Volcano-Magnetic Effect Observed on Mt. Ruapehu, New Zealand

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A differentially connected pair of proton precession magnetometers has been operated on a baseline of 8 km, with one detector on the side of each of two neighboring active volcanoes, near to the middle of North Island, New Zealand. In April 1968, during and preceding an eruption, variations in the difference field up to 10 γ in amplitude were observed, greatly exceeding variations during the preceding months of inactivity and apparently correlated in detail with the volcanic activity. The variations were too rapid to be explicable in terms of thermal changes; the favored explanation is based on the piezomagnetic effect.

INTRODUCTION

A unique opportunity to seek evidence of rapid magnetic changes associated with volcanic eruptions was provided by facilities established by the Geophysics Division of the New Zealand Department of Scientific and Industrial Research. The Division maintains a seismological observatory on the slopes of Mount Ruapehu, an active volcano on the North Island, and telephone lines run approximately 8 km from the observatory to a former seismometer site on the side of a neighboring volcano, Mount Ngauruhoe. Our development of a recording differential proton precession magnetometer coincided with the availability of the telephone lines for a new experiment. With a single pair of detectors we therefore had the opportunity to observe two volcanoes and to record the volcano-magnetic effect of their eruptions, which appeared not to be correlated. A continuing watch is kept on the activities of the volcanoes; an accompanying paper [*Dibble*, 1969] reports observations relevant to our measurements.

Local magnetic variations accompanying, and perhaps preceding, earthquakes and volcanic eruptions are being sought by several groups, particularly in Japan and the United States. The anticipated magnitudes of the effects are small [*Stacey*, 1964; *Stacey et al.*, 1965], necessitating the use of multiple detectors to distinguish crustal effects from broader scaled magnetospheric disturbances. The obvious method of taking simple differences between synchronized readings of spaced detectors was found to give a standard deviation of less than 1 γ in the difference field between detectors 25 km apart in southeast England [*Stacey and Westcott*, 1965] but substantially more in similar experiments in Japan [*Rikitake*, 1966; *Rikitake et al.*, 1968]. The difference is evidently due to greater inhomogeneity in ground conductivity, so that each series of observations has its own local background disturbance problems; prolonged measurements in seismically and volcanically quiet times are required before seismomagnetic or volcanomagnetic effects can be recognized.

SUMMARY OF MAGNETIC OBSERVATIONS

The first experiment with the differential magnetometer on Mount Ruapehu was a trial early in 1966 at the end of a period of minor volcanic activity. The detectors were spaced nearly ¾ km apart, one outside the seismological observatory and the other towards the top of the mountain. The first few hours of readings appeared to differ by a few γ from those that followed, the change coinciding with the decline in activity. However, the observations were tentative and justified renewed experimental effort rather than definite conclusions.

Measurements on the 8 km baseline, using the telephone lines, began in February 1967 and, with instrumental breaks but without movement of the detectors, continued through several weeks of eruptive activity in April–May 1968. Readings of the total field at one detector and of the difference field between the two were taken every two minutes. The difference field remained very steady until a few days before the first eruption, the standard deviation being 1.6 γ. The standard deviation of hourly (30-value) means was only slightly less (1.45 γ), indicating that the disturbances that occurred were prolonged enough to affect hourly values almost to the same extent as individual values.

In the first four days of April 1968, the difference field began to depart from the previous steady value, reaching a deviation of about 5 γ on April 4, when it suddenly increased to 10 γ. It then remained steady for 8 hours before falling again; it was more or less disturbed, occasionally violently, during the following several weeks. Hourly means of the difference field for 5 weeks are plotted in Figure 1, with standard deviations of individual values and hourly means for the preceding quiet months. Inspection of the total field records from individual sensors indicates that the rapid changes apparent in the difference record occurred only, or at least much more strongly, at the Ruapehu end of the line. Also indicated are observed and suspected eruptions of Mt. Ruapehu. These observations are very incomplete. The extended eruption or sequence of eruptions indicated on April 4–6 by E_7 is based on the sudden development of unusual cloud formations above the crater. Some of the numbered eruptions were observed directly, the minor ones on April 7 by E. Lloyd of New Zealand (Department of Scientific and Industrial Research) standing on the rim of the crater. It is presumed that if such observations had been possible at other times, many more eruptions would have been observed.

Four features of Figure 1 differ most strikingly from the records obtained during inactive periods:

1. The steady buildup in difference field for 3 days to April 4 and the 8-hour peak, followed by eruptive activity for 2 days. There appear to have been no eruptions before April 4, but apparently there were many during the following 2 or 3 days.

2. Pronounced peaks on April 9 and 10, when we have no observations of eruptions.

3. A period of high field difference, April 12–14, again with no reported eruptions.

4. A sequence of striking peaks on April 26–27, coincident with observed eruptions. Only in this case is there an obvious correspondence with the volcanic noise level recorded by *Dibble* [1969].

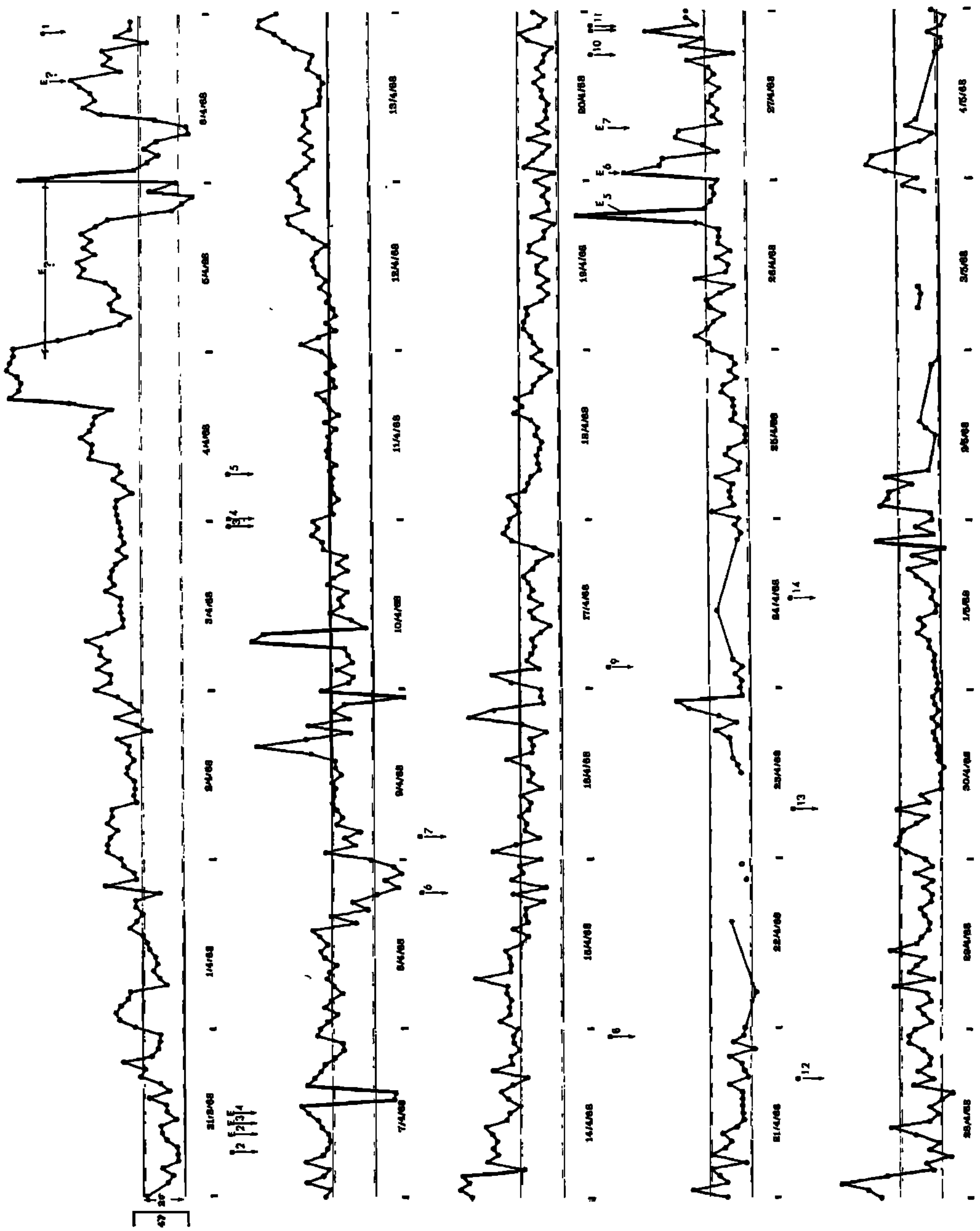
Of greatest interest is the observation that a magnetic change preceded the first eruption. It strongly supports the expectation that magnetic observations could provide a quantitative tool for the prediction of volcanic eruptions [*Rikitake and Yokayama*, 1955; *Stacey et al.*, 1965].

A Consideration of the Mechanism

Since it is possible to have magnetic changes of 10 γ occurring within one or two hours, and since even more rapid changes can be found when our individual readings are examined, it is apparent that no slow process, such as thermal diffusion, can be invoked. Japanese observations of volcano magnetic effects [*Rikitake and Yokayama*, 1955; *Uyeda*, 1961], both reversible and permanent, have been attributed to thermal changes, i.e., movements of the Curie point isotherm within a volcano. While this may be admitted as a cause of very slow changes, it cannot be relevant to our observed effects, which are not only rapid but completely reversible. Similarly the complete reversibility makes any hypothesis of appreciable geometrical displacements difficult to accept.

Two possibilities remain: either there are substantial electric currents within a volcano during and preceding an eruption, or else stresses cause piezomagnetic effects and consequent time-dependent local magnetic anomalies. It appears to us much easier to visualize the switching on and off of a piezomagnetic stress effect than an electric current, but we cannot discount the electric current explanation with any certainty.

Fig. 1. (*Opposite*) Hourly means of the difference field (Ngaurahoe minus Ruapehu) between two proton precession sensors, 8 km apart. Each experimental point is an average of 30 readings, taken at 2-min intervals. The few eruptions that were observed are marked $E_1 \cdots E_7$; earthquakes beneath the volcano are indicated by $e_1 \cdots e_{14}$. The light lines bracket the mean value and indicate the standard deviation of individual readings for the preceding months of inactivity; the broken lines show the standard deviation for hourly means. (To facilitate comparison, the time scale of this figure has been made to coincide with that of the volcanic noise record shown as Figure 2 of a companion article by *Dibble* [1969] appearing in this issue.)



Either would give the precise return to the pre-eruption field that we have found.

The magnitude of the effect can be compared with the theory [*Stacey et al.*, 1965] using values of the magnetizations of Ruapehu and Ngaurahoe andesites measured by T. Hatherton (private communication). Hatherton found susceptibilities in the range (0.75 to 1.2) $\times 10^{-3}$ emu, but Koenigsberger ratios (ratio of remanence to induced magnetization) of the order of 40, so that the total magnetization is dominated by the remanence and has a mean value of about 2×10^{-2} emu. This is stronger by a factor of 8 than the value used in a calculation of the volcanomagnetic effect for Caribbean volcanoes [*Stacey, Barr and Robson,* 1965] and explains why the effect is easily observed without especially favorable siting of the magnetometers. Since it appears that Ruapehu-Ngaurahoe is an especially favorable area for the observation of the volcanomagnetic effect, a more elaborate magnetometer array is being considered with a view to obtaining information on the mechanism of eruptions.

Acknowledgments. This experiment was made possible by the collaboration of the Geophysics Division, New Zealand Department of Scientific and Industrial Research.

The work is supported by a grant from the Australian Research Grants Committee and by a General Motors-Holden fellowship to one of us (Johnston).

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(Received February 17, 1969;
revised March 24, 1969.)