This paper is not for publication or distribution. It is based upon field observations made using an array of rubidium magnetometers operated along the San Andreas fault in the mid-60s. The interpretation and conclusions based upon that field experiment long ago were sufficiently intriguing and presumptuously profound that I want to repeat the above field experiment knowing now what is critical and more about what the mechanism behind the observations than I knew then. In this paper, I pretend that I have either concluded the lab experiment and/or found the results I am looking for and have conducted the repeat of the field observations – confirming what I had earlier reported. Moreover, The act of writing this (putative) paper forces discipline to what lab and field experiments would be necessary to support and confirm, to some degree, the interpretation and conclusions.

Geomagnetic Indications of Apparent Deep Crustal Deformation
(Draft of proposed paper to follow lab and field confirmation)
Sheldon Breiner 15 August, 2006

Introduction

Magnetic field changes associated with local earthquakes have been widely reported for many decades (ref XX). Explanation of such magnetic events include anomalous electric current associated with streaming potential, changes in conductivity related to fracture or dilation of rocks, electrostatic or piezoelectric field changes associated with "earthquakes lights", and stress-induced or strain-dependent resistivity changes modifying the induced electric current from micropulsations. Other explanations included mineralogical phase changes of ferrimagnetic rocks, stress-dependent magnetization, and others, XX.

In spite of the large body of literature describing these observations, none of the above phenomena has been observed on a sufficiently reproducible basis to achieve acceptability by the scientific community. Lack of reproducibility or predictability has, in some cases, been limited due to the paucity of seismic, strain or other correlative events often used to mark the occurrence of such events. In other cases, the repeated, dependable observation of these geomagnetic events has been limited by instrumentation constraints or the result of non-systematic, opportunistic experiments.

It is the purpose of this paper to present the combined results of new and old observations of magnetic field changes associated with surface creep of the San Andreas fault in California and the results of recent laboratory experiments supporting a piezomagnetic explanation for the observations. The theories and observations presented are not intended, however, to explain other reported changes in local magnetic field associated with earthquakes.

Reports have appeared in the literature for more than five decades (See Nagata, Kapitsa, XX) demonstrating that magnetic susceptibility and remanent magnetization is stress dependent. Early experiments were conducted to support the of study rock magnetism. Later studies were largely driven by the need to better study the paleomagnetism of surface rocks to aid the understanding of plate tectonics. All such studies of the stress-dependence of magnetic susceptibility were conducted at room temperature typically using astatic magnetometers and mechanical presses. For all of these objectives, room temperature experiments were considered satisfactory.

This stress dependence of magnetization also inspired efforts to conduct field observations of magnetic field changes associated with earthquakes and deformation. Such field experiments, variously described as *piezomagnetism, inverse magnetostriction, tectonomagnetic effects or seismomagnetic effects* were reported by Johnston, Rikitake, Breiner, (XX) and others. They all relied upon the above body of laboratory evidence to explain and predict observed changes in the local magnetic field.

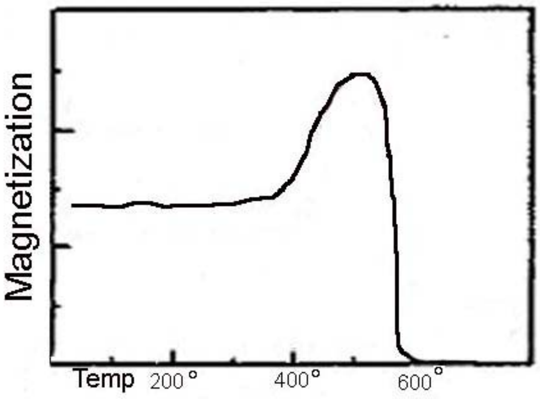
Provided that laboratory evidence or theory can reconcile observed local magnetic field changes with deformation due to tectonic creep or earthquakes, there is a basis, but not necessarily proof, that these magnetic field changes are due to piezomagnetism arising from stress changes related to deep-seated deformation of the crustal rocks.

The possibility also exists that the observed changes in magnetic field are due to the same changes in stress, but which modulate the electrical resistivity (or conductivity) of the rocks and cause changes in telluric currents. Telluric currents are electrical currents in the subsurface strata induced by the magnetospheric current system, a million-ampere current flowing eastward at the magnetic equator on the sunlit side of the earth. The stress-induced changes in resistivity would then manifest themselves as local magnetic field changes. Looking very similar to piezomagnetic events from the surface of the earth, such changes would be sharply different, if such putative resistivity changes had a dramatic difference between observed magnetic events associated with stress events occurring on the night-time versus sunlit side of the earth. Such observations as reported here do not support this resistivity-related basis for these magnetic events. Therefore, for the sake of this paper, local magnetic events associated with creep or earthquakes will be assumed to be originating from piezomagnetic effects. As a practical matter, except for the modeling and laboratory results, the source of local magnetic events -- whether they be due to the effects of stress on resistivity or magnetization -- may not make a difference in the conclusions, other than not being representative of good science.

Field experiments designed to observe seismic- or strain-related events are governed by phenomena that occur at depths which are the consequence of tectonic stress, deformation and shear. At such depths, typically from a few to tens of kilometers, the temperatures are in the range of hundreds of degrees centigrade. Therefore, all field experiments to observe and explain the relationship of stress or strain to local changes in magnetic field must be based upon appropriate laboratory experiments that relate stress changes *and temperature*, especially high temperature, as independent variables and magnetization changes as the dependent variable.

In fact, it will be demonstrated herein that the magnitude of observed piezomagnetic effects and the probable mechanism must involve stress and magnetization phenomena at considerable depth, i.e., under conditions of high temperature and pressure. Conversely, there may not be any observable stress-related effects in the magnetic field large enough to be observed at shallow depths, that is, at depths corresponding to temperatures less than about 100° C or less than 10 or 15 km, in the brittle zone.

The Hopkinson Peak



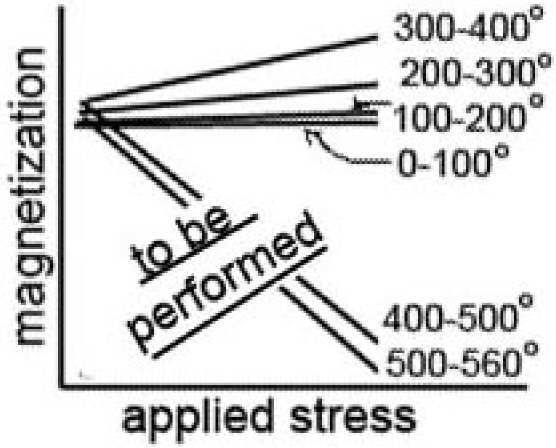
Nagata and others (ref XX) have published laboratory studies of the variation of magnetic susceptibility of magnetite with temperature (see Figure Y). Magnetite is but one representative mineral of the class of spinels or titanomagnetite. In general, most petrologists and rock magnetics workers operate on the premise that magnetite is the principal ferrimagnetic mineral in the earth's crust. Magnetite loses its ferrimagnetic properties at temperatures exceeding the Curie point, which, for magnetite, is 560 ºC. The Hopkinson peak is a sharp change with temperature of magnetic susceptibility from about 400 ºC. to the Curie point [expand and confirm]. Note that the inflection point at which the temperature dependence of susceptibility begins to change is very abrupt.

Each specie of the spinel series exhibits a different inflection point (≠ 50 ºC), though it retains its abrupt onset characteristic. This behavior of magnetic susceptibility at such temperatures [check on whether the higher temp dependence is Hopkinson] is described as the *Hopkinson Peak* (ref XX).

Magnetic susceptibility and remanent magnetization can be characterized as the macroscopic response of magnetic domains to the applied magnetic field, i.e., orientation of domains and geometry and movement of domain walls. These domain phenomena are very temperature dependent, increasing their mobility with temperature up to the Curie temperature. It stands to reason, therefore, that the special, particularly non-linear, behavior of magnetic susceptibility and remanent magnetization in the Hopkinson range, being largely of a mechanical nature, would also be very evident on the effects of stress on magnetic susceptibility. On this theory, the author predicted that the piezomagnetic effect of magnetite-bearing rocks would be substantially greater, possibly by a factor of ten or more, than that indicated by the room temperature experiments from the then current body of literature.

Laboratory Experiment for Hopkinson Effect

(This is a putative experiment, not yet conducted, but with the goal of observing the Hopkinson Effect as it relates to the piezomagnetic effect.]
A laboratory experiment was conducted to confirm the predicted behavior of stress and temperature on the magnetic susceptibility of rocks. The experiment was comprised of a phosphor-bronze mechanical press; a small refractory oven through which the arms of the press passed; thermistors in the oven near the sample; and one of a pair of cesium magnetometer sensors placed 15 cm. from the oven along the direction of the local magnetic field vector (to enhance the effects by a factor of two). Various samples, typically cylindrical cores 3 cm.. long and 3 cm. in diameter, of magnetite-bearing rock were subjected to uniaxial stress by turning the screws of the press after the temperature was raised to various equilibrium temperatures at intervals of 50 ºC. See Figure Y.



From these results one can predict for a series of rock layers, each equivalent to vertical thicknesses of 100º C, the magnetic effects of a given increment of stress. It is expected that there is a substantially larger effect for those layers at depths corresponding to the "Hopkinson range." In any calculations for a piezomagnetic effect, then, the temperature would have to be incorporated into the integral for the computation of the piezomagnetic anomaly expected as a function of the stress applied to this region, more or less as,

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$$\mathbf{P}(Z,S,T) = \int_{T_2,S}^{T_1,S} C \int_{X_1,Y_1,Z_1}^{X_2,Y_2,Z_2} M$$

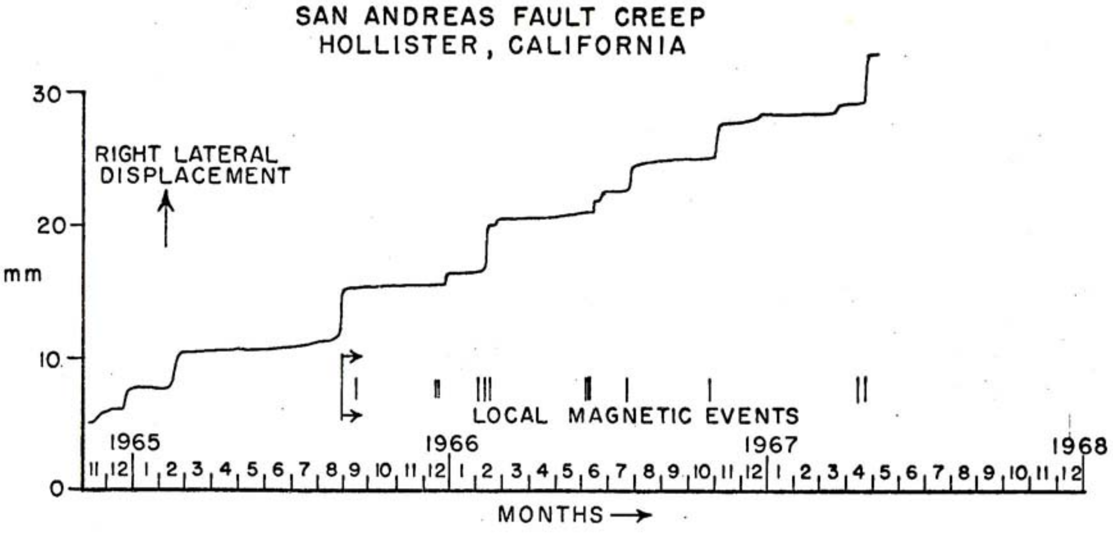
where P Is the piezomagnetic anomaly amplitude Integrated from depths Z1 to Z2 calculated on the basis of the piezo-transducing factor, C, at T1 and T2 the temperatures at the depths corresponding to Z1 and Z2**,** M, the magnetizations at those temperatures, and S, changes in stress.

The definitive laboratory experiment, from a theoretical respect, would be performed under hydrostatic stress comparable to that present at the depths where the changes in stress are supposedly occurring, namely, from X to Y kilometers. After all, it is the behavior of domains, their orientation and wall movements that are of interest and the mobility of these variables might very well depend upon the ambient pressure as well as the temperature.

Field Observations

Data were collected at various locations at ground zero over an underground nuclear explosion at Yucca Flats in Nevada; telluric arrays in California; and magnetometer arrays in active seismic areas in Matsushiro, Japan; Mount Borah, Idaho; Imperial Valley, California; Southeastern Missouri; Fairview, Nevada; and elsewhere.

The most productive experiment was a differential rubidium magnetometer array set up on the San Andreas fault from San Francisco to Hollister, California, and operated for about 2 years. Part way through the experiment, interesting magnetic events were noted in the Hollister area and the array was modified to place more instruments in that area. This area of the San Andreas fault in the vicinity of Hollister is the junction of several fault systems: the San Andreas, Hayward and Calaveras faults. The region is recognized for the occurrence, across a distance of less than 1 km, of tectonic creep totaling 5 cm/yr -- the yearly average for plate boundary displacement. (This is, in fact, the point that represents the southern terminus of displacement of the 1906 earthquake on the San Andreas fault, not a surprising fact considering its annual rate of slip.)



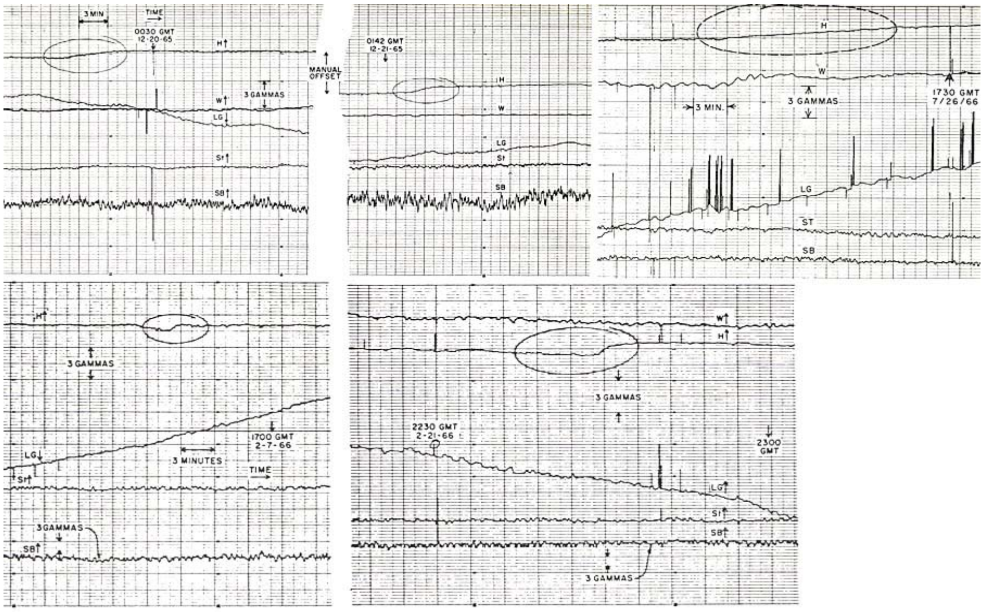
Figure

Creep has been monitored for several years in and around a local building (a winery) built across the active trace of the San Andreas fault where individual creep events each with a displacement of about 5 mm, were observed using linear variable differential transformers (LVDTs) to measure the displacement of adjacent concrete blocks in the building. Local earthquakes usually follow such creep events, particularly larger creep events and should probably be considered aftershocks of the zero-frequency earthquake, adjusting to the new local strain environment. Creep observations are, at best, inaccurate quantitatively, but are reliable as qualitative indications of a strain event.

For the objective of observing the piezomagnetic effect, that is, the relationship, if any, between magnetic events and changes in stress and/or strain, this area is considered to be a useful field site, partly due to the correlative strain information available and the frequency of local strain events.. The author conducted such studies from 1965 through

1967 (ref XX). The magnetometers used for the field experiment utilized an array of five rubidium magnetometers, each with a resolution of 0.01 nanoTesla.

For the 23 month period of the study, local magnetic changes were observed that appeared to precede by a few hours to a few days local creep events.



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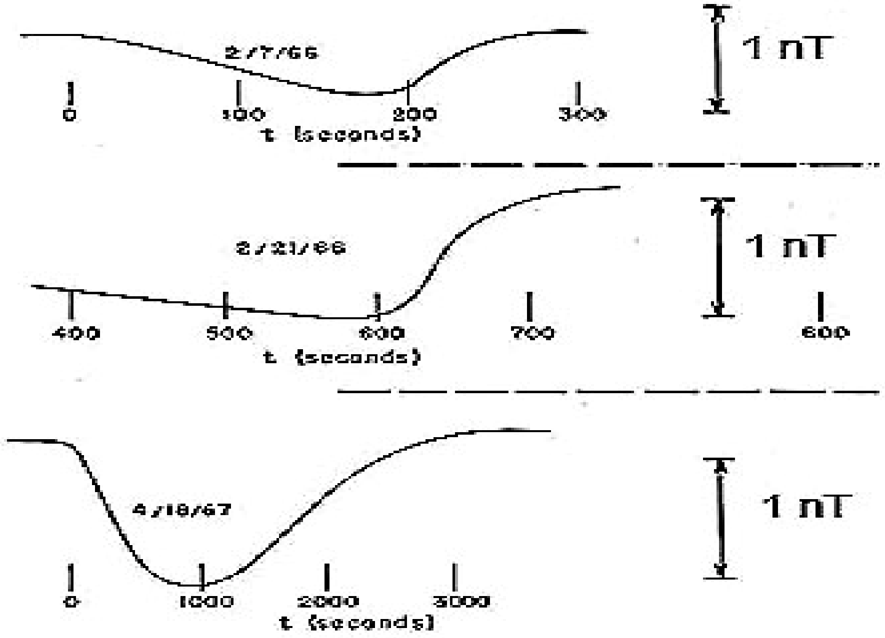
Sample piezomagnetic events -- rubidium magnetometer array

Figure

The magnetic events, some of which are shown in Figure __, exhibit a decrease in the local magnetic field with a duration of five or ten minutes or somewhat longer and an amplitude of one or two nanoTesla. The events also exhibit intriguing characteristics which, if caused by the piezomagnetic effect, are thought to be diagnostic of the stress-induced source mechanism.

Piezomagnetic Events

(rubidium magnetometer array)



[The following is a proposed repeat field array.] To confirm the reality of these events, the above field experiment was repeated using an array of proton precession magnetometers established in the same region and operated for 18 months. Proton magnetometers have the ability to measure the absolute intensity of the magnetic field with sufficient sensitivity to observe the expected piezomagnetic anomalies.

Observations with the proton magnetometer array confirmed the local magnetic events and are shown in Figure B. Table C shows the creep events and local earthquakes which occurred during the period of the observations. The results of the correlation of magnetic field events, creep events and earthquakes are summarized in Table A.

The model on which the findings are based is as follows: The crust in this area of the San Andreas fault can be characterized as the brittle zone from surface to the depths of the foci of observed earthquakes, or about 20 (*confirm)* kilometers. Below that depth, the ductile zone responds plastically to changes in stress. The region which overlaps these zones, that is, the t*ransition zone* and, for the purposes of this paper, is estimated to be approximately 10 (*confirm)* kilometers in thickness, with its upper extent at an average depth of 15 kilometers.

This region of the San Andreas, arguably tectonically anomalous, exhibits creep events every six months or so. Shear stress is transferred from the underlying, always-moving North American and Pacific plates to the rocks in the transition zone above. These transition rocks, through increased pore pressure or the time-dependent behavior of ductile materials, respond with strain, transferring the stress to rocks above them in a slowly rising 'stress bubble'. Once the stress, and consequential strain, reaches the shallower brittle region in, say, the upper 10 to 15 kilometers of the crust, these brittle rocks react through shear. In this *very anomalous area*, this shear *occurs* in minutes, hours, days, we recognize as creep. In most other areas of the San Andreas fault, the same stress at the transition/brittle zone interface would cause the brittle zone rocks above to shear in seconds as an earthquake. Exactly what is unique about this brittle zone in Hollister to shear more slowly is not known, other than there being a low-friction fault plane, high pore-pressure or some similar low-strength, easy path of resistance.

This area around Hollister is, for the reasons above, almost ideal as a laboratory for such tectonic observations to enable us mortals who must have results in months or a very few years to allow us to publish papers. On the other hand, it is important to derive a meaningful model that applies more generally to regions of the San Andreas and perhaps other fault systems. What is it that can be learned from this Hollister model that either scales or extrapolates to other regions, say, the northern San Andreas fault that empirically responds to plate movements through earthquakes rather than creep?

The principal difference between Hollister and much or all of the San Andreas fault north of Hollister would appear to be in the response of the brittle region. Arguments could be made that it is the transition region that is anomalous, however, the deeper one goes the more uniform the rock characteristics. It is also more difficult to postulate a plausible model with an anomalous transition zone.

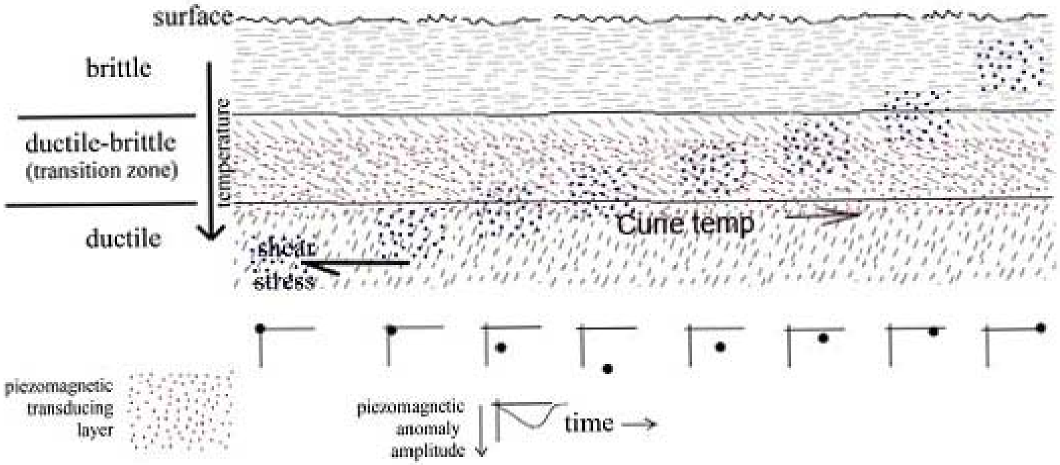
Piezomagnetic Transducing Zone

The average depth of the Curie isotherm is estimated to be D1 kilometers and is based upon the geothermal gradient [*calculate or research this*]. This layer of Y kilometers corresponding to the upper and lower limits of the Hopkinson Effect, is the layer which provides most of the measurable signal of the piezomagnetic effect.

Based upon the laboratory data, the stress-induced magnetic susceptibility (and possibly, some remanent magnetization) changes are based upon the value of what we shall call the *piezomagnetic factor*, the change in observed magnetization per unit stress, the larger the factor, the larger the piezomagnetic effect for a given stress increment. For a piezomagnetic event large enough to observe over the background geomagnetic noise, the rocks under stress have to be within the temperature range of about 200° C and 560° C. That translates to a band of rocks from XX kilometers to YY kilometers which we shall call the *piezomagnetic transducing zone*.

As this stress bubble rises and reaches depths that correspond to temperatures lower than 560° C, the magnetite in the rocks, modulates the geomagnetic field sufficiently to act as a stress transducer, in effect transmitting signals, measurable at the surface, that represent an analog of these stress changes at depth. This is, effectively, the definition of piezomagnetism and, from this, its utility as a tool for a better understanding of the 'micro-process' that takes place at a this site and other such locations of active tectonic deformation.

It is proposed that, when the rocks in the ductile region have moved sufficiently to create shear stresses exceeding the strength of the rocks in the transition zone above them, the vertical component of stress vector is transmitted upwards as shear takes place in the lower transition zone. Just before the shear of the transition zone, the shear stress increases in this piezomagnetic transducing zone increasing the volume of the transducing zone being subjected to stress. In other words, both the volume and the magnitude of stress increases, contributing to the magnitude of the piezomagnetic signal. This model is computed by integrating both the piezomagnetic stress/magnetization factor over the volume subjected to stress.



Figure

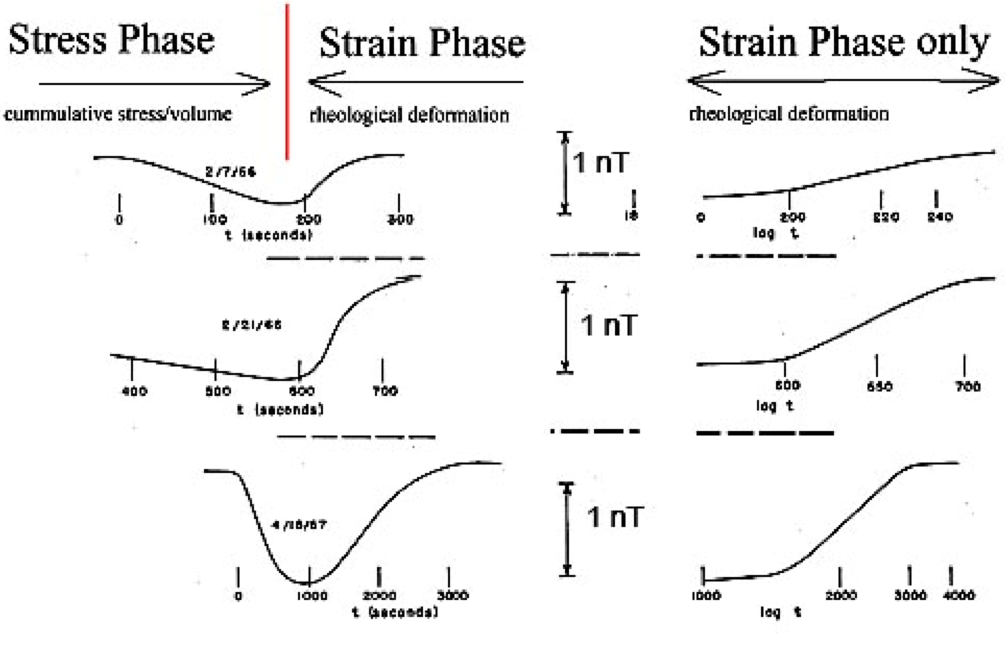
The episodic shear starts in the upper ductile and, perhaps, lower transition zone where the real action is taking place. Then, it passes through that part of the transition zone co-located by the piezomagnetic transducing zone producing a magnetic signal. This stress increases until it translates to strain, i. e., the rocks shear. The stress magnitude in the transducing zone returns to the pre-stress level. Meanwhile, the stress 'wave' travels upwards (horizontally, as well) through rocks of lower temperature out of the transducing zone.

While the stress increases in this brittle zone, the (observable) piezomagnetic anomaly reduces to zero. By invoking the experimental laboratory results, it can be demonstrated that the piezomagnetic signal, for temperatures in the shallow, upper brittle zone at temperatures of less than T ºC, does not create an observable piezomagnetic effect because the stress/magnetization factor is too small to be seen in the presence of normal geomagnetic noise (chiefly, micropulsations).

One might ask whether a piezomagnetic effect might not be seen if the transducing zone is below the transition zone, say, in the ductile region, where the rocks are not subjected to high values of stress. The ductile/transition zone and the piezomagnetic transducing zone are both strongly temperature-determined. The ductile and lower transition zones exhibit their elastic behavior at pressures at about 15 km depth and deeper and temperatures exceeding 500° or 600° C. Since the transducing zone ceases at depths deeper than those depths where the temperatures exceed the Curie point at 560° C, the transducing zone will always be shallower than the ductile zone.

Time as a Factor – Rheological Response

Assuming that this model holds, analysis of the signature of some of the piezomagnetic events suggests that there might be a time factor involved. One can divide the signature in two distinct phases, the first, a linear stage,, called the "stress" phase; and the second, a logarithmic stage, called the "strain" phase. Note that in some cases (in about half the instances) as can be seen in the right hand side of Figure S, it is only the Strain Phase that was observable. The Stress phase, presumably occurred at an earlier time (most likely hours earlier) and with an amplitude of only 1 or 2 nT, equal to this Strain Phase, that it was not easily discernible.



Because the rocks involved are still in the transition zone, they exhibit a behavior characteristic of plastic deformation. Such deformation has a time constant and responds logarithmically. In fact, the response time for this deformation to occur is an important piece of evidence characterizing the actual deformation of the rocks under high stress and temperature. It is this time constant and the conditions that define it, such as the time required for pore fluids to invade the rocks, perhaps the asperity of the rocks or rheological factors, to name a few.

This time constant, therefore, is really the most interesting phenomenon of these piezomagnetic events, punctuated by the 'solitary' appearance of the Strain Phase without its antecedent Stress Phase as cited above (right side of Figure X). Assume that the Stress Phase actually occurred at some time before the solitary Strain Phase, at a time of perhaps hours or days. The piezomagnetic magnitude of the associated Stress Phase signal will, of course, have been equal to what appears in the Strain Phase. It would appear as though the stress is applied for a period of time before the ensuing shear accommodates such forces.

In other words, there is a time constant involved in this process for the strain to respond to this applied stress. This is not unusual in laboratory experiments of rheological deformation of materials under heat and pressure. The time constants for rheological experiments on plastic or ductile behavior under high pressure and temperature, are often very long relative to what is observed in normal laboratory conditions.

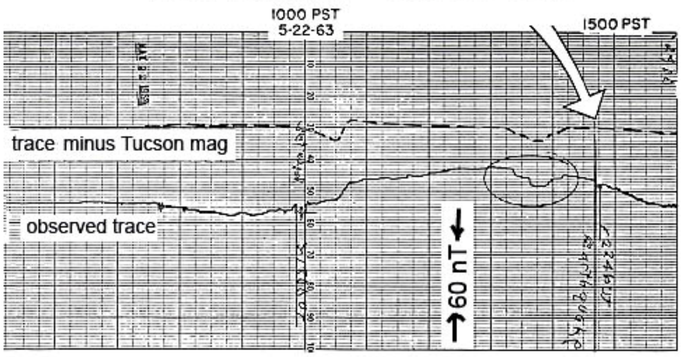
A further indication of a possible time constant in the Strain Phase is the empirical observation that while each of the Strain Phase signals exhibits a different signature, they all have the same macroscopic appearance and suite of sub-phases: early rise time, a linear portion, inflection point, asymptotic finish, etc.

Earthquake-related magnetic events

For comparison of creep-related and earthquake-related magnetic events, consider the observations of the observed magnetic changes that occurred in connections with two earthquakes on the San Andreas north of Hollister. One with a magnitude 4.6 in 1963 and the other, the Loma Prieta in 1989 with a magnitude 7.1.

In the case of the magnitude 4.6 event, a magnetometer operated by the Radioscience researchers at Stanford University and examined regularly for events that might be relevant. A record from a horizontal-force magnetic variometer is shown at right from an earthquake 19 km from the magnetometer. There appears to be a magnetic event a few hours before this 4.6 magnitude earthquake.

M 4.6 earthquake -- epicenter 19 km

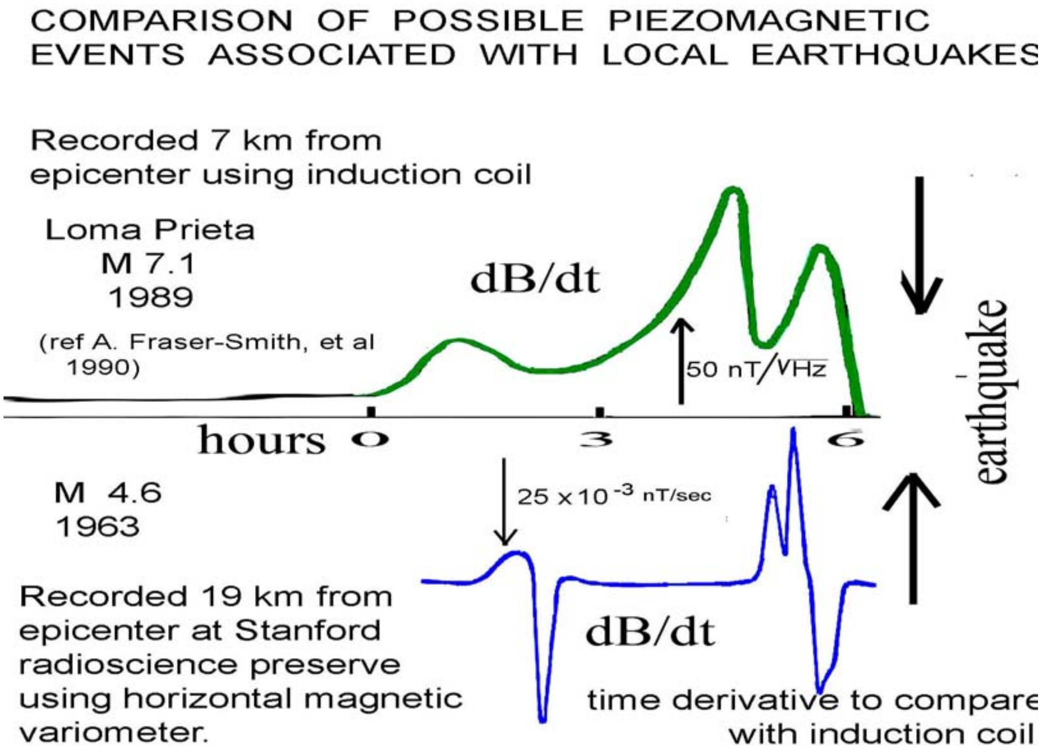


Possible piezomagnetic event before local earthquake
Stanford University Radioscience Field Site 501

Figure

Fraser-Smith (1990) recorded data from a set of induction coils, serendipitously placed beforehand only 7 km from the magnitude 7.1 Loma Prieta earthquake in California on October, 1989. The only signals of interest came from the low-pass coil with a bandpass of 0.01 to 10 Hz. The magnetic data from an induction coil is only the time-varying magnetic field, or 'dB/dt' and as such cannot be compared directly to the measured observations from the other magnetometer at Stanford which records magnetic field directly. However, it is possible convert the magnetic field recording to one which is time varying by computing its time derivative. The results are shown in

Figure below with the Stanford magnetic recording and the Loma Prieta plotted on the same time scale for qualitative comparison



Figure

The nature of the information appears very similar in that there are two distinct events a few hours before and another set of sinusoids more complex just before the local earthquake in both cases. {check and compare amplitude]

Both of these recorded magnetic events might be piezomagnetic in origin. Additionally, these events, if indeed they are piezomagnetic, support the deformation model enumerated above where plastic shear takes place in the ductile zone (maybe 25 km or deeper) and works its way up through the transition zone before it results in shear as an earthquake. The time constant, or supposed time between application of stress in the transducing zone and its consequential strain of a few hours, is more-or-less the same as that observed before the creep-related events and the possible piezomagnetic-related earthquake event reported here. The magnetic change associated with the Stanford-recorded earthquake is about 10 times that observed for the creep events at Hollister (notwithstanding that the earthquake event represents the horizontal component of the magnetic field and the creep events, the total field vector, about 65° from the horizontal). Both the earthquake and creep events occur episodically, breaking through to the transition zone and eventually reaching the brittle zone. There it either produces tectonic creep, if that is the nature of that region of the fault, or results in shear producing an earthquake.

Conclusions

The significance of these findings lies in the applications of this information to rheology and deformation of crustal rocks by tectonic forces. What is particularly interesting is the interpretation of the time signature of the piezomagnetic events, which if analyzed as a direct analog of the behavior of creep in ductile rocks, should be a very useful input for analyzing failure of rocks under stress. Extensions of the mechanics of such deformation should shed some light on earthquake mechanisms, shear of rocks at the edges of plates and suggest further research on these topics, particularly slow deformation by aseismic means – even in the case of the pre-earthquake deformation, as proposed here.

The data shown in this paper suggests that, contrary to a long-standing belief, there is no long-term build-up of stress in the brittle zone. This is based upon the interpretation of piezomagnetic events showing the appearance of stress accumulation and consequential stress relief (strain) followed soon, in a matter of hours, by brittle zone deformation in the form of creep or earthquake. Admittedly, it is difficult to use the piezomagnetic phenomenon to observe stress in the brittle zone because such stress would be expressed as very small amplitude piezomagnetic events due to the low Piezomagnetic Factor at the low temperatures (relative to Hopkinson Peak) one finds at brittle zone depths. Nevertheless, any stress accumulating in the brittle zone would have passed through the transducing zone on its way up through the section and those piezomagnetic events and its associated stress-relieving events have already occurred as described in the preceding.

Though the tectonic forces involved are immense, the time signature, if treated as an analog of both stress and consequential strain, can be considered a microscopic snapshot in the scale of time and dimensions. This would thus complement the nature of information derived from long term observations of surface deformation due to earthquakes. Currently, observations of surface features and interpreted earthquake mechanisms provide only a narrow window on crustal deformation compared to the ability to observe deformation at depths where the principal deformation takes place. Using the piezomagnetic effect as a proxy, is true remote sensing as if a microscope and stop-action photography were used to examine the dynamics of plate boundaries during deformation.

Future field experiments can be designed with these criteria in mind. Many such experiments, strategically planned at other faults, thrust faults and in other geologic conditions, will add to the body of knowledge. Confirming evidence supporting – or denying -- whether such means as suggested in this paper have wide applicability, is needed, much as the theory of Plate Tectonics was only well understood and accepted after the weight of considerable observations produced a more complete and convincing understanding of the phenomena. Similar experiments, conducted in time periods acceptable to investigators' patience, will confirm whether the Hollister area is fortuitous or typical of other areas where earthquakes and/or strain events can be monitored as correlative events.

A broader view of deformation would be very useful to support the observations reported here. Measurements using GPS, LIDAR, space-borne interferometers or land-based infrasound detector arrays could be used to monitor deformation over a large area. A very intriguing experiment could be set up to measure the deformation, now referred to as Episodic Tremor and Slip (ETS) occurring during the ‘strain-phase’ of the piezomagnetic signal, a time during which there is likely to be some deformation taking place over an area of several hundred to a thousand square kilometers, albeit over a short period of time. Such measurements of *dynamic* plate movements may give us a hint on how the "locked" regions of the San Andreas fault behave where this rheological time constant is measured in tens of years instead of hours or days. [Include here the recently reported results of Rogers, et al, Obara, et al, and Ito, et al in Cascadia and in SW Japan. Observations of the piezomagnetic events, VLF seismic and the slip measured by the long period strain measurements of the Hi-net TILT devices would be an interesting complementary data set, for it would combine different modalities: seismic, strain and, through the piezomagnetic measurements, stress changes.

Possible variables to be considered when assessing whether such phenomena can be observed would be: where the geothermal gradient places the transition zone with respect to the Curie isotherm; whether for some reason, there is insufficient magnetite in the rocks in the transducing layers; whether the region of applied stress is of sufficient dimensions to manifest itself, in the integral, as a detectable piezomagnetic signature; the geometry of observation points to maximize the size of the signal or measuring at multiple points to add to signal; or clever arrangements of observations points to reduce the quasi-coherent micropulsation noise background or use a correlative signal to accomplish this such as phase-associated telluric currents to reduce the micropulsation noise and squeeze a factor of two or more in resolution of local magnetic events.

The time signature of the piezomagnetic effect is perhaps the most critical and most useful single observation in this report. The piezomagnetic signature, if confirmed to exist and behave as presented in this paper, would represent a major breakthrough. It would provide a surface-measurable effect from changes in stress at depths of tens of kilometers illustrating the basic tectonically-driven deformation taking place at plate boundaries that is the ultimate cause of earthquakes, and for that matter, of plate movements. By removing the basic factor of time, one can, I believe, equate plastic deformation with brittle fracture and thereby put a stop-action view on the processes that cause earthquakes. It is the same deformation, but one with a different response to stress after it reaches ‘brittle space’, one occurring in days and the other in seconds. We thus have a remote-sensing tool, using a natural force (earth’s magnetic field) that is pervasive, undiminished (except for distance) by kilometers of rock that, when acting on material at depth, enables a transducer for measuring stress and indirectly the resulting deformation. Incorporating the interpreted rheological time constant in our understanding of rock deformation on a large scale may eventually lead to methods for increased earthquake understanding.

The study of events such as earthquakes requires tens of years and vast unpredictability and is thus a non-productive research career for any scientist. The creep region around Hollister is a handy laboratory that Nature, in her deference to mortal research-challenged scientists, has provided with frequent tectonic events in slow-motion – an ideal combination. We should then be able to apply what we learn about this ductile shear-cum-*creep* rupture to the those conditions where the fault is locked and undergoes ductile shear-cum-*brittle* rupture. If we consider these piezomagnetic stress analogs as “quantum stress” events, we can extrapolate this deformation model, paying close attention to the expected problems of scaling in both time and space. Thus, we could add to our understanding of earthquakes and maybe, just maybe, predict them, if only within hours or days. Hey, it is better than no prediction at all.

All of the conclusions and the interpretation of the observed data described herein are based on the assumption that what was measured, as reported here is, in fact, the piezomagnetic effect. Therefore, it is hoped that through peer review, others conducting similar experiments and/or looking over the raw data, this assumption of piezomagnetism survives. My description of the mechanism is a presumptive opinion and not being a tectonophysicist, I defer to others who know more. My contribution stops at reporting the raw observed geomagnetic events.

– Sheldon Breiner