VOLCANOMAGNETIC OBSERVATIONS DURING ERUPTIONS, MAY-AUGUST 1980

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ABSTRACT

Three recording magnetometers of 0.25 nT (nanotesla) sensitivity were installed on Mount St. Helens 10 days before its catastrophic May 18 eruption. Two units were lost in this eruption. The third, located about 5 km to the west of the main crater, continued to operate through two subsequent eruptions at a recorded rate of once every 10 min. By referencing these data to other synchronized data at Victoria, Canada, and from a recording magnetometer array in California, magnetic field transients exceeding 10 nT can be identified at the times of three major eruptions. Precursive activity may have occurred prior to the May 25 and June 12 eruptions. No precursive transients are apparent in the data in the few hours before the May 18 eruption, but a positive offset of 9 ± 2 nT occurred during this eruption. This offset is more easily explained by elastic strain release than as a result of the removal of 2.5 km^3 of magnetic material during the May 18 eruption.

INTRODUCTION

The increase in seismic and volcanic activity from March–August 1980, offered the first opportunity in the continental United States for a definitive determination of rapid magnetic changes associated with volcanic activity. Transient magnetic anomalies have been observed on a number of volcanoes throughout the world, but many details remain unclear. The best studies have been made on Oshima volcano in Japan (Rikitake, 1951), Ruapehu and Ngaurahoe volcanoes in New Zealand (Johnston and Stacey, 1969a, 1969b), Kilauea volcano in Hawaii (Davis and others, 1979) and La Soufrière volcano in the Caribbean (Pozzi and others, 1979).

Three proton magnetometers, each with a 0.25 nT (nanotesla) sensitivity, were installed on Mount St. Helens on May 8 at sites on the northeast (SHN), east (SHE), and west (SHW) sides of the mountain (fig. 110). The instruments sampled synchronously once every 10 min and data were recorded with on-site digital printers.

Unfortunately, two of the magnetometers, at stations SHN and SHE, were lost in the May 18 eruption. As indicated in figure 110, both sites were covered by ash and mudflows. The magnetometers (and records up to the time of the site destruction) may have survived intact due to the solid and sealed construction of the instrument case, but neither unit has yet been found.

The amplitudes and spatial scales of magnetic effects of volcanic origin are difficult to ascertain with the records from only the one magnetometer at SHW during the May 18, and subsequent large eruptions on May 25 and June 12. Some discrimination against broad-scale magnetospheric disturbances is possible by referencing to the nearest synchronized magnetometers at the Victoria Geomagnetic Observatory (VIC) or to the most northern USGS proton magnetometer stations BLM and MTH (fig. 110) near San Francisco. The measurement precision that can be ob-

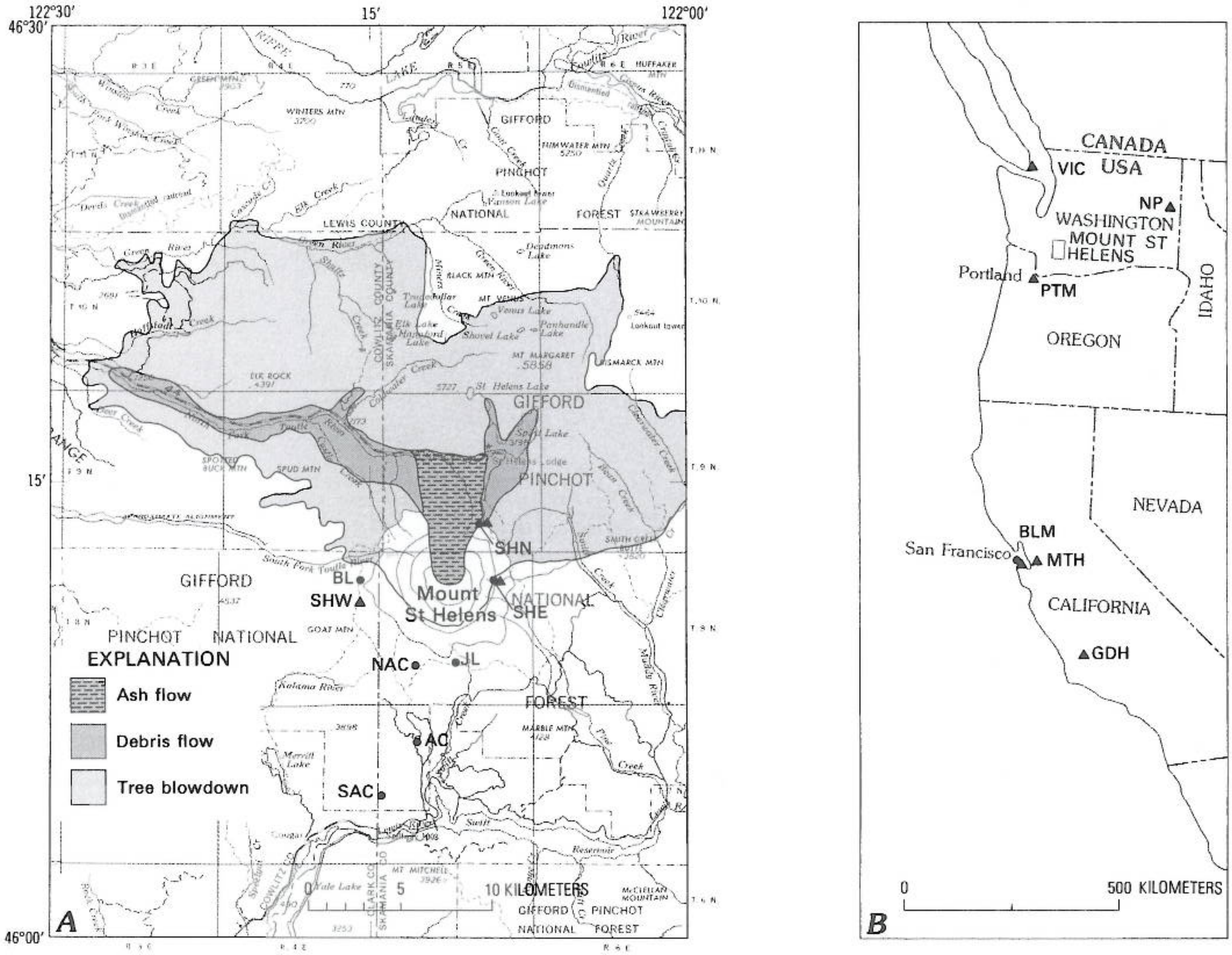

Figure 110.—Locations of proton magnetometer and tiltmeter stations discussed in this report. A, Proton magnetometer stations installed on Mount St. Helens prior to May 18 eruption (triangles) and recording tiltmeter stations installed before and after eruption (solid dots). B, Large-scale map shows locations of permanent recording magnetometer stations (triangles) in Canada, Washington, Oregon, and California used in this study.

tained for the VIC-SHW station pair is about 5 nT for hourly means. For the BLM-SHW station pair it is about 8 nT.

By a remarkable coincidence, a recording proton magnetometer was operated at the Portland airport by Carson Geoscience Co. for a few hours before and after the May 18 eruption. Because the airport is only 80 km from the volcano, the measurement precision for determination of changes during the eruption is less than 2 nT.

The purpose of this report is to present the magnetic observations at SHW during three magmatic eruptions from Mount St. Helens and to discuss the implications that these data have for physical processes that occur during an eruption sequence of this scale.

MAGNETIC OBSERVATIONS

Figure 111 shows comparative difference plots using similar 280-km baselines and time spans for stations VIC and SHW and a station pair in California, BLM and GDH. The VIC-SHW difference should show any volcanomagnetic effects generated by eruptions of Mount St. Helens whereas the BLM-GDH difference should not. Although BLM and GDH are at a slightly lower geomagnetic latitude than VIC and SHW, these data indicate a measurement resolution (standard deviation of hourly means) for a 280-km station separation of 4.2 nT. The standard deviation of hour averages during times when the mountain was not erupting was 4.8 nT for the VIC-SHW difference and 8.2 nT for the BLM-SHW difference.

The occurrence times of the three major eruptions on May 18 at 0832 PDT (1532 UTC), on May 25 at 0232 PDT (0932 UTC), and on June 12 at 2110 PDT (June 13 at 0410 UTC) are also shown in figure 111. Many minor eruptions occurred also during this period. However, the total energy release for the three major events, particularly the one on May 18, dominates the record of energy release for any of the other eruptions. If volcano-related effects occurred, therefore, they should be most clear for these three events.

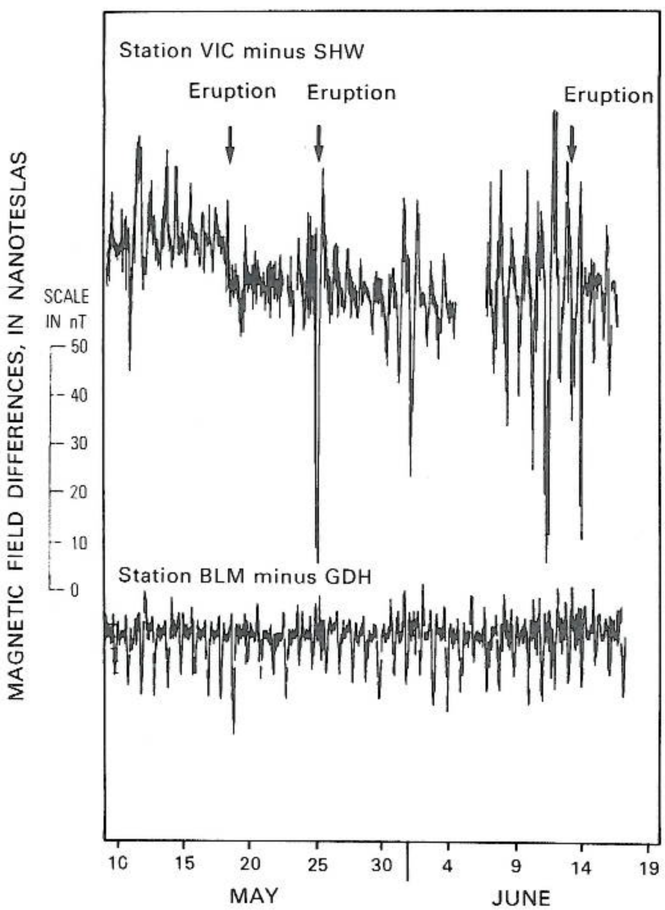

Figure 111.—Comparative plots for the same 280-km baseline of magnetic-field differences between stations VIC and SHW and stations BLM and GDH. Occurrence times (in UTC) of major eruptions on May 18, May 25, and June 12 are indicated by arrows.

The main features of the data are as follows:

1. Generally greater variability in the VIC-SHW record, particularly at times of the May 25 and June 12 eruptions.
2. An increase in magnetic field at SHW during the May 18 eruption of 9 ± 2 nT as indicated by the decreased daily means of the VIC-SHW difference. We note that because the ambient field at VIC is greater than that at SHW, an increase at SHW will decrease the difference (VIC-SHW).
3. Transient variations apparently associated with the May 25 and June 12 eruptions exceeding 50 nT. These are comparable with, and have time scales similar to, records from eruptions of New Zealand volcanoes (Johnston and Stacey, 1969a, 1969b).

Of particular interest is the question of whether magnetic changes preceded these eruptions, as apparently happened for eruptions from New Zealand volcanoes. Figure 112 shows the individual 10-min differences, together with their standard deviations, between SHW and the station PTM magnetometer operated by Carson Geoscience Co. at the Portland airport on the morning of the May 18 eruption. It is evident that no short-term precursor occurred up to the point 2 min before this eruption at 1532 UTC. Because the eruption was probably triggered by landsliding of the volcano's bulging north face, this result is perhaps not surprising.

The first indications of positive field offset are apparent right after the beginning of the eruption (fig. 112). Superimposed on this offset are cyclic variations having amplitudes of about 5 nT. Because these variations are evident also in the total-field record at PTM but with different amplitude, they probably resulted from shock-wave perturbation of the ionosphere.

During the May 25 and June 12 events, the records are less clear because we have no reference magnetometer at the Portland airport to reduce normal geomagnetic disturbances below the 2-nT level. Figure 113*A* shows 2 days of individual 10-min differences between station VIC and SHW around the time of the May 25 eruption. Some indication of disturbed magnetic field at SHW is evident for several hours before the eruption. The most dominant feature of the record, however, is the amplitude of the field fluctuations that occurred after the eruption.

These exceeded 50 nT in amplitude and probably resulted in part from eruptive shock-wave effects on the ionosphere, as large perturbations are evident in the total-intensity records at VIC and the Newport Geomagnetic Observatory (NP) in western Washington. However, similar perturbations are not apparent in the total-field records on the 28 recording magnetometers in California from 800–1,600 km to the south.

After about 12 hr, the field returned approximately to its preeruptive value and no net offset is apparent above the measurement error. Because the energy dissipated by this eruption was from two to four orders of magnitude less than that for the May 18 eruption and was of different form, an offset of comparable amplitude should not be expected.

An expanded time scale around the time of the June 12 eruption is shown in figure 113*B*. Pronounced disturbance is apparent in this record near the time of this eruption. Even larger disturbances (>50 nT) occurred during the few days prior to the eruption (fig. 111).

The total-intensity record from station BLM (fig. 114) shows no large perturbations at the times of each eruption, but some minor variations are apparent on May 25 and perhaps also in early May and early June. The shock wave from the relatively small May 25 eruption would appear therefore to have been more efficient at producing an ionospheric perturbation than that from the other eruptions. The May 25 perturbation is apparent in records of other recording magnetometers located out to at least 1,000 km from the mountain.

DISCUSSION

We have made some general investigations of tł possible physical mechanisms that might have cor tributed to these records. Thermal-diffusion effec can be ruled out because the process is too slow. Ma netogasdynamic (MGD) effects certainly occurre within the eruption clouds. For gas velocities of a much as 100 m/s and using reasonable estimates c pressure, density, and charge density of hot ionize air, resulting magnetic and electric field perturbatior in excess of 300 nT and 2000 V/m, respectively, coul have occurred within the cloud (Shercliffe, 1965 Lightning was observed both within the eruptio cloud and from the cloud to ground. However, ther are two reasons why these effects are an unlikely ex planation for the main features of the magnet record. Firstly, the MGD effects from a turbulent ga cell within the eruption cloud would fall off at least a the inverse square of distance or more probably, a the inverse cube of distance. To be observable a distances in excess of 5 km, the source fields woul need to be at least several orders of magnitude large than the values calculated. Secondly, these MGD ef fects would be apparent as high-frequency transient (>1 Hz) and would cause random scatter in the data Inspection of figure 112 indicates that, during th eruption period, sequential 10-min samples diffe only slightly, and many do not deviate from the pre ceding sample by more than one standard deviatio (2 nT).

Four possible causal mechanisms remain: remova of magnetic material, electric currents, stress

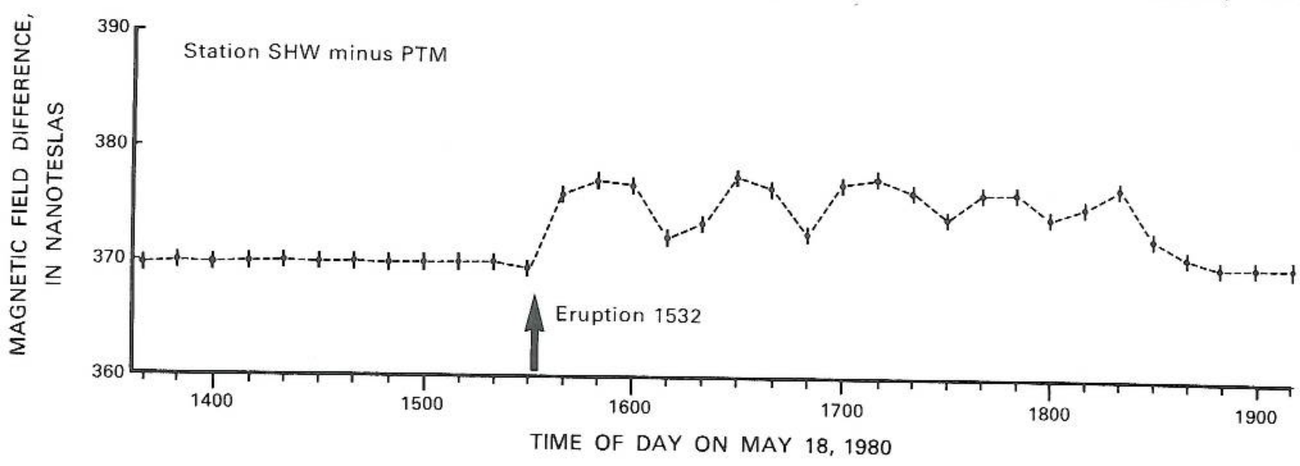

Figure 112.—Magnetic-field differences between stations SHW and PTM recorded at 10-min intervals for several hours preceding and following catastrophic May 18 eruption (arrow) at 0832 PDT (1532 UTC). Time scale is in UTC.

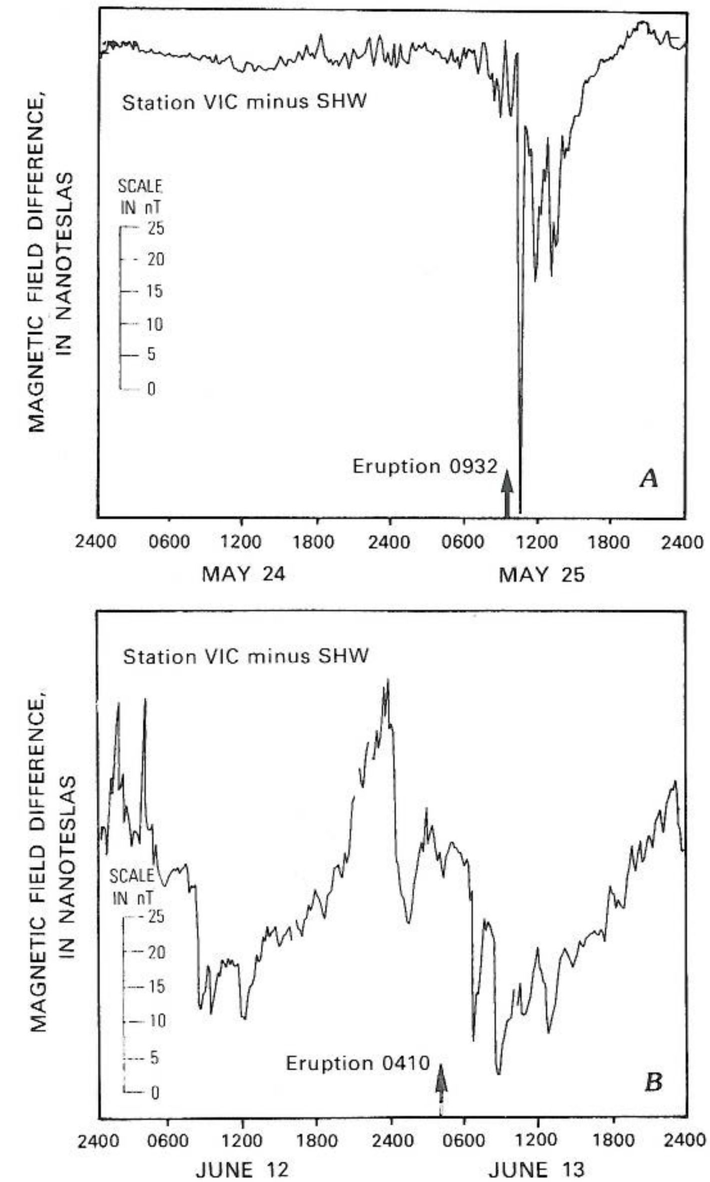

Figure 113.—Magnetic-field differences between stations SHW and VIC recorded at 10-min intervals. A, data for 2 days around the time of the May 25 eruption (arrow) at 0232 PDT (0932 UTC); B, data for 2 days around the time of the June 12 eruption (arrow) at 2110 PDT (0410 UTC on June 13). Time scale is in UTC.

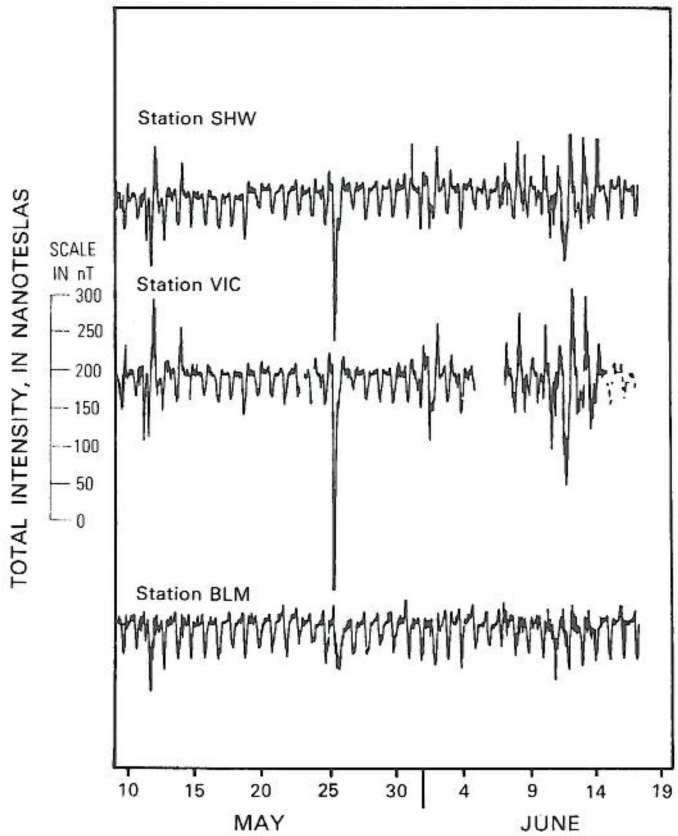

Figure 114.—Total-intensity plots from Mount St. Helens (SHW), Victoria (VIC), and Black Mountain (BLM) during May and June 1980. Time scale is in UTC.

magnetic or piezomagnetic effects and interaction between the eruptive shock wave and the Earth's ionosphere. The first process can only be relevant for the May 18 eruption when 2.5 km^3 of material was removed from the mountain (Moore and Albee, this volume) and for which a clear offset was observed.

Assuming all of this material was cool enough to have a normal magnetization of 0.5 ampere/m (as indicated by our later surface samples of this material), a simple spherical model of the removed material indicates that an anomaly of 8 nT could have been generated by the May 18 eruption. However, the offset expected at SHW as a result of the removal of material is negative, whereas the offset observed was positive. Because the regional magnetic anomaly at Mount St. Helens (U.S. Geological Survey, unpub. mapping, 1975) can be fitted most easily with a distribution of normally magnetized material, appealing to the occurrence of reverse magnetization in the removed material is unreasonable. The only real option for a mass-removal explanation is to appeal to an unknown, complex magnetization distribution whose interaction was such that the field at SHW changed in a positive sense when mass was removed during the formation of the new crater.

Given the observed magnetic data, we find it hard to propose a realistic physical source of substantial electric currents within the volcano. The offset following May 18 could not have been caused by electrical currents, but some of the rapid transients may have been. Good physical models that identify the form and likely amplitudes of electric current systems during volcanic eruptions have yet to be developed. So, although electric current systems may have been generated, we cannot estimate their importance.

Because the stress state of the mountain changed during these eruptions, piezomagnetic effects should have occurred. The magnitudes of the effects expected can easily be calculated from various models (Stacey and others, 1965), provided reasonable assumptions can be made regarding change in stress state and magnetization. An anomaly with the correct amplitude and sense can be generated by a piezomagnetic model of the volcano in which we have either a spherical or a cylindrical (Yukutake and Tachinaka, 1967) pressure source of about 1 km in diameter. In order to get the correct magnitude and to not violate the surface observations of tilt and displacement, it is necessary that the source extend to at least 5 km. At this depth the pressure release at the time of the May 18 eruption would be of the order of 1 kbar.

Interaction between the eruptive shock waves and the ionosphere can be easily demonstrated by the total-intensity records at PTM, VIC, NP, and stations in California. It does seem that the effects were different for the different eruptions and were quite significant out to distances of a few hundred kilometers from Mount St. Helens. Figure 114 shows the extremely disturbed field at VIC following the May 25 eruption and also the disturbance preceding and following the June 12 event. Data for NP in eastern Washington (fig. 110) show similar disturbances after the May 25 and June 12 events. Curiously, no really significant disturbance occurred at the time of the May 18 eruption.

The total-intensity records that were taken almost continuously at the Portland airport (PTM), which is at a distance of 80 km from Mount St. Helens, by Carson Geoscience Co. show no disturbance until about 13 min after the eruption initiation. This would be quite consistent with the time required for an eruption shock wave, traveling at about 250 m/s, to reach the E-region of the ionosphere. The maximum initial disturbance from the shock wave would be about 20 nT. This would rapidly become lost within the normal diurnal or S_Q variation which occurred at most western stations about 1000 local time. At a propagation velocity of several hundred meters per second, the time of arrival of a propagating wave at most western magnetometers is just at the onset time of the S_Q variations.

CONCLUSIONS

Magnetic transients occurred at the times of three major eruptions from Mount St. Helens. Some precursive activity may have occurred prior to the May 25 and June 12 eruptions, but no activity is apparent in the few hours before the catastrophic May 18 eruption. This would be consistent with the prevailing view that the eruption was landslide triggered. The 10-day record prior to this eruption may be too short to identify any longer term precursors, if they occurred.

An offset of 9 ± 2 nT occurred during the first 12 hr following the May 18 eruption. This is most easily explained as the result of a release of stress during the eruption. To explain the offset by mass removal requires a complex magnetization distribution that somehow reverses the sign of the expected field anomaly when 2.5 km^3 of material is removed from the volcano. Reverse magnetization of the removed material is not consistent with a regional magnetic anomaly map.

The shock waves from the eruptions produced ionospheric perturbations, apparently of different form for different eruptions. These perturbations were apparent in magnetic records at points out to several hundred kilometers from Mount St. Helens. The amplitudes of these perturbations are about 20 nT at Portland for the May 18 eruption; at greater distances from the mountain these are correspondingly smaller and cannot be uniquely separated from the onset of the S_Q variation.

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