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A POSSIBLE SEISMOMAGNETIC OBSERVATION ON THE GARLOCK FAULT, CALIFORNIA

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ABSTRACT

Simultaneous measurements of geomagnetic fields have been made at pairs of sites approximately 12 km apart along the Garlock fault. On June 9 and 10, 1974, several minor earthquakes (M = 2.6 to 4.3) occurred near one of these sites 3 weeks after the first measurements were made. Two repeated data sets were taken 2 weeks and 3 months after the earthquakes. The differenced data indicate that, relative to pre-earthquake values, the local magnetic field at this site had increased by about 2γ. A piezomagnetic source for this change implies a stress change that would exceed 10 bars. After 3 months the same form of anomaly still remained although larger in spatial scale. This might indicate dispersion of the stress discontinuities produced by the earthquake.

INTRODUCTION

Wilson (1922) first suggested that the detection of stress-induced changes in a local magnetic field could be used for monitoring tectonic activity. Kalashnikov (1954) and Kapitsa (1955) further stimulated this idea by illustrating that the stress sensitivity of magnetization in rocks containing magnetic grains is approximately 10^{-4} bars^{-1}; a value that has subsequently been verified in similar experiments at crustal fields (0.5 oe), temperatures, and stress differences by Ohnaka and Kinoshita (1968), and theoretically justified by Kern (1961), Stacey (1962), Nagata (1970), and Stacey and Johnston (1972).

Experiments designed to detect this effect in the western United States were reported by Breiner (1967), Smith *et al.* (1973), and Johnston *et al.* (1973). A 0.5 γ change associated with a magnitude 2 earthquake near Fairview Peak was reported by Breiner (1964). However, since this effect occurred during a period of increased global geomagnetic activity, it is unlikely that it is of tectonic origin. Breiner and Kovach (1967) have obtained indications of interrelated creep and local magnetic field change. More recently, Johnston (1974) observed broad-scale local magnetic anomalies associated with seismic activity on faults within the San Andreas fault system.

The merits and limitations of seismomagnetic techniques for detection of tectonic activity and, more importantly, for earthquake prediction in seismically active areas have not been determined. This paper reports the observation and possible implications of changes in the local magnetic field after several magnitude 4 earthquakes on the Garlock fault. A second data-set taken subsequent to the earthquake indicates similar form with possible spatial dispersion.

INSTRUMENTATION

The U.S. Geological Survey operates a differential magnetometer array to detect seismomagnetic effects that currently involves more than 120 sites, 10 to 15 km apart, along active faults in California and Nevada. The instruments used are total field proton magnetometers with 0.25 γ absolute sensitivity.

At most of these sites, data are taken using a resurvey technique on either a 6-month interval or more frequently if changes in seismicity occur. The primary object is to search for long-lived magnetic anomalies that might indicate a major earthquake. Along the most seismically active section of the San Andreas fault, seven installations operate continuously and synchronously with the data transmitted via digital telemetry to Menlo Park (Smith *et al.*, 1974).

At the periodically resurveyed sites, which also cover the continuously monitored section of the fault, sets of approximately 75 total magnetic field values are recorded between each site pair in 10 min with synchronized magnetometers. These data are subsequently differenced to isolate the local field and reduce effects of geomagnetic variations.

RESULTS AND DISCUSSION

On June 9 and 10, 1974, nearly 4 weeks after initial data were obtained for 12 sites located approximately 12 km apart along the Garlock fault from Castaic (34°52.6′N, 118°49.45′W) to Randsburg Wash (35°34.5′N, 117°5′W), three earthquakes with magnitudes 2.6, 3.8 and 4.3 occurred on the Garlock fault south of Owens Valley (California Institute of Technology, unpublished data). These earthquakes were the largest that had occurred near magnetic survey sites since this program was initiated in September 1972 and offered the first good opportunity with this simple technique to search for local magnetic field changes uniquely related to earthquake stress variations.

The rocks in the epicentral region with any substantial magnetization are of Tertiary volcanic origin. Surface samples indicate magnetizations, I_T, in the range 10^{-3} to 10^{-4} e.m.u. If significant stress change σ_{av} occurs between the pre- and postearthquake period and if the magnetization at the surface adequately represents the magnetization at greater depths, a detectable static magnetic field change proportional to σ_{av} should result. Subsequent measurements should reflect the decay or readjustment of the post-earthquake stress field. The sites that span the section of the fault from 60 km to the southwest and 50 km to the east of the earthquakes were resurveyed, therefore, on June 25 and again in October, 1973.

Figure 1 shows a simplified fault map of the region on which the magnetometer sites from 3 to 12 are located. The epicenters of the earthquakes are marked with a star. The location error (shaded) is approximately 5 km. The local magnetic field differences for each of the site pairs can be compared before and after the earthquake. If a systematic tectonomagnetic effect has occurred, this can be isolated by differencing the pre- and postearthquake data. Subsequent sets of postearthquake data can be checked for details of stress-field decay and, more importantly, for consistency in the data.

The first plot in Figure 1 is the difference between the pre-earthquake (i.e., May 16 data) and postearthquake data (i.e., June 25 data). The most interesting features are the site 9-site 8 and site 10-site 9 data that decreased and increased, respectively, indicating an increase in local magnetism primarily near site 9 (the background field at each site increases from west to east). If this effect is of earthquake origin, then the earthquakes probably occurred quite close to this site. The error bars indicate one standard deviation of individual differences about the mean difference and are a measure of the geomagnetic noise during the sample interval. During times of high geomagnetic noise, disturbances with periods larger than the sample interval occur, and it is important for assessing the validity of the data to determine whether errors from this source are underestimated with such a short sample. Experience with the continuously telemetered array data indicates that during magnetically quiet times a short sample error could underestimate the background noise by up to a factor of three. For magnetically noisy times the short sample noise estimate could be underrated by up to a factor of five (U.S. Geological Survey, unpublished data). The array data probably provide worse case tests since the installations are relatively close to a conductivity discontinuity (i.e., the ocean) whereas the Garlock sites are not.

The Garlock fault is a left-lateral strike-slip fault, and an increase in local field at site 9 could be interpreted as local stress change in terms of a dislocation model. The

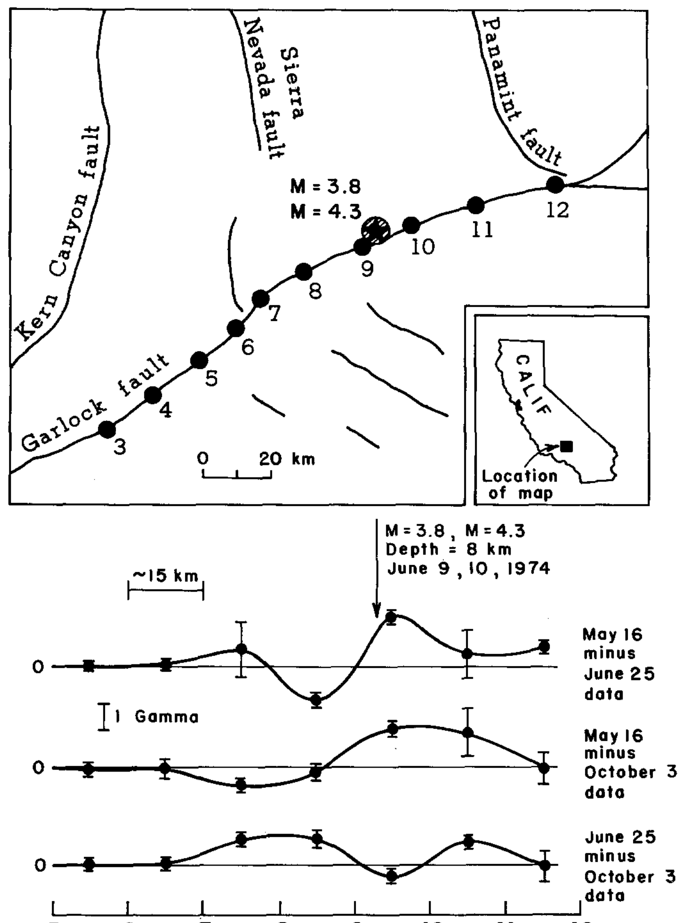

FIG. 1. Simplified fault map showing magnetometer sites and earthquake locations along the Garlock fault, California. Magnetic field changes as a function of site location are plotted for the periods May 16 to June 25, May 16 to October 3, and June 25 to October 3, 1974. Earthquakes of magnitude $M = 3.8$ and 4.3 occurred on June 9 and June 10. The error bars represent one standard deviation of individual values about a mean of 75 values.

model of Shamsi and Stacey (1969) of the San Andreas is sufficiently similar to the present geometry that it can be used directly—the primary difference being the orientation of the principal stresses with respect to the magnetization direction. Neglecting geometrical factors and using a magnetization of 10^{-3} e.m.u., the minimum, although poorly constrained, stress change that could produce the effects is 10 bars. For 10^{-4} e.m.u., the stress change would exceed 100 bars.

The second plot on Figure 1 is the difference between the pre-earthquake data and the second postearthquake data set. Although only marginally above the noise, the same form of anomaly apparently still remains but with larger spatial scale. A possible explanation could be stress readjustment by relaxation, and outward diffusion with time, of stress discontinuities at the edges of the focal zone produced by the earthquakes. These postearthquake effects can be isolated by differencing the June 25 and October 3 data sets. This is plotted also on Figure 1.

If these results are indeed indications of crustal stress change coincident with and following an earthquake, then it does appear possible that stress accumulation or change prior to earthquakes, although probably site unique, could also be monitored in this way.

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