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SEISMIC EVIDENCE FOR A DEEP HEAT SOURCE ASSOCIATED WITH THE COSO GEOTHERMAL AREA, CALIFORNIA

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ABSTRACT

Analysis of both compressional (P) and shear (S) waves from a recent large mine blast indicate seismic anomalies associated with the Coso Geothermal Area in California. Five, short-period, high-gain, three-component and three, single-component, magnetic-tape recording seismographs were deployed in a fan configuration 100 km from the mine blast of October 26, 1976 located at 36°09.40'N and 117° 24.50'W. Relative P-wave delays were observed on ray paths which passed south of the surface manifestations and zone of high heat flow associated with the Coso Geothermal Area. The P delays and the strong attenuation of higher frequency P and S waves infer the existence of an extensive body of low velocity material at depth in the area north of Airport Lake and southeast of Volcano Peak, the youngest volcanics in the area with a K-Ar age of about 0.04 m.y. These travel-time delays and seismic attenuation suggest the possibility of a deep magma chamber which has provided the most recent basaltic and rhyolitic rocks and continues to function as a heat source for the Coso geothermal system.

INTRODUCTION

The Coso Range, California (Fig. 1) has been recognized for a number of years as a geothermal area (Combs and Rotstein, 1976). Obvious surface manifestations of an anomalous concentration of geothermal resources include weak to moderate fumarolic activity, intermittently active hot springs, and associated hydrothermally altered rocks. Closely related evidence of a geothermal anomaly is provided by extensive late Cenozoic volcanism, including a cluster of thirty-seven rhyolite domes which are indicative of recent shallow intrusion of magma beneath the area.

Geologic mapping by Duffield (1975) has shown that the youngest volcanic rocks and associated fumaroles lie at the center of a 50 km wide ring fault structure which is superimposed on regional fault patterns. Duffield (1975) interpreted this structure as reflecting an underlying magma/thermal anomaly, with the late Cenozoic volcanics providing evidence of such magma. The youngest K-Ar age (Lanphere, et al., 1975) determined on the rhyolitic domes was 0.041 m.y. for Sugarloaf Mountain which is located at the virtual center of the ring fault structure, the center of the silicic dome field, and is adjacent to Devils Kitchen, one of the major fumarolic areas. The most recent basalt flow, located near Volcano Peak at the southern end of the rhyolite domes, has been dated at an age of 0.038 m.y. (Lanphere, et al., 1975). Combs (1976; and unpublished data) found that heat flow (Fig. 2) is generally high through the dome field, with values ranging from about 2 HFU (heat flow units) to greater than 15 HFU compared with the worldwide average of about 1.5 HFU. The highest heat flow values occur near Sugarloaf Mountain whereas the heat flow near Volcano Peak is less than 3 HFU.

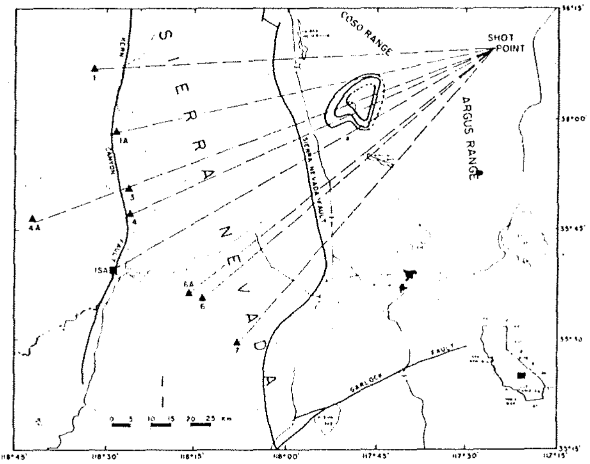

Figure 1. Location map showing configuration of stations that recorded Revenue Canyon event. Contours in north central part of map represent the heat flow anomaly over the Coso Geothermal Area.

Seismic data can provide additional evidence for determining the existence of a magma chamber underlying the Coso Geothermal Area. Increased subsurface temperatures in the vicinity of active volcanoes and geothermal areas are known to cause seismic wave travel time and attenuation anomalies (e.g., Matumoto, 1971; Steeples and Iyer, 1976; Hadley, et al., 1976). Since the depth of penetration for seismic body waves is determined by the distance between the source and observation point, the three-dimensional velocity structure of the subsurface can be obtained by varying the azimuth and distance between the source and receiver.

A modification of the refraction method, known as fan shooting, can be used to find anomalous

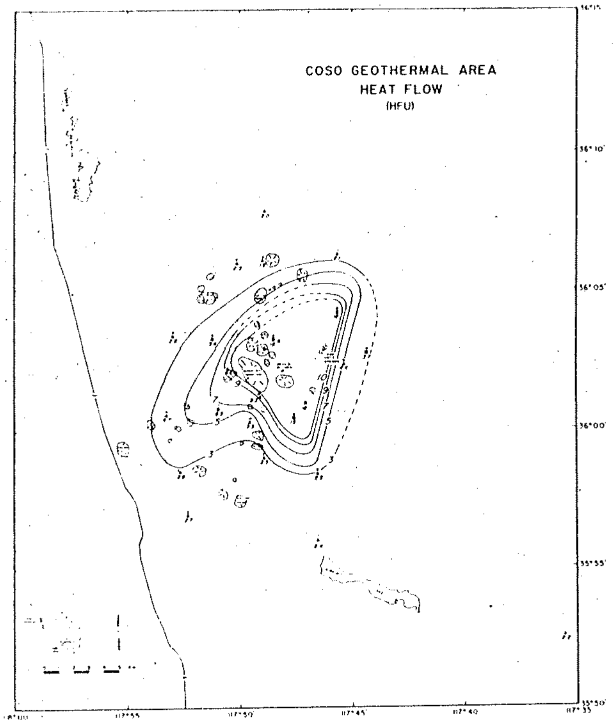

Figure 2. Observed heat flow at the Coso Geothermal Area (Combs, 1976; and unpublished data) contoured in units of HFU (1 HFU = 1 x 10^{-6} cal/cm^2-sec = 41.8 mW/m^2).

subsurface structures. In this method, the travel times for paths of equal lengths are compared. The velocity of seismic waves in geothermal (high temperature) areas can be much less than that in the subsurface material surrounding the geothermal anomaly. Therefore, a wave which has passed through a geothermal area could have a significantly lower average velocity than a wave traveling the same distance in a nearby area where anomalous high temperature phenomena are not present. In addition, it is to be expected intuitively that attenuation increases with increasing temperature, though there is very little observational evidence. Therefore, the relative attenuation of seismic waves along the different ray paths could be used to infer anomalous subsurface temperatures.

RESULTS AND DISCUSSION

A large mine shot, located in Revenue Canyon at 36° 09.40'N and 117°24.50'W (Shot Point, Fig. 1), was exploded on October 26, 1976. In order to record the event, five, short-period, high-gain, three-component and three, single-component, magnetic-tape recording seismographs were deployed in a fan configuration (Fig. 1) at a distance of 100 km from the shot point. The shot time was interpolated to ±0.03 sec from a seismic record obtained at the shot point. P-wave and S-wave arrival times were determined to ±0.05 and ±0.10 sec, respectively. The field data were recorded in analog form, then digitized at 100 samples/sec for subsequent computer processing.

Seismograms for the five, three-component, and the single-component station at 6A are illustrated in Figure 3. Because of low signal-to-noise level and instrument failure, usable seismograms were obtained at only six (1, 3, 4, 6A, 6 and 7) of the eight recording stations. The top trace on each record consists of a series of 1-sec time marks produced by an internal clock. The second trace is the vertical component of ground motion; while the third and fourth traces are the orthogonal horizontal components of ground motion. The horizontal seismometers failed at station 1 and the seismogram presented on the third trace is a 5-15 Hz bandpass filtered version of the vertical component of ground motion.

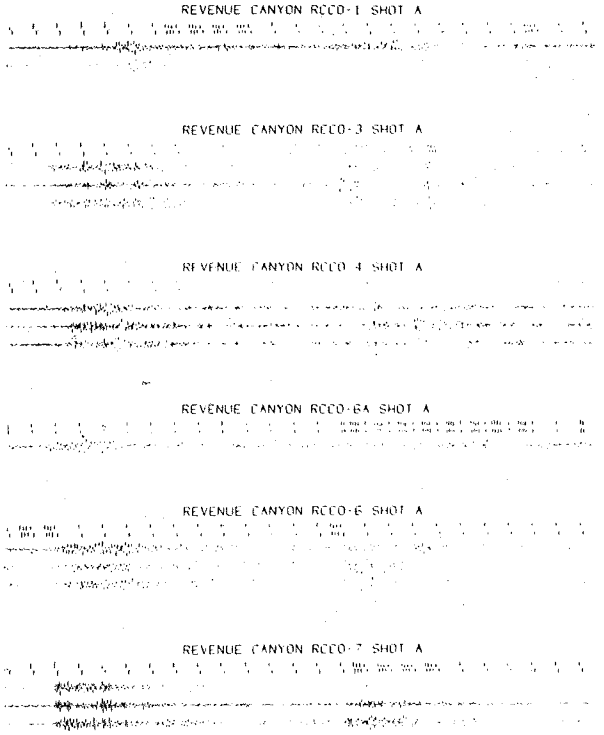

Figure 3. Seismograms of the Revenue Canyon event obtained at six of the recording stations.

Travel-times from the shot point to each station for both compressional (P) and shear (S) waves were determined. In order to examine the possibility of relative travel-time delays along the separate ray paths, the observed times at stations 1, 3, 4, 6, and 6A were compared with the times at station 7. Station 7 was chosen as the standard because the ray path from the shot point lies entirely outside the Coso ring structure defined by Duffield (1975). The high signal-to-noise ratio and apparent lack of attenuation to station 7 provided the best P- and S-wave times. Relative P-wave delays of at least 0.2 sec were observed on stations 6 and 6A, whereas the other three stations did not exhibit significant P-wave delays. However, the high noise level at station 4 made it extremely difficult to determine the first swing of the P wave. As can be seen from Figures 1 and 2, these travel-time delays were observed on ray paths which passed south of the surface manifestations and zone of high heat flow associated with the Coso Geothermal Area.

Time segments of 2.5 seconds for both P and S phases obtained on each seismic channel were subjected to spectral analysis. A standard 256-point Fast Fourier Transform routine with a 3-point Hamming-Tukey window (Robinson, 1967) applied in the frequency domain resulted in the relative power versus frequency spectra shown in Figure 4. A dashed line has been drawn at 10 Hz to enhance the comparison of these spectra. From Figure 4, it can been seen that the dominant frequencies of both P and S phases are shifted to lower values for the inner stations (3, 4, 6A and 6). In addition, the frequency content above 10 Hz is significantly attenuated for the inner stations when compared with the outer stations (1 and 7). The S-wave spectra for stations 1 and 6A are less reliable than the other stations since they were obtained from the vertical channel. The north-south component was used for the remaining S-wave spectra in Figure 4. Some of the higher amplitudes above 10 Hz for station 4 may be attributed to the relatively low signal-to-noise ratio of the recorded data (Fig. 3). The observed shift in dominant P-wave and S-wave frequencies observed in Figure 4 can be explained by having the ray paths to the inner stations pass through a zone of lower rigidity material.

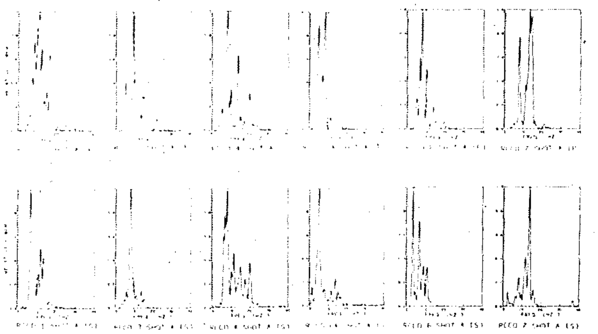

Figure 4. Power spectra for P-phase (top) and S-phase (bottom) for each of the six seismograms of the Revenue Canyon event.

These attenuation phenomena, combined with P-wave delay times, suggest the existence of a localized body of low velocity material at depth, possibly a magma chamber, which has provided the most recent basaltic and rhyolitic rocks and continues to function as a heat source for the Coso geothermal system. The location of the inferred anomalous body is constrained to lie along the ray paths to stations 6 and 6A. However, based on power spectral analyses of the P and S phases, the low velocity zone may extend as far northward as the ray path to station 3. Assuming that the anomalous body is a deep-seated magma chamber, the most likely location is just south of Volcano Peak, where the youngest volcanics of the area are observed. It should be noted that the heat flow data as well as shallow microearthquake data (Fig. 2 and Combs and Rotstein, 1976) indicate that the shallow geothermal anomaly is located farther to the north. By examining seismic events from various azimuths and using fan shots with different dimensions, we intend to determine the geometry of the anomalous subsurface zone.

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REFERENCES

Combs, J., 1976, Heat flow determinations and implied thermal regime of the Coso Geothermal Area, California (abs.): EOS, Trans. Amer. Geophys. Union, v. 57, p. 1009.

Combs, J., and Rotstein, Y., 1976, Microearthquake studies at the Coso Geothermal Area, China Lake, California: in Proceedings of Second United Nations Symposium on the Development and Use of Geothermal Resources, v. 2, p. 909-916.

Duffield, W. A., 1975, Late Cenozoic ring faulting and volcanism in the Coso Range area of California: Geology, v. 3, p. 335-338.

Hadley, D. M., Steward, G. S., Ebel, J. E., 1976, Yellowstone: Seismic evidence for a chemical mantle plume: Science, v. 193, p. 1237-1239.

Lanphere, M. A., Dalrymple, G. B., and Smith, R. L., 1975, K-Ar ages of Pleistocene rhyolitic volcanism in the Coso Mountains, California: Geology: v. 3, p. 339-341.

Matumoto, T., 1971, Seismic body waves observed in the vicinity of Mount Katmai, Alaska, and evidence for the existence of molten chambers: Geol. Soc. Amer. Bull., v. 82, p. 2905-2920.

Robinson, E. A., 1967, Multichannel Time Series Analysis with Digital Computer Programs: Holden-Day, Inc., San Francisco, Ca., 298 pp.

Steeples, D. W., and Iyer, H. M., 1976, Teleseismic P-wave delays in geothermal exploration: in Proceedings of Second United Nations Symposium on the Development and Use of Geothermal Resources: v. 2, p. 1199-1206.