"ANOMALOUS EM SIGNALS AND CHANGES IN RESISTIVITY AT PARKFIELD: COLLABORATIVE RESEARCH BETWEEN THE UNIVERSITIES OF CALIFORNIA AT BERKELEY AND RIVERSIDE AND OREGON STATE UNIVERSITY"

FINAL REPORT FOR JANUARY, 2003- JANUARY, 2004
MARCH, 2004

STEPHEN PARK
University of California, Riverside
The Institute of Geophysics and Planetary Physics
Riverside, California 92521
(909)-787-4501;(909)-787-4324(fax)
magneto@ucrmt.ucr.edu

Submitted to:

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

Grant 03HQGR0041

"ANOMALOUS EM SIGNALS AND CHANGES IN RESISTIVITY AT PARKFIELD: COLLABORATIVE RESEARCH BETWEEN THE UNIVERSITIES OF CALIFORNIA AT BERKELEY AND RIVERSIDE AND OREGON STATE UNIVERSITY"

FINAL REPORT FOR JANUARY, 2003- JANUARY, 2004
MARCH, 2004

STEPHEN PARK
University of California, Riverside
The Institute of Geophysics and Planetary Physics
Riverside, California 92521
(909)-787-4501;(909)-787-4324(fax)
magneto@ucrmt.ucr.edu

Submitted to:

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

Grant 03HQGR0041

Abstract

Since 1988, continuous measurements of natural electrical currents (telluric currents) have been made in Parkfield in order to detect relative changes of resistivity of 1% or less over both short (days) and long (years) term periods. Small changes of resistivity prior to rock failure, well documented in laboratory measurements, will rearrange the distribution of telluric currents. This rearrangment will manifest itself in changes in telluric coefficients relating electric field strength between dipoles. Fractional changes in these coefficients are computed daily and then compared to the time of local earthquake. Previous work has shown that it is unlikely that changes greater than 0.1% are associated with earthquakes with ML<5.0. Parkfield had only one earthquake with a magnitude larger than 3.0 (ML=3.05), so the lack of significant fluctuations in telluric coefficients in 2003 is not surprising. In the absence of substantial earthquakes, progress was made in the application of robust processing to the telluric data. We identified timing errors in the older data that were degrading the estimates of transfer functions. A retrospective analysis of the past 16 years' of data is proceeding. We are also now refining the 3-D resistivity model by inverting MT data collected from several sources. Reinterpretation of MT data previously published has led to the suggestion that the seismogenic section of the San Andreas fault is actually shifted ~1 km southwest of the surface trace in the vicinity of Middle Mountain.

Introduction

Changes of electrical resistivity and anomalous electrical signals due to compression and shearing of rocks has been observed in many laboratory experiments [e.g., Brace, 1975; Yoshida et al., 1998]. Field observations, although more controversial because of the magnitudes of the changes, have also reported variations of electrical resistivity and anomalous signals prior to earthquakes [e.g., Zhao et al. 1991; Park, 2002]. In all of these cases, fluids play a crucial role in the resistivity changes and anomalous signals because most of the electrical current in crustal rocks is transferred through conductive brines occupying the pore/fracture space of the rocks.

Monitoring Array

Natural electric currents are induced in the earth by a fluctuating magnetic field and are redistributed by the resistivity structure. If the wavelength of the source field is much larger than the dimension of the array, then the electric field measured on one dipole is related to the fields on arbitrarily designated reference dipoles (dipoles 7 and 8, Figure 1) through the following equation:

$$D_i = x\, D_7 + y\, D_8 \,, \qquad (1)$$

where D_i is the signal on dipole i and x,y are the telluric coefficients. X and y are the telluric coefficients which should vary when changes in the electrical resistivity occur. Park [1991] found that the daily variations of the telluric coefficients from long-term average values were still too large to provide stability at the level of 1% or less. Thus, these variations were projected onto average electric field eigenvectors perpendicular (P1) and parallel (P2) to the San Andreas fault. These projections for 2003 are shown in Figures 2-7 for dipoles 1-6, respectively.

The dipoles are constructed electronically by differencing potentials from 5 electrodes in the system Figure 1). Thus, a single electrode will appear in three dipoles. Historically, the line from Lc has always been noisier than the others. Thus, dipoles 2,5, and 6 have always been noisier than the others. Comparison of Figures 2 and 3 reveals that stabilities of 0.1% are achievable on a quiet dipole such as dipole 1 but that noise leads to fluctuations of 0.5-1% on dipole 2. Notice the lack of any change prior to or at the time of the ML=3.05 earthquake on August 28, 2004 (Julian day 241 on Figures 2-7). The only other notable feature in the projections is the loss of dipole 3 (Figure 4) from January 22 (day 022) to March 12 (day 071) inferred to be due to problems with a bad telephone line to Hr (Figure 1). However, that electrode should have also affected dipoles 7 and 8 which are the reference dipoles for the array (1). None of the other dipoles are off scale, so the simple explanation of the telephone line is probably incorrect. Closer examination of dipole 3 reveals that these projections are not plotted because they differ by more than 20% from the annual average. If the cause of this were related to the earth or the telephone line, similar behavior would have been seen on dipoles 7 and 8. I therefore conclude that the problems in Figure 4 must be due to the circuitry and that these were successfully corrected in March. Loop tests, wherein three dipoles forming a loop are summed, confirm that circuitry was the culprit. Because the dipoles are constructed electronically, the sum over a closed loop must be zero in the absence of noise or malfunction (Park, 2002). Loop sums of D5-D2+D3 and D8-D3+D4 are off scale during this period.

Robust Analysis

Several years ago, we began to apply Larsen's robust processing (Larsen et al., 1996) to the telluric data in order to reduce the scatter apparent in Figure 2-7 and therefore increase our sensitivity. Initial attempts produced telluric coefficients that were no more stable than the processing currently used (Park, 1991). In the past year, we have identified a source of the scatter in the errors in timing of the data before 1998 when data were digitized by the Quanterra. Hand synchronization with a satellite clock was used from 1988-1998, and local time was used prior to 1995. With the large number of employees who have worked on the project since its inception, errors were introduced. While we kept records of the time stretch of contraction on the computer clock relative to the satellite time, less clear was whether UT, standard local, or daylight savings time was used. Additionally, some employees were unclear how to apply the correction for daylight savings. We have now adjusted all of the data to a satellite time base and much (some?) of the scatter in the robust processing has vanished. Use of magnetic data from Fresno has also allowed us to examine changes in the MT impedance tensor over time.

Reinterpretation of 1997 MT Data

Unsworth et al. [1997] presented an MT model across the San Andreas fault that showed a conductive zone in the upper 3-4 km that they attributed to a damaged zone consisting of highly fractured rock filled with conductive brine. Because there are Tertiary sandstones and siltstones forming the Parkfield syncline (Figure 8), we suspected that the conductive damaged zone was simply brine-saturated sediments. Samples of these sandstones were collected, and we measured the resistivity of the samples (Figure 9). With brines such as those found in the Varian hole (Figure 8), the sandstone resistivities fall precisely within the ranges estimated by Unsworth et al. [1997]. We offer an alternative suggestion that the conductive zone is really the Parkfield syncline adjacent to the fault and that the active fault is really located ~1 km southwest of its current, mapped trace (Figure 10). This result was published in Park and Roberts [2003].

Parkfield Model

In 2001-2002, we began constructing a 3-D resistivity model of the Parkfield region based on model results from MT data (Unsworth, et al., 1997; 2000; Park et al., 1991; 1996) and dc resisitivty data (Park and Fitterman, 1990). This was a multiscale model that represented the detailed structure in the vicinity of the array with ~100 m blocks and the more distant structure with larger scale lengths. This model and MT data from Unsworth et al. [1997;1999; 2000] have been sent to Randy Mackie for 3-D inversion.

Data Availability

Time series data and processed results are available via anonymous ftp from vortex.ucr.edu (138.23.185.132) in pub/emsoc/1/pkfld. Data from 1988-2003 are presently available. Time series data from 1998-present are also available from the Northern California Earthquake Data Center at UC Berkeley.

Conclusions

No significant fluctuations were observed in 2003, corresponding to a lack of earthquakes with magnitudes greater than 3.05. Robust processing has been improved by correcting the data for timing errors. Auxiliary work on rock properties leads to the suggestion that the seismogenic zone may be shifted 1 km southwest of the mapped trace of the San Andreas fault. Finally, work on a 3-D Parkfield model is proceeding.

Bibliography

Park, S.K. and J.J. Roberts, Conductivity Structure of the San Andreas Fault, Parkfield, Revisited, Geophys. Res. Lttrs, 30, doi:10.1029/2003gl017689, 2003.

References

Brace, W.F., Dilatancy-related electrical resistivity change in rocks, *Pure Appl. Geophys., 113*, 207-217, 1975.

Larsen, J.C., Mackie, R.L., Manzella, A., Fiordelisi, A., and Rieven, S., Robust smooth magnetotelluric transfer functions. *Geophys. J. Intl., 124*, 801-819, 1996.

Park, S. K., Monitoring resistivity changes prior to earthquakes in Parkfield, California with telluric arrays, J. Geophys. Res., 96, 14, 211-14,237, 1991.

Park, S.K., Perspectives on Monitoring Resistivity Changes with Telluric Signals at Parkfield, California: 1988-1999, *J. Geodynamics, 33*, 379-399, 2002.

Park, S.K. and D.V. Fitterman, Sensitivity of the telluric monitoring array in Parkfield, California to changes of resistivity, *J. Geophys. Res., 95*, 15,557-15,571, 1990.

Park, S.K., B. Hirasuna, G.R. Jiracek, and C. Kinn, Magnetotelluric evidence of lithospheric thinning beneath the southern Sierra Nevada, *J. Geophys. Res., 101*, 16241-16255, 1996.

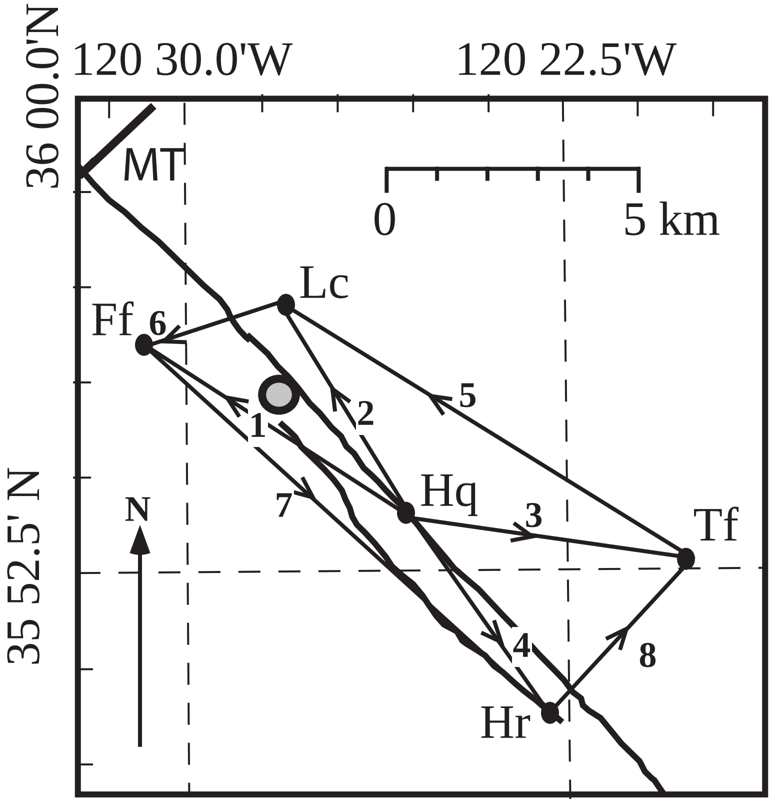
Unsworth, M., P. Bedrosian, M. Eisel, G. Egbert, and W. Siripunvaraporn, Along strike variations in the electrical structure of the San Andreas fault at Parkfield, California, *Geophys. Res. Lett., 27*, 3021-3024, 2000.

Unsworth, M.J., P.E. Malin, G.D. Egbert, and J.R. Booker, Internal structure of the San Andreas fault at Parkfield, California, *Geol. 25*, 359-362, 1997.

Yoshida, S., O.C. Clint, and P.R. Sammonds, Electric potential changes prior to shear fracture in dry and saturated rocks, *Geophys. Res. Lett., 25*, 1577-1580, 1998.

Zhao, Y., F. Qian, and T. Xu, The relationship between resistivity variation and strain in a load-bearing rock-soil layer, *Acta Seismol. Sinica, 4*, 127-137, 1991.

Figure 1 - Location map showing array in Parkfield. Dipoles 1-8 are labeled and polarities are shown with arrows. Heavy b lack lines are strands of the San Andreas fault. Dipoles 7 and 8 are used as references for dipoles 1-6. Electrode locations are labeled dots. Grey circle is only earthquake above M3.0 to occur in Parkfield in 2003. Line labeled 'MT' is the profile reinterpreted by Park and Roberts [2003].



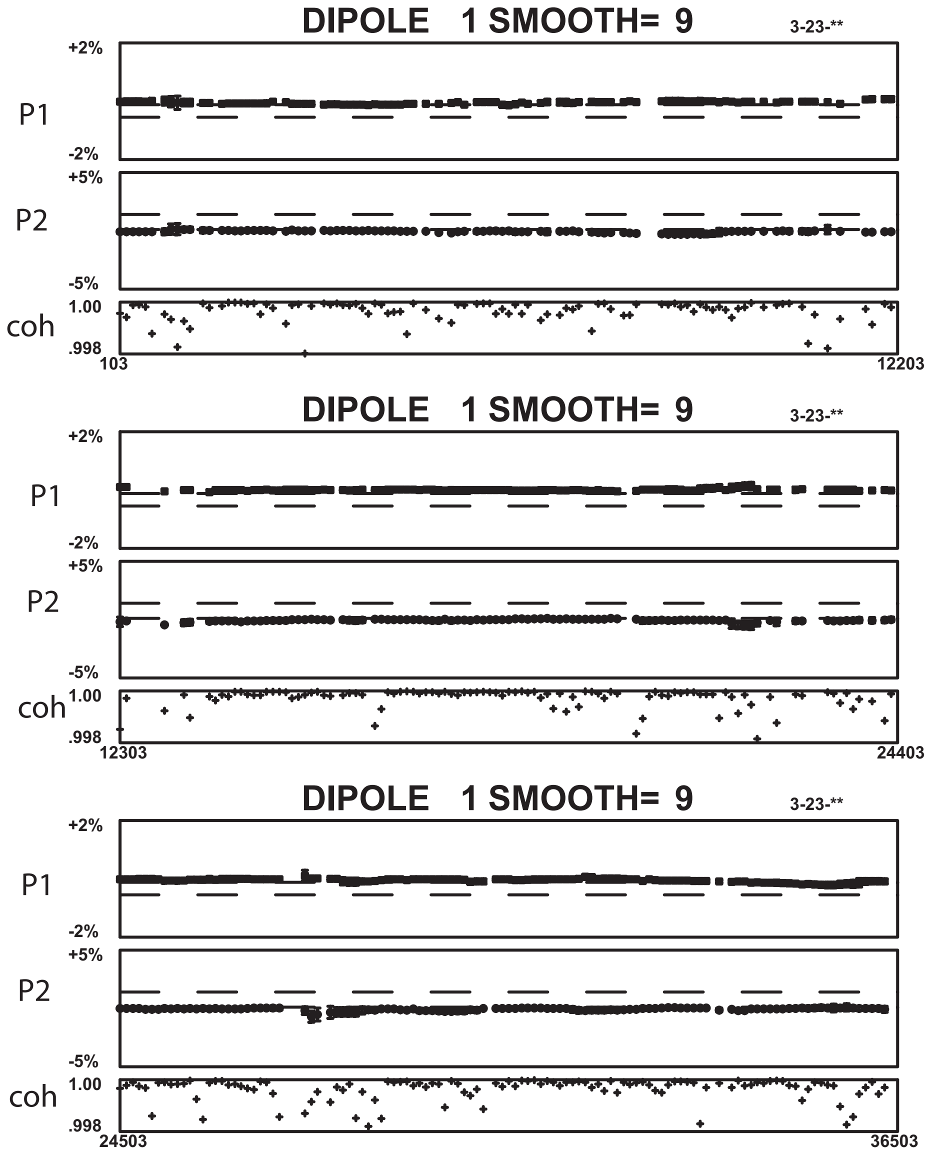


Figure 2- Projections of daily fluctuations of telluric coefficients for dipole 1 in directions perpendicular (P1) and parallel (P2) to the San Andreas fault. Coherency for the signals is shown as a measure of data quality. Nine day running average is used to smooth out the daily fluctuations and achieve stabilities of < 1%.

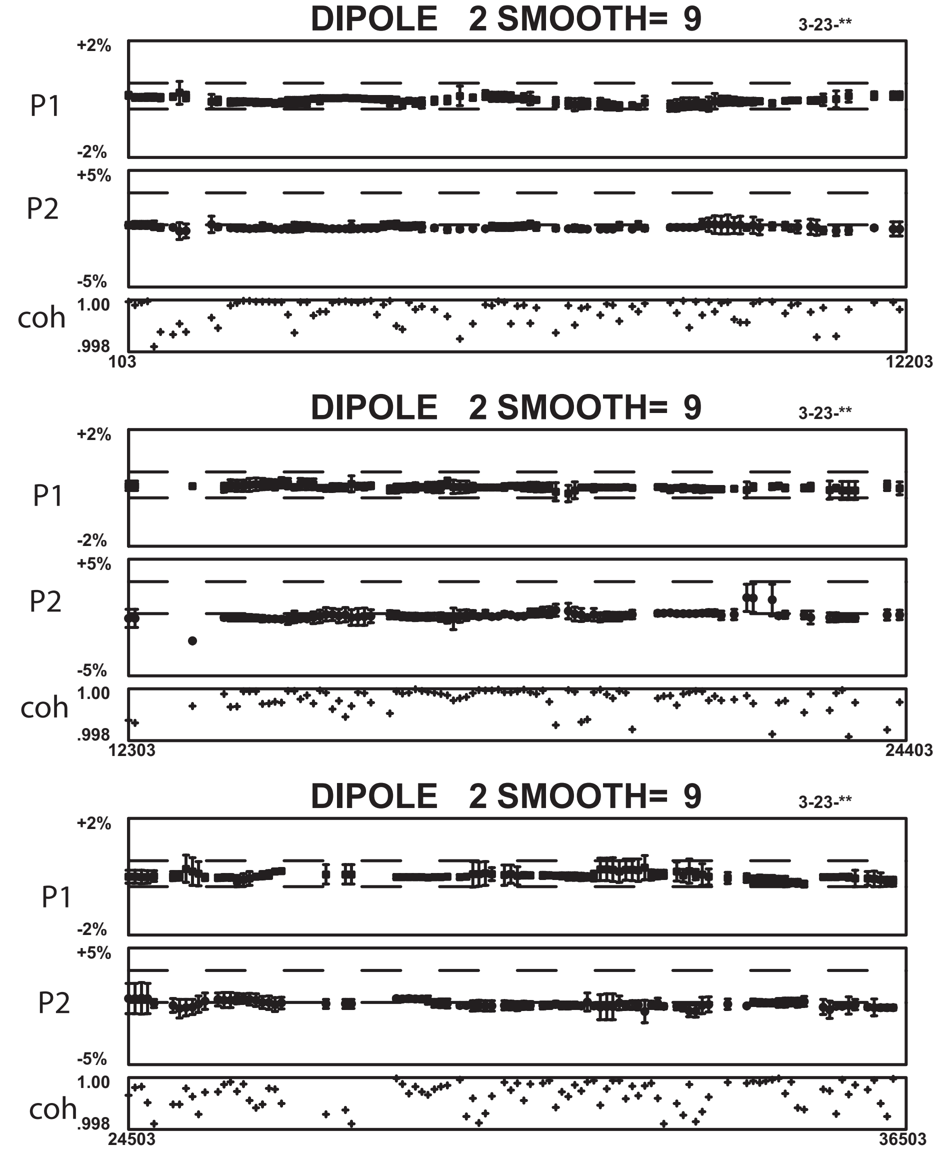


Figure 3- Projections for dipole 2 for 2003. See Figure 2 caption for explanation. Note that this dipole is much noisier than dipole 1, as indicated by the larger error bars. Gaps in data are due to noisy telephone line to electrode at Hr (Figure 1).

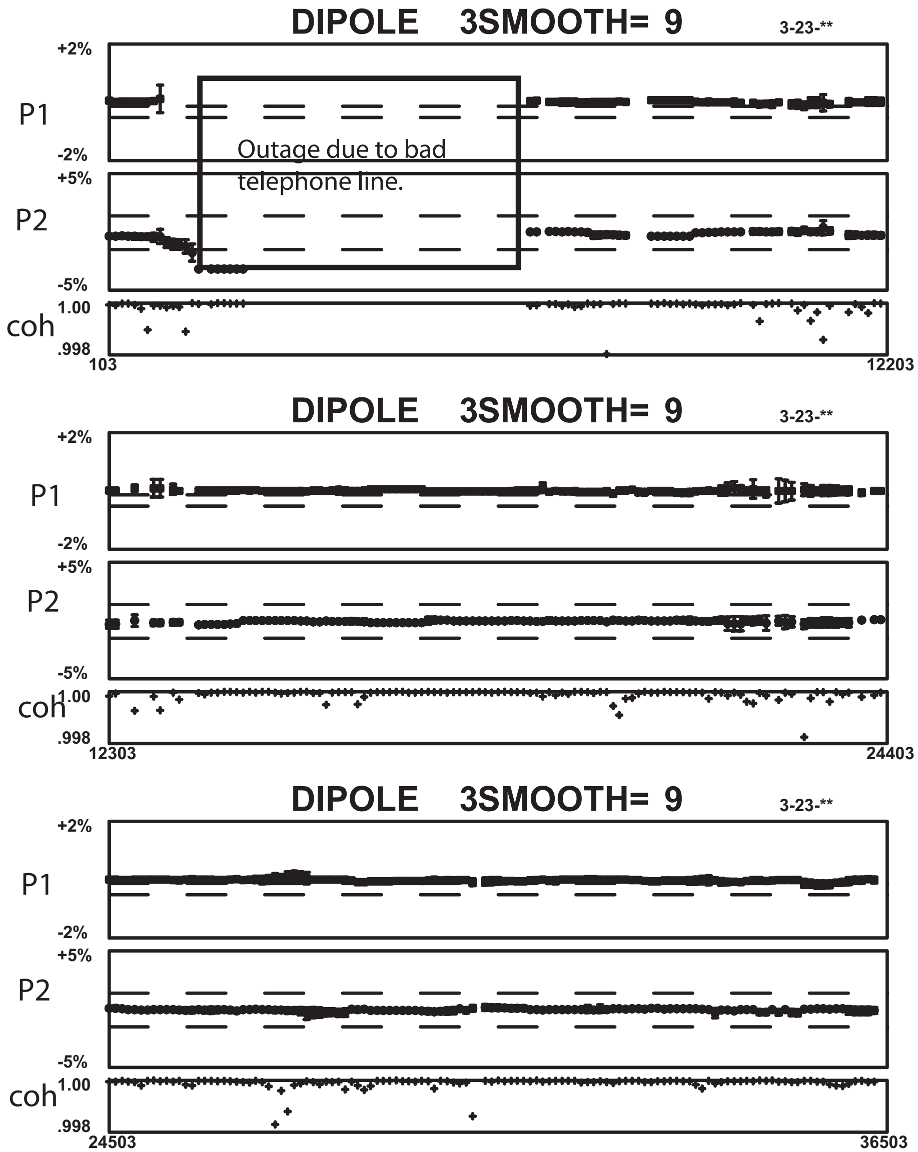


Figure 4- Projections for dipole 3 for 2003. See Figure 2 caption for explanation.

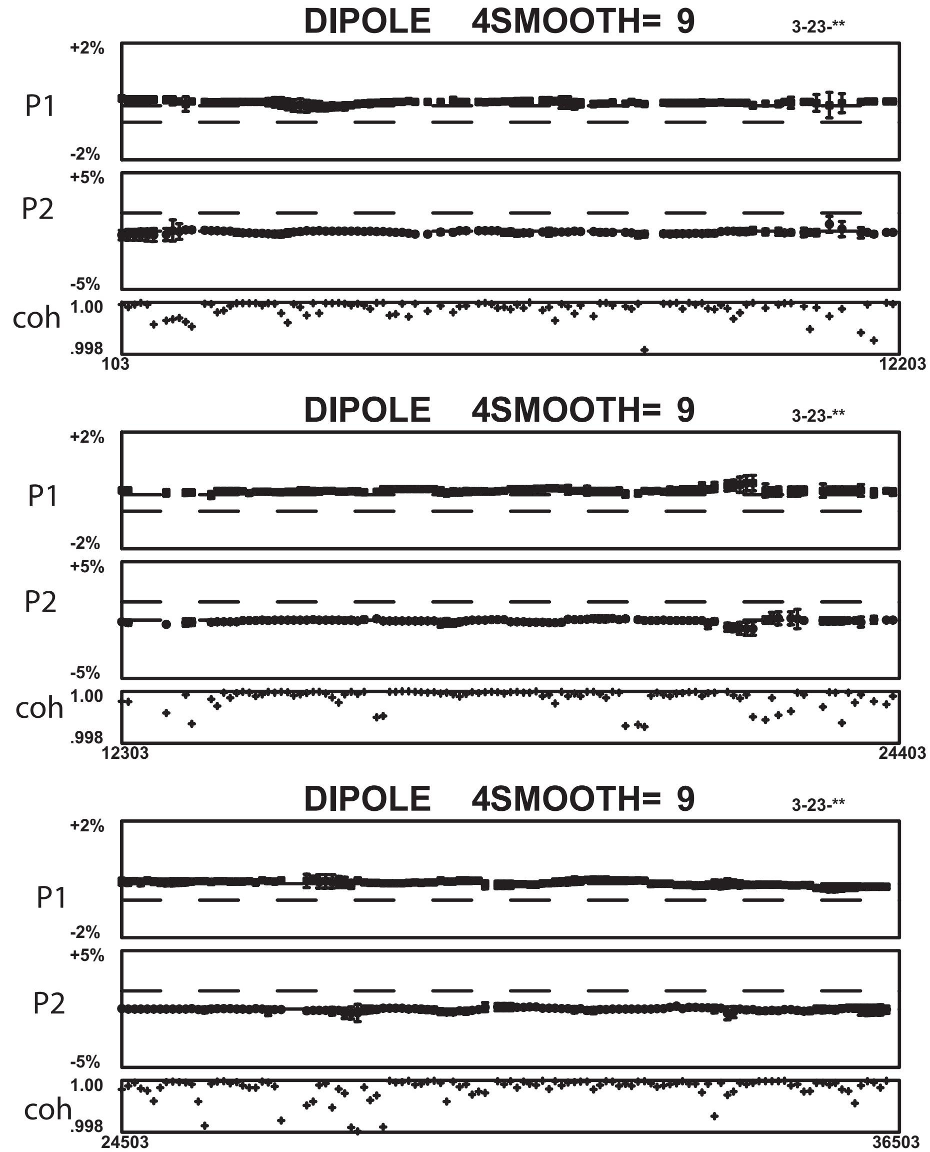


Figure 5- Projections for dipole 4 for 2003. See Figure 2 caption for explanation.

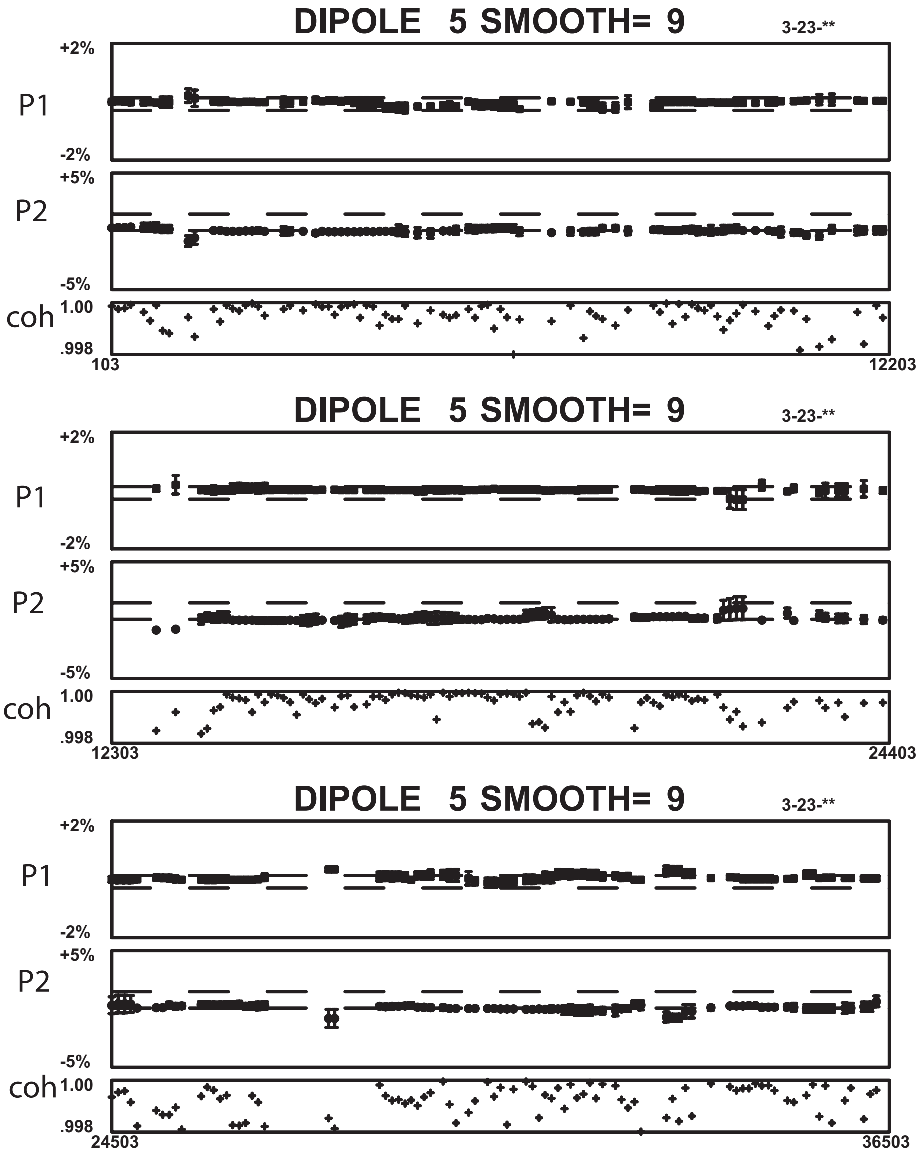


Figure 6- Projections for dipole 5 for 2003. See Figure 2 caption for explanation.

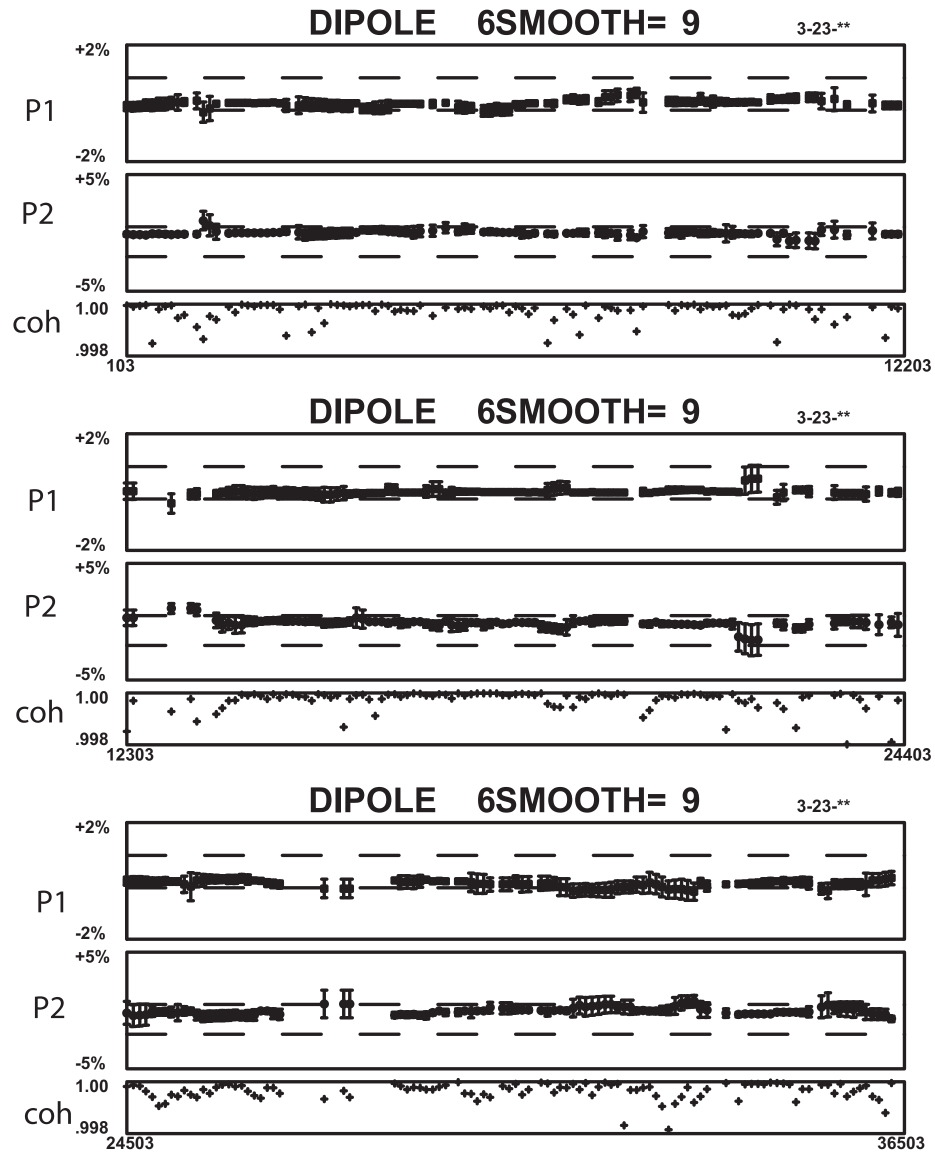


Figure 7-Projections for dipole 6 for 2003. See Figure 2 caption for explanation.

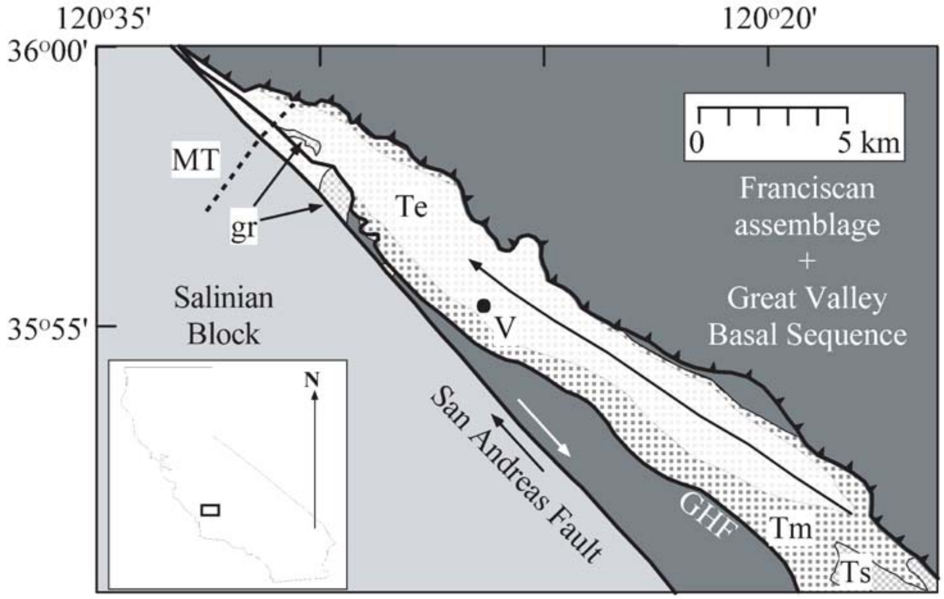


Figure 8 - Generalized geologic map of Parkfield region from Park and Roberts [2003] showing Parkfield syncliine with Tertiary Monterey (Tm) and Etchegoin (Te) formations. Other symbols used are gr, granite; GHF, Gold Hill fault; Ts, Tertiary Sandstone; and V, Varian Ranch. Samples from the Etchegoin formation were analyzed in the laboratory.

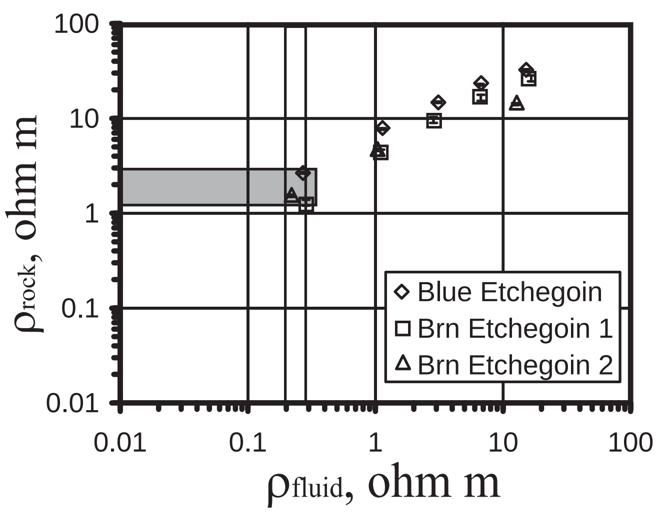


Figure 9 - Measurements of electrical resistivity of Etchegoin samples from Park and Roberts [2003]. Fluid resistivities from the Varian hole are shown on the figure and the grey region is the range of resistivities identified by Unsworth et al. [1997] for the damaged zone of the San Andreas fault. Note that the resistivities for the Etchegoin samples fall within this grey region.

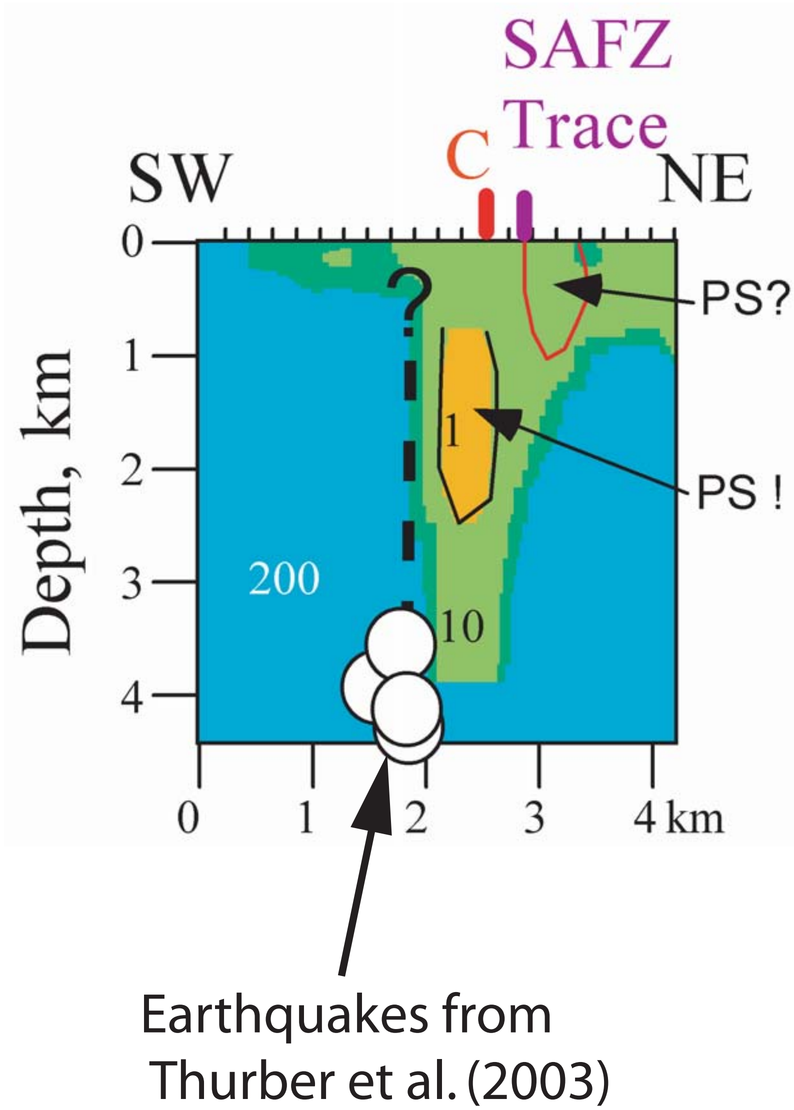


Figure 10- MT-derived resistivity section showing expected location of Parkfield syncline (PS?) and proposed location (PS!). Dashed line is proposed location of seismogenic San Andreas fault to southwest of Parkfield syncline. Other symbols used are: C, crest of Middle Mountain; SAFZ trace, surface trace of San Andreas fault zone.