kissling, J.H. Luetgert and U. Kradolfer, Constraints on the upper crustal structure of the Long Valley-Mono Craters volcanic complex, Eastern California, from seismic refraction measurements, Jour. Geophys. Res., 90, 11,135-11,150, 1985.

Hubbert, M. King, A line-integral method of computing the gravimetric effects of two-dimensional masses, Geophysics, 13, 215-225, 1948.

Pakiser, L.C., Gravity, volcanism, and crustal deformation in Long Valley, California, U.S. Geol. Surv. Prof. Paper 424-B, B250-B253, 1961.

J.F. Hermance, Department of Geological Sciences, Brown University, Providence, RI 02912.

R. Karlsdottir, Department of Natural Heat, National Energy Authority, Reykjavik, Iceland.

(Received February 3, 1986;
Accepted February 25, 1986.)