UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

DESCRIPTION AND HISTORY OF MERCURY-TUBE TILTMETERS USED IN THE SAN FRANCISCO BAY AREA, CALIFORNIA

by

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MERCURY-TUBE TILTMETERS IN THE SAN FRANCISCO BAY AREA, CALIFORNIA

Four mercury-tube type tiltmeters, operated by the U.S. Geological Survey, have been in continuous operation since 1969 in the San Francisco Bay area. This paper contains a brief description and history of these tiltmeters, and a summary of data recorded during the years 1974 to 1983.

Two of these tiltmeters are located in the University of California, Berkeley, Byerley seismic vault just east of the Hayward fault, lat. 37°51.6', and long. 122°14.9' at an elevation of 276 meters, as shown in Fig. 1. The tunnel for the Byerley vault is drilled into the steeply folded beds of the Clairemont formation. This formation consists of thin bedded shales and cherts. The vault is about 2 km from the Hayward fault. The Wildcat, University, and the Strawberry Canyon faults are also located in the area. The University and Strawberry Canyon faults run perpendicular to the Hayward and Wildcat faults.

The other two instruments are located in a vault in the Presidio of San Francisco, lat. 37.79, and long. 122.47. The vault was originally constructed as an ammunition bunker during the Spanish-American war. This vault has been used as a test facility by the USGS since 1968. It is built on Franciscan chert and sandstone on top of a hill, overlooking the Pacific Ocean near the Golden Gate bridge. The walls are reinforced concrete approximately 1/2 meter thick, and the roof is heavily reinforced with the steel girders. The interior rooms can be isolated from one another. A thick (5 meter) overburden of sand covers the bunkers.

In the Presidio installation, the instruments are installed in two tunnels at right angles to each other as shown in Fig. 2A. PDON measures tilt in a direction N28W, and PDOE in a direction N72E. In the Berkeley vault one instrument, BRKN, is installed parallel to the tunnel, as shown in Fig. 2B. It is oriented N45E. The other instrument, BRKE, is installed across the tunnel in a direction N45E.

The Presidio site seems to be the most mechanically and thermally stable of the two sites in the long term. The temperature within the Presidio vault changes less than 0.05°C per day and 0.5°C per year. Rainfall effects are also much less noticeable on the Presidio tiltmeters than on the Berkeley instruments. This is important, since during periods of heavy rainfall, signals from tectonic sources are apt to be masked by near surface local effects. While the Presidio site is much less affected by heavy rainfall, it is subjected to higher ocean loading effects. Earthtides recorded on PDOE have a maximum peak-to-peak semidiurnal amplitude of about 0.29 μradian, and PDON records tides having an amplitude of about 0.25 μradian. BRKE records tides at about 0.15 μradian, and the BRKN instrument records tides of about 0.11 μradian. These tides have greater amplitudes than the theoretical tides computed for these two stations, especially those in the east-west direction. An independent Kinemetrics tiltmeter installed near PDON corroborates the existence of unusually high earthtides here. Apparently the ocean loading at the Presidio causes the increase in actual tidal amplitude over the computed tidal amplitude of 0.11 μradian.

The four mercury-tube tiltmeters were originally built and installed by Rex Allen of the USGS. They are modified versions of a tiltmeter designed by William Gile of the California Institute of Technology in Pasadena, California. Each tiltmeter consists of two lucite pots containing mercury, interconnected by a Butyrate plastic tube. See Figures 3 and 4. A capacitor plate is suspended in each pot above the surface of the mercury. When the instrument is tilted (one end elevated with respect to the other), the capacitance plates are displaced relative to the mercury surface. The relative displacement, d, of these two sensor capacitors is determined by the balance of an L-C resonant bridge operating at 3 MHz. The mercury is kept at ground potential. The capacitance of each pot of mercury is 15 pF $\pm$ 5 pF.

One of the capacitor sensor pots can be raised or lowered by means of a micrometer jack, as shown in Figure 5. This allows calibration of each instrument, and a means to compensate for accumulated long-term changes in the tilt of the sites. The micrometer drives the jack through a 10:1 reduction lever using a cardon hinge. The length, L, of both Presidio instruments is 513 cm. The tilt measured by the instruments is given by

$$0 = \tan^{-1} \frac{d}{L}$$

Referring to Fig. 5, the micrometer jack changes the elevation of the instrument 0.0002 mm at point B for each small division change of the micrometer. Due to the configuration of the tiltmeter, this means the mercury pot is displaced 0.0001 mm for each small division of the micrometer. One large division of the micrometer on the Presidio instruments is equal to a displacement of 0.0005 mm, or 0.0975 μradian of tilt. The Berkeley instruments are limited in length due to the tunnel width in the Berkeley vault. BRKE is 256.86 cm long, and BRKN is 269.24 cm long. One large division of the micrometer jack on the BRKE instrument is equal to

0.19466 μradian. One large division of the micrometer jack on BRKN is equal to 0.1857 μradian.

The electronics can be operated from two 12-volt car batteries; however, the four mercury-tube tiltmeters are presently operated from 115-volt AC power.

The data from San Francisco are transmitted directly to Menlo Park in continuous analog form, and by digital telemetry (Rogers et al., 1977) from both sites. Figure 6A and Figure 6B show 9 years of data from the Berkeley location in order to determine the relative importance of each event. The weight or amplitude of these bars is determined by a simple magnitude divided by distance formula as used in Mortensen and Johnston, 1975. Using this formula did not produce any earthquakes of any consequence for the Presidio during the 9 years. Rainfall is plotted in inches on the top of the figure. The secular rate for PDOE is about 0.914 μradian/year, and for PDON is 2.4 μradians/year. The secular rate for BRKE is 17 μradians/year. For BRKN, it is about 3.2 μradians/year.

The Presidio records show a remarkably low secular drift in 9 years. These values are in approximate agreement with tilts expected on the basis of geodetic strain measurements in this area (Savage and Prescott, 1978). These instruments are located 10 km from the San Andreas fault in a region that is both aseismic and apparently not actively creeping. This may be the reason for the difference in tilt rate observed on this instrument compared with either the Berkeley instrument or other instruments to the southeast on the creeping and seismically active section of the fault.

The Berkeley instruments are located much closer to a creeping fault. There are also other nearby faults that may be contributing to the long period tilt. BRKE has shown a steady tilt down-to-the northeast. This seemed to accelerate in December 1976, then change direction to tilt down-to-the southwest. Just before the Briones Valley earthquake on January 1977 the tilt again changed abruptly to a down-to-the northeast direction (Johnston et al., 1978). Heavy rains started on November 21, 1977, and continued into March 1978. The tilt again changed direction from down-to-the northeast to down-to-the southwest in mid-January 1978. Some of this unusual behavior was probably the result of heavy rains in the Berkeley hills. It should be noted that this and other rainfall in previous years did not affect the Presidio records very much. An increase in tilt rates in 1976, expecially noted in August 1978 was followed by a large landslide on the road up Strawberry Canyon near where the small road turns off to the Berkeley vault. A creepmeter, operated by the University of California, is located under the University of California stadium (Bolt and Marion, 1976). Steady creep usually occurs during periods of rain. The creep seemed to stop in the winter of 1977-78 and did not start up again until May 1978.

The near-surface seismogenic region with about a 10 km thickness is apparently being loaded non-uniformly in time, and is responding in different ways in different places (Savage and Prescott, 1977).

Conclusion

These instruments were originally installed to test the feasibility of constructing a network of tiltmeters in central California. While the mercury-tube type tiltmeter has proven to produce excellent long-term records, installation of such instruments on a large scale basis in the field is not practical because of the horizontal configuration and the fragile nature of the instrument. The mercury surfaces can become oxidized, and a disturbance, such as a small local earthquake or human contact, can easily cause the mercury to splash onto the capacitance plates, necessitating disassembly and thorough cleaning. The instruments have to be recalibrated each time the mercury is disturbed.

The low drift of the Presidio instruments may be due to the fact that they are located at a greater distance from faults than the instruments presently used to attempt detection of earthquake precursors. The fact that these instruments are in an underground vault does not seem to be the dominant factor in providing better long-term stability than the standard USGS shallow borehole instruments, since the Berkeley instruments also are in a vault and have much higher tilt rates than the Presidio instruments. This observation also seems to apply to horizontal strainmeters located close to and at a distance from a fault (Johnston et al., 1978).

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FIGURES

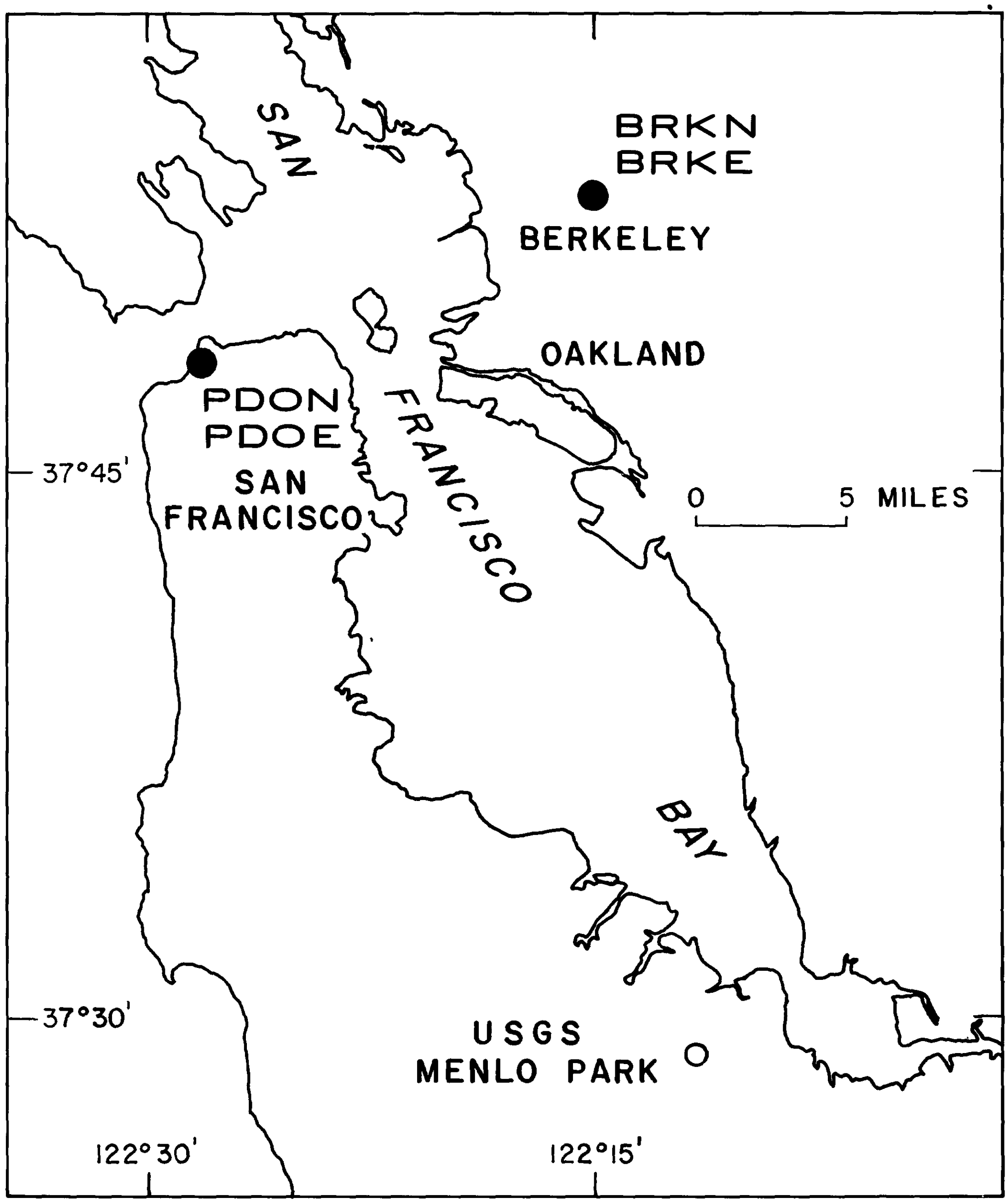

SAN
FRANCISCO
BAY
BRKN
BRKE
BERKELEY
OAKLAND
PDON
PDOE
SAN
FRANCISCO
37°45'
0
5 MILES
37°30'
USGS
MENLO PARK
122°30'
122°15'

Figure 1

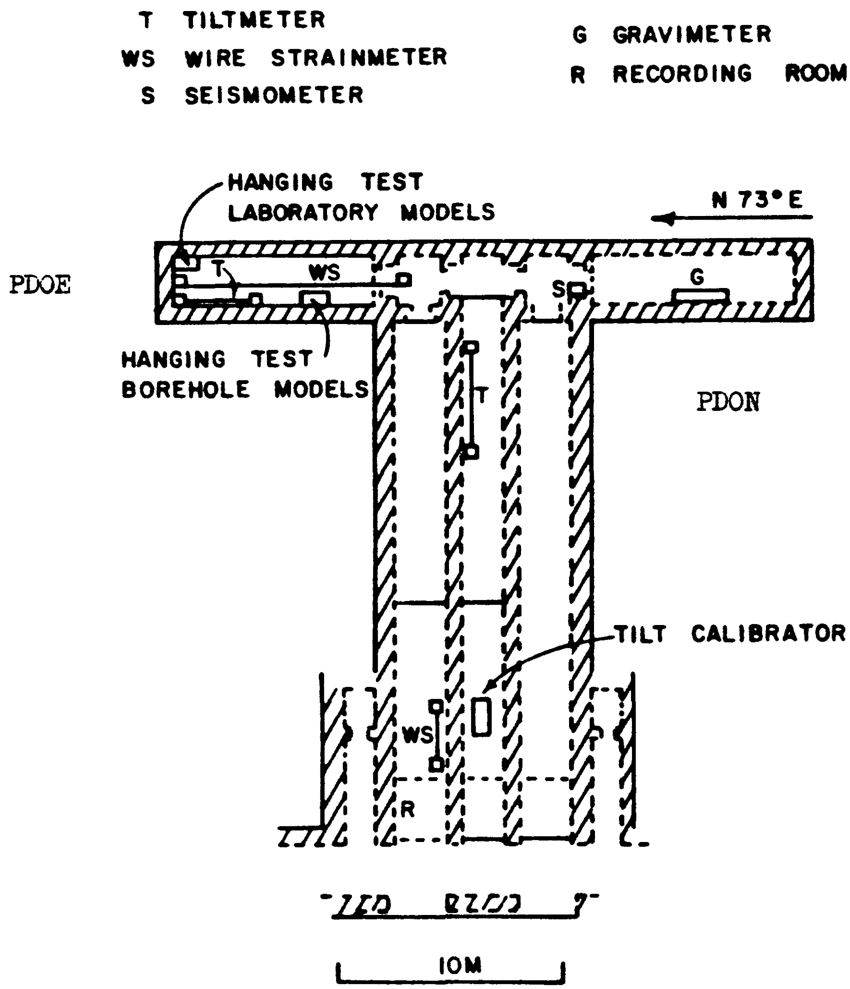


Figure 2A Layout of the Presidio Vault Test Facility

Figure 2B Byerly Seismic Vault

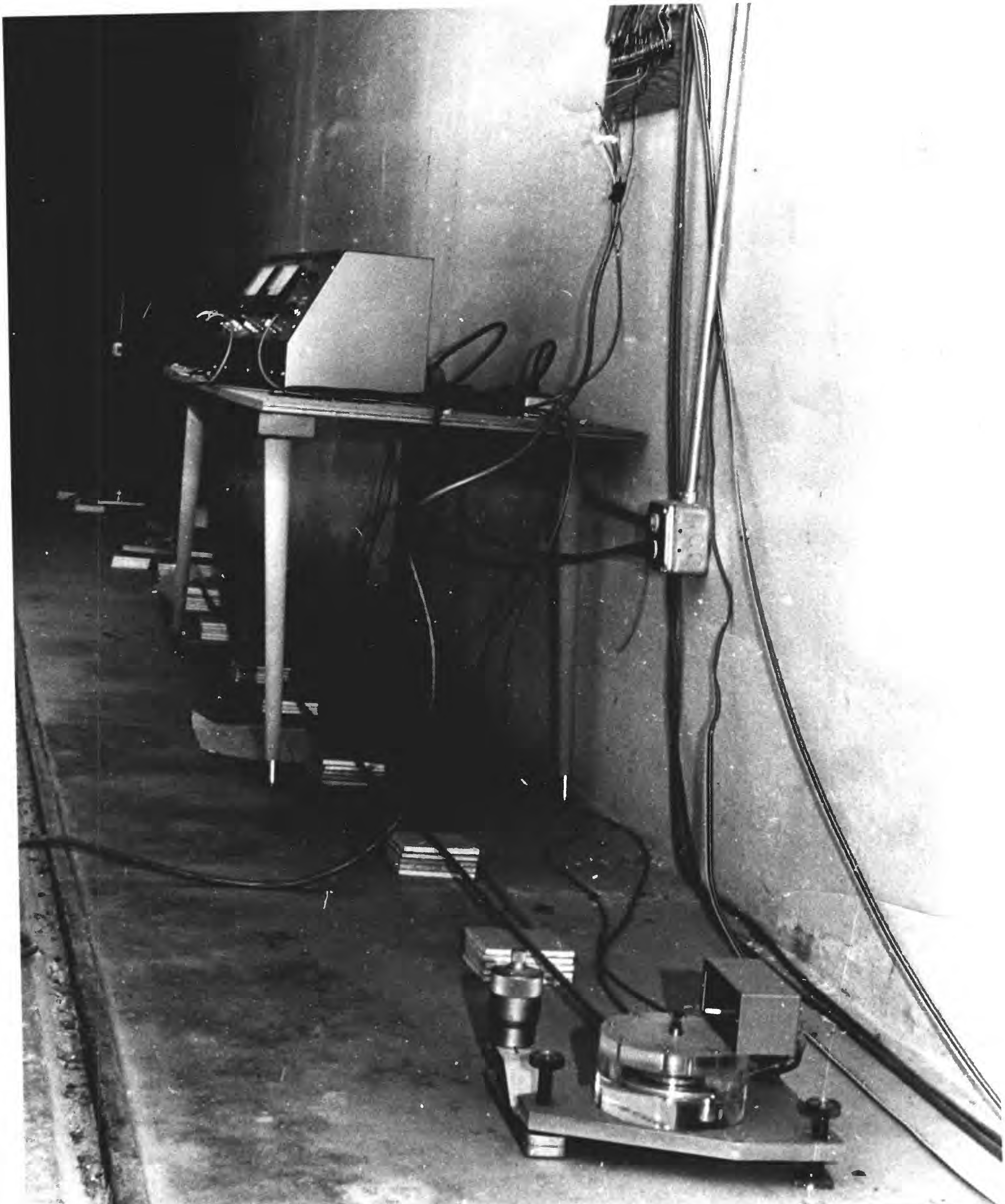


Figure 3

MERCURY TUBE TILTMETER

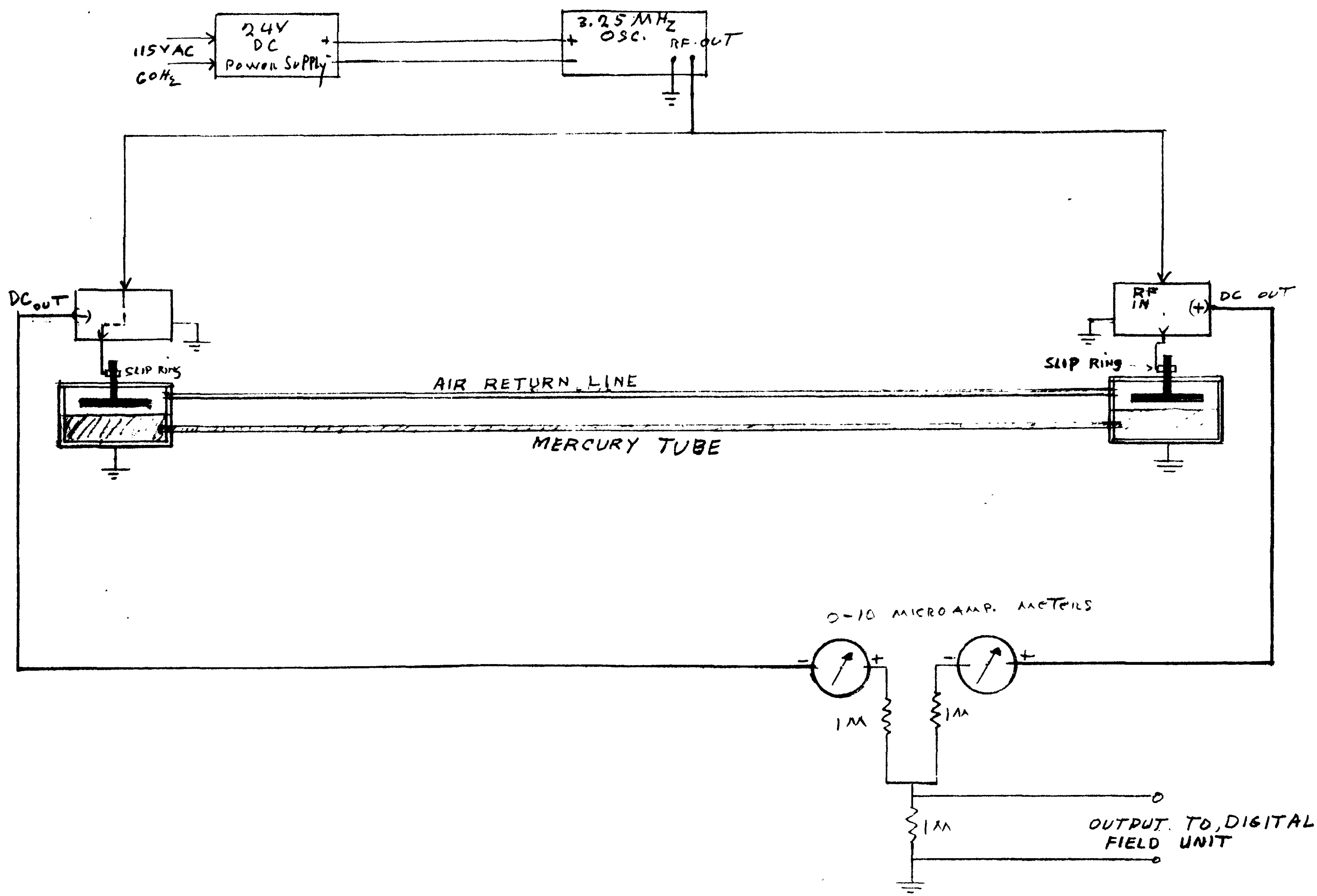
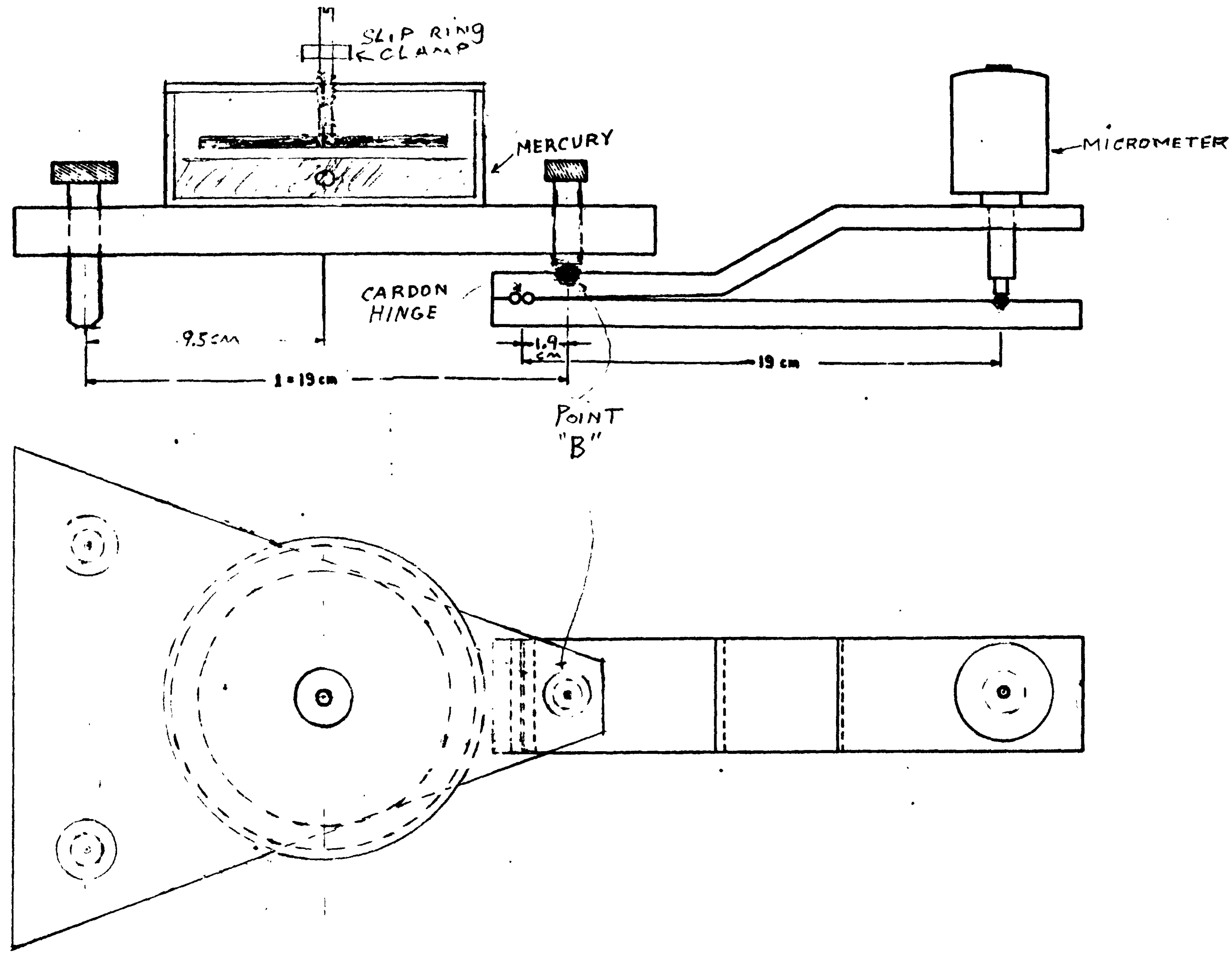
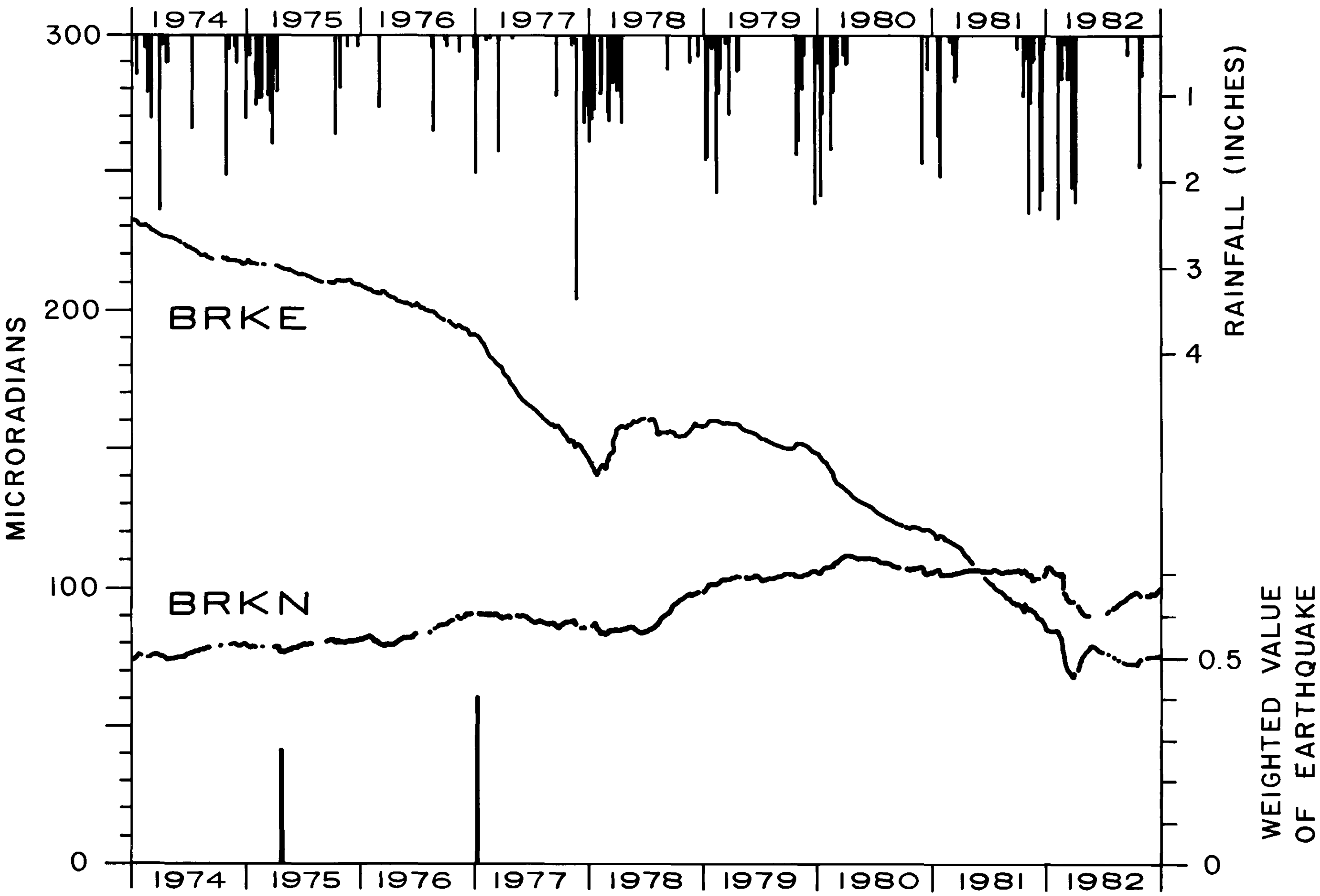


Figure 4



MERCURY TUBE TILTMETER
ADJUSTMENT HINGE MECHANISM

Figure 5



1974
1975
1976
1977
1978
1979
1980
1981
1982
300
200
100
0
MICRORADIANS
BRKE
BRKN
1
2
3
4
RAINFALL (INCHES)
0.5
0
WEIGHTED VALUE
OF EARTHQUAKE

Figure 6

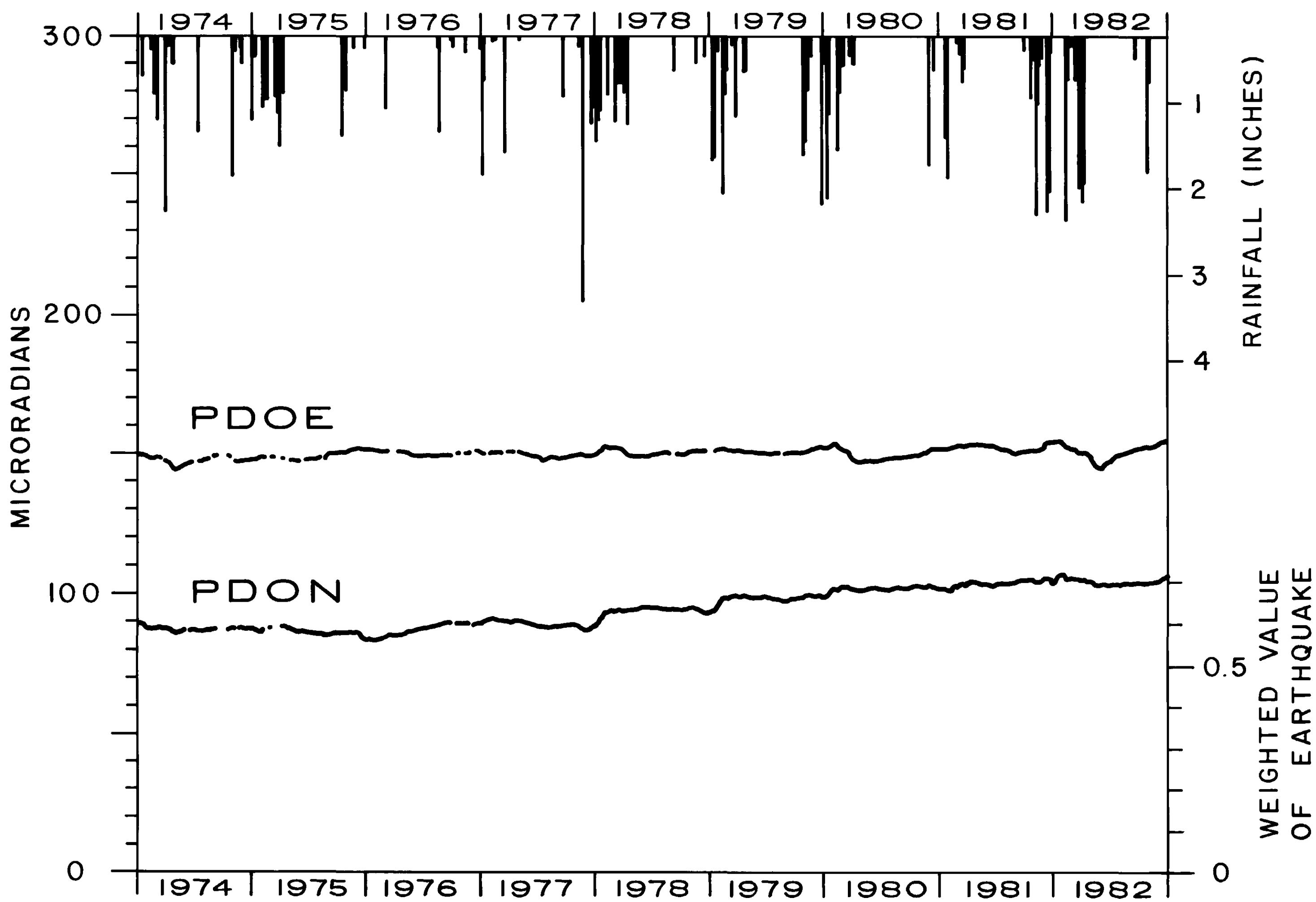

300
200
100
0
MICRORADIANS
1974
1975
1976
1977
1978
1979
1980
1981
1982
PDOE
PDON
RAINFALL (INCHES)
1
2
3
4
WEIGHTED VALUE
OF EARTHQUAKE
0.5
0

Figure 7