17

Magnetic-Field Measurements

By R.J. Mueller *and* M.J.S. Johnston

CONTENTS

Abstract

The magnetometer stations located along the Calaveras fault were not operational at the time of the earthquake or for the 16-month period before, but were reinstalled within hours of the main shock. Comparison of the magnetic-field differences after the earthquake with those 16 months before indicates no significant variations greater than 0.75 nT. Analysis of hourly magnetic-field differences for the 12-day period after the earthquake indicates no significant variations greater than 1.0 nT associated with the aftershock activity. A seismomagnetic model of the earthquake, assuming uniform magnetization, indicates that the magnetometer stations along the Calaveras fault are poorly located to detect stress-generated magnetic-field changes. The same model, using a distribution of magnetic material on only the west side of the fault, indicates that station C1Y was located near the point of maximum expected field changes. The absence of any magnetic-field changes greater than 1.0 nT at station C1Y requires a stress change of less than 1.2 MPa for the 12-day period after the earthquake.

INTRODUCTION

The U.S. Geological Survey (USGS) operates a network of magnetometer stations in central California to detect local magnetic-field perturbations generated by changes in tectonic stress (fig. 17.1). Previous studies of magnetic-field perturbations associated with earthquakes in this region are inconclusive. A 2-nT variation in the local magnetic field was observed during the 2-month period before an M_L=5.2 earthquake in November 1974 (Smith and Johnston, 1976). However, no significant magnetic-field variation was observed before or during the August 6, 1979, Coyote Lake, Calif., earthquake (Johnston and others, 1981).

Station MTH, the nearest station in the USGS magnetometer network, is located 2 km east of the epicenter of the earthquake (fig. 17.1). Both stations MTH and C0Y have not been operational since January 1983, but they were reinstalled with portable onsite recording systems after the earthquake. Station MTH was operational within 3 hours, and station C0Y within 24 hours, of the main shock. In addition, station C1Y, which was established after the Coyote Lake earthquake, was reoccupied; and a new station (EMT) was established as a reference for station MTH (fig. 17.1). In this chapter, we examine the data collected with the onsite recording systems at these four stations and the data from two telemetered magnetometer stations (EUC, SAR, fig. 17.1), in an attempt to isolate any local magnetic-field variations associated with the April 24 earthquake.

DATA

The four onsite recording systems measure total magnetic-field intensity at 0.25-nT sensitivity and the data from the two telemetered stations at 0.125-nT sensitivity. The field at all stations is synchronously sampled at a 10-minute sampling interval. All stations use an E.G.& G. Geometrics, Inc., model G-816 or G-826 proton-precession magnetometer. Instrumental details were described by Mueller and others (1981).

Because none of the magnetometer stations was in operation along the Calaveras fault at the time of, or 16 months before, the April 24 earthquake, observation of coseismic and preseismic effects with periods of less than 16 months is not possible. What may be investigated are the long-term net offsets that accumulated during this period, and the postseismic local magnetic-field variations related to aftershocks.

The simplest method of isolating magnetic-field changes and of reducing the effects of ionospheric and magnetospheric disturbances is to difference the magnetic-field observations between adjacent stations. Figure 17.2 shows 3-day averages of differenced 10-minute magnetic-field data for stations near the epicenter of the earthquake. The top three plots include data from stations along the Calaveras fault, and the bottom reference plot includes data from two stations located off the Calaveras fault. An annual cycle is apparent in the two middle plots. We suspect that this cycle is due to a temperature-related response at station C0Y, although we have no good evidence. Thermal testing of the electronic equipment at station C0Y when it was operational indicates no response to temperature over the range 5°-$30^{\circ}C$.

No significant offsets greater than 0.75 nT are observable in these data from magnetometer stations along the Calaveras fault after the April 24 earthquake relative to data from 16 months before. In addition to these data, comparison of the averaged magnetic-field differences for difference plot C1Y-C0Y in August 1979 with April 1984 indicates only a -0.16±0.25-nT change for this 56-month period.

Figure 17.3 shows hourly averages of 10-minute differenced magnetic-field data for stations along the Calaveras fault during the 12 days after the April 24 earthquake. The tickmarks at the bottom of figure 17.3 represent the logarithm of hourly averaged moment, where $\log \underline{M}_0=1.5\underline{M}_L+16$ (Thatcher and Hanks, 1973). This quantity is intended to indicate the seismic energy released during the aftershock period.

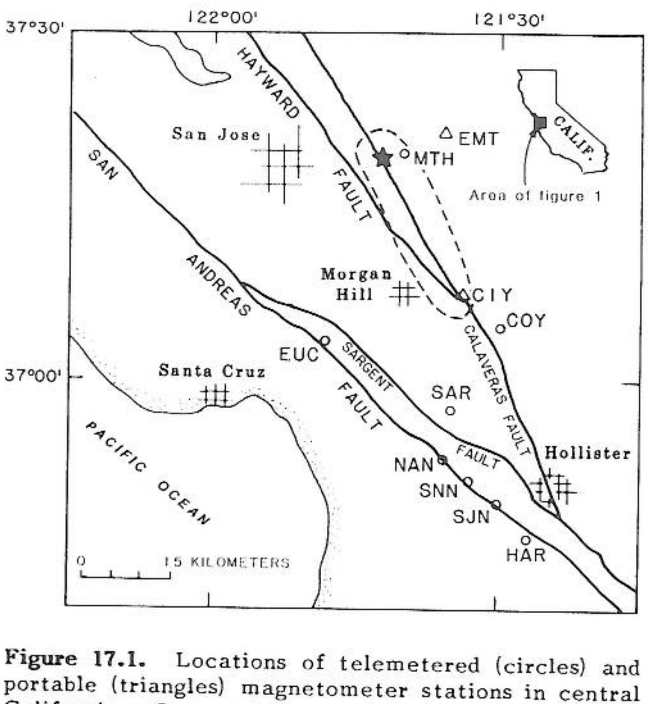

Figure 17.1. Locations of telemetered (circles) and portable (triangles) magnetometer stations in central California. Star, epicenter of $\underline{M}$=6.2 main shock of April 24 earthquake; dashed line, approximate boundary of aftershock zone.

To further complicate interpretation of these differenced magnetic-field data, storm-level conditions existed in the geomagnetic field beginning at 1200 G.m.t. April 25 and continuing to the end of April 26. These geomagnetic-field storm conditions are suspected to be responsible for the 3-nT positive spike on April 26 shown on difference plot EMT-MTH and the changes at the beginning of difference plots EMT-C0Y and C1Y-C0Y (fig. 17.3). The increasing noise level of the differenced data for difference plot EMT-C0Y (σ=0.92 nT) is due to a greater station-separation distance of 34 km versus station-separation distances of approximately 8 km for difference plots EMT-MTH (σ=0.60 nT) and C1Y-C0Y (σ=0.25 nT). No significant changes greater than 1 to 2 nT are observed in these magnetic-field data that relate to seismicity during the 12-day period after the April 24 earthquake.

DISCUSSION

Local magnetic-field perturbations are expected to result from stress drops before and during moderate to large earthquakes. These seismomagnetic effects (Stacey, 1964) are derived from the stress dependence of the magnetic properties of crustal rocks near active faults. Models used to calculate the form and amplitude of magnetic-field changes on the Calaveras Fault for the Coyote Lake earthquake (Johnston and others, 1981) can also be applied to the Morgan Hill earthquake. These models calculate the seismomagnetic anomaly on the Earth's surface as a function of fault geometry, the distribution of magnetic material, and the stress change in the region.

Figure 17.4 illustrates the calculation of the seismomagnetic effect, using a vertical finite-slip patch, 1 to 11 km deep and 21 km long, with 10 cm of fault slip, assuming a uniform magnetization of 1 A/m on both sides of the fault. This solution indicates that the three magnetometer stations near the Calaveras fault are poorly located for detection of local magnetic-field changes and that the amount of slip would have to triple to produce a change greater than 1 nT at any of these stations.

Aeromagnetic surveys (U.S. Geological Survey, 1974) indicate that more magnetic material is located on the west side of the Calaveras fault in this area. Figure 17.5 illustrates the calculation of the seismomagnetic effect, using the same fault geometry as in figure 17.4, but with a magnetization of 1 A/m on only the west side and of 0.1 A/m on the east side of the fault. For this solution, station C1Y is best located to detect magnetic-field changes from the April 24 earthquake. The differenced data for difference plot C1Y-C0Y (fig. 17.3) indicate no significant magnetic-field changes greater than 1 nT during the aftershock period from April 26 to May 6. For this solution, if the signal were at the level of the noise, these data require a stress change no greater than 1.2 MPa for the period April 26-May 6.

The two solutions using the seismomagnetic model indicate that the optimum array of magnetometers for an earthquake of this magnitude would consist of pairs of stations located about 1 to 2 km on either side of the fault, at approximately 5-km intervals along the fault.

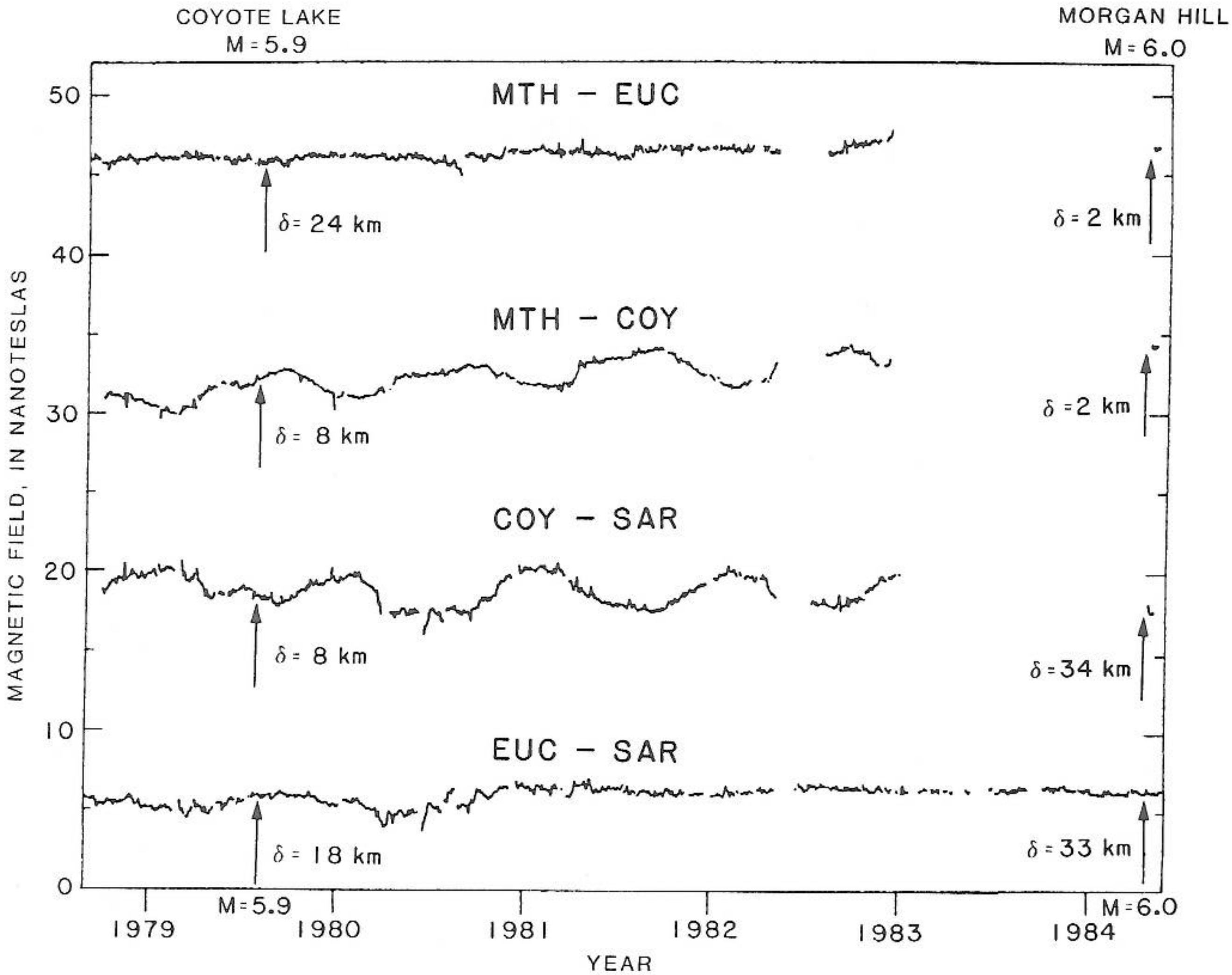

Figure 17.2. Three-day averages of differenced magnetic-field data between 1978 and 1984. Three upper plots include data from stations located along the Calaveras fault. δ, distance from epicenter to nearest station used in the difference. Arrows mark times of two moderate earthquakes that occurred on the Calaveras fault during this period.

CONCLUSIONS

Analysis of magnetic-field data from stations located near Morgan Hill indicate no anomalous preseismic variations larger than 0.75 nT with periods longer than 16 months. For the 12 days after the April 24 earthquake, no magnetic-field variations larger than 1.0 nT were associated with the postseismic activity. Seismomagnetic models indicate either that the magnetometer stations are poorly located for this earthquake or that any stress changes during the 12-day period after the earthquake were no greater than 1.2 MPa. The absence of data at the time of, and for the 16-month period before, the earthquake preclude the identification of magnetic-field perturbations during this period.

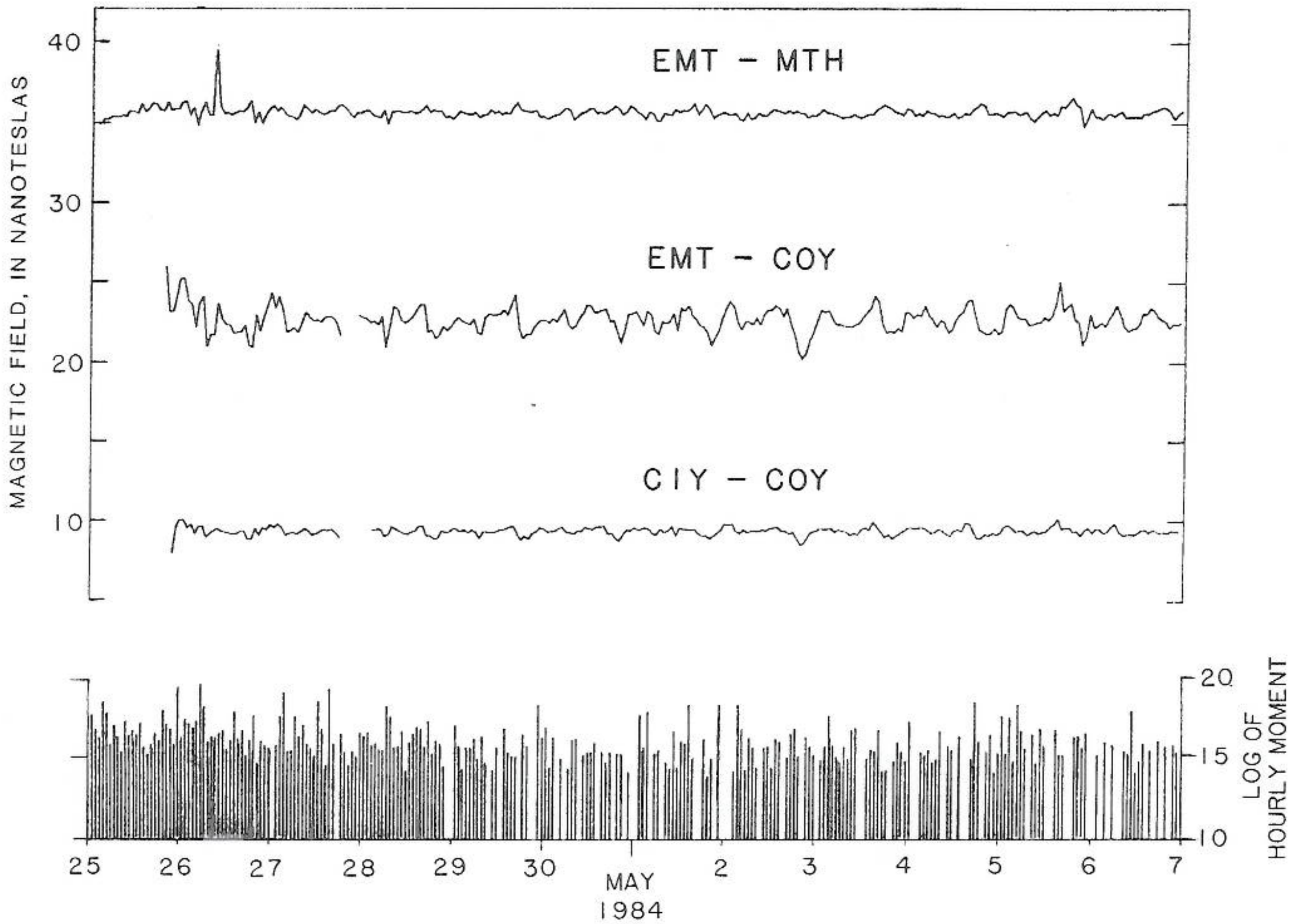

Figure 17.3. Hourly averages of differenced magnetic-field data from stations along the Calaveras fault during 12-day period after the April 24 earthquake. Tickmarks represent logarithms of hourly averaged seismic moment ($\log \underline{M}_0 = 1.5\underline{M}_L + 16$).

REFERENCES CITED

Johnston, M.J.S., Mueller, R.J., and Keller, Vincent, 1981, Preseismic and coseismic magnetic field measurements near the Coyote Lake, California, earthquake of August 6, 1979: Journal of Geophysical Research, v. 86, no. B2, p. 921-926.

Mueller, R.J., Johnston, M.J.S., Smith, B.E., and Keller, Vincent, 1981, U.S. Geological Survey magnetometer network and measurement techniques in Western U.S.A.: U.S. Geological Survey Open-File Report 81-1346, 44 p.

Smith, B.E., and Johnston, M.J.S., 1976, A tectonomagnetic effect observed before a magnitude 5.2 earthquake near Hollister, California: Journal of Geophysical Research, v. 81, no. 20, p. 3556-3560.

Stacey, F.D., 1964, The seismomagnetic effect: Pure and Applied Geophysics, v. 58, p. 5-22.

Thatcher, Wayne, and Hanks, T.C., 1973, Source parameters of southern California earthquakes: Journal of Geophysical Research, v. 78, no. 35, p. 8547-8576.

U.S. Geological Survey, 1971, Aeromagnetic map of parts of the San Jose, Santa Clara, and San Francisco 1° by 2° quadrangles, California: Open-File Report 74-79, scale 1:125,000.

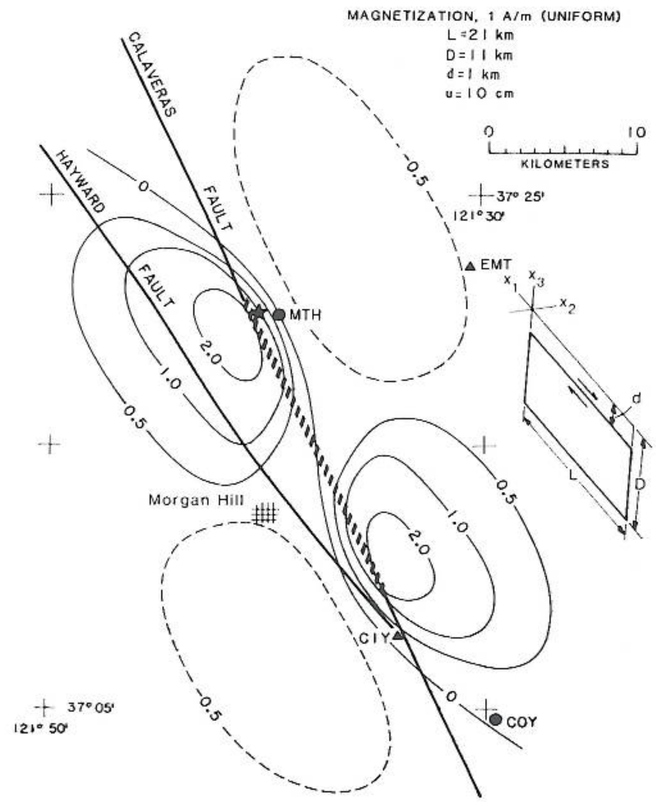

Figure 17.4. Locations of magnetometer stations and epicenter of the April 24 earthquake (star) in relation to magnetic-anomaly contours (in nanoteslas). Magnetic-anomaly contours represent 10 cm of slip on a fault plane 10 km by 21 km, with a uniform magnetization of 1 A/m. Dashed-outlined area denotes rupture zone.

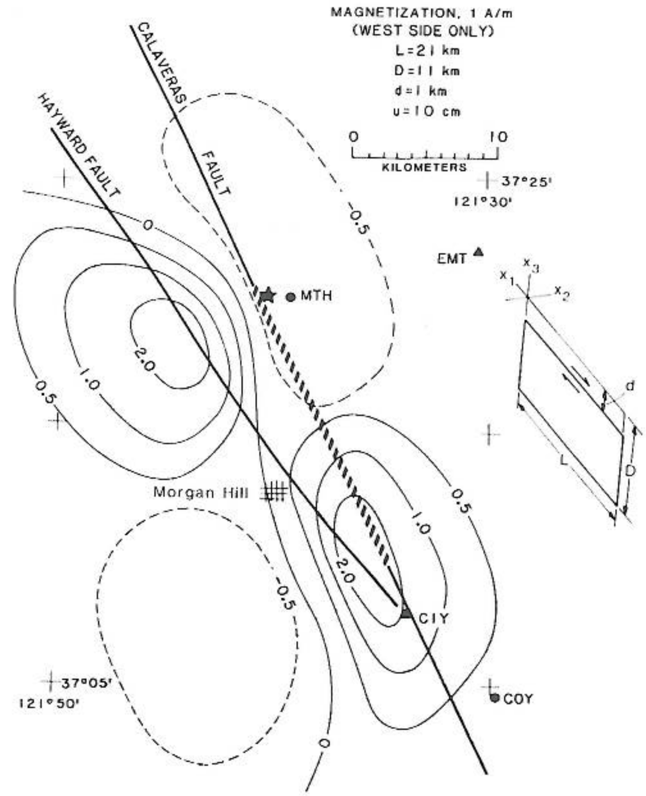

Figure 17.5. Magnetic-anomaly contours (in nanoteslas), using same model as in figure 17.4 but with magnetic material on only the west side of the fault.