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TILT NEAR AN EARTHQUAKE (M_L = 4.3), BRIONES HILLS, CALIFORNIA

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ABSTRACT

Three years of continuous records of surface tilt preceding a moderate earthquake (M_L = 4.3) on January 8, 1977, have been obtained at a point 5.5 km from the earthquake epicenter. A possible short-term percursive tilt to the southwest started December 18, 1976 and reached a maximum amplitude of 2 μradians relative to the tilt trend at this time. Other changes of this amplitude are evident, however, in the 3-year record. The sense of tilt changed abruptly following the earthquake, gradually returning to the general tilt trend. A substantial postseismic tilt of 10 μradians is consistent with aseismic slip of the Hayward fault, or on any of several other faults local to the tiltmeter in this region. The data are insufficient to discriminate between these possibilities, and accompanying surface displacements are apparently too small to be detected in the geodetic records. Short-term accelerated tilting just preceding the seismic events, as proposed by Wood and Allen (1971), are not apparent in these data. An observed coseismic tilt step of 0.14 μradians does not agree with that expected from current fault-failure models.

Introduction

A moderate earthquake (M_L = 4.3) occurred on January 8, 1977, at a depth of 9.5 km just southeast of the Briones Reservoir in central California (Bolt *et al.*, 1977). Its epicenter was just 5.5 km from the location of a single two-component tiltmeter. Since this instrument has been continuously recording at tidal sensitivity for more than 3 years in a region without other moderate magnitude earthquakes, this earthquake affords one of the infrequent opportunities to search for indications of ground deformation for events at this magnitude level along the San Andreas fault system. Furthermore, geodetic data obtained in the same area (Savage and Prescott, 1978) allows comparison of point tilt and space-averaged geodetic strain, although the resolution of the average strain is only 0.5 microstrain at the 95 per cent confidence level for a 20-km line. Finally, data from the same tiltmeter were used by Wood and Allen (1971) to argue for short- and long-term tilt changes before the 1970 Danville earthquake swarm 25 km to the southeast of the tiltmeter. The recent earthquakes were much closer (5.5 km epicentral distance) and provide data for a comparative study. According to Bolt *et al.* (1977), the earthquake occurred at 0938.13 UTC on January 8, 1977. Its epicentral location was (37°54.31′N, 122°10.97′W) and its focal-plane solution indicated right-lateral slip on a plane striking N28°W with a dip 65°SW. The slip area, displacement, and moment were approximately 4 by 2 km, 1 cm, and 10^{22} dyne-cm, respectively.

Data and Discussion

The tiltmeter is a mercury tube type with the two components, each with a 3-m base line, oriented parallel (N45°W) and perpendicular (N45°E) to the tunnel axis of the University of California, Byerly Seismic Vault (BKS). The tiltmeter was installed in 1970 and its operation is described in Wood and Allen (1971). The operating sensitivity is about 10^{-8} radians and the data are now sent by digital telemetry to

Menlo Park. Several other short-base-line tiltmeters have been recently installed in the area but were not operating at the time of the earthquake. The location of the tiltmeter, geodimeter lines, the earthquake epicenter and important faults in this region are shown in Figure 1.

The tilt records obtained at BKS from January 1, 1974 to April 30, 1977 are shown in Figure 2a together with rainfall records at the nearby Berkeley weather station.

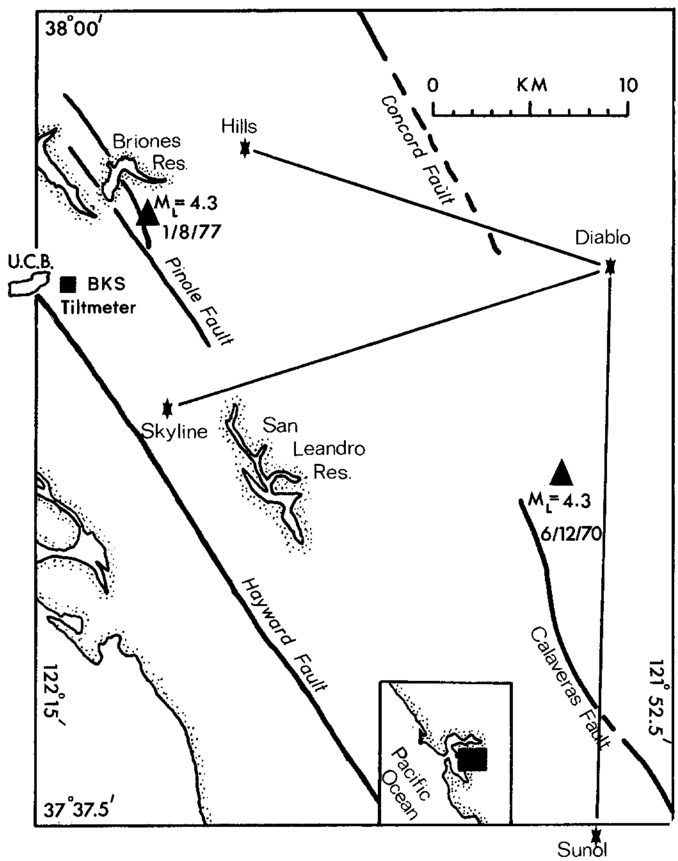

FIG. 1. Location of the BKS tiltmeter site (square) in relation to the epicenter of the largest Briones Hills earthquake (triangle). Shown also are epicenters of the Danville earthquakes, geodolite lines (straight-line connecting starlike symbols) reported in Savage and Prescott (1978), the University of California campus (UCB) and some main faults in the area.

The only other earthquakes of possible significance that occurred during this 3-year period were: (1) a magnitude 3.3 on April 18, 1975, about 10 km to the west of BKS and 9 km deep and (2) a magnitude 2.8 on December 29, 1974, about 7 km to the north and 5 km deep on the Hayward fault. The times of these earthquakes are plotted in Figure 2a. Positive tilt on the SW component implies tilt down to the SW and on the NW component positive tilt is down to the NW.

The rainfall records show heavy rain in the winters of 1974 and 1975 with some falls exceeding 5 cm. The winter of 1976 was drier. Of particular importance because of its possible effect on the tilt record is the fall of 4.6 cm on December 30.

An expanded record section for 100 days centered round the occurrence time of the largest earthquake is shown in Figure 2b. The BKS(NW) component was disrupted by the earthquake when mercury splashed onto the capacitance displacement detection system. This component was not fully repaired until January 26, 1977.

The apparent smooth trend on BKS(SW) for 3 months prior to December 18 and for almost a month following January 24, 1977, has been fit with a quadratic in a least-squares sense. The best-fitting curve is shown as a dashed line in Figure 2b. Similar lines have been fit to BKS(NW) prior to January 8 and after January 26.

With only one instrument it is not possible to determine unambiguously whether

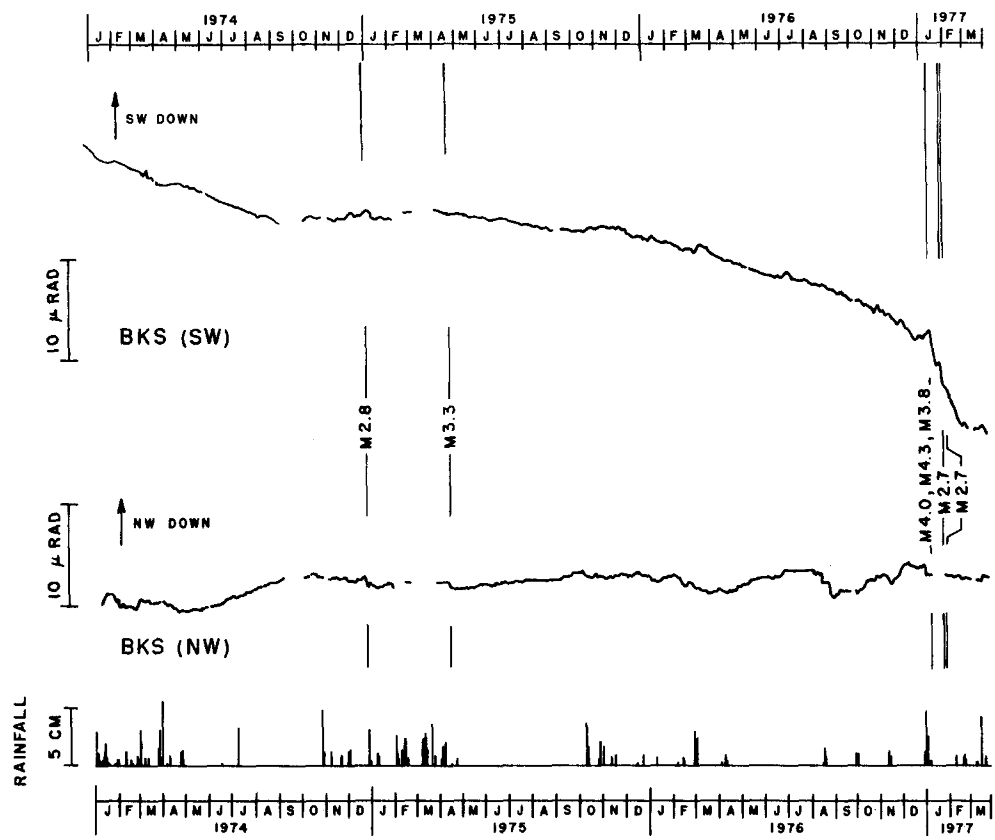

FIG. 2a. Tilt recorded at BKS for 3 years from January 1, 1974, to March 1977. Shown also is rainfall recorded at the Berkeley Weather Station and the occurrence time of earthquakes (arrows) with $M_L > 2.5$ and epicentral distance <10 km.

aspects of the record are associated or not with a particular earthquake. It could be argued that the excursion from the smooth trend on BKS(SW) starting on December 19 is earthquake related. No other change with this amplitude occurred on this component in the 3 years of record. However, other changes of similar or greater amplitude occurred on BKS(NW). The perturbation on December 31 on both components is almost certainly rainfall related.

The direction of tilt on BKS(SW) does change after the earthquakes and the trend gradually decreases finally returning to the November–December tilt trend in late January. This change in direction contrasts with the smooth continuous accelerated tilts observed with other moderate magnitude earthquakes in this region [see for example the record for the magnitude 5.2 earthquake on November 28, 1974 in Mortensen and Johnston (1976)].

Based on the focal parameters postulated by Bolt *et al.* (1977) a dislocation model of the earthquake, such as used by Press (1965), was used to estimate the coseismic tilt at the tiltmeter site. This model gives an expected tilt of 0.01 μradians in the southeasterly direction. The observed coseismic tilt was 0.14 μradians in a direction S86E if the disruption of BKS(NW) did not occur until the arrival of the longer-period surface waves. In any case, an offset of more than 0.1 μradians occurred on BKS(SW). While the direction of the observed offset is not inconsistent with that expected from this model the amplitude is more than an order of magnitude too large.

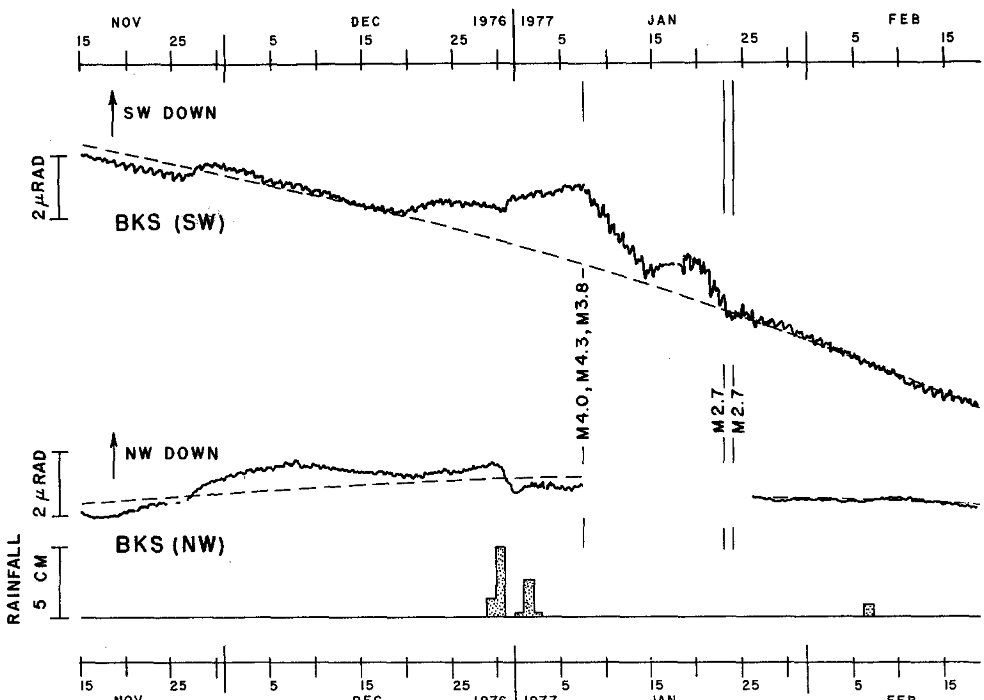

FIG. 2b. Expanded record of the tilt time history on BKS round the time of the Briones earthquake swarm. Earthquakes and rainfall are marked as for Figure 2a. Least-squares quadratic fits to the apparent smooth trend prior to December 20 and after January 24 are shown with dashed lines.

In a study of many similar coseismic tilt steps observed on an array of near-surface tiltmeters McHugh and Johnston (1977) found that the observed steps were scattered in direction and were systematically larger than expected. They conclude that the steps probably do not reflect properties of the earthquake source.

A more interesting question concerns whether indications of pre- or postseismic deformation are evident in the record. If the short-term tilt-change, seen most clearly before the earthquake on the NE-SW component is related to the earthquakes, it is difficult to explain with a model of aseismic slip in the hypocentral region. In order to explain observations of large apparent precursive tilts Stuart and Johnston (1974) have suggested that aseismic slip with a moment more than an order of magnitude greater than the seismic moment may occur with some earthquakes on the San Andreas fault.

A dislocation model in which aseismic right-lateral slip occurs on a vertical fault in the hypocentral area generates tilt at the BKS instrument down toward the southeast. Allowing a 65° dip on the fault plane as inferred by Bolt *et al.* (1977) from the seismic data does not substantially change in the sense of tilt at this point. This implies, if the change were detectable, a tilt preferentially on the NW-SE component and almost no tilt in the NE-SW direction. The observed excursions, if real, are most clear on the NE-SW component.

The section of the record from November to February exhibits a tilt change of about 10 μradians and is the clearest feature in the 3-year record. It is of course possible to fit these data with models of slip farther to the southeast on the Pinole fault or on any of several other faults more local to the tiltmeter in this region. The latter does seem more likely due to the large slip amplitude necessary on the Pinole fault to generate the observed tilts at BKS. Without more comprehensive data, however, it is not possible to determine which of these models is realistic or whether, for example, a triggered rotation effect near the tiltmeter would be the preferred explanation. Unfortunately, the geodetic coverage (Savage and Prescott, 1978) is neither detailed enough nor sufficiently accurate to check these possibilities. In any case, if movement on other faults in this region is the reason for the tilt changes, information concerning the earthquake source, derived by modeling the tilt data, becomes rather tenuous. If the observed tilts are related to the earthquakes then determination of this relation will certainly require a more comprehensive array than presently exists.

Wood and Allen (1971) have argued for the existence of anomalous microtilts recorded on the BKS tiltmeter 3 days prior to the Danville swarm in June of 1970. The Briones earthquakes had magnitudes comparable with the largest in the Danville swarm and were only 5.5 km, rather than 25 km, distant. Although it is never possible to be certain when searching for tilts below the 0.1-μradian level no significant short-term accelerated tilt is evident in Figure 2b in the period a few hours to a few days prior to the earthquake.

Acknowledgment

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