# TELESEISMIC P-DELAYS AT THE GEYSERS-CLEAR LAKE, CALIFORNIA GEOTHERMAL REGION

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The Geysers-Clear Lake geothermal field, site of the only commercial geothermal power facility in the U.S.A., is located 130 km north of San Francisco, California. Twenty-four teleseisms recorded during 1976 and 1977 by the U.S. Geological Survey telemetered seismic network in The Geysers-Clear Lake region were analyzed for teleseismic residuals (P-delays). In addition to this permanent seismic network, a northwesterly profile of fourteen portable seismic stations recorded twenty-four teleseisms from July, 1976 to September, 1976 (Fig. 1). The results of this investigation suggest that the teleseismic residual technique may be useful in delineating the presumed magmatic heat source in The Geysers region.

A minicomputer was used in timing P arrivals of the teleseisms recorded by the permanent network. Up to 32 digitized seismic traces may be displayed simultaneously on a cathode ray tube and digitally timed. Teleseisms recorded by the temporary network were timed by hand: accuracy of the picks for both networks is ± .10 sec. Considerable signal shape change was observed for stations GMK, GBO, GGL, GSG, CLØ5, CLØ6, and CLØ7 in comparison to other recording stations.

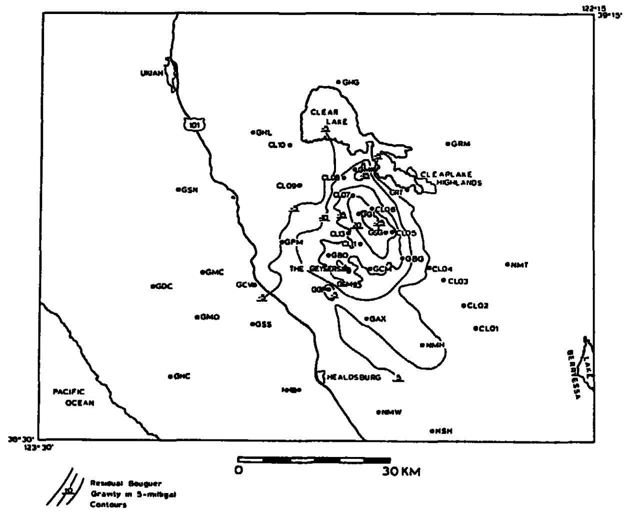


Figure 1. Station locations and residual gravity map (after Isherwood, 1976). Contour interval is 5 mgal.

Raw traveltime residuals are determined by subtracting from the observed traveltimes the theoretical traveltimes, calculated from the standard Herrin traveltime tables (Herrin, 1968). Contributions to the raw residuals due to errors in earthquake source location, origin time, structure beneath the earthquake source and along the path of the seismic ray through the mantle are reduced by subtracting from the raw residuals the residual at some reference station located outside the anomalous area. Stations NMW and CLØ2 were used to compute these relative residuals for the permanent and temporary networks respectively. The use of other stations outside the immediate study region as reference stations does not alter significantly the results reported here.

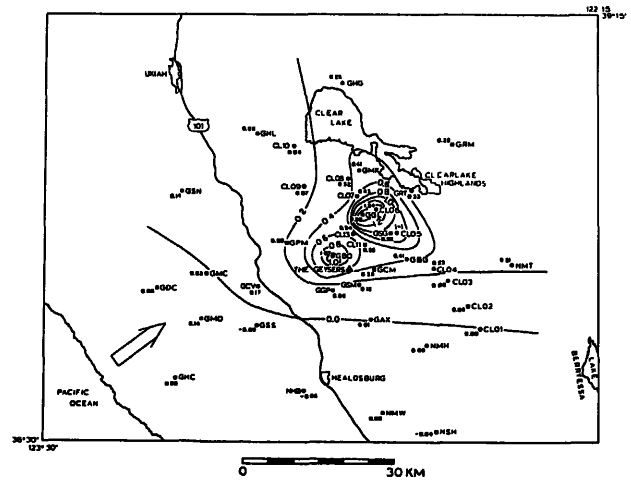


Figure 2. Mean relative residuals for teleseisms from the southwest azimuth. Contour interval is .20 sec.

Fig. 2 shows the mean relative residuals for events from the southwest azimuth. The standard deviation at a site for all azimuths is typically less than .15 sec. The delay field is dominated by residuals exceeding 1 sec of GGL, GBO and CLØ6 in comparison to smaller delays (< .2 sec) elsewhere. The data are clearly sufficient to distinguish two delay maxima. Note that the two separate P-delay maxima correspond to the dual gravity minima as does the .5 sec residual contour to the -15 mgal contour (Fig.'s 1, 2). The correspondence of the region of teleseismic delay and gravity suggest that the two have a common origin, a body composed of abnormally low compressional velocity and density.

Fig. 3 shows the average delays for events from the northwest azimuth. The average delay field is similar to that of the southwest azimuth. However, the maximum delays are smaller, and the dual peaks are not observed. Fig. 4 shows the average delays for events from the southeast azimuth. Delays greater than .5 sec are observed over a much smaller area from this azimuth than from the northwest or southwest.

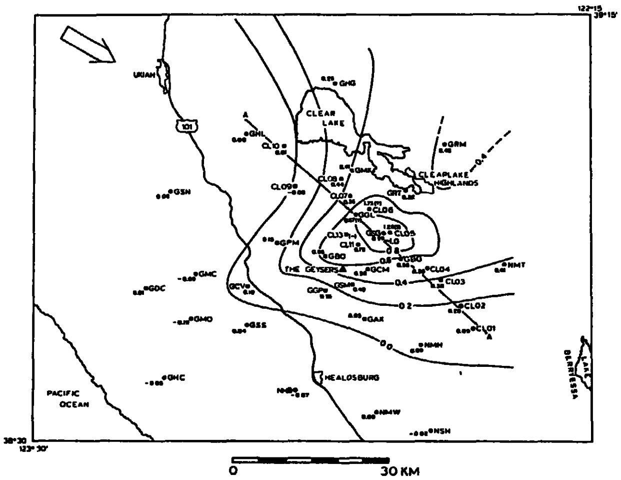


Figure 3. Mean relative residuals for teleseisms from the northwest azimuth.

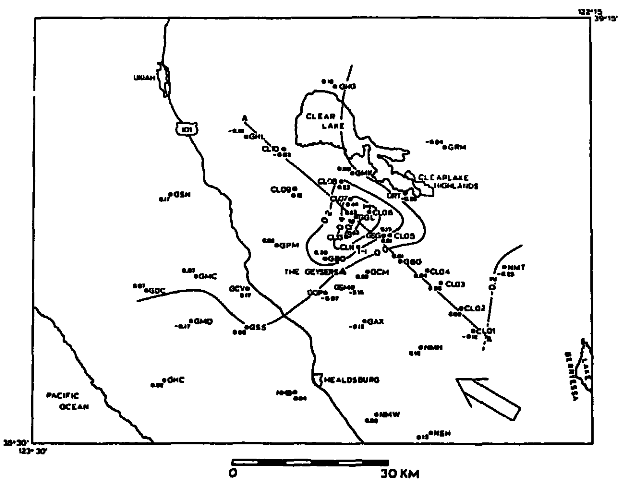


Figure 4. Mean relative residuals for teleseisms from the southeast azimuth.

The dimensions of a body of abnormally low velocity may be calculated from the relative residuals if a percent decrease in velocity relative to surrounding regional velocity is assumed for the body. Steeples and Iyer (1976) have found that a velocity contrast of 10-15% is necessary to satisfy the teleseismic delays observed at Long Valley. A refraction study conducted by Majer and McEvilly (1978) indicates that abnormal velocity structures beneath The Geysers in the top 3 km of the crust are responsible for no more than 0.2 sec delay at stations GGL, GBO, and GSG for sources from the southwest when the regional velocity structure is removed. Therefore, assuming a 15% decrease in velocity for a partially molten body with an upper boundary of 3 km, a total depth of approximately 20 km is required to produce a relative delay of .5 sec. Isherwood (1976) has interpreted both the gravity and aeromagnetic data at The Geysers as also being caused by a magma chamber 10 to 15 km in diameter with its center at depth of 15 km beneath station GGL.

Stations GGL, GMK, GBO, and GSG all show large azimuthal variation of relative delays. Such delays in excess of 1 sec over small spatial extent become difficult to explain in terms of large velocity contrasts associated with partial melt. Anisotropic crack structure in the top 5 km may be responsible for these variations. Bufe et al. (1978) find the direction of maximum compressional stress to be N30°E. Therefore, cracks oriented N15°W due to regional stress may account for the variation of residuals with azimuth. It is not clear now how much delay may be attributed to this effect.

A conceptual model of the subsurface structure of The Geysers-Clear Lake region is seen in a southwest-northeast profile through the anomaly center in Fig. 5. Percentages represent percent decreases in velocity necessary to satisfy relative residuals observed at the surface. We attribute these delays to a magma chamber centered between stations GGL and GBO and extending into the upper mantle. Additional delays may be attributed to anisotropic crack distribution in the top 3 to 5 km. Future teleseismic residual work is anticipated and may resolve the subsurface structure in greater detail.

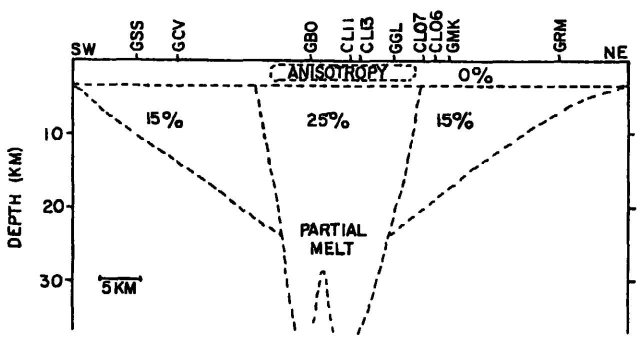


Figure 5. Model of percent decrease in velocity along southwest-northeast line through anomaly center.

## REFERENCES


Bufe, C., Marks, S., Lester, F., Louie, K., and Briscoe, S., 1978, Seismicity of The Geysers-Clear Lake Geothermal Area, California: Abstr., Seismol. Soc. Am. 73rd Annual Meeting 1978.

Herrin E., 1968, Seismological tables for P: Bull. Seismol. Soc. Am., v. 58, p. 1196-1219.

Isherwood, W. F., 1976, Gravity and magnetic studies of The Geysers-Clear Lake geothermal region, California: Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources, v. 2, p. 1065-1073.

Majer, E., and McEvilly, T. V., 1978, Seismological investigations at The Geysers geothermal field (in press): Geophysics.

Steeples, D. W., and Iyer, H. M., 1976, Low velocity zone under Long Valley as determined from teleseismic events: J. Geophys. Res., v. 81, p. 849-860.