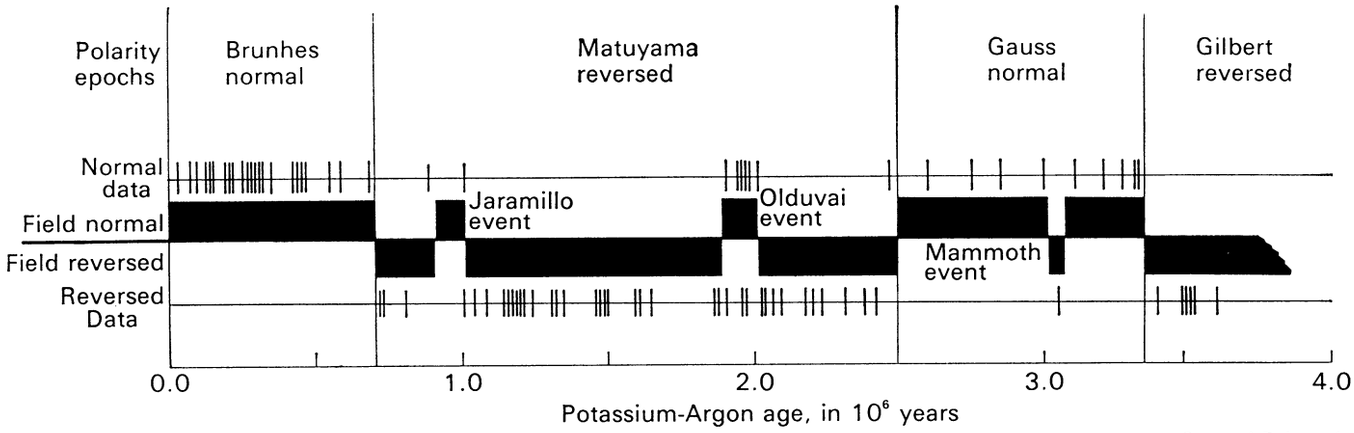


Cox and Dalrymple

Schedule for reversal: The magnetic field has reversed at least nine times over the past four million years.

When the north pole goes south

For reasons still not clearly understood, the polarity of the earth's magnetic field undergoes periodic reversals, leaving a record of its vagaries in magnetic rocks

by Louise Purrett

The magnetic north pole, used for centuries as a means of orientation, is far from stable. Nearly 500 years ago, navigators found that their compass needles deviated from the "true north" of the pole star at different places on the earth. And in 1635 the English astronomer Henry Gellibrand noted a steady change in the angle between the magnetic and geographic north poles. Nor is the magnetic field constant in intensity; since 1830 it has diminished by about 0.05 percent.

But even more startling was the discovery that the earth's magnetic field has reversed itself at least nine times in the last 4 million years.

When certain molten rocks cool in the presence of a magnetic field, they become magnetized in the direction of that field. The earth's magnetic field, though relatively weak, is sufficient to magnetize many rocks. Thus certain volcanic rocks and baked clays contain a record of the direction of the earth's magnetic field at the time of their formation.

The Japanese geophysicist Motonori Matuyama found in 1929 that many volcanic rocks of the early Pleistocene, about 700,000 years ago, are reversely magnetized, as though the positions of the north and south magnetic poles were reversed. Evidence accumulated since then shows that there have been long epochs of about a million years during which one polarity or the other predominated. The present polarity has lasted about 700,000 years. For a period of 1.8 million years before that, now called the Matuyama Epoch, the polarity was reversed. Before that—between 3.36 million and 2.5 million years ago—there was the Gauss Epoch, in which polarity was the same as it is today, or "normal." These epochs were occasionally interrupted by brief magnetic events, in which the poles reverse again for perhaps 100,000 to 200,000 years. During the Matuyama (reversed) Epoch, for example, there were two brief periods of normal polarity.

This pieced-together picture of the earth's fickle magnetic history caused more than a little mystification among the scientific community. Three U.S. Geological Survey researchers, Drs. Allan Cox (now at Stanford), G. Brent Dalrymple and Richard R. Doell, put it this way: "The idea that the earth's magnetic field reverses at first seems so preposterous that one immediately suspects a violation of some basic law of physics, and most investigators working on reversals have sometimes wondered if the reversals are really compatible with the physical theory of magnetism."

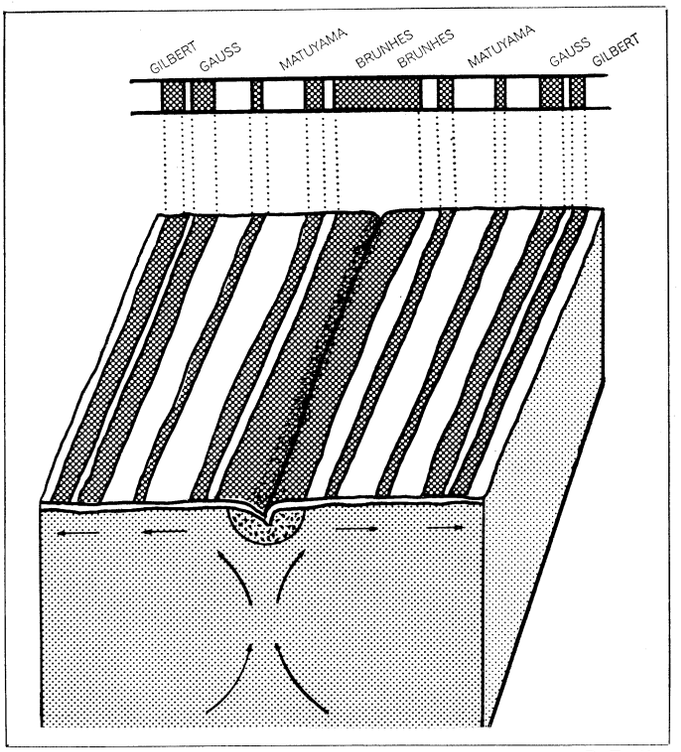
The magnetic reversals, aside from their inherent interest, have provided confirmation for sea-floor spreading and continental drift. Polar wandering curves for the various continents—variations with time of the apparent location of the pole as inferred from magnetized rocks—coupled with knowledge of the polarity existing at a given period, reveal the past movements of the continents.

In 1962, scientists on the HMS Owen conducted a magnetic survey of a 200-square-mile region over the Carlsberg Ridge in the Indian Ocean, and found that the ocean floor on both sides of the ridge contained strips of rock alternately magnetized. It was proposed that the ridge was slowly exuding lava that became magnetized in the direction of the earth's magnetic field at the time of its solidification. This discovery, later found to be true of other ridges throughout the world, is among the strongest evidence for sea-floor spreading.

Magnetic reversals have also been proposed to explain various natural events. One of the more persistent theories is that they have influenced evolution and may even have been responsible for the extinction of several species.

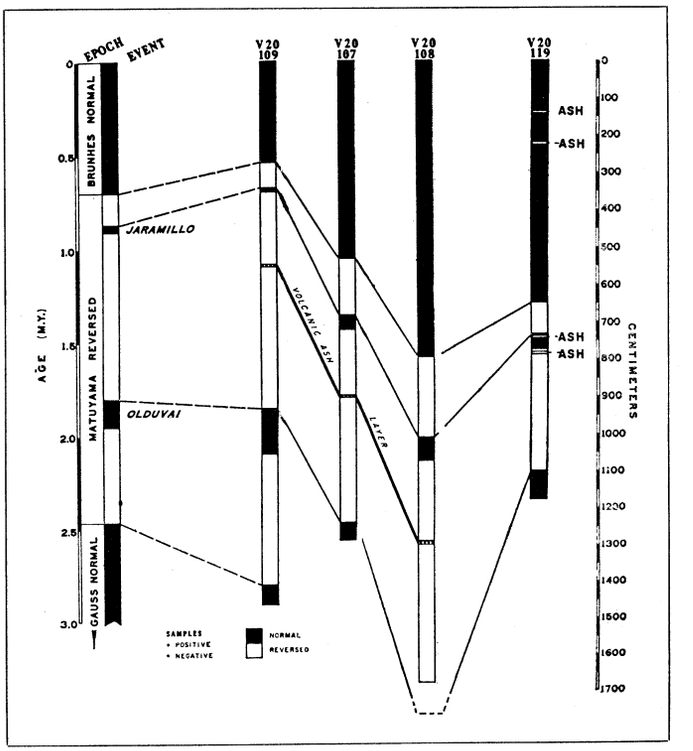
Dr. R. J. Uffen, a Canadian geophysicist, was one of the first to suggest a connection between reversals and evolutionary processes. His idea received some support when, in 1966, a group of researchers discovered an apparent correlation between field reversals and discontinuities of microfauna in deep-sea sediment cores. At least two authorities have noted that six species of radiolaria, a one-celled marine animal, became extinct simultaneously throughout the world about 700,000 years ago, the time of the last major magnetic field reversal (SN: 11/21/70, p. 392).

Dr. Bruce Heezen of Columbia University's Lamont-Doherty Geological Observatory and others reason that when a reversal occurs, the magnetic field gradually diminishes in intensity until it reaches zero and then builds up again in the opposite direction.



R. Trotter

Magnetic pattern in crust created at an ocean ridge.



Volcanic ash layers in ocean cores show past polarity.

Since the magnetic field shields the earth from cosmic radiation, they point out, the influx of radiation allowed by a weakened field may profoundly affect life on earth.

Another explanation, proposed by Drs. James P. Kennett and Norman D. Watkins of the University of Rhode Island, is that volcanic ash spewed into the atmosphere during the activity accompanying a reversal inhibited solar radiation and brought about climatic changes.

For a while, there was some doubt about whether these apparent reversals really occurred, however. In 1950, Dr. John Graham, now with the Southwest Center for Advanced Studies, suggested that rocks magnetized in reverse may be the result not of a reversal of the earth's field, but of a mineralogical property that causes them to become magnetized in a direction opposite to that of the prevailing field. His suggestion was confirmed when rocks with the property of self-reversal were discovered.

Subsequent evidence, however, indicates that self-reversals are rare. Experiments in which hundreds of rock samples were heated and then cooled in a known magnetic field showed that fewer than one percent were self-reversing. Furthermore, if the earth's magnetic field actually reverses, the geologic ages of normal and reverse rocks all over the world should fall into corresponding intervals. This has been found to be the case.

But though reversals of the earth's magnetic field have been established with reasonable certainty, their cause is much less certain.

The field itself is generally attributed to convection in the earth's core. If static magnetization is excluded, the only known way to produce a magnetic field is with electric currents; any electric current is accompanied by a magnetic field. But where do the electric currents that generate the earth's magnetic field occur? Metals and ionized gases are the best conductors of electric current. A small part of the earth's magnetic field, therefore, comes from currents in the ionosphere, which is composed of ionized gases. But in 1830 the mathematician Karl Friedrich Gauss showed that most of the magnetic field must originate inside the earth.

In the mid-1950's two scientists, Dr. Walter M. Elsasser, now at the University of Maryland, and the British geophysicist Sir Edward Bullard, independently arrived at a mechanism by which the earth's magnetic field might be generated from within the core. All large-scale magnetic fields in the universe arise out of mechanical motions of a conducting fluid, and the earth's core is composed mostly of molten iron, a good conductor of electricity. Bullard and Elsasser thus proposed that motions in this iron core generate electric currents and amplify their accompanying magnetic fields in much the same way as the dynamos in a conventional power station. This motion, Dr. Elsasser suggests, is a result of thermal convection, in which heat is delivered from the core to the mantle as the earth slowly cools.

The dynamo theory is now generally accepted. But the way in which it accounts for magnetic reversals is still unclear. Reversals apparently are not inconsistent with the dynamo theory; they simply require a differential motion between core and mantle opposite to that prevailing. Dr. S. K. Runcorn of the University of Newcastle-upon-Tyne in England points out that reversals seem to be the result of the lack of preference of the system for one polarity.

The Japanese geophysicist Tsuneji Rikitake in 1958 set out the equations for two disk dynamos coupled to one another and concluded that it was possible for the fields produced to show reversals. Dr. D. W. Allan of the University of Cambridge in England then carried out more extended numerical calculations and found that reversals could occur under a wide range of conditions. The system has two states of equilibrium, with the currents for the one the reverse of the currents for the other. The equilibrium is stable for small oscillations of the field, but for larger ones the points of equilibrium may change.

This discovery might explain the observed weakening of the earth's magnetic field, Dr. Allan suggests. He

believes there may be oscillations of the main field with periods of several thousand years and reversals of the field at intervals of hundreds of thousands of years.

But all this leads to still another question: Is a trigger needed to set off this change, and if so, what? The time of the last reversal coincides with the meteorite or comet collision thought to have created the Australian tektite field, and several scientists have suggested this as a trigger.

Dr. J. R. Heirtzler of Lamont-Doherty Geological Observatory speculates that major earthquakes may cause wobble in the earth's spin axis which in turn might trigger a reversal. Since stress release is often manifested in volcanic activity, Drs. Kennett and Watkins reasoned recently that an investigation of past volcanic activity might reveal a correlation with magnetic polarity changes. The two scientists took cores from various locations in the South Pacific, demagnetized them to remove the effects of the present magnetic field, and measured their remanent magnetism. They found that when geomagnetic polarity changes were taking place, volcanic maxima were also occurring.

Another team of researchers, Drs. I. K. Crain and P. L. Crain of the Australian National University in Canberra and Dr. M. G. Plaut of the University of Western Ontario, analyzed the alternation of geomagnetic polarity over a long period of time—about 350 million years. They found two peaks in the proportions of normal polarity at about 300 million and 80 million years. These, they say, represent a magnetic era of 150 million years and a magnetic period of 40 million years.

The period of rotation of the Milky Way is about 280 million years and the vibrational period of the sun perpendicular to the galactic plane is about 84 million years. "This apparent correlation between the galactic oscillations and observed geomagnetic periods may indicate an external cosmological influence on the earth's magnetic field," the three conclude.

The cause of magnetic reversals is generally agreed to be some variation on the dynamo theory, though the nature of this variation, and the event that might set it off are uncertain. What does seem clear is that geomagnetic reversals are tied in some as yet undefined way to a number of other physical phenomena. But, in the words of three prominent magnetic field researchers, "after centuries of research the earth's magnetic field remains one of the best-described and least-understood of all planetary phenomena." □

books OF THE WEEK

CONTROLLING THE WEATHER: A Study of Law and Regulatory Procedures—Howard J. Taubenfeld, Ed.—Dunellen, 1971, 275 p., $10. Comprehensive report on studies of the legal, scientific, political and social implication of problems raised by national and international weather modification efforts, such as rain making, hail and lightning suppression, and fog clearance.

ELECTRONS IN METALS: A Short Guide to the Fermi Surface—J. M. Ziman—Barnes & Noble, 1971, 76 p., illus., paper, $3. Deals with the electron gas, bands and zones, dynamics of Bloch electrons and the calculation of band structure, the properties of real metals, and the gauging of the Fermi surface.

ETHICS FOR SCIENTIFIC RESEARCHERS—Charles E. Reagan—C. C. Thomas, 1971, 2nd ed., 166 p., $9. Combines a theoretical study of the logic and structure of ethics with a casebook of practical applications. Includes annotated bibliography.

HISTORICAL STUDIES IN THE PHYSICAL SCIENCES, Vol. 2—Russell McCormmach, Ed.—Univ. of Pa. Press, 1971, 356 p., photographs, diagrams, $8.50. Contains eight articles dealing with the intellectual and institutional developments in physics from the mid-1840's to the mid-1920's, with primary focus on the quantum and relativity theories.

THE HOE AND THE HORSE ON THE PLAINS: A Study of Cultural Development among North American Indians—Preston Holder—Univ. of Neb. Press, 1970, 176 p., plates, illus., $6.95. A study of two native modes of life in the Great Plains—the village way of life and the nomadic bison hunters on horseback, and the pattern of their encounters with the encroaching Europeans.

THE KUROSHIO: A Symposium on the Japan Current—John C. Marr, Ed.—East-West Center Press, 1970, 614 p., diagrams, maps, $17.50. Based on the field work of 98 oceanographic cruises, this intensive study of one of the principal currents in the Pacific covers such subjects as physical and chemical oceanography, fish and fisheries, planktonology and bottom topography of the area.

MEASUREMENTS OF SPECTRAL IRRADIANCE UNDERWATER—John E. Tyler and Raymond C. Smith—Gordon and Breach, 1971, 103 p., diagrams, tables, $19.50. Quantitative information on the underwater light field, details on its variation with depth, and the optical attenuating properties of various types of natural water.

PALEOZOIC PERSPECTIVES: A Paleontological Tribute to G. Arthur Cooper—J. Thomas Dutro, Jr., Ed.—Smithsonian Institution Press, 1971, 390 p., photographs, illus., paper, $4. Collection of research papers concerned with the study of brachiopods and their biostratigraphic application to geologic problems, especially the Paleozoic Era.

PILGRIMS OF THE WILD—Grey Owl (Wa-sha-quoin-asin), new introd. by V. B. Scheffer—Scribner, 1971, 282 p., sketches by author, $7.95. Reprint (1935) of a personal narrative about life in the Canadian wilderness, and the author's efforts to establish a beaver sanctuary.

PLANTS WE LIVE ON: The Story of Grains and Vegetables—Carroll Lane Fenton and Herminie B. Kitchen—Day, 1971, 128 p., illus. by C. L. Fenton, $4.29. Informative reading for younger readers about the families of grains and vegetables, and the process of their improvement.

PULSATING STARS 2: A NATURE Reprint—Introd. by T. Gold—Plenum Press, 1971, 116 p., illus., $12. Collection of articles (1968-1969) that deal with the fast pulsars, with pulsar distributions and distances, theories, and observations by radio, optics, gamma-ray and X-ray.

RHIZOCTONIA SOLANI: Biology and Pathology—J. R. Parmeter, Jr., Ed.—Univ. of Calif. Press, 1971, 255 p., photographs, diagrams, $11.50. Presents comprehensive, condensed treatise, organizing present knowledge of the widely studied pathogenic fungus of the potato tuber, its taxonomy, nomenclature, biology and pathology.

SOCIAL IMPLICATIONS OF BIOLOGICAL EDUCATION—Arnold B. Grobman, Ed.—Darwin Press, 1971, 134 p., diagrams, $5.95. Prepared in cooperation with the National Association of Biology Teachers, the book offers discussions by distinguished biologists of questions of behavior, medicine, genetics, population control, evolution and other social issues.

THE SUN BENEATH THE SEA—Jacques Piccard, transl. from French by Denver Lindley—Scribner, 1971, 405 p., photographs, $12.50. Describes the construction of the mesoscaphs, and gives an account of the 30-day drift of the *Ben Franklin,* led by the author, with a crew of six, exploring the currents of the Gulf Stream and observing underwater life.

THEORY AND PRACTICE OF FAMILY PSYCHIATRY—John G. Howells with edited contributions—Brunner/Mazel, 1971, 953 p., illus., $25. Explains the author's dimensional system of family psychiatry and its clinical practice, and illustrates the different aspects of the system in systematically grouped papers relating to the main theme.

THE UNIVERSE: From Flat Earth to Quasar—Isaac Asimov—Walker, 1971, rev. ed., 315 p., photographs, diagrams, $6.95. A highly readable scientific survey of what is presently known about the universe, guides the reader from discovery to discovery while explaining the principles.

THE URBAN MOSAIC: Towards a Theory of Residential Differentiation—Duncan Timms—Cambridge Univ. Press, 1971, 277 p., maps, $11.50. A study of urban structure, characteristics of residential location and choice, the development of social area models, and their use in the spatial patterning of residential differentiation.

THE WORLD OF ANTS: A Science-Fiction Universe—Rémy Chauvin, transl. from French by George Ordish—Hill & Wang, 1971, 216 p., photographs, drawings, $5.95. Entomologist explores in detail the world of ants from the behaviorist's point of view, shows how the ants' apparent social organization and intelligence is really a combination of chance and cybernetics, resulting from the enormous numbers involved and the variety of their adaptive mutations.

YEARBOOK ON INTERNATIONAL COMMUNIST AFFAIRS 1969—Richard F. Staar, Ed.—Hoover Institution Press, 1971, 1170 p., $19.95. Provides, chiefly on the basis of primary sources, a comprehensive survey of the organizational structure, internal development, domestic and foreign policies, and activity of the communist parties throughout the world in 1968.

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