SUMMARY OF ELECTRONIC TILT STUDIES AT MOUNT ST. HELENS

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ABSTRACT

During April and early May 1980, a network of five electronic iltmeters was installed around Mount St. Helens, at radial listances ranging from 3 to 15 km from the center of the volcano. ach instrument telemetered two perpendicular components of ilt in approximately 10-min intervals to a monitoring station 0 km to the southwest, in Vancouver, Wash.

From the beginning of their operation, two of the three iltmeters that were within 6 km of the volcano continued to ndicate a general inflation or uplift of the region surrounding the olcano. The end of this general inflationary trend roughly oincided with the appearance of the first lava dome in mid-June 980. The third tiltmeter within 6 km of the summit recorded an pparent deflationary trend that was probably related to ormation of an east-west summit graben, whereas the two iltmeters more than 6 km away recorded only very minor tilt hanges. From mid-June to early October, data from the iltmeters closest to the volcano showed a possible very slight ubsidence of the region surrounding Mount St. Helens.

No obvious tilt changes immediately preceded any of the major ruptions of Mount St. Helens that occurred between April and eptember 1980. At the onset of eruptive activity on May 18, a iltmeter 6 km south-southwest of the volcano indicated an brupt inflationary change in tilt of roughly 4 μrad microradians); possible short-term, transient tilt changes of as nuch as 2 μrad occurred during the time when the highest mplitude of harmonic tremor was recorded during this eruption.

Only during one post-May 18 eruption has a definite change in ilt been measured during eruptive activity at Mount St. Helens. A tiltmeter 6 km south-southwest of the center of the volcano ecorded a deflationary change of 2 μrad, corresponding to the eginning of eruptive activity on May 25. Through September, 1o tilt changes larger than 0.5 μrad have corresponded to any other eruptive activity of Mount St. Helens.

INTRODUCTION

The precise measurement of surface deformation around active volcanoes gives an indication of unseen long-term changes taking place beneath the surface that, in part, are related to subsurface movement of magma. Following the initiation of eruptive activity at Mount St. Helens in March, a network of electronic tiltmeters was installed to monitor possible ground deformation.

The first instruments were installed during the latter half of April, within 1 mo of the beginning of earthquake activity (Malone and others, this volume) and phreatic activity (Christiansen and Peterson, this volume). Five Kinemetrics biaxial tiltmeters were installed at radial distances ranging from 3 to 15 km from the center of the volcano prior to the large eruption of May 18 (fig. 102). These are platform-type instruments that measure horizontal tilt about two perpendicular axes over a horizontal base length of approximately 200 mm. They were secured with expansion bolts to cast-concrete baseplates that were firmly cemented to rock outcrops.

The two tiltmeters north and east of Mount St. Helens were destroyed at the beginning of the May 18 eruption. These instruments were later replaced by two borehole tiltmeters installed west and south of the volcano, out of the area devastated by the May 18 eruption and in locations probably safe from future minor pyroclastic flows or mudflows. The borehole surrounding the volcano to increase the chance continued operation throughout the winter.

Perpendicular components of tilt were telemetered from each site in approximately 10-min intervals to a monitoring station 70 km to the southwest in Vancouver, Wash., where they were digitally recorded on paper tape. Each instrument is capable of measuring short-term tilt changes as small as 0.1 μrad; however, owing to drift of the electronic components and to the short base of these instruments, long-term tilt trends cannot be confidently determined to this accuracy. To partly reduce the diurnal contribution to the background noise, the three most southerly instruments were placed inside lava tubes to achieve a more stable thermal environment.

ACKNOWLEDGMENTS

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LONG-TERM TRENDS IN TILT

The tilt vectors estimated by fitting linear trends to the tilt data received between May 6 and May 18 are shown in figure 102. The Ape Cave South station did not operate until May 9. During this 2-week period, both the Timberline and Ape Cave North tiltmeters indicated continual inflation at a rate of 1–1.5 μrad per day, recorded at radial distances of 4–6 km from the center of the volcano. The apparent deflation indicated by the station on East Dome was probably the result of the formation of the east-west summit graben (Moore and Albee, this volume). Data from the

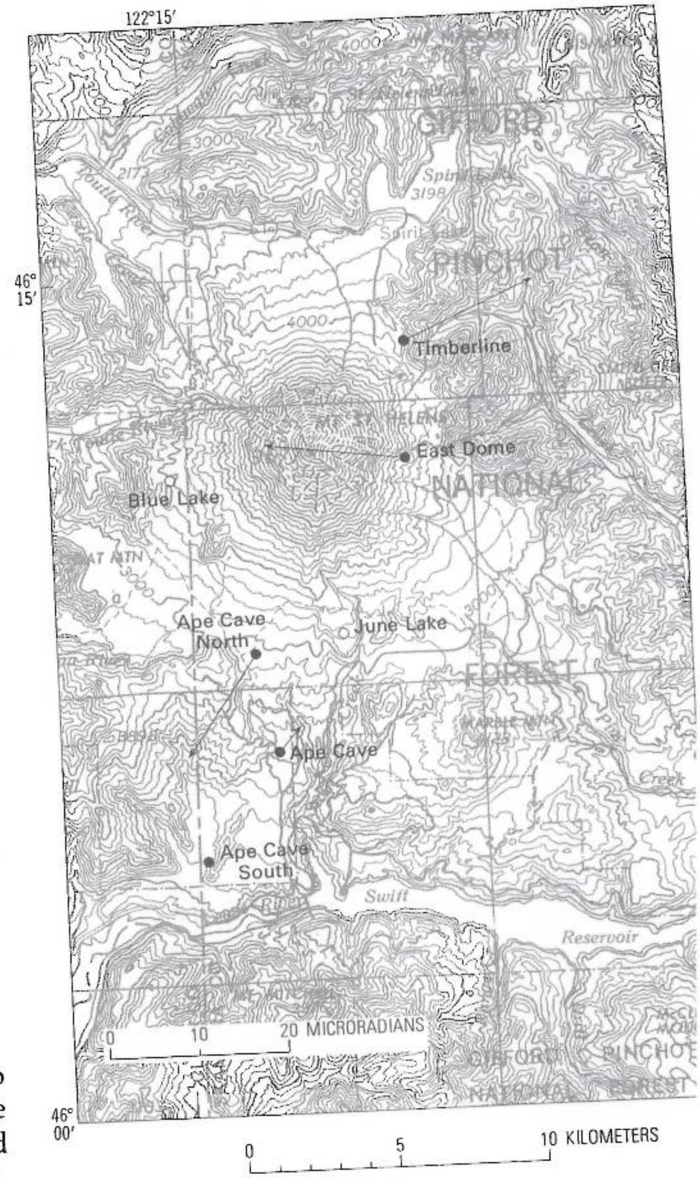

Figure 102.—Locations of electronic tiltmeters arour Mount St. Helens. Those indicated by solid circles are pla form instruments, installed before May 18; the two ope circles indicate borehole instruments, installed aft May 18. Tilt vectors indicate approximate tilt directi and magnitude determined at each site from May 6 May 18.

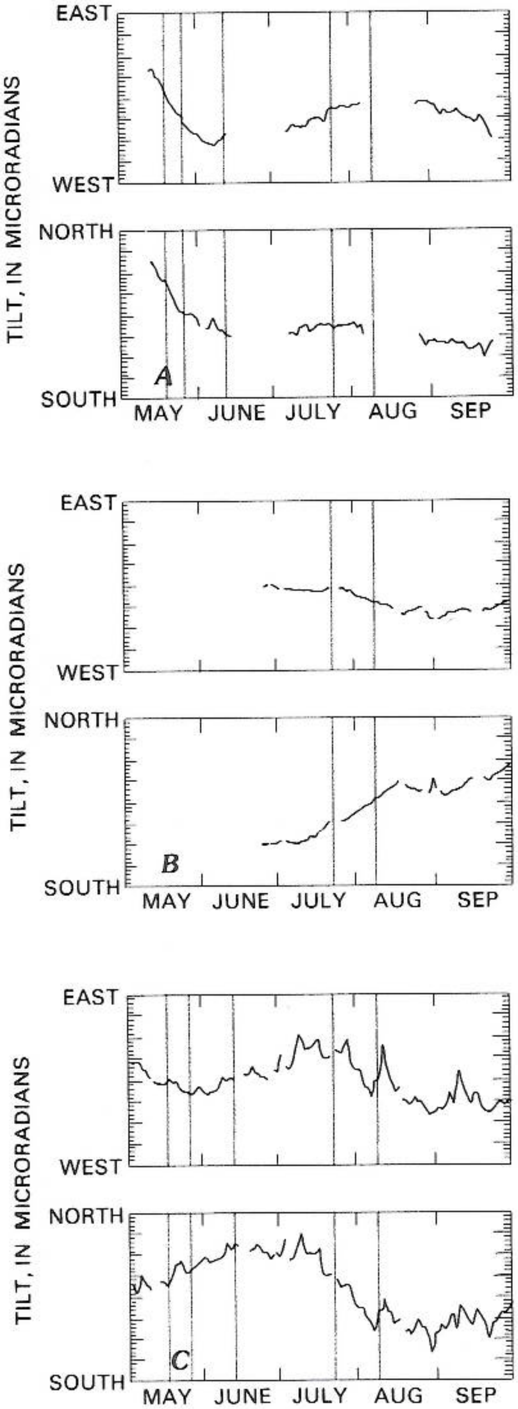

Figure 103.—Daily averages of tilt (in two directions) at each of three stations near Mount St. Helens. A downward tilt to east or north is defined as positive. Vertical lines indicate major eruptive activity. Gaps in the data indicate times when no usable data were collected. A, data from Ape Cave North station; B, from June Lake station; C, from Ape Cave station.

by averaging all of the data received during 6-hr intervals, thus minimizing diurnal variations.

Baseline values were lost at the Ape Cave North station during two long time gaps, in mid-June and mid-August, because of electronic difficulties and physical problems, such as rock falls and rock cracking at the site. Data recorded at the nearby June Lake station suggest that only small tilt changes occurred during these intervals.

No long-term changes in tilt are directly associated with major eruptive activity, including the large May 18 eruption. The overall tilt pattern indicated by data from the Ape Cave North station (fig. 103*A*) is an almost constant inflation rate beginning at the time the tiltmeter became operational and continuing until mid-June. The measured tilt change at this station was 30 μrad recorded between May 6 and June 13. Data for the initial 9-day adjustment period for this tiltmeter is not shown in figure 103*A*. By mid-June, the tilt change apparently was reduced. Data recorded by the June Lake station tiltmeter (fig. 103*B*) suggest a possible slight deflation or subsidence between June and October 1. The change in the tilt pattern from an inflationary trend to a constant or slightly deflationary trend occurred approximately at the same time as the appearance of the first lava dome, shortly after the June 12 eruption. The measured amount of deflation recorded by the June Lake tiltmeter (fig. 103*B*) suggests a net deflation of as much as 20 μrad, which occurred between mid-June and early October. However, Ape Cave North station data do not indicate a deflation larger than 5–10 μrad, a deflationary change in tilt that is considerably less than the inflationary change measured between late April and mid-June.

The more distant tiltmeter, at Ape Cave station, recorded a much more erratic tilt pattern than was recorded by the other instruments, and long-term variations (fig. 103*C*) as large as 30 μrad occurred for several months. However, this long-term variation is questionable, because these changes could not be corroborated by other tiltmeters installed at similar distances from the volcano.

MAY 18 ERUPTION

Two tiltmeter stations, Timberline and East Dome, were destroyed by the blast of May 18. The remaining three tiltmeters continued to transmit data throughout this eruption, and these data (received from the two

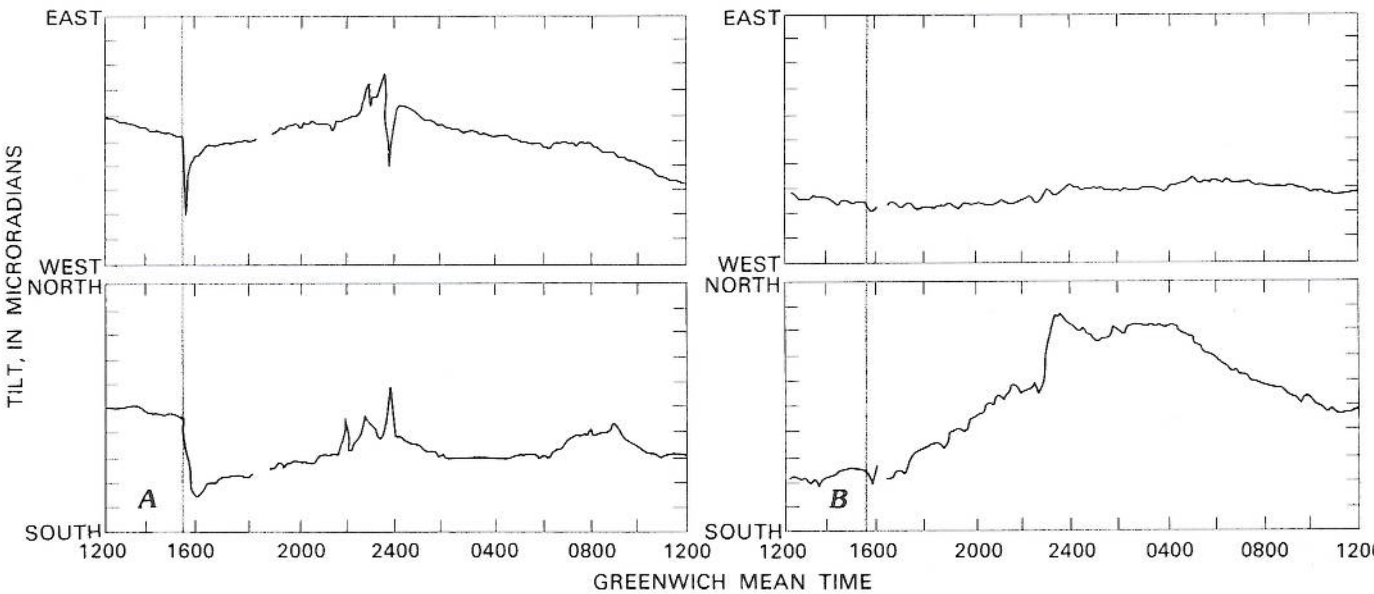

Figure 104.—Twenty-four-hour tilt data that span the May 18 eruption. A downward tilt to east or north is defined as positive. Data were taken at approximately 10-min intervals; diurnal variations have not been removed. Vertical line indicates 0832 PDT, time of earthquake that initiated eruptive activity. A, data from Ape Cave North station; B, data from Ape Cave station.

nearest stations) are shown in figure 104. These data were received in approximately 10-min intervals, and they are shown beginning from 1200 GMT on May 18—that is, 3.5 hr before the onset of eruptive activity.

The closer station, Ape Cave North, recorded a sudden inflationary tilt change of about 4 μrad, which coincided with the beginning of eruptive activity; at the same time, the more distant station, Ape Cave, did not record any abrupt change in tilt larger

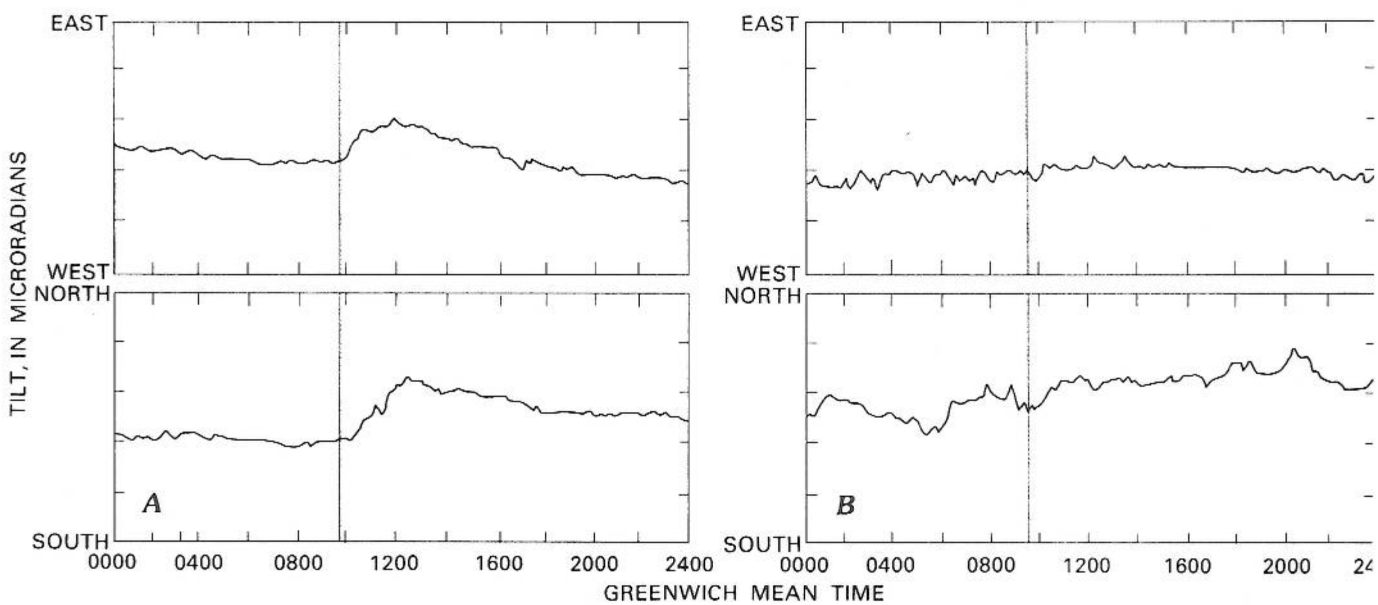

Figure 105.—Twenty-four-hour tilt data that span the May 25 eruption. A downward tilt to east or north is defined as positive. Vertical lines indicate onset of major eruptive activity as indicated by seismic data. A, data from Ape Cave North station; B, data from Ape Cave station.

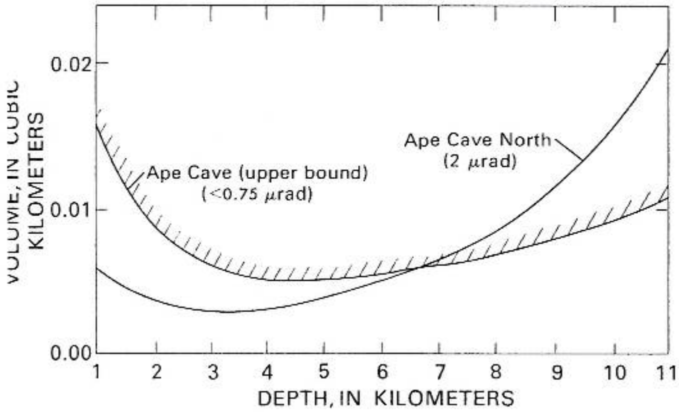

Figure 106.—Plot of theoretical volume of material transported during May 25 eruption. Calculation based on tilt data shown in fig. 105, assuming a point source in an elastic half-space. The family of possible solutions must lie on the solid line (determined from tilt data from Ape Cave North) below the hachured line (upper bound, determined from tilt data from Ape Cave).

than 1 μrad. Between 2200 and 2400 GMT, when the highest amplitude of harmonic tremor was being recorded (Malone and others, this volume), short-term, transient deflationary tilt changes of a few microradians were recorded by both instruments.

No obvious precursory tilt changes preceded the large eruption of May 18. A more complete picture of the tilt changes that occurred during this eruption, and possibly of short-term changes that may have preceded the eruption, may be revealed when the diurnal variation has been removed from these data.

POST-MAY 18 ERUPTIONS

A series of eruptive plumes and dome extrusions occurred at Mount St. Helens during the months after the large eruption on May 18. The timing and style of this eruptive activity are discussed by Christiansen and Peterson (this volume). Of the four major eruptive sequences that occurred between late May and September 1980, definite tilt changes accompanied only the May 25 eruption.

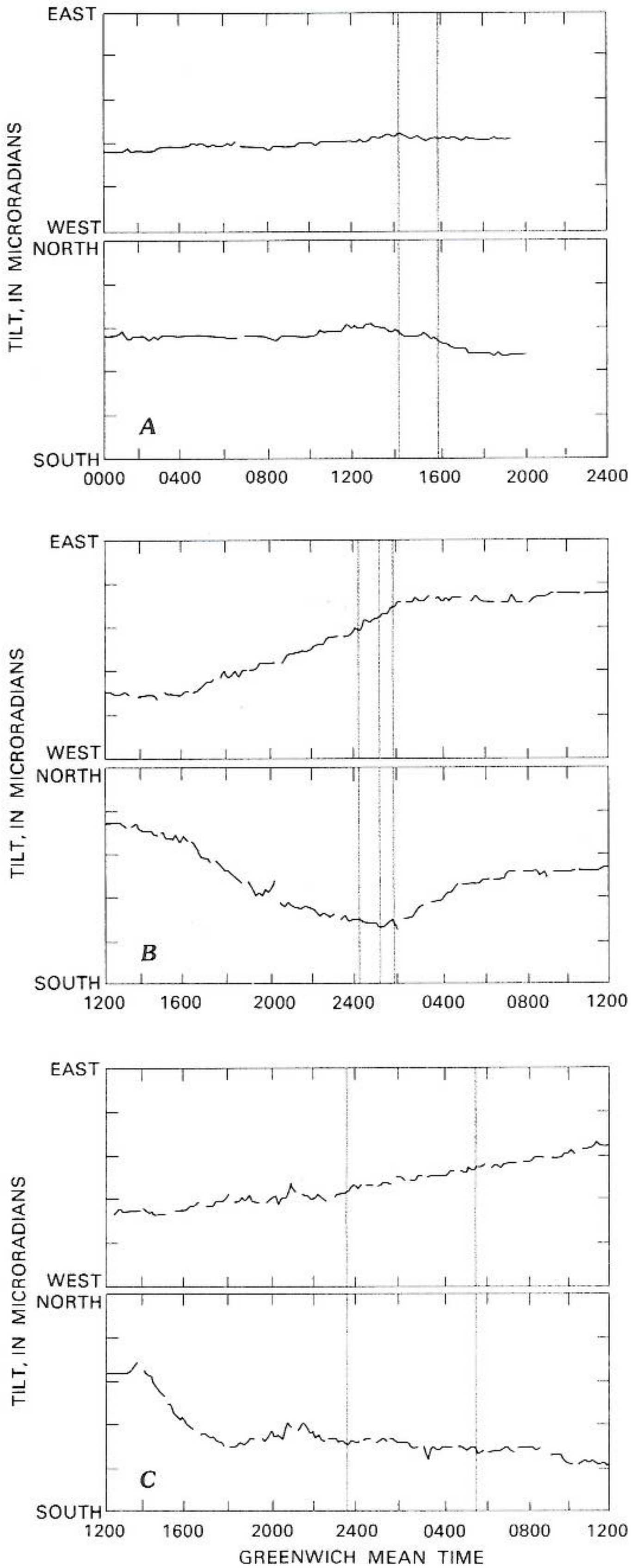

Figure 107.—Twenty-four-hour tilt data recorded at Ape Cave North station that span the eruptions of June 12, July 22, and August 7. A downward tilt to east or north is defined as positive. Vertical lines indicate onset of major eruptive activity as indicated by seismic data. A, June 12; B, July 22–23; C, August 7–8, 1980.

Tilt data received in approximately 10-min intervals during the 24 hr spanning the May 25 eruption are shown in figure 105. An abrupt deflationary change in tilt that coincided with the beginning of the major eruptive phase was recorded at the Ape Cave North station (fig. 105*A*). A similar though much smaller deflationary change in tilt may also have been simultaneously recorded by the Ape Cave station (fig. 105*B*); however, the magnitude of this change is not convincingly above the noise level of this station, which is about 0.75 μrad. A maximum value of 0.75 μrad tilt change is indicated by the record shown in figure 105*B*.

The tilt change recorded on May 25 at the Ape Cave North station and the maximum value estimated for the change at the more distant Ape Cave station allow the rough estimation of the maximum depth of the source giving rise to these possible tilt changes (fig. 106). Assuming a small spherical or point source in an elastic half-space, the volume change of the volcano as a function of depth may be computed from the observed and the bounded values of changes in tilt. Assuming that this point source is directly below the center of the volcano, a tilt change of 2 μrad at the distance of the Ape Cave North tiltmeter would result in a volume transported from various depths to the surface as indicated by the solid curve. An upper bound on the change in tilt recorded by the Ape Cave tiltmeter of 0.75 μrad requires all possible volume changes to lie below the hachured line in figure 106. The intersection of these two curves indicates that the maximum source depth for this eruption, based on this model, is less than 7 km.

None of the eruptions later in the summer at Mount St. Helens produced immediate tilt changes larger than 0.5 μrad at the Ape Cave North station (fig. 107) or at other stations (fig. 102).

SUMMARY

Electronic tiltmeters are well suited to measure rapid, small changes in tilt that accompany eruptive activity of short duration; however, these instruments do not allow dependable determination of long-term tilt changes of small magnitude because of drift of the electronic components, the short base of the sensor, and the site installation.

At Mount St. Helens, the electronic tiltmeter network has met with modest success; changes associated with eruptions produced small changes in tilt. These instruments recorded the gradual inflation of the region surrounding the volcano, which continued until the appearance of the first lava dome in mid-June. Since then, additional tiltmeters, together with those that survived the May 18 eruption, have indicated no net change or at most a very minor deflation or subsidence of the region immediately surrounding the volcano from mid-June to early October. Rapid changes in tilt of a few microradians were recorded at the onset of activity during the May 18 and May 25 eruptions. No immediate tilt changes larger than 0.5 μrad accompanied surface activity during subsequent major eruptions of Mount St. Helens, which occurred on June 12, July 22, and August 7.

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