velocity of 4×10^{-3} cm s^{-1}, with an upper limit to the mean of 1×10^{-2} cm s^{-1}.

Assuming a period of half an hour completely still water at slack tide, equation (1) with $t = 1,800$ s, $w = 4 \times 10^{-3}$ cm s^{-1} and $c_b = 2$ mg l.$^{-1}$ gives a depositional rate of $2{\cdot}3 \times 10^{-3}$ mg cm^{-2} h^{-1} or 2·02 g cm^{-2} 100 yr^{-1}. With a near-surface sediment density of 1·5 g cm^{-3} (ref. 9) the rate is 1·34 cm/100 yr. Even with $w = 1 \times 10^{-2}$ and $c_b = 3{\cdot}2$ mg l.$^{-1}$ the rate is only 5·36 cm/100 yr, significantly less than Reineck's 15·5 cm/100 yr. Because the model fails in prediction of rates, and the tides in this area are actually rotatory, it seems that the slack tide settling model must be rejected. The quasi-continuous mechanism of equation (2), with $c_b = 2$ mg l.$^{-1}$ and $w = 4 \times 10^{-3}$ cm s^{-1}, gives 25·2 g cm^{-2}/100 yr or 16·8 cm/100 yr, which agrees with Reineck's figure. With the bottom concentration $c_b = 3{\cdot}2$ mg l.$^{-1}$, the rate of deposition becomes 26·9 cm/100 yr.

The quasi-continuous model will only give roughly correct values when there is negligible erosion of sediment after deposition, that is, when the bed shear stress is less than the critical value for erosion of unconsolidated fine silt, a friction velocity of about 1·2 cm s^{-1} (ref. 10). Such conditions obtain most of the time in the German Bight, but increased shear due to wave action may give higher bed shear stresses. These tend to make calculated rates somewhat higher than those observed, and could account for the high value of 26·9 cm/100 yr. The failure of the periodic settling model means that, in general, mud layers thicker than a fraction of a millimetre cannot be deposited at slack tide. Mud layers in tidally deposited sands therefore are not related to tidal rhythm and are not diagnostic of the tidal environment, except in special cases, such as some tidal flats[11]. In all situations, whether tidal or not, under low shear stresses, the quasi-continuous model should roughly account for sedimentation rates.

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Transient Magnetic Anomalies accompanying Volcanic Eruptions in New Zealand

A VOLCANO magnetic effect associated with the April 1968 eruptions of Mount Ruapehu, New Zealand, has been reported already[1]. We have since observed even more striking magnetic changes associated with the November 1968 eruptions of a second New Zealand volcano, Mount Ngauruhoe. It seems that magnetic changes are normal features of volcanic eruptions. On no occasion when our magnetometers have been operating have there been similar magnetic changes without eruptions or eruptions without magnetic effects. The observations are consistent with an explanation in terms of the piezomagnetic effect of ground stress[2] if stresses associated with eruptions are at least 75 kg cm^{-2}. This seems plausible and encourages the continued search for an equally striking seismomagnetic effect[3–5].

Our measurement system consists of two proton precession total field detectors about 8 km apart, one on the side of Mount Ruapehu and the other on Mount Ngauruhoe, connected by telephone lines to electronic circuits which record the total field strength at one sensor and the difference in field strengths between the two. The difference field record is sensitive to local crustal effects (that is, those which are not remote compared with the sensor spacing) but discriminates against both secular variation and short term fluctuations of magnetospheric origin.

Fig. 1 is a plot of three weeks of hourly mean values through the first few of a series of eruptions from Mount Ngauruhoe during November–December 1968. Although they look quiet, the first few days of this record are significantly noisier than records obtained during volcanically quiet times. Standard deviations of the hourly values from the mean for six 24 h periods to November 24 are 2·4, 2·6, 2·2, 2·5, 2·0, 2·3 gamma compared with the quiet time standard deviation of 1·3 gamma. The first dramatic change in the field appeared some hours before the first eruption, which is presumed to have occurred late on November 25, when the mountain could not be seen. An observed eruption the following morning is indicated on the record by E_1; this was followed by a series of observed eruptions, $E_2 \ldots E_5$ (all of ash), and almost certainly by others which were not seen because of poor weather or darkness (the seismometers in the area were not working at the time). The second phase of the eruption series (November 28–December 1) was accompanied by a continued striking departure of the difference field from the normal value, to which it returned after the activity subsided.

Records of following eruptions were marred by the temporary erection of a steel hut near to the Ruapehu sensor and we therefore have no satisfactory record of the

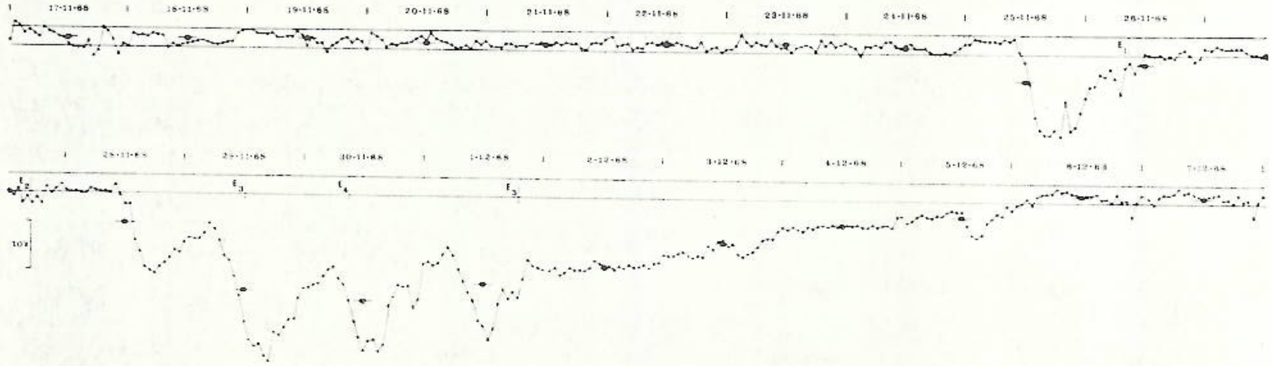

Fig. 1. Record of the difference in total field on an 8 km baseline through the first of the 1968 Ngauruhoe eruptions. Experimental points are hourly (30 value) means and heavy points are 24-hour means. The standard deviation of individual readings from the mean during volcanically quiet times (1·65 gamma) is indicated by lines bracketing the mean value. Standard deviations for hourly and 24-hourly values are 1·30 gamma and 0·42 gamma. Observed eruptions are indicated by E_1 (Johnston) and $E_2 \ldots E_5$ (W. Crafar, NZ Geological Survey).

most violent eruption in the series (December 14, 1968). After complete cessation of all activity and removal of the hut, however, the steady mean difference field was found to differ by 7 gamma from the value before the eruptions, and examination of total field data indicated that the change occurred at the Ngauruhoe end of the line. Magnetic changes accompanying both the Ruapehu[1] eruptions and the first two of the Ngauruhoe series (Fig. 1) were completely reversible; after activity ceased, the field returned exactly to its original value. We therefore have two effects to explain: a reversible effect, which has accompanied every eruption, and a smaller permanent change which has been observed only once. It is possible that the permanent effect was caused by a relative movement of materials on Ngauruhoe during the most violent eruption, so it seems more important to explain the reversible effect.

That the magnetic changes accompanying volcanic activity can occur very quickly is seen by examining sequences of individual difference field readings. The r.m.s. values of differences between successive readings taken at intervals of 2 min during a volcanically quiet time (May 25–26, 1969) and during the first of this series of Ngauruhoe eruptions (November 25–26, 1968) were 1·13 gamma and 5·2 gamma respectively. Any physical explanation must therefore be capable of explaining very rapid fluctuations.

Magnetization and thermal demagnetization of volcanic rock near to its Curie point, which has been invoked to explain Japanese observations of long term volcano magnetic changes[6,7], can have no relevance to our observations because thermal diffusion is many orders of magnitude too slow. To explain the rapid fluctuations in terms of bodily movements of the volcano in the vicinity of the sensors, the movements would have to be implausibly large and rapid. The possibility that electric currents are generated within a volcano cannot be discounted, but we are unable to envisage a satisfactory mechanism. We therefore favour an explanation in terms of the piezomagnetic effect[2-8].

A. V. Cox has sent us his recent data on magnetic susceptibility and remanence of New Zealand volcanic rocks, supplementing the data of T. Hatherton, which we used previously[1]. From these data we estimate an average total magnetization of about 10^{-2} e.m.u. for the Ruapehu–Ngauruhoe rocks. On this basis the observed magnetic changes of about 30 gamma require stresses not less than 75 kg cm^{-2} to have occurred during the Ngauruhoe eruptions, corresponding to strains of about $1·5\times10^{-4}$. We have no strain observations to check this, but surface strains and tilts of about 10^{-4} have been observed during eruptions in Hawaii[9] and presumably stresses at depth are greater than at the surface. It also seems likely that somewhat larger stresses accompany eruptions of acid volcanoes of the Ngauruhoe type, so that within the uncertainties of these estimates, the piezomagnetic effect provides an adequate explanation.

The important practical application which suggests itself is the use of magnetic data for the prediction of eruptions. A magnetic anomaly built up over a period of days before the April 1968 Ruapehu eruptions, but no more than a few hours' notice seems to be possible from the Ngauruhoe record (Fig. 1). This may still be useful, but leaves in doubt the reliability of precursive magnetic indication. Another possibility is to look at the rapid fluctuations, but the most violent are associated with eruptive activity itself rather than the build-up. Our conclusion is therefore that magnetic preindications could be useful in at least some cases—more examples are needed for an assessment of their reliability.

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Cosmic Ray Electron Spectrum above 200 GeV

THE shape of the spectrum of cosmic ray electrons in the 100 GeV range and beyond can provide information about a variety of problems in cosmic ray astrophysics. The differential energy spectrum between a few GeV and about 100–200 GeV can be reliably represented[1] by a single power law with an index of −2·62. We now describe an investigation designed to determine the electron spectrum beyond 200 GeV.

We have explored the advantages of a pure nuclear emulsion stack in the study of high energy electrons[2] by using a horizontal sandwich assembly consisting of an upper block of pure emulsion 1·8 cm thick followed by sixteen alternate layers of 600 μm thick emulsion pellicles and lead sheets of varying thicknesses. The detector system had a total depth of 8·3 radiation lengths and an area of 45 cm × 30 cm. The assembly was flown horizontally in a balloon launched from Hyderabad, India, and was flipped through 180° when it reached the ceiling altitude of 10·3 mb where it floated for 352 min.

We searched the emulsion layer at a depth of 3·2 radiation lengths at a magnification of 225 for events with more than five parallel tracks. Such events, if due to electrons, would have energies $\gtrsim 50$ GeV. About 700 such events with zenith angle $<65°$ found so far have been traced through successive emulsions and classified unambiguously as due to nuclear interactions, gamma rays and electrons. In the final analysis only those events which had zenith angles between 20° and 55°, which entered the stack as a single track and which had at least two close tracks in the emulsion under the top 1 mm lead sheet, were accepted. For electrons of 200–300 GeV, there are on average about thirty tracks in a circle of radius 68 μm in the scanning plate, while at 400–500 GeV there are about fifty tracks. Even allowing for cascade fluctuations such events cannot be missed in the microscope scanning. Further evidence for the near 100 per cent detection efficiency at energies >200 GeV is our flux value between 200 and 250 GeV which agrees with our earlier data from pure emulsion stacks (Fig. 1). Below 200 GeV we find that the detection efficiency decreases with decreasing energy and such events have not been considered here.

For selected events we counted tracks in a circle of radius 68 μm in all emulsions within the lead–emulsion assembly. These measurements determined the longitudinal development of the cascade and thus the energy of the incident electron could be estimated.

So far we have covered an area of 820 cm^2, about two-thirds of the total useful area of the stack. We have found thirty-five electrons of energy >100 GeV at the top of the atmosphere, of which 22 are >200 GeV. The highest energy so far observed is 670 GeV. Of the 22 electrons of energy >200 GeV, 20 had associated electron pairs and/