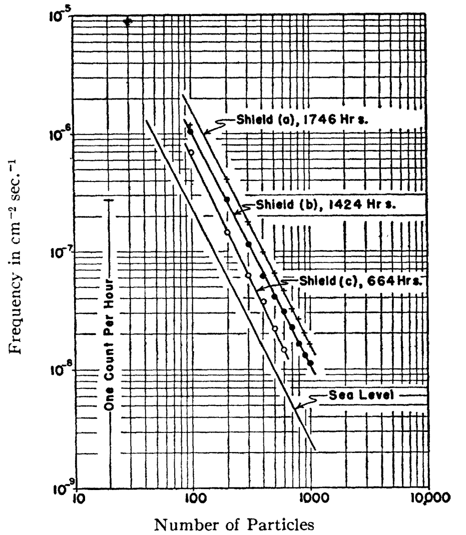

FIG. 3. Frequency *versus* size curves for large cosmic-ray bursts under several lead shields at an altitude of 3500 meters. The number of hours data obtained with each shield is shown in the figure. The sea level curve was obtained with a 10.7-cm Pb shield.

A schematic drawing of the ionization chamber, the 10.7-cm Pb shield, and the Geiger-Müller counters is shown in Fig. 1. This arrangement corresponding to the 10.7-cm Pb shield is similar to that used by Lapp[1] at sea level. Both the electrometer trace from the ionization chamber, which registers the cosmic-ray intensity and the bursts, and the recording lights of the coincidence circuits were recorded on the same 5-inch wide photographic paper as shown in Fig. 2.

By means of this arrangement, it was found that, within experimental error, less than 5 percent of the bursts were caused by air showers even with shield (a). It is very difficult to see any mechanism by which an atmospheric shower of very high energy could produce more than 100 particles below 10.7-cm Pb without tripping the shower recording arrangement. If we should assume that these bursts are produced by μ-mesons of energies greater than 10^{10} ev,[2,3] then we would expect that the burst producing radiation would exhibit no detectable absorption in lead and, also, that there would be very little, if any, absorption in the atmosphere from Climax to sea level. The experimental data in Fig. 3 shows that this is not the case, however. For burst sizes of more than 300 particles, corresponding to an energy of 4.5×10^{10} ev of the burst producing radiation,[3] there is clearly a decrease in frequency by a factor of approximately 6.7 on going from Climax to sea level. This fact demonstrates that these large bursts at high altitude are not produced by μ-mesons. The burst producing radiation is absorbed by a factor of 1.52 on increasing the lead shield from 10.7-cm to 26.7-cm Pb. This figure corresponds to a mean free path of 434 g/cm^2 in lead, assuming that the burst producing radiation is absorbed exponentially. This value is considerably larger than the mean free path of a high energy nucleon which is absorbed according to a cross section equal to the geometrical cross section of a lead nucleus which can be estimated to correspond to a mean free path of about 160 g/cm^2 in lead.

Some indication regarding the zenith angle dependence of the intensity per steradian of the burst producing radiation can be obtained from the data with shield (c). This shield is not hemispherically symmetrical and, therefore, the absorption in it, expected according to the above measured mean free path of 434 g/cm^2 in lead, is a function of the zenith angle dependence of the particles initiating the bursts. At 300 particles it can be seen from Fig. 2 that the burst frequency was changed by 1.83 on going from shield (b) to shield (c). Furthermore, this change in a spherical shield of 30.5-cm Pb, according to the mean free path of 434 g/cm^2, should be 2.22. This means that only 0.83 of the burst producing radiation encountered the flat absorber of shield (c). In order to make this so, it is necessary for the intensity per steradian of the radiation producing more than 300 particles to vary as between $\cos^5\theta$ and $\cos^6\theta$. This strong zenith angle dependence is further evidence for the fact that the burst producing radiation exhibits a strong absorption in the earth's atmosphere.

We wish to express our thanks to Dr. M. A. Tuve, Department of Terrestrial Magnetism, Carnegie Institution, for putting the Model "*C*" meter at our disposal.

* Assisted by the joint program of the Office of Naval Research and Atomic Energy Commission.

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[2] Marcel Schein and Piara S. Gill, Rev. Mod. Phys. **2**, 267 (1939).
[3] R. F. Christy and S. Kusaka, Phys. Rev. **59**, 414 (1941).

Erratum: Nuclear Spins and Quadrupole Moments of B^{10} and B^{11}

[Phys. Rev. **74**, 1191 (1948)]

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November 10, 1948

IN the above letter the nuclear quadrupole couplings of B^{10} and B^{11} in borine carbonyl were erroneously listed with negative signs. These constants are both positive.

Rock Magnetism as a Clue to Earth's Magnetic History

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November 15, 1948

DURING June, July, and August this past summer, an expedition to the western United States made measurements of the magnetization of rocks in several localities.

This work was undertaken on the supposition that fine-grained, undisturbed sedimentary rocks which had been laid down in tranquil water millions of years ago might still retain a magnetic polarization acquired as a result of the orientation of magnetic particles in the direction of the earth's field existing at the time of deposition.

Measurements were made at eight sites in Colorado, Utah, Washington, Idaho, Wyoming, and South Dakota. These sites, together with a number of others, were suggested as suitable for the work by members of the United States Geological Survey. The rocks range in age from Jurassic (100 million years) to Miocene (10 million years). Altogether sixteen sites were examined for suitability, the requirements being that the rock have a workable exposure, be fine-grained, be flat-lying, appear undeformed, lack any history of thermal disturbance, have sufficient cohesion to permit preparation of 3 cm cubic samples, and be sufficiently magnetic to be measurable (minimum measurable moment 10^{-7} c.g.s. units per cc).

The expedition had a staff of three, and utilized two six-by-six 2½ ton trucks as mobile equipment. One of these was fitted as living quarters and the other was fully equipped to make complete determinations of magnetic polarization in the field.

At the eight sites a total of 94 samplings was made, the smallest number at a given site being two and the largest twenty-one.

The directions of magnetization for all 94 samples are used in plotting the frequency distribution curves in Fig. 1. At the eight sites the present magnetic declination ranges from 13° to 22° east of geographic north, and the inclination from 66° to 72°. It is seen from Fig. 1 that there is a marked tendency for the horizontal component of rock magnetism to center on geographic north rather than on the present geomagnetic north. This result is to be expected if, through geologic time, magnetic north has oscillated 30 to 40 degrees to either side of a mean which is geographic north, a cyclic pattern found from magnetic measurements made in 1947[1] on 5000 years of glacial clay deposits in New England (15,000 to 20,000 years old[2]) and on ocean bottom samples (1,000,000 years). The magnetic stability of glacial clays has been established by studies of folded strata.

The inclination values in the rocks are seen in Fig. 1 to be slightly less than the present inclination of the earth's field.

All the sites did not give equally concordant results. At Glenns Ferry, Idaho, for example, thirteen samples averaging 2° east of geographic north in declination gave a very small scatter of polarizations, whereas the 21 samples from the Badlands at South Dakota gave a very great scatter. Stream bedding may be one of the factors responsible for the scattered polarizations at the latter site.

At one site, studies of the polarizations of sedimentary pebbles in a conglomerate give evidence that fine-grained, water-deposited material can retain a direction of magnetization for millions of years. Polarizations of the same material in the undisturbed condition at this site are included in the data of Fig. 1.

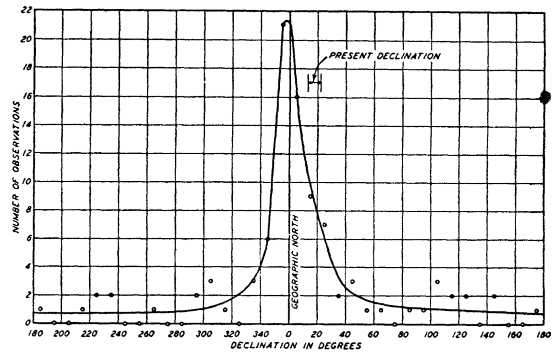

FIG. 1A. Frequency distribution of declination measurements on rock samples.

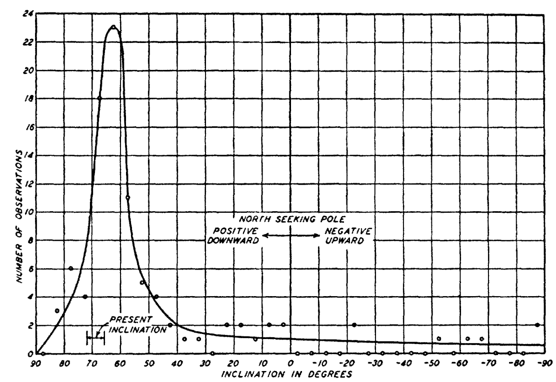

FIG. 1B. Frequency distribution of inclination measurements on rock samples.

These observations, with two-thirds of the declination values in a narrow band centered on geographic north and inclination values differing little from present inclination are consistent with the idea that, for the past 100 million years, the earth's magnetic field has been approximately centered on the earth's geographic axis. They do not support the contention, recently reiterated on the basis of measurements of the polarizations of 50-million year old igneous dikes in England,[3] that the earth's field in the past has had a reverse polarity.

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[1] Terr. Mag. **53**, December, 1948.
[2] Am. J. Sci. **246**, 689–700 (1948).
[3] Nature **161**, 462–464 (1948).

The Formation of U^{232} by Helium Ions on Thorium

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GOFMAN and Seaborg first produced the isotope U^{232} by deuteron bombardment of thorium.[1] Studier and Hyde[2] have reported the occurrence of the α, $p3n$ reaction