quantities. Some more detailed calculations using the Gaussian correction term in the nucleon distribution showed how sensitive the analysis is to small details of the distribution. The solid curve in the figure for ^{208}Pb shows the improvement that can be obtained by including this term, compared with the dashed curve when it is omitted.

These calculations are only preliminary and will certainly soon be improved. In particular, the use of parametrised nucleon distributions is known to introduce undesirable correlations between the densities at different radial distances, and it is preferable to use either an expression with no such correlations, or a charge distribution with a more fundamental theoretical basis. Work along these lines is in progress.

Similar analyses of the cross sections for the elastic scattering of 1,000 MeV protons measured by the Saclay group are being made by Varma and Zamick at Rutgers (*Phys. Rev.*, **C16**, 308; 1977) and it will be of great interest to compare the results of the two groups. All this work will certainly lead to more precise knowledge of the distribution of nucleons in the nucleus. □

Dilatancy has magnetic effect

from Peter J. Smith

WHEN a stress is applied to, or removed from, a rock there is a distortion of crystal structure which often gives rise to a small change in the rock's remanent magnetisation. This is known as the piezomagnetic effect and has an obvious application to the prediction of earthquakes. The variations in upper crustal stress which precede a seismic event should manifest themselves as changes in crustal magnetism and hence in that small part of the local geomagnetic field arising from permanent rock magnetisations. Continuous monitoring of the geomagnetic field should therefore lead to the observation of geomagnetic variations which reflect subsurface stress changes occurring before the onset of an earthquake.

At least, that is the theory. In practice, piezomagnetism has been of little use in earthquake prediction, partly because very small field changes are difficult to measure, partly because piezomagnetic changes tend to be swamped by normal geomagnetic noise, and partly because magnetometers are liable to be jolted by seismic vibrations and thus indicate spurious field changes Most of the seismic–geomagnetic correlations reported since 1799 are therefore certainly not valid. Moreover, even when the practical problems have been solved by carefully designed investigations with modern techniques and equipment, the piezomagnetic effect has often proved elusive in the field. Breiner (thesis, Stanford University, 1967), for example, was unable to discover any seismomagnetic changes preceding Californian earthquakes, although he did manage to correlate local magnetic changes with creep events on the San Andreas fault during the period 1965–67.

Following the publication of Breiner's disappointing results, interest in seismomagnetism withered as attention shifted to newly-discovered and apparently more promising phenomena such as premonitory variations in the seismic velocity ratio. But in recent years there has been a minor revival, with possible seismomagnetic effects being reported by Johnston *et al.* (*Seismol. Soc. Am. Bull.*, **65**, 1129; 1975) and B. E. Smith and Johnston (*J. geophys. Res.*, **81**, 3556; 1976) in connection with Californian earthquakes. At the same time there has been a change in the theoretical background against which the piezomagnetic effect in Earth materials must be viewed. For as Revol *et al.* (*Earth planet. Sci. Lett.*, **37**, 296; 1977) point out, most laboratory studies have been concerned with stresses in the elastic range, a reflection of the view that earthquakes are the result of elastic processes. The more recent dilatancy model offers a new perspective, however. Before failure, rocks undergo an inelastic volume increase which is believed to result from the formation and propagation of cracks; and although the volume of rock subject to near-breaking stress before an earthquake is likely to be small, it may nevertheless 'hold the key to prediction because the approach to failure may be accompanied by detectable time-dependent magnetic effects'.

With this in mind, Revol and his colleagues have carried out an exploratory series of experiments in which small cylindrical rock samples submitted to isothermal uniaxial compression without confining pressure were gradually stressed to failure. At the same time both induced and remanent magnetisations in the rocks were monitored continuously and their variations recorded. The results were very varied, depending on the rock type (natural magnetite, serpentinite, granodiorite) and on the particular magnetic parameter (susceptibility, saturation isothermal remanent magnetisation, thermoremanent magnetisation, and so on). Nevertheless, it is evident that dilatancy does have a magnetic expression in many cases.

As far as the natural magnetite is concerned, the susceptibility parallel to compression decreases with increasing stress, but the onset of dilatancy (at about half the breaking stress) is marked by a reduction in the rate of decrease and just before failure there is a small anomalous increase in susceptibility. Increasing stress also generally results in a decrease in remanent and induced magnetisations, again with noticeable changes at the onset of dilatancy. Thermoremanent and partially demagnetised isothermal remanent magnetisations are unexpected exceptions, however, for these initially increase with increasing stress but then decrease in such a way that they return to their original values when dilatancy begins. For all types of magnetisation there are small but inconsistent magnetic changes immediately before failure.

Some serpentinite samples exhibit magnetic changes with stress and some do not, whereas none of the granodiorite samples does. The deciding factor here seems to be the domain state of the magnetic minerals, multidomain material such as the natural magnetite reacts to compression whereas single domain material remains unaffected, although it is not clear whether the smaller single domain grains are incapable of reacting to stress or whether they simply do not see the stress before failure is reached. Where magnetic changes do occur, however, they are generally similar to those in magnetite. In other words, they always indicate in some way the onset of dilatancy and there are always small anomalous effects close to failure, enabling the failure to be predicted.

Clearly these experiments are only a beginning. The initial increases in thermoremanent and partially demagnetised isothermal remanent magnetisations obviously require further study. And more generally, Revol *et al.* plan experiments to stimulate the temperatures and confining pressures found at depth in the Earth's crust. But whether any magnetic effects seen in the laboratory will be detectable in the field is another matter. Past experience suggests that a pessimistic view must be taken, although Revol and his coworkers do offer one ray of hope. They find that the application of stress to a rock also gives rise to magnetic directional changes which are, if anything, more marked than the changes in total magnetisation. This suggests that three-component field observation may be rather more successful than total field intensity observation in detecting piezomagnetic effects in the Earth's upper crust. □

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