of the predicted reading based on the prior 2 years of data generated by that sensor. The reading of 15 October (before the Calexico earthquake) showed a further increase in stress on the north-south sensor. Possible anomalous changes can be imagined for the east-west and N45°W sensors, but the data are not so convincing. There is no doubt that the next measurements on 2 November were all anomalous. This set produced the largest north-south change, but the 14 November readings showed the largest changes for the east-west and N45°W sensors. No measurements are available for the period 15 October through 2 November due to a failure of the on-site digital recording system. By 3 January 1980, the excursion appeared to be complete, and the sensors were indicating normal readings again.

Because three independent sensors oriented along different azimuths all recorded the anomaly, it is possible to calculate the principal change in the components of stress in the horizontal plane. The principal stress changes are defined as the magnitudes and directions of the maximum and minimum compression (or decompression) produced during the anomaly. The maximum horizontal compression of approximately 0.24 MPa (2.4 bars) occurred in the N12°E direction and the minimum horizontal compression was actually a decompression of 0.12 MPa (1.2 bars) in the N78°W direction. The maximum horizontal shear stress generated by the anomaly was approximately 0.18 MPa (1.8 bars) in the N33°W direction in a right lateral sense,

Reports

Stress Anomaly Accompanying the 1979 Lytle Creek Earthquake: Implications for Earthquake Prediction

Abstract. *An unusual stress transient was recorded 15 kilometers from the epicenter of the Lytle Creek earthquake in southern California. It was observed at the recording site as an increased shear stress parallel to the fault surface and with the proper sense of shear to have triggered the earthquake. The anomaly began 2 to 4 weeks before the earthquake and lasted for 3 months.*

From 27 September 1979 through 3 January 1980, a stress anomaly was recorded on the vibrating-wire Stressmeter array at San Antonio dam, approximately 60 km east of downtown Los Angeles, along the southern boundary of the San Gabriel Range. Three significant earthquakes occurred in southern California between 15 and 19 October: Calexico (M_L 6.6, distance from the dam = 225 km, 15 October), Malibu (M_L 4.2, distance = 100 km, 17 October), and Lytle Creek (M_L 4.1, distance = 15 km, 19 October). The anomaly is believed to be directly associated with the Lytle Creek earthquake because of its proximity to the monitoring site and because a 2- to 4-week precursory anomaly would be consistent with an earthquake of this magnitude (*1*). However, the Calexico earthquake was a large earthquake that spawned numerous aftershocks felt in the Salton trough, and it cannot be entirely precluded from association with the stress pulse.

The Lytle Creek earthquake has been tentatively linked to the nearly vertical, northwest-trending Duncan Canyon fault, similar in nature to the larger strike-slip San Jacinto fault to the east (Fig. 1). The preliminary fault plane solution constrains the fault movement to right lateral strike-slip offset on a nearly vertical fault surface striking approximately N56°W. The epicenter of this earthquake lay approximately 15 km to the northeast of the San Antonio dam, and the focal depth of the earthquake was approximately 5 km (*2*).

The network of stress-monitoring sites was established in 1977 to search for detectable stress anomalies along active faults in southern California (*3*). The sensors are vibrating-wire Irad Stressmeters (*4*), which are wedged against the walls of a small borehole at a depth of approximately 20 m below the ground surface. The Stressmeters contain a tautly drawn wire stretched across the diameter of the hole in such a way that distortion of the borehole wall changes the resonant period of the wire. The sensors act as rigid inclusions in the hole and prohibit the borehole wall from distorting freely as the external stress changes. Thus, in effect they measure the stress required to keep the borehole from straining. The sensitivity of the units is calibrated directly in the laboratory. Three sensors aligned along different azimuths in a vertical hole yield the principal changes in direction and magnitude of stress in the horizontal plane.

The anomaly was first observed on the north-south sensor at San Antonio dam between the readings of 27 September and 4 October (Fig. 2). The reading of the north-south sensor on 4 October was outside the 99 percent confidence limits

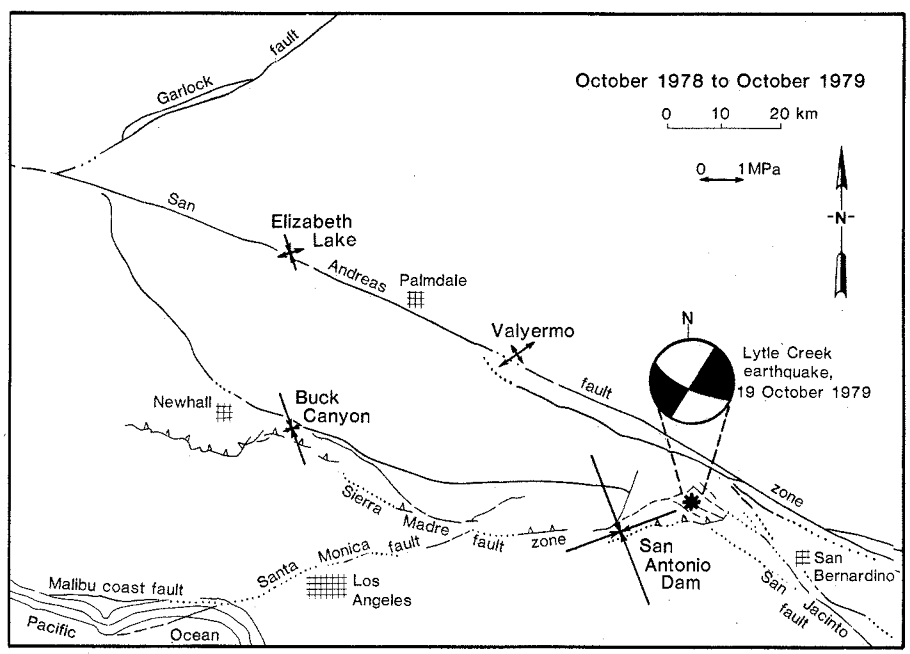

Fig. 1. Pattern of stress changes measured from 15 October 1978 to 15 October 1979. The location and preliminary fault plane solution for the Lytle Creek earthquake are shown.

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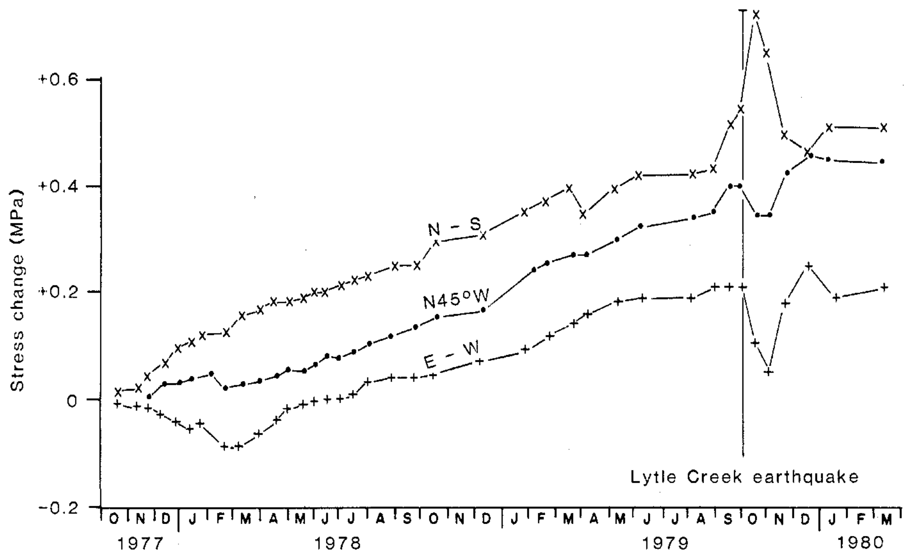

Fig. 2. Preseismic and coseismic changes in the stress anomaly associated with the Lytle Creek earthquake (positive change is compressive).

consistent with the first-motion data for the Lytle Creek earthquake. The instruments recorded a slight bulk compression during the period of the anomaly, but it would be reasonably accurate to characterize the event as one of pure shear consisting of north-northeast compression and accompanying west-northwest decompression.

The Lytle Creek stress anomaly is the best documented stress or strain anomaly yet detected in that the entire planar components of the change, rather than a single linear measurement, were obtained. The magnitude of the anomaly is similar to the strain anomalies detected by the Geodimeter survey lines in California for the Hollister (1960) and Corralitos (1964) earthquakes, among others (*5*). However, the Lytle Creek anomaly was detected well away from the fault zone that was activated and cannot be interpreted as the result of preseismic or coseismic displacement along the fault trace itself. The possibility of this type of displacement was a problem in interpreting data from the long survey lines for the Hollister and Corralitos earthquakes because in both cases the survey lines crossed active fault traces.

Comparable point measurements of stress or strain anomalies have been described from Utah (*6*) and Japan (*7*). The Utah anomaly was on the order of 0.01 MPa (100 mbar) and preceded a large rockburst (M_L 1.0). The Japan anomaly preceded a large earthquake (magnitude = 6.5), began 6 weeks before the earthquake, and consisted of a volumetric strain of approximately -2×10^{-6} over a period of approximately 20 days, after which dilatation occurred. The borehole strainmeter was approximately 33 km from the epicenter. Both of these events were detected only on a single instrument, which recorded either unidirectional (Utah) or volumetric (Japan) changes. Similar strain anomalies have occurred before several Chinese earthquakes, sometimes at distances of more than 100 km from the epicenter (*8*).

Before the 28 November 1974 earthquake near Hollister, large magnetic and tilt anomalies were observed (*9*). The magnetic anomaly occurred entirely within a period of 4 to 8 weeks before the earthquake. If the anomaly is modeled by a finite dislocation on a locked fault in elastic rock with a magnetization of 10^{-3} to 10^{-4} electromagnetic unit, a stress change near the site of 1 to 10 MPa (10 to 100 bars) is required to account for the magnetic change. The anomaly was recorded approximately 10 km from the earthquake epicenter. The tilt anomaly was not easily interpreted because it was far larger than an elastic model could predict. The epicentral area also lay within the Hollister Geodimeter net, but no demonstrable preseismic or coseismic strains larger than noise level (1×10^{-6}) were detected (*10*). A similar lack of anomalous strain was reported from a magnitude 4.8 event at Horse Canyon on the San Jacinto fault, 17 km from the recording observatory, in 1975 (*11*).

In contrast to other reported anomalous geophysical events, the Lytle Creek anomaly began shortly before the earthquake and continued for 2 months after it. The maximum deviation from background stress level was contemporaneous with or shortly after the earthquake, not before it, as reported for most other anomalies. Furthermore, the anomaly had different algebraic signs and magnitudes in different azimuthal directions. In other ways it was similar to previously reported anomalies. The anomaly was a "hump shaped" episodic excursion from a well-defined background level, and there was no measurable permanent offset of the background level.

The predicted change in stress during an earthquake at a location away from the moving fault can be generated from a model of the fault as a vertical dislocation in an elastic half-space. If the Lytle Creek earthquake had a seismic moment of 1.4×10^{22} dyne-cm, and resulted in an average slip of 100 mm over a region of 1 km^2 at a depth of 5 km, then at the location of the San Antonio array, the model predicts a small permanent stress increase in all horizontal directions: 3.8×10^{-3} MPa (0.038 bar) in the north-south direction and 2×10^{-3} MPa (0.020 bar) in the east-west direction (*12*). These values are below the level of resolution of the Stressmeters. Clearly, this anomaly, in contrast to most others that have been reported, cannot be directly explained by such a release of elastic stress accompanying the earthquake itself. No short-term precursory anomaly is predicted at all in the model of offset by a dislocation moving in an elastic half-space, and even the step changes recorded at the time of the earthquake are smaller by orders of magnitude than the reported anomalies.

The most direct explanation of the Lytle Creek anomaly is that it was the record of a short-term regional stress transient that also triggered the earthquake. Not only did the applied shear stress recorded at the San Antonio dam array rise dramatically, but its orientation (N33°W) was consistent with a large (0.12 MPa) increase in shear stress in the orientation of the activated fault (N56°W). This explanation is supported by the onset of the change in stress before the earthquake and the occurrence of the earthquake as the stress level was rising. Thus, the earthquake might be considered a result of a stress transient rather than its cause.

The transient was not recorded at the Stressmeter site at Valyermo, approximately 40 km northwest of the dam. Nor did other geophysical monitoring instruments in southern California apparently sense the event. Because of the relatively short duration of the event, it would not have been detected by geodetic or gravity resurveys unless they were being conducted monthly or more frequently. The lack of corroborative signals from other geophysical measurements suggests that the transient was local, perhaps limited to the basement complex of the eastern San Gabriel Mountains, on which virtually no other continuous measurements are being made.

The detection of a change in a stress anomaly of this scale associated with a relatively small (magnitude ~ 4) earthquake provides new evidence about another important question in earthquake prediction: whether near-surface rocks (< 100 m deep) are well coupled to rocks at greater depth and thus accurately reflect stress conditions at depth (*13*). Local conditions may dictate the quality of this coupling. The San Antonio dam site would not appear to be ideally coupled to deeper rocks. Fractures abound, and the geology of the site is complicated by numerous faults, from microscopic offsets to the Cucamonga thrust fault, which forms the boundary of the Transverse ranges, a few hundred meters beneath the site. Absolute stress levels in the rock, even at a depth of 20 m, would not necessarily be associated with tectonic stress fields generating earthquakes at depths of several kilometers. Yet the long-term data on changes in stress at San Antonio dam are remarkably consistent with predicted tectonic stress changes (Fig. 1), and the anomaly, particularly the existence of a preseismic portion, strongly suggests that stress changes in the focal region were being transmitted to shallow depths 15 km away (Fig. 2). Absolute stress levels or long-term changes might still be relaxed with time at such shallow depths, but short-term coupling appears to be good.

The Lytle Creek stress anomaly is superposed on more than 2 years of data from the San Antonio dam site that indicate that a long-term rise of compressive stress is occurring, especially in the north-south direction (Fig. 1). The San Antonio site is the only one displaying such a consistent change, although other sites indicate an increase in levels of horizontal shear stress. In this portion of southern California, thrust faulting along the several active frontal faults, collectively called the Sierra Madre fault system, is consistent with increased north-south compressive stresses. The San Fernando earthquake of 1971 ruptured a segment of this fault system to the west of Los Angeles, but the faults to the east did not move. Consequently, the continuing buildup of stress being measured at the San Antonio dam site, only 60 km east of Los Angeles, is a source of considerable concern.

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Siliceous Microfossils from the Lower Cambrian of Northwest Canada: Possible Source for Biogenic Chert

Abstract. *Round to oval, scalelike siliceous microstructures from cherts in Cambrian limestones of the western Yukon Territory suggest affinity with chrysophycean algae. At least six morphotypes present include porous forms with single branching processes and nonporous oval, ringlike forms. Partially dissolved specimens may indicate a contribution to contemporaneous or early diagenetic chert formation.*

The early fossil record of silica-secreting organisms is sparse, probably at least in part because both plants and animals deposit hydrated amorphous silica which is mineralogically unstable. Of the considerable variety of fossils known from rocks of Cambrian age, only some sponges have been thought to have siliceous skeletons (*1*). Radiolarians, first identified with confidence in Lower Ordovician rocks (*2*), are the earliest silica-secreting, single-celled organisms heretofore known. Marine primary cherts of Ordovician and younger age are commonly interpreted to reflect accumulations of sponge spicules, radiolaria, or other siliceous microorganisms, whether or not skeletal remains can be recognized in them. This interpretation, however, is not readily applied to Cambrian and older rocks because the existence of contemporaneous siliceous microorganisms has not been demonstrated.

Fossils reported here come from the west-central Yukon Territory in nearly flat-lying, peak-capping outcrops at 65°16′N, 140°55′W. They occur in thin-bedded, dark gray to black, finely laminated, fetid limestones and gradationally overlying massive, medium gray silicified limestones. Angular clasts that appear to be rip-ups host the fossils in the massive limestones; in the underlying beds they occur both in black chert nodules and, rarely, in the surrounding recrystallized limestone.

The transitional contact involved is that of the uppermost Tindir Group fetid limestone unit and the overlying Funnel Creek Limestone (*3*). In the Tatonduk River section to the southwest, the fetid limestone grades downward into dolomitic sandstones and shales that in turn grade downward into maroon shales and glacial mixtites of the lower Upper Tindir Group basalt and red beds unit. The Cambrian lower boundary is thought to fall within, or at the base of, the basalt and red beds (*4*). Archaeocyathids in carbonates which conformably overlie the Funnel Creek Limestone are late Early Cambrian in age, referrable to the Lenian stage of the Siberian platform. Thus the Funnel Creek Limestone and Tindir fetid limestone unit are no younger than late Early Cambrian and are more likely of middle Early Cambrian age.

The siliceous microfossils occur with a wide variety of organic-walled algal microfossils (*5*). These are particularly abundant and well preserved in siliceous nodules in the fetid limestone but rare and generally degraded in the surrounding recrystallized material. In the Funnel Creek Limestone, organic-walled cells are less common, although similar and well preserved.

Because the siliceous fossils are very delicate, they have been examined only in thin section under ordinary light microscopy. Their indigenous nature is confirmed by the facts that they do not occupy fractures, they commonly lie oblique within the rock slice, they are typically not in focus at the top or bottom of the slice, and nearby algal cells lie in planes both above and below the siliceous fossils. These fossils tend to occur in closely spaced groupings, a few of which are cut by calcite-filled fractures.

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