BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 71, PP. 645-768, 35 FIGS. JUNE 1960

REVIEW OF PALEOMAGNETISM

BY ALLAN COX AND RICHARD R. DOELL

ABSTRACT

This review is an attempt to bring together and discuss relevant information concerning the magnetization of rocks, especially that having paleomagnetic significance. All paleomagnetic measurements available to the authors are here compiled and evaluated, with a key to the summary table and illustrations in English and Russian. The principles upon which the evaluation of paleomagnetic measurements is based are summarized, with special emphasis on statistical methods and on the evidence and tests for magnetic stability and paleomagnetic applicability.

Evaluation of the data summarized leads to the following general conclusions:

(1) The earth's average magnetic field, throughout Oligocene to Recent time, has very closely approximated that due to a dipole at the center of the earth oriented parallel to the present axis of rotation.

(2) Paleomagnetic results for the Mesozoic and early Tertiary might be explained more plausibly by a relatively rapidly changing magnetic field, with or without wandering of the rotational pole, than by large-scale continental drift.

(3) The Carboniferous and especially the Permian magnetic fields were relatively very "steady" and were vastly different from the present configuration of the field.

(4) The Precambrian magnetic field was different from the present field configuration and, considering the time spanned, was remarkably consistent for all continents.

RÉSUMÉ

Ce compte-rendu s'efforce de rassembler et de discuter les données utiles sur la magnétisation des roches, et en particulier celles qui ont un intérêt paléomagnétique. Toutes les mesures paléomagnétiques connues des auteurs sont rassemblées et évaluées (avec un indexe du tableau-résumé et des illustrations en anglais et en russe). Les principes sur les quels se base l'évaluation des mesures paléomagnétiques sont resumés, en appuyant sur les méthodes statistiques et sur les données et les tests qui révèlent la stabilité magnétique et l'utilisation possible en paléomagnétisme.

L'étude des données mène aux conclusions générales qui suivent:

1. Le champ magnétique moyen de la terre, de l'Oligocène à la période actuelle suit de très près ce qui résulterait de la présence d'un dipôle au centre de la terre, orienté parallèlement à l'axe de rotation actuel.

2. Les *données paléomagnétiques du Mésozoique et Tertiaire inférieur pourraient* être expliquées d'une manière plus plausible en supposant un champ magnétique variant rapidement, plutôt qu'une dérive continentale à grande échelle, avec ou sans déplacement du pôle de rotation.

3. Les champs magnétiques du Carbonifère et particulièrement du Permien étaient très "stables" en comparaison de ceux des périodes antérieure et postérieure, et avaient une configuration profondément différente de celle du champ actuel.

4. Le champ magnétique précambrien avait une configuration très différente de celle du champ actuel, mais, si l'on tient compte de la durée représentée, était remarquablement constant pour tous les continents.

ZUSAMMENFASSUNG

Diese Zusammenstellung ist ein Versuch, wichtige Informationen zusammen zu bringen und zu diskutieren, die den Magnetismus der Gesteine behandeln, vor allem solcher, die die paläomagnetische Bedeutung haben. Alle den Autoren zur Verfügung stehenden paläomagnetischen Messungen sind hier zusammengestellt und ausgewertet worden, mit einem Schlüssel in Englisch und Russisch für die zusammenfassende Tabelle und die Illustrationen. Die Prinzipien, auf welchen die Auswertung der paläomagnetischen Messungen basiert, sind zusammengefasst, wobei besonderes Gewicht auf statistische Methoden und auf die Ergebnisse und Versuche betreffend magnetischer Stabilität und paläomagnetischer Anwendbarkeit gelegt wird.

Die Auswertung der zusammengestellten Ergebnisse führt zu den folgenden allgemeinen Schlussfolgerungen:

1. Das durchschnittliche magnetische Feld der Erde vom Beginn des Oligozäns bis zur Gegenwart ist fast gleich geblieben, vermutlich infolge eines Dipols im Mittelpunkt der Erde, wobei der Dipol parallel zu der augenblicklichen Rotationsaxe orientiert ist.

2. Die paläomagnetischen Ergebnisse aus dem Mesozoikum und dem Unteren Tertiär können besser durch ein verhältnismässig schnell wechselndes magnetisches Feld als durch eine weiträumige Kontinentalverschiebung, mit oder ohne Wanderung des Rotationspols, erklärt werden.

3. Verglichen mit denen früherer oder späterer Zeiten, waren die magnetischen Felder des Carbons und besonders des Perms, sehr "beständig". Sie waren vollkommen verschieden von der augenblicklichen Gestaltung des Feldes.

4. Das magnetische Feld des Präkambriums war verschieden von der augenblicklichen Konfiguration des Feldes und, wenn man die Zeitspanne in Betracht zieht, auffallend einheitlich für alle Kontinente.

ОБЗОР ЯВЛЕНИЙ ПАЛЕОМАГНЕТИЗМА

Аллан Кокс и Ричард Р. Долл

Резюме

Настоящий обзор является попыткой собрать воедино и обсудить сведения о намагничивании пород, особенно данные, имеющие значение. Все доступные авторам данные о палеомагнетизме были тщательно проанализированы. условные обозначеиян на сводной таблице и на рисунках снабжены пояснениями на английском и русском языке. Сделано обобщение принципов, на которых основана оценка палеомагнитных измерений. Особо подчеркивается значение статистических методов и данных об измерении магнитной стабильности, в свете их применения к изучению палеомагнетизма.

Анализ собранных данных приводит к следующему общему заключению:

1. В течении олигоцена, вплоть до позднечетвертичного времени, среднее магнитное поле земли приближается весьма близко к полю, образованному магнитным диполем в центре земли, ориентированному параллельно к современной оси вращения.

2. Результаты измерений палеомагнитных свойств мезозойских и третичных пород свидетельствуют об относительно быстро изменяющемся магнитном поле, нежели о крупных перемещениях материков, со смещением или без смещения полюсов вращения.

3. Магнитные поля каменноугольного и, особенно, пермского периода были очень "постоянны", по сравнению с полями более раннего или позднего времени, и весьма отличались от современного очертания поля.

4. Докембрийское магнитное поле отличалось от современного очертания магнитного поля и, принимая во внимание промежуток времени, отделяющий нас от докембрия, было в высшей степени постоянным на всех материках.

CONTENTS

TEXT

ILLUSTRATIONS

INTRODUCTION

Studies of the magnetic properties of rocks have accelerated so rapidly during the past 2 decades that the accumulated information and special techniques of rock magnetism may now well be regarded as a separate geologic discipline. Current interest in the subject has been greatly stimulated by interpretations of the magnetic data as evidence relevant to two persistent geologic hypotheses, continental drift and polar wandering. Moreover, further interest in paleomagnetism has been aroused by observations suggesting that the earth's magnetic field has undergone periodic reversals. While continental drift and polar wandering hypotheses have been proposed for many decades, and remanent magnetization has been recognized for centuries, a brief description of the recent rise of interest in paleomagnetism through the union of these rather diverse elements will form an appropriate introduction to this review.

The classic early work in paleomagnetism is that of Chevallier (1925), who demonstrated that the remanent magnetizations of several lava flows on Mt. Etna were parallel to the earth's magnetic field measured at nearby observatories at the time the flows erupted. (For earlier studies of rock magnetism *see* the references cited in Chevallier, 1925, and Matuyama, 1929.) Mercanton (1926, p. 860) appears to have been the first to foresee clearly the possibility of using rock magnetism as a tool for testing the theories of polar wandering and continental drift, and he also anticipated the field-reversal hypothesis.

Since these early studies, great progress has been made in understanding the processes by which rocks become magnetized. For the past 20 years, Thellier and his colleagues have been concerned with several of these processes, including magnetization acquired by rocks over long periods of time in weak fields and magnetization by heating and cooling in weak fields. They have applied the results of these studies principally to determinations of the intensity of the earth's field in the past. (*See* Thellier and Thellier, 1959, for an important review of this work.) Important contributions to an understanding of magnetic minerals and magnetizing processes have also been made by other workers, including Rimbert, Haigh, Gorter, Nicholls, and especially the Japanese workers Nagata, Uyeda, Kobayashi, and Akimoto.

The periodic field-reversal hypothesis in its modern form, with the last reversal ending in early Quaternary time, was first proposed by Matuyama (1929, p. 205). Recent interest in reversals stems from Graham's observations (1949, p. 156) of opposing directions of magnetization in sediments, which lead Néel (1951) to propose four mechanisms by which a magnetization might be acquired in a direction opposite to that of the magnetic field acting. Néel's theoretical prediction was brilliantly confirmed when Nagata and Uyeda discovered that the Haruna dacite reproducibly acquired a remanent magnetization opposing the applied field (Nagata and others, 1951; Nagata, 1953b; Uyeda, 1958), suggesting that reversed magnetizations were not due to reversals of the earth's field. However, at about the same time Hospers (1951), working in Iceland, and Roche (1951), working in France, found that the presence or absence of reversals in otherwise indistinguishable lavas depended on the stratigraphic position of the flows. Their data strongly pointed to field reversals, with the most recent one occurring early in the Pleistocene. Research on the reversal problem is continuing, and Uyeda's review (1958) of the self-reversal mechanism of the Haruna dacite is one of the outstanding contributions in recent years.

Methods of using field relationships for demonstrating stability of remanent magnetization have been developed by Graham (1949) and are now standard techniques in paleomagnetic investigations.

With the development of a very sensitive spinner magnetometer by Johnson and McNish (1938), and an astatic magnetometer by Blackett (1952) with a sensitivity close to the theoretical limit, measurements of weakly magnetized sediments became possible. A large number of measurements by Graham (1949; 1955), by Clegg and others (1954a), and by Creer and others (1954) soon confirmed the fragmentary evidence from previous studies indicating that pre-Tertiary rocks do not usually have magnetizations parallel to the present field. Graham (1949) pointed out possible applications to an evaluation of the continental-drift and polar-wandering hypotheses.

Concurrently advances were made by Elsasser and Bullard in explaining the origin of the earth's field by the dynamo theory (reviewed in Elsasser, 1955; 1956). These studies suggested that the earth's axis of rotation and the average axis of the earth's magnetic field should coincide. Encouraged by theoretical developments, Creer and others (1954) proposed a paleomagnetically determined polar wandering path from Precambrian to present times.

When more measurements from other continents became available, it soon appeared to many workers that polar wandering alone would not adequately explain all the data. At the present time relative displacements of nearly all continents, with respect to Europe, have been suggested, for North America by Runcorn (1956b, p. 83) and by Irving (1956a, p. 40), for India by Clegg and others (1956, p. 430), for Australia by Irving and Green (1958, p. 71), for South America by Creer (1958, p. 389), for Africa by Creer and others (1958, p. 500), and for Japan by Nagata and others (1959, p. 382).

One purpose of this review is to bring together the relevant paleomagnetic data. In order properly to evaluate these data, the reader should be acquainted with the principles of paleomagnetism, and a review of these principles precedes the table of data. After a discussion of these data, we conclude with a short subjective evaluation of some of the paleomagnetic interpretations and suggest a few topics for future study.

ACKNOWLEDGMENTS

This review was begun in 1958, when Doell was a member of the faculty at the Massachusetts Institute of Technology, aided by a grant from the National Science Foundation, and when Cox was studying at the University of California, Berkeley, aided by grants from the American Petroleum Institute and the Institute of Geophysics of the University of California. It was completed after both authors joined the U. S. Geological Survey. Our colleagues at these and other institutions aided greatly in the preparation of the review, and we wish especially to acknowledge the value of discussions and correspondence with J. R. Balsley, M. R. Banks, J. C. Belshé, A. F. Buddington, J. A. Clegg, R. W. Girdler, L. G. Howell, E. Irving, S. K. Runcorn, S. Uyeda, and J. Verhoogen. Paleomagnetic data were generously furnished in advance of publication by D. W. Collinson and S. K. Runcorn, by R. W. Girdler, and by D. Bowker. Special thanks are due J. R. Balsley and J. Verhoogen for their critical reviews of the manuscript. Mrs. E. Harper prepared the illustrations.

THE BASIS OF PALEOMAGNETISM

Magnetization of Rocks

General statement.—The magnetization observed in a rock is determined by two factors, the magnetic field applied to the rock up to the time of observation of the magnetization, and the occurrence of one or more of the several processes by which materials become magnetized. Different magnetizing processes may operate on the rock at different times during its history; the earth's magnetic field may change from time to time, and the magnetization acquired may not in all cases be parallel to the applied field. It is not surprising, therefore, that magnetization is one of the most complex properties that the geologist can study in rocks. Moreover, geologic interpretations of magnetic measurements are critically dependent on the availability of techniques for distinguishing the various magnetic components.

The first two components of magnetization to be distinguished are *remanent* magnetization and *induced* magnetization. Whereas induced magnetization requires the presence of an applied field, remanent magnetization does not. In fields as weak as the earth's, induced magnetization is proportional to the field; the constant of proportionality is called the *susceptibility*. Magnetic-anomaly maps of the earth's field are usually interpreted by assuming that the magnetization in the rocks producing the anomalies is induced magnetization and parallel to the earth's field. However, remanent magnetizations are often not parallel to the earth's field and may be stronger than the induced magnetization. (*See* Nagata, 1953a, p. 128–129, for some typical values.) Therefore, the assumption of a predominance of induced magnetization should be tested by sampling wherever possible.

Each grain of magnetic material in a rock consists of one or more magnetic domains, and although the directions of magnetization are different in different domains, the intensity of magnetization per unit volume, termed the spontaneous magnetization J_S, is the same in all domains of the same mineral. Quantity J_S decreases with increase in temperature and vanishes at the Curie temperature. Sufficiently small grains consist of single domains, and in the absence of an external magnetic field the direction of magnetization in each domain will lie along one of several preferred axes. The directions of these preferred axes and the heights of the magnetic energy barriers that separate them are determined by the shape of the grain, the crystalline anisotropy of the mineral, or both. In an applied magnetic field of increasing intensity the direction of magnetization in the grain is pulled away from the preferred axis toward the field direction. If the energy supplied by the applied field is not greater than the magnetic energy barriers, the direction of magnetization will return to its former position when the field is removed. This magnetization, which is reversible and depends on the applied field, is by definition an induced magnetization.[1]

When the applied field is increased above a critical value termed the *coercive force*, the direction of magnetization in a single-domain grain crosses over a magnetic energy barrier, and when the field is removed the magnetic vector comes to rest along a new direction. In

[1] The term *induced magnetization* is used, as defined here, in geophysical prospecting applications and should not be confused with *induction*, *B*, of the usual hysteresis curve.

this case the irreversible change in magnetization is a *remanent* or permanent magnetization. Larger grains contain many domains, and, in an increasing magnetic field, domains with magnetizations nearly parallel to the applied field grow at the expense of others. Magnetic energy barriers again prevent an unlimited reversible growth of domains, and the coercive forces of multidomain grains correspond to the magnetic fields necessary to overcome these energy barriers.

A single rock sample may contain several magnetic minerals with a wide range of grain sizes and a wide coercive force spectrum (Graham, 1953, p. 249). The intensity of natural remanent magnetizations is commonly several orders of magnitude less than the maximum intensity that could be developed if the rock were placed in a magnetic field much larger than any of the coercive forces of the different magnetic constituents. This indicates that only a small fraction of the domains in a naturally magnetized rock have a preferred direction of magnetization causing the observed remanent magnetization; the majority have random directions. Whether the domains with preferred orientations occur in constituents with high or low coercive forces depends on the process by which the remanent magnetization was acquired. The natural remanent magnetization acquired by some processes is very "hard" and similar to the remanent magnetization of a good permanent magnet, whereas that acquired by other processes is "soft," corresponding quite closely with the magnetization of "soft" iron. Because rocks are not homogeneous materials and because many of them have been subjected to several magnetizing processes, both types may be found in the same rock. (*See* Graham, 1953, p. 249–252; Clegg and others 1954a, p. 593.) During the past several decades considerable progress has been made in understanding some of the processes by which natural remanent magnetization is acquired by rocks, and in developing techniques for analyzing the observed magnetizations into components corresponding to the various processes.

In the following paragraphs consideration will be given to the principal processes causing natural remanent magnetization in rocks. Processes leading to remanent magnetizations parallel to the applied field will be discussed first. Then factors leading to remanent magnetizations which are not parallel to the applied field will be considered.

Isothermal remanent magnetization.—A rock placed in a magnetic field at room temperature and subsequently removed will acquire a remanent magnetization, provided the field is larger than the lowest coercive force of the magnetic minerals in the rock. The process is simply one in which domains having magnetic energy barriers with corresponding coercive forces less than the applied field align their magnetic moments with the field. When the field is removed, the energy barriers prevent these domains from returning to their former positions, and a net magnetization results. Since minerals in rocks usually have coercive forces of the order of 100 oersted or more, the earth's field of about 0.5 oersted is, in general, not strong enough to produce isothermal remanent magnetization (IRM). On the other hand, the large magnetic fields associated with lightning bolts may impart a substantial IRM to rocks (Cox, 1959). The IRM may easily be removed, or changed in direction, by any field as large as that which produced it.

Viscous magnetization.—If a rock remains in a field too weak to cause IRM for a sufficiently long period of time, it is often possible to measure a new component of remanent magnetization in the direction of the field (*e.g.*, Rimbert, 1956b, p. 2536; Brynjólfsson, 1957, p. 250–251). Such a magnetization, requiring a relatively long time to form, is termed viscous magnetization. In rocks, as in other materials, it is due to the Boltzman distribution of thermal energy which, when converted to magnetic energy, allows the magnetic domains to cross energy barriers that they otherwise could not cross in the weak field of the earth. Although the thermal-energy distribution has a random nature, the weak field of the earth provides a slight bias sufficient to cause a net change of magnetization in the direction of the field. The theory of viscous magnetization is similar to that of thermo-remanent magnetization.

Thermo-remanent magnetization.—Of much more importance for paleomagnetic studies is the process of thermo-remanent magnetization. As a rock cools in the earth's magnetic field it begins to develop spontaneous magnetization at the Curie temperature T_C and a preferential alignment of domains parallel to the field. The resulting magnetization is thermo-remanent magnetization (TRM). It is important to note that not all of the TRM is acquired at the Curie temperature, but rather over a temperature interval extending some tens of degrees below T_C. If, during a cooling experiment, a weak magnetic field is applied only in the temperature interval T_1 to T_2 ($T_2 < T_C$), with zero magnetic field at all other temperatures, a magnetization known as the partial thermo-remanent magnetization (PTRM) is developed.

An example of the PTRM acquired in equal temperature intervals on cooling from the Curie temperature is shown in Figure 1a, where the values are plotted as a function of the mean

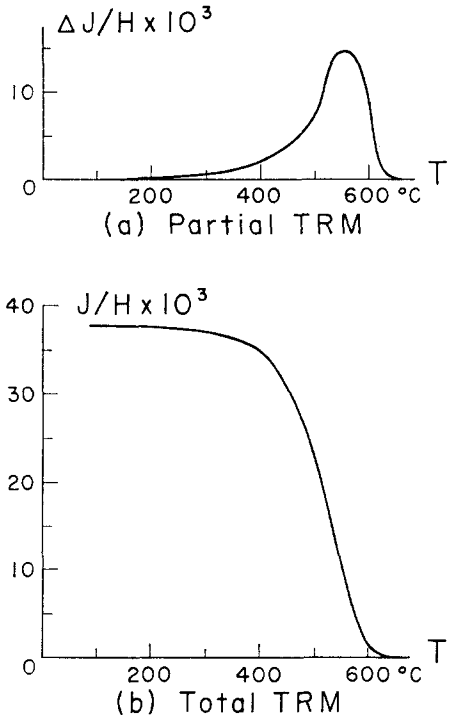

FIGURE 1.—ACQUISITION OF THERMO-REMANENT MAGNETIZATION IN WEAK MAGNETIC FIELDS

(a) Partial thermo-remanent magnetization (PTRM) acquired in field H over equal temperature intervals as a function of mean temperature of interval; (b) thermo-remanent magnetization (TRM) acquired on cooling from Curie temperature to any temperature T in field H and from T to ambient temperature in zero field (for weak field the quantity J/H is approximately constant).

temperature of the interval. Experimentally it is found that for lavas and baked sediments the PTRM acquired in a weak field over any temperature interval T_1 to T_2 is independent of the magnetization acquired in adjacent temperature intervals (Thellier, 1951, p. 213; Nagata, 1953a, p. 142–153); Thellier reports that the rock preserves an exact memory of the temperature and field which produced the PTRM (quoted in Néel, 1955, p. 212). If the rock is heated to temperatures up to T_1 no effect on the PTRM acquired between T_1 and T_2 is observed, whereas it is completely destroyed at temperatures above T_2. The total TRM acquired in a given field is very close to the sum of the PTRM's acquired in the same field between the Curie temperature and room temperature. (*Compare* Figs. 1a and b.)

The theory of TRM for single-domain particles (Néel, 1955, p. 209–212) explains many of these characteristics. In Néel's model (which will be followed here) each grain has two directions in which the magnetic vector can lie with minimum magnetic energy in the absence of a magnetic field; these directions are 180° apart and are separated by a magnetic barrier of energy

$$E = vH_C J_S/2 \qquad (1)$$

where v is the volume of the grain, H_C the coercive force, and J_S the spontaneous magnetization of the mineral. When E is greater than the thermal energy (kT), where k is Boltzmann's constant and T the temperature, the thermal fluctuations are not able to move the direction of magnetization across the energy barrier. However, for sufficiently small values of v or sufficiently high values of T, the thermal fluctuations can cause the magnetic moment to move across the barrier. Thus, a total remanent magnetization of initial amount J_0 due to the preferential alignment of a large number of identical single domain grains will, after time t, have decayed to the value J_R given by

$$J_R = J_0 \exp(-t/\tau_0) \qquad (2)$$

where τ_0 is termed the *relaxation time*. As in other decay processes, one may speak of the "half-life" of thermo-remanent magnetization which has the value 0.693 τ_0. Quantity τ_0 is given by the equation

$$1/\tau_0 = A(v/T)^{1/2} \exp(-vH_C J_S/2kT) = A(v/T)^{1/2} \exp(-\gamma v/T) \qquad (3)$$

Quantities A and γ depend on the elastic and magnetic properties of the minerals, and the other quantities are as defined for equation (1).

An important feature of this model for TRM is that a small change in the quantity (v/T) can cause a very large change in τ_0. For example, the physical constants necessary to evaluate A and γ are known for iron (Néel, 1955, p. 211); and values for the quantity (v/T) of 3.2×10^{-21}, 7.0×10^{-21}, and 9.6×10^{-21} correspond respectively to values of 10^{-1} seconds, 10^9 seconds (3.4×10^2 years), and 3.4×10^9 years for τ_0. At room temperature the grain diameters corresponding to these values of (v/T) are roughly 120 Å, 160 Å, and 180 Å. Thus, the direction of magnetization in a grain with a diameter less than 120 Å is easily and quickly changed by the thermal fluctuations, and the application of a weak field h to a number of such grains causes a net magnetization in the direction of the field. This "equilibrium" magnetization is given (Néel, 1955, p. 211) by the equation

$$J_E = NvJ_S \tanh (vhJ_S/kT) \quad (4)$$

where N is the number of grains with volume v.

Because of the strong dependence of τ_0 on (v/T) in equation (3), there is a *critical blocking diameter* for a given mineral, dependent only on the temperature; grains with smaller diameters come to equilibrium very quickly with the magnetization indicated in equation (4), while those with substantially larger diameters maintain their original magnetizations over long intervals of time, regardless of the external field. Similarly, there is a *critical blocking temperature* for all grains of the same diameter.

The acquisition of TRM by single-domain grains is very simple in terms of this model. As a rock cools from its Curie temperature, a given grain assumes the equilibrium magnetization, J_E, until the temperature passes through the critical blocking temperature of the grain. As the temperature goes below this critical value, τ_0 for the grain increases rapidly, and the magnetization becomes "frozen" at the equilibrium level. The independence of partial thermo-remanent magnetizations acquired in different temperature ranges is thus explained as due to the magnetization residing in grains of different diameter. This simple theory explains many of the characteristics of TRM such as its great stability to disturbing fields and its remarkably slow decay.

The acquisition of TRM by most rocks is certainly more complex than indicated here, since many rocks contain magnetic minerals differing in physical properties as well as in grain size. Moreover, rocks containing multidomain grains, and even massive ferromagnetic mineral specimens, also acquire TRM which, commonly, has the characteristics described above. Verhoogen (1959) suggests that the TRM of these materials may reside in small, highly stressed regions within the ferromagnetic crystals.

The Curie temperatures of magnetic materials in igneous rocks lie below 700° C and, in many rocks, below 600° C. The major portion of the natural remanent magnetization measured in many igneous rocks appears to be TRM. (For more complete discussions of TRM *see* Nagata, 1953a, p. 123–192; Néel, 1955, p. 208–218, 225–241; Verhoogen, 1959.)

Depositional magnetization.—As demonstrated in artificially deposited sediments, previously magnetized magnetic particles attain a preferential alignment during deposition and maintain this alignment after consolidation, giving the sediment a remanent magnetization (Nagata and others, 1943, p. 277–279; Johnson and others, 1948, p. 357–360; King, 1955, p. 120). The stability of such a magnetization depends upon the process by which the grains originally acquired their magnetization. (Processes that cause depositional magnetization to have a direction other than that of the applied field will be discussed later.)

Crystallization or chemical magnetization.—Although the magnetization of some sediments is undoubtedly acquired by the depositional process, studies by Martinez and Howell (1956, p. 205) and by Doell (1956, p. 166) indicate that the magnetization of sediments may also be associated with chemical changes taking place after consolidation. Moreover, Haigh (1958, p. 284–285) and Kobayashi (1959, p. 115–116) have shown in the laboratory that a remanent magnetization is acquired by magnetic materials undergoing a chemical change (*e.g.*, reduction of hematite to magnetite) at constant temperature in a weak magnetic field. These authors also show that the stability of this magnetization, under the effects of higher temperature and demagnetizing fields, is very similar to that for TRM, although the intensity is not so great.

Haigh (1958, p. 278–281) points out the theoretical similarity of the processes causing chemical magnetization and TRM of small grains. As the grains of magnetic material grow chemically, the value of the critical quantity (v/T) in the equations for TRM increases because of an increase in v rather than a decrease in T. As the grain grows through the critical blocking diameter appropriate to the temperature at which the chemical reaction occurs, the equilibrium magnetization J_E (equation 4) is, as in the case for TRM, effectively frozen in. Theoretically, the stability properties of crystallization magnetization and TRM should be similar, and laboratory experiments indicate that this is true.

Self-reversed magnetization.—The most striking example of a magnetization acquired in a direction other than that of the field acting during the acquisition of the magnetization is that of self-reversal. In many paleomagnetic studies directions of magnetization fall into two distinct groups nearly or exactly opposed to each other. Two interpretations of this phenomenon have been proposed: that the earth's magnetic field may periodically reverse itself, or, alternatively, that some rocks may become magnetized in a direction opposite to that of the field acting on them by a process called self-reversed magnetization.

Several mechanisms may theoretically give rise to self-reversed magnetization. The first to be considered requires two magnetic constituents A and B in the rock. Constituent A has a higher Curie temperature than B and acquires a TRM parallel to the applied field. As the rock cools through the Curie temperature of constituent B, the TRM of constituent A acts by one of several interaction mechanisms to order the magnetization of B in a direction exactly opposite to that of A and, hence, reversed with respect to the original applied field. A self-reversal occurs if, after cooling, the total magnetization of B exceeds that of A (Néel, 1951, p. 92), or if constituent A is later selectively removed chemically (Graham, 1953, p. 252–255).

The simplest type of interaction is magnetostatic (Néel, 1951, p. 100; Uyeda, 1958, p. 50–56), in which the field in the region of constituent B at the time the temperature passes through its Curie point is controlled by the magnetization of A, and is reversed with respect to the applied field. The relationship is shown schematically in Figure 2. For this type of interaction to lead to a self-reversal, very stringent requirements are placed on the geometrical arrangement of the two constituents and on the ratio of the applied field to the spontaneous magnetization of constituent A when B becomes magnetized. In rock-forming minerals this mechanism could occur only in very weak applied fields; it is possible but rather improbable in fields as strong as the earth's, and no example has been found in nature (Uyeda, 1958, p. 52).

A second type of interaction between the two constituents is an exchange interaction across their common boundary. If good registry exists between the crystal lattices of the two constituents, the spontaneous magnetizations on one side of the boundary will tend to become aligned either parallel or antiparallel to the spontaneous magnetization on the other side. The Weiss-Heisenberg exchange interaction between spinning electrons, which is also responsible for spontaneous magnetization, provides the coupling, which may be very strong. Uyeda (1958, p. 104) finds that members of the ilmenite-hematite series $xFeTiO_3 \cdot (1-x) Fe_2O_3$, with $.45 < x < .6$, become self-reversed, even when the applied field is as high as 17,000 oersted. This type of interaction appears to be responsible for the reversed magnetization of the Haruna dacite (Uyeda, 1958, p. 120), which is one of the two or three rocks reported to be reproducibly self-reversing.

The spontaneous magnetization of some

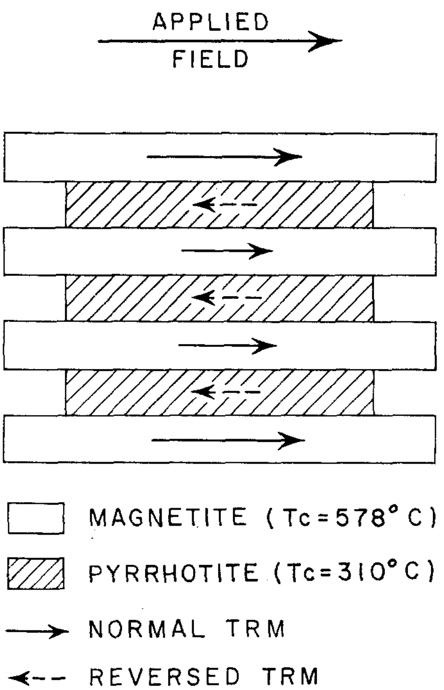

FIGURE 2.—REVERSAL IN PYRRHOTITE CAUSED BY MAGNETOSTATIC INTERACTION BETWEEN TWO DIFFERENT CONSTITUENTS

On cooling, magnetite with higher Curie temperature becomes magnetized first. Further cooling results in magnetization of pyrrhotite in "reversed" field between magnetite layers. Net TRM is 'normal". (After experiment by Uyeda, 1958)

minerals, for example magnetite, is actually made up of two superimposed opposing spontaneous magnetizations, each associated with a separate sublattice in the magnetic mineral. If these two spontaneous magnetizations have different temperature coefficients, the total net spontaneous magnetization may change sign with temperature, as shown in Figure 3. This type of self-reversal mechanism has been demonstrated by Gorter and Schulkes (1953, p. 488) in certain synthetic materials but has not been found in rocks.

A mineral may also undergo self-reversal when cations migrate from disordered to ordered distributions on cooling (Néel, 1955, p. 204; Verhoogen, 1956, p. 208). Moreover, when cooled quickly, cations may be frozen in a disordered state corresponding to a high-temperature equilibrium. Over very long periods of time the cations will then slowly migrate to the equilibrium-ordered positions, and the process may be accompanied by a self-reversal of the TRM. Verhoogen (1956, p. 208) shows that this mechanism is possible for natural magnetites containing impurities; he estimates that the ordering process would require at least 10^5 to 10^6 years. Such a self-reversal mechanism would therefore not be reproducible in the laboratory.

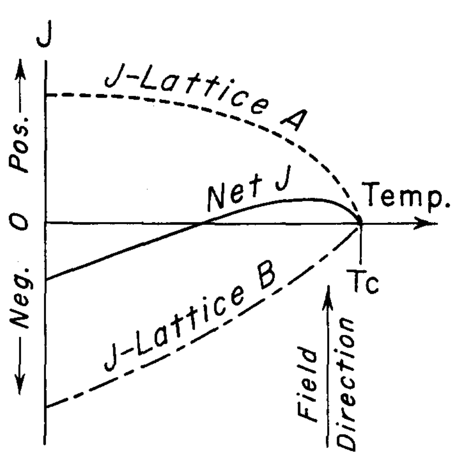

FIGURE 3.—SELF-REVERSAL BY J_S-T DIFFERENCES IN TWO ANTIPARALLEL SUBLATTICES

On cooling, sublattice A is initially dominant and is aligned with applied field. Sublattice B is locked antiparallel to A and is dominant at low temperatures.

This brief and incomplete review of a rather large field of research serves to emphasize several important points about reversely magnetized rocks. The reversed magnetization of some rocks is now known to be due to a self-reversal mechanism. Moreover, many theoretical self-reversal mechanisms have been proposed, and additional mechanisms will doubtless be suggested in the future. However, in order definitely to reject the field-reversal hypothesis it is necessary to show that *all* reversely magnetized rocks are due to self-reversal. This would be a very difficult task since some of the self-reversal mechanisms are difficult to detect and are not reproducible in the laboratory. A further discussion of this problem will be postponed until some of the relevant paleomagnetic data have been considered.

Other processes affecting remanent magnetization.—King (1955, p. 120), in his experiments on artificially deposited varved silts, found that the inclination measured in the samples ranged some 20 to 30 degrees less than the inclination of the field acting, although the declination was faithfully reproduced. This "inclination error" decreased as the field inclination approached the vertical or horizontal. Like most sedimentary minerals, magnetic mineral grains are rarely uniformly equidimensional; moreover, the common magnetic minerals tend to have directions of magnetization parallel to their longest dimension. The "inclination error" arises during the depositional process since the grains will tend to lie with their longest dimension, and hence magnetic direction, parallel to the horizontal bedding plane and not exactly along the applied field direction. King has also demonstrated that an error in the direction of magnetization can occur due to rolling of grains as they settle on the bottom, caused either by deposition on sloping surfaces or by currents.

The magnetic properties of minerals resemble other physical properties in that they are not, in general, completely isotropic; in particular, individual mineral grains usually cannot be magnetized with equal ease in all directions. In all minerals there exist easy and hard directions of magnetization systematically oriented with respect to the crystal lattice, a property called *magneto-crystalline anisotropy.* A single crystal of magnetite, for example, is magnetized more easily along the [111] axes than along the [100] axes, and a crystal of hematite much more easily in the *c* plane than along the *c* axis. A second factor causing anisotropy is the shape of the individual grain. An aggregate of randomly oriented magnetite crystals should have no crystalline anisotropy, but a single grain of the aggregate will be more easily magnetized parallel to its longest dimension. In any of the magnetization processes considered above, except depositional magnetization, in which the grains are already magnetized, the magnetization direction of a single crystal or of an elongated grain will lie between a direction of easy magnetization and the direction of the applied field. However, when preferred-crystal directions or longest-grain dimensions are randomly oriented within a rock sample, the net magnetization direction will be that of the applied field.

Deformation of rocks with a remanent magnetization may also cause a change in the magnetization due to a mechanical rotation of the magnetic particles. A vertical compaction in sediments might, for example, be expected to reduce the inclination of the magnetization vector (Clegg and others, 1954a, p. 596). Graham (1949, p. 156–158) has considered the effects of plastic deformation on remanent magnetization in the limbs of a fold. However, this phenomenon has rarely been cited as a cause of scattered directions of magnetization, probably because highly deformed beds are usually not chosen for paleomagnetic investigations.

Magnetostriction—the effect of stress on magnetization—is another phenomenon which may be important in the magnetization of rocks. In the investigation by Graham and others (1957, p. 471–472) axial compressive stresses of slightly more than 2500 lbs/sq. in. changed the magnetization in the rocks studied (mostly gneisses and iron ores) by as much as 25 per cent; moreover, the magnetization of some of the samples did not return to the original state after the stress was removed. Many rocks are subjected to large stresses during their histories—the stresses developed during the cooling of basalt, for example, are sufficient to fracture the rock—, and the research described above strongly suggested that magnetostrictive effects might, in general, cause the recorded remanent magnetizations of rocks to be in directions that are not those of the fields acting when remanent magnetization was originally acquired. Stott and Stacey (1959, p. 385) investigated this possibility for TRM by cooling several types of igneous rocks (including basalts, dolerites, andesites, and rhyolites) from above their Curie temperatures in the earth's field while under compressive stresses of 5000 lbs/sq. in. Identical samples were similarly cooled without an applied stress, and in all cases the resulting TRM, measured at room temperature after the stress had been removed, was parallel to the applied field.

Since some magnetostrictive processes may be time-dependent (Graham and others, 1959), field tests are also of interest in evaluating the role of magnetostriction in paleomagnetism. Different magnetic minerals respond in different ways to the same stresses; thus the consistency of results from rocks of the same period that have different mineral assemblages, or were magnetized by different processes, or have had different stress histories would indicate that, for such rocks, magnetostrictive effects have not been important.

Tests for Paleomagnetic Applicability

General statement.—When a study of the remanent magnetism of a suite of samples from a given geologic formation is undertaken, the paleomagnetist is usually less interested in the magnetism itself than in the direction of the magnetic field that produced it. A paleomagnetic study of rocks should therefore yield two pieces of information: the average direction of the magnetic field at the locality where the rocks were collected, and the time or geologic age when the field had that direction. It is usually assumed for paleomagnetic purposes that the magnetization measured is in the direction of the earth's magnetic field existing at the time rocks were magnetized, and that the magnetization was acquired during the formation of the rocks or soon after. We have noted in the preceding sections, however, that rocks may receive a magnetization in several different ways, some of which do not satisfy the assumptions just outlined. For example, depositional magnetization or TRM acquired by rocks with a crystalline or shape anisotropy may not be parallel to the field acting during the magnetization process; and viscous or chemical magnetization may be acquired long after the formation of the rocks.

Fortunately, the magnetizations acquired by the different processes commonly have very different properties which in many cases can be investigated in the laboratory. Many of the magnetic anisotropic properties of rocks can also be measured. Finally, certain geological field tests give very definite limits to the time at which the magnetization took place. The importance of these tests in paleomagnetic studies cannot be overemphasized. Because the critical reader must know whether or not the magnetization was acquired at the time of formation of the rocks, and also whether or not it was acquired parallel to the field acting, it is important to consider the field and laboratory tests in some detail.

Field tests.—Consistency among the directions of magnetization of many samples is sometimes used as a criterion for stability. Although this test is far from conclusive, directions of magnetization that are tightly grouped away from the present field direction have more significance than is often realized. Such a consistency demonstrates immediately the absence of a dominant component of magnetization parallel to the present field, such as might be caused by viscous magnetization or chemical magnetization associated with surface weathering. Moreover, gross petrologic differences of rocks within a formation are usually recognized, and similar differences exist in the magnetic minerals. These differences are commonly indicated by large differences in the intensity of magnetization from sample to sample. Consistency of directions of magnetization in such

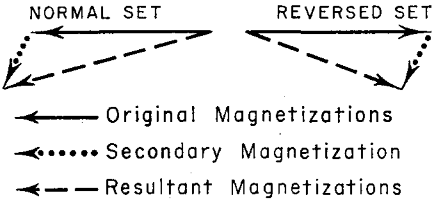

FIGURE 4.—CONSISTENCY-OF-REVERSALS TEST FOR STABILITY

Two sets of magnetization with initial direction 180° apart are no longer exactly reversed if secondary component has been added.

reversals. This test applies to reversals due either to field or self-reversal, since in both cases the mean directions of magnetization are 180° apart. If, subsequent to the original magnetization, both groups acquire an additional component of magnetization as shown in Figure 4, the two resultant groups will no longer be 180° apart. This test is very powerful, since it is also valid for completely homogeneous groups of samples and does not depend on the relative intensity or direction of the secondary magnetization.

In the above field tests the tacit assumption has been made that the rocks have not been tilted or folded. Rocks are, of course, subjected to folding, and Graham's classic fold

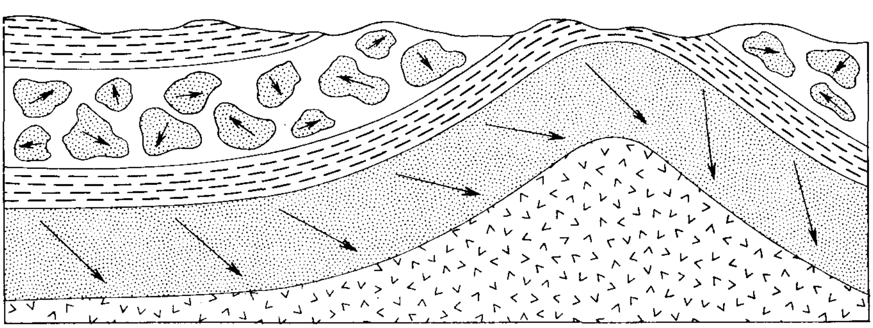

FIGURE 5.—FIELD RELATIONSHIPS INDICATING STABLE MAGNETIZATIONS BY GRAHAM'S "FOLD" AND "CONGLOMERATE" TESTS

a case strongly suggests that the magnetization was acquired in an unchanging magnetic field. If it were acquired by one or more processes acting when the field had different directions, the inhomogeneities would probably result in magnetization directions spread out between the two field directions rather than tightly grouped at some fixed angle between them. Magnetic directions of samples from the same formation are frequently distributed along a plane passing through the present direction of the earth's field (Runcorn, 1956a, p. 305; Creer, 1957a, p. 132–136; Howell and Martinez, 1957, p. 390). The consistency test is not satisfied in this case, and two components of magnetization in varying amounts are present, one of which is parallel to the present field. The significance of a consistency test depends largely on the extent of the sampling and the range in size and composition of the magnetic minerals represented.

Parallelism between tightly grouped mean directions of magnetization in two groups of samples which are reversely magnetized with respect to each other is a much stronger test than simple consistency of directions without

test (Graham, 1949, p. 158) uses folding to establish stability of magnetization. The test is very simple and has great significance. Suppose the directions of magnetization of samples collected from one limb of a fold have a mean direction significantly different from the mean direction of samples collected from the other limb (see Fig. 5). If on conceptually "unfolding" the beds and rotating the directions of magnetization along with them, the mean directions from the two limbs coincide, then the following conclusion is valid: the beds received a magnetization of uniform direction at some time prior to the folding, and the magnetization has not subsequently changed direction. The application of this test to some Precambrian sedimentary rocks is shown in Figure 6. This "tilt correction" is usually made by rotating the beds into the horizontal about the strike direction, a procedure which tacitly assumes that the axes of the folds are horizontal. If the fold is plunging and the magnetic inclinations are other than vertical, this method of correction can lead to serious errors. An extreme example showing how a serious error may be introduced is shown in

Figure 7. The field direction erroneously reconstructed by the simple "tilt correction" differs in azimuth by 90° from the correct direction, and, moreover, a false "reversal" has been generated. Although errors this large occur only for steeply plunging folds and small inclinations, one should, before applying the simple tilt correction, be sure that the fold axes are horizontal. A proper correction for plunging folds can, of course, be made with an additional operation.

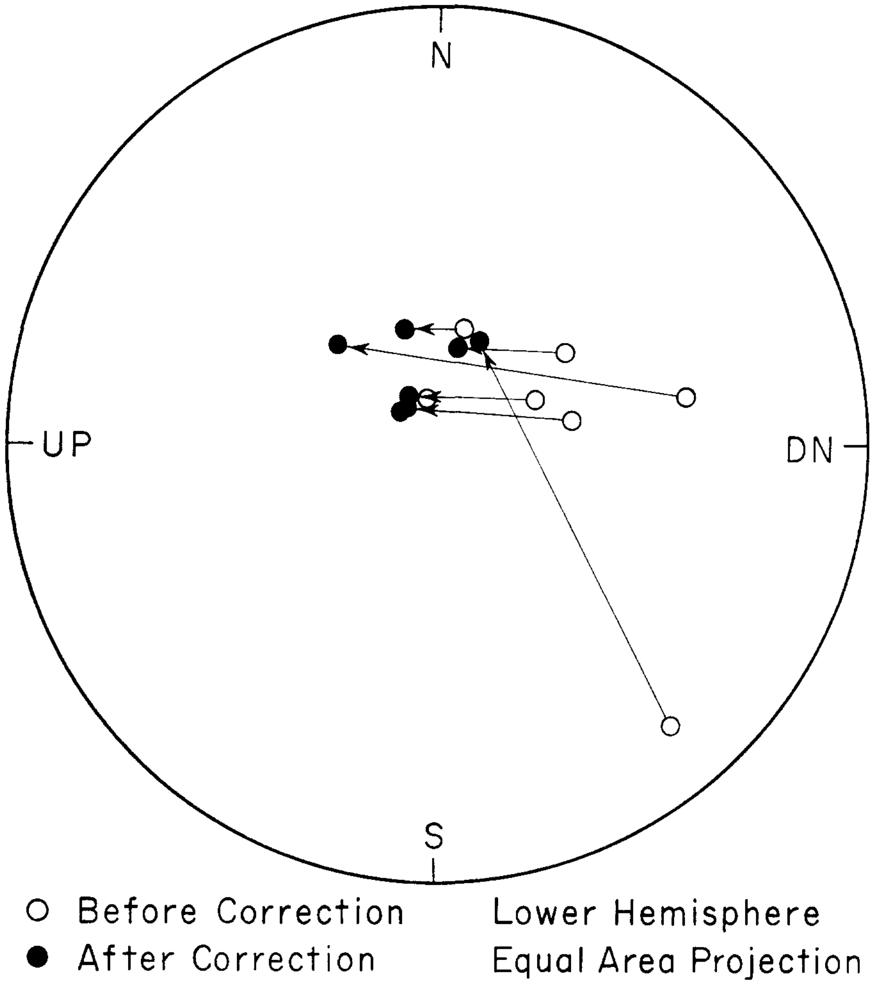

FIGURE 6.—REDUCTION IN SCATTER OF DIRECTIONS OF MAGNETIZATION BY APPLYING CORRECTION FOR TILT OF BEDS

Graham's fold test applied to directions of magnetization in folded Keweenawan sediment. (After Du Bois, 1957)

The conglomerate test of Graham (1949, p. 158) may also be used to establish magnetic stability. The stability of a formation is tested by locating cobbles or pebbles from the formation in stratigraphically higher conglomerates and measuring the directions of magnetization in these fragments. Since aligning forces associated with the magnetic moment of these large fragments are very much smaller than other forces acting during deposition, the earth's field will not be effective in aligning them. Therefore, a completely random set of directions from the fragments is to be expected if the fragments are stably magnetized. Stability of magnetization of the parent formation is then usually inferred from random directions of magnetization in the fragments, as depicted in Figure 5. Care must be taken in establishing that the random magnetization of the fragments has not been caused by other than the depositional process, and the test gains in significance when different samples from the same fragment have parallel magnetizations, while samples from adjacent pebbles with the same lithology have different directions of magnetization.

Laboratory tests.—Field tests yield important but not particularly detailed information; at best they tell us that the magnetization has been stable since the occurrence of some event such as folding. Laboratory tests, on the other hand, give more specific and detailed information useful in unraveling the often complex nature of the magnetization found in rocks. Laboratory techniques are also useful for "washing" out unstable components of magnetization as well as the effects of other randomizing processes. Much is now known about the properties of some types of magnetization due, in large part, to the extensive and careful experiments of Nagata and his group, and to the works of Thellier, Rimbert, and Haigh. Thus, it is now often possible, by laboratory analysis, to distinguish the principal components of natural magnetization found in rocks.

An important laboratory experiment is that of examining the magnetic properties of a rock under the effects of demagnetizing processes. Magnetic minerals in rocks consist of many domains with a wide spectrum of coercive forces, and, as noted previously, natural remanent magnetization is due to a preferential alignment of only a few per cent of these domains. Different magnetizing processes tend selectively to align domains concentrated in different parts of the coercive force spectrum, and by means of demagnetization techniques it is possible to learn whether a given natural remanent magnetization resides in domains with low coercive forces ("soft" magnetization), high coercive forces ("hard" magnetization), or perhaps is distributed throughout the coercive force spectrum. In a demagnetization analysis, the "soft" magnetization in the rock is destroyed first by giving low coercive force domains a random orientation; the remaining remanent magnetization is then meas-

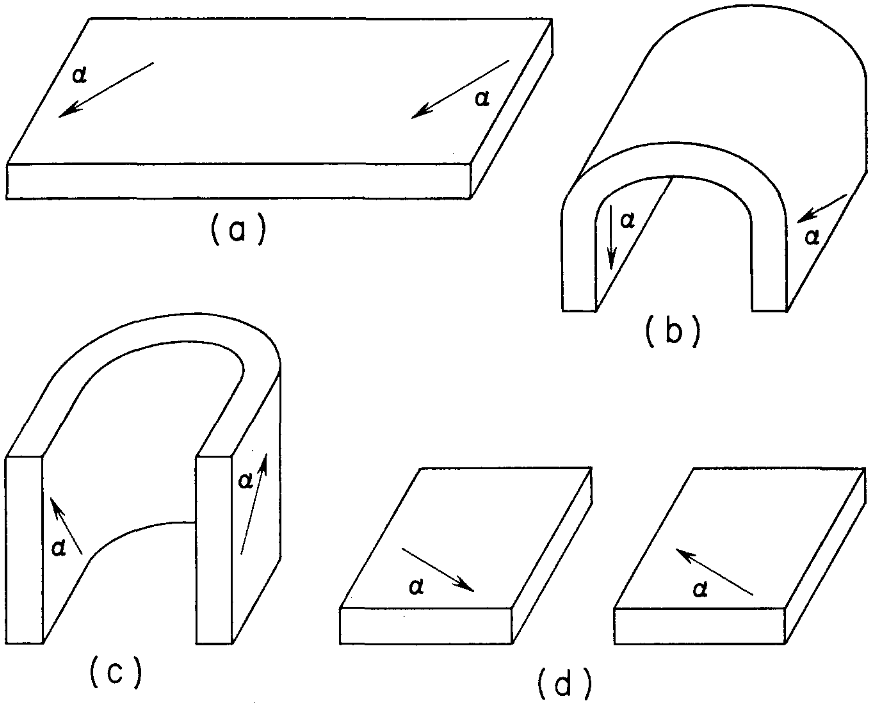

FIGURE 7.—APPLICATION OF SIMPLE "TILT CORRECTION" TO PLUNGING FOLDS

(a) Original uniform directions of magnetization; (b) direction in fold with horizontal axis—"tilt correction" restores to condition (a); (c) directions in fold with steeply plunging fold axis; (d) result of applying simple "tilt correction" to fold (c)—false "reversal" has been generated.

ured, and the process is repeated with progressively stronger demagnetizations. Two demagnetization processes may be used: heating the rock to a given temperature followed by cooling in zero magnetic field, or placing it in an alternating magnetic field, whose amplitude slowly decreases to zero.

Although Figure 1b shows the acquisition of TRM as a sample is cooled from above the Curie point, it may also be used to show the amount of TRM remaining after heating to any temperature. As discussed in more detail in the section on TRM for single-domain grains, heating to a given temperature in zero field causes a random orientation in all domains with magnetic barriers having energies less than or equal to the thermal energy. An upper temperature limit beyond which heat demagnetization is not useful is frequently set by chemical changes or phase transitions which may occur at temperatures as low as a few hundred degrees Centigrade.

If a rock is placed in an AC magnetic field with peak value $\tilde{H}$, all domains with coercive forces less than $\tilde{H}$ will follow the field as it alternates. As the AC field is then slowly decreased to zero, domains with progressively lower coercive forces become fixed in different orientations, and hence all domains with coercive forces less than $\tilde{H}$ will have random orientations. If a constant magnetic field is superimposed on the alternating field, or if the variation of the magnetic field with time is not symmetrical, an anhysteretic magnetization will develop (Thellier and Rimbert, 1954, p. 1400) which may mask the remaining remanent magnetization. The development of this magnetization may be prevented by performing the AC demagnetization in the absence of a constant field with the even harmonics filtered out from the current supplying the AC field coil (As and Zijderveld, 1958, p. 310), or by spinning the sample as the alternating field decreases (Brynjólfsson, 1957, p. 248; Cox, 1959, p. 122).

Many of the processes causing remanent magnetization can be reproduced in the laboratory, and demagnetization experiments on such magnetization of known origin are important in interpreting similar experiments on natural remanent magnetism. Figure 8 shows the results of alternating field demagnetization experiments on thermoremanent and chemical magnetizations produced in weak fields and on isothermal remanent magnetization produced in a relatively strong field (Kobayashi, 1959, p. 104). The IRM acquired in a 100-oersted field is effectively destroyed in an alternating field with a peak value of 100 oersteds; however, the TRM acquired in a field of 0.5 oersted has decreased only slightly

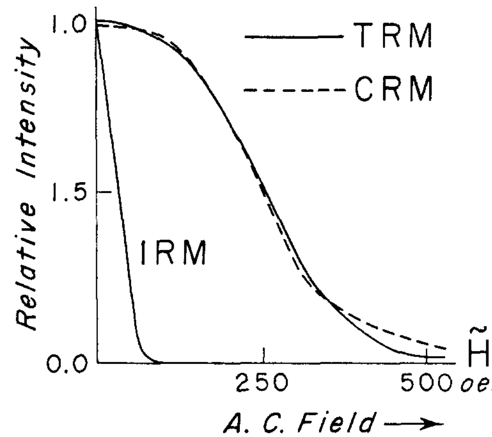

FIGURE 8.—ALTERNATING FIELD-DEMAGNETIZATION CURVES FOR VARIOUS TYPES OF REMANENT MAGNETIZATION

Normalized isothermal, chemical, and thermoremanent magnetizations remaining after demagnetization in A. C. fields, shown as a function of the peak value $\tilde{H}$ of the demagnetizing field. TRM and CRM were acquired in 0.5 oersted field, IRM in 30 oersted field. (After Kobayshi, 1959)

in the 100-oersted alternating field, and a measurable part still remains above 500 oersted. Rimbert (1956a), p. 892 in other experiments noted an appreciable TRM remaining above 900 oersted and only a small change between 500 and 900 oersted. Chemical magnetization has a stability comparable with that of TRM, as was suggested by the similarity of the TRM and CRM theories for single domains. Thus, with these and similar experiments (*see* aspecially Thellier and Rimbert, 1955, p. 1406), it is relatively simple to distinguish IRM in rocks from CRM or TRM, but not to distinguish CRM from TRM.

Viscous magnetization differs from IRM in requiring, for its destruction, an alternating field larger than the field in which it was produced. Rimbert (1956b, p. 2538) found that the magnitude of the AC field needed to destroy viscous magnetizations acquired by volcanic rocks over periods of time up to 2 months varies linearly with the logarithm of the time. For example, the viscous magnetization acquired in a 5-oersted field during 5 minutes required a 37-oersted alternating field for its

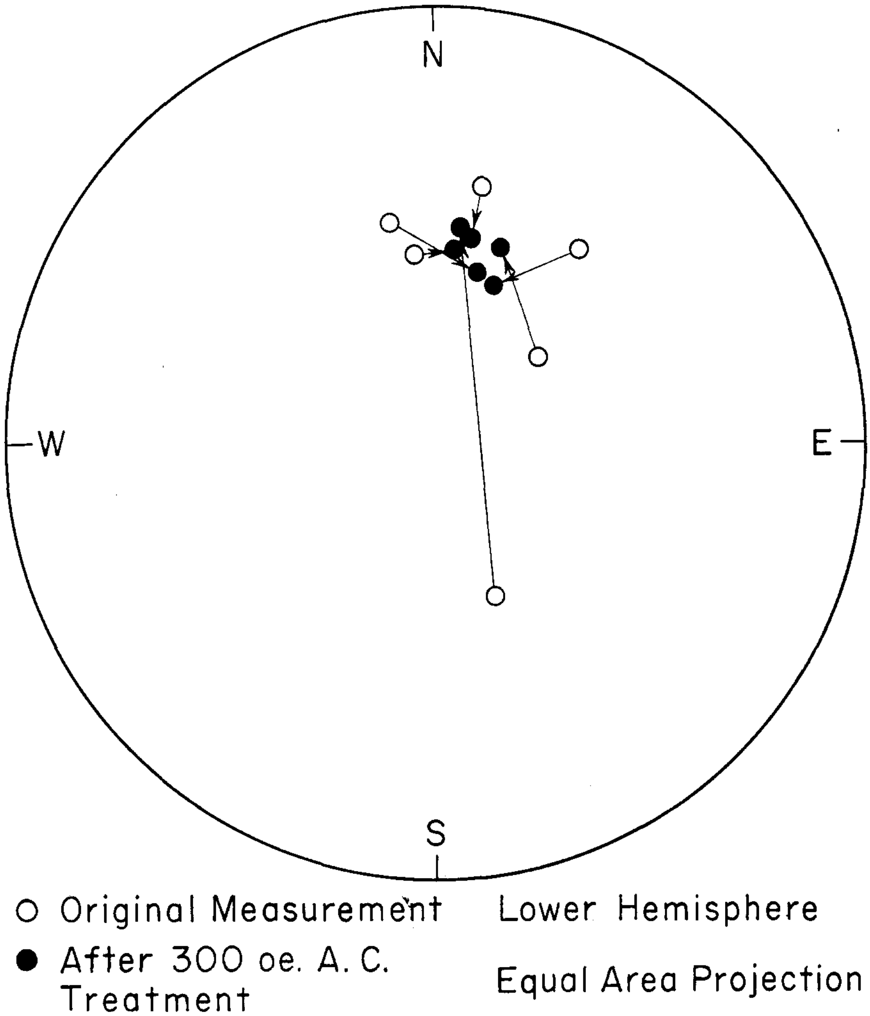

FIGURE 9.—DIRECTIONS OF MAGNETIZATION BEFORE AND AFTER ALTERNATING-FIELD PARTIAL DEMAGNETIZATION

All samples are from the same lava flow. (Data from Cox, 1959)

destruction, and that acquired in 2 months in the same field required a field of 180 oersted. Although it is dangerous to extrapolate these results to geologic times, they suggest that viscous magnetization acquired during a million years in a field of 1 oersted would probably be destroyed in alternating fields of the order of a few hundred oersted. A rough verification of the extrapolation may be found in demagnetization studies by Brynjólfsson (1957, p. 251) and Cox (1959, p. 129) in which a viscous magnetization in volcanic rocks about half a million years old was destroyed in alternating fields of 50 to 100 oersted.

Since viscous magnetization acquired in the earth's field and isothermal remanent magnetization due to lightning are probably common sources of scatter in paleomagnetic measurements, these experiments suggest an obvious way of "washing" away these unstable secondary components. Partial thermal and alternating field demagnetization have been used by a number of workers for this purpose (Doell, 1956, p. 165; Cox, 1959, p. 122; Brynjólfsson, 1957, p. 253; Hood, 1958; Creer, 1958, p. 379; As and Zijderveld, 1958, p. 318). Figure 9 shows an example of the effects of alternating field demagnetization on volcanic rocks; most of the initial scatter in these measurements has been shown to be due to lightning (Cox, 1959, p. 135).

Demagnetization experiments are important in paleomagnetic studies not only for decreasing scatter in the data but also for shedding light on the origin of the remanent magnetization. Moreover, natural magnetizations remaining after demagnetization in fields of the order of 400 oersted are very stable "hard" magnetizations and will certainly not have been disturbed by the effects of sampling, transporting, coring, or measuring operations, or by any process capable of magnetizing only low coercive force domains.

A special series of laboratory tests has been devised by Nagata and hi group (Nagatas and others, 1954, p. 184–185; Nagata and others, 1957, p. 32) for determining whether reversely magnetized rocks represent field or self-reversals. The tests are primarily concerned with the detection of self-reversal properties in the rocks, and for details the reader is referred to the works cited as well as to that of Uyeda (1958).

The field and laboratory tests discussed above are primarily concerned with establishing the stability of natural remanent magnetizations and removing the scattering effects of "soft" magnetizations. However, the very important question of whether the magnetization was acquired parallel to the magnetic field that produced it remains unanswered. In order to devise tests to answer this question one must first consider processes whereby magnetizations are acquired in directions that are not parallel to the applied field direction.

Nonparallel magnetization will be acquired if the magnetic grains in a rock have a shape or crystal anisotropy; rocks with thin layers of magnetite crystals or hematite crystals with parallel axes would possess, respectively, these two types of magnetic anisotropy. Inclination errors associated with depositional magnetization also cause nonparallel magnetization and probably cause anisotropy as well, since flat or elongated grains tend to lie with their longest axes in the bedding plane. Nonparallelism in depositional magnetization may also arise when grains are rolled down inclined depositional planes or moved by bottom currents; Granar (1959, p. 32) has shown that anisotropy will probably be associated with bottom currents, since elongated grains tend to roll with their long axis normal to the current direction.

Magnetostriction might also cause a nonparallel magnetization, but tests for its occurrence cannot be devised until the process is better understood. It appears therefore that most processes known to cause a magnetization direction that is not parallel to the field acting are associated with magnetic anisotropy in the rocks.

However, magnetic anisotropy of a rock may be as complex as its remanent magnetization, and no single measurement can completely describe it. Anisotropy of the induced magnetization is, to our knowledge, the only magnetic anisotropy property that has been measured in paleomagnetic studies (Howell and others, 1958, p. 286). If the susceptibility is plotted as a function of the orientation of the magnetic field with respect to the sample, a triaxial ellipsoid is described. For example, the susceptibility ellipsoid of a rock containing only hematite crystals with parallel *c* axes is a very flat oblate spheroid with its short axis, the axis of minimum susceptibility, parallel to the *c* axes of the hematite crystals. In using susceptibility anisotropy as a test for paleomagnetic applicability, care must be taken that the magnetic anisotropy measured corresponds to the remanent magnetization of interest. For example, the remanent magnetization in a rock might be due to hematite with strong susceptibility anisotropy, but this would not be detected if a small proportion of isotropic magnetite were also present.

The Earth's Magnetic Field

Description of field.—The present shape of the earth's magnetic field and its changes during the last several hundred years are of primary importance in paleomagnetism, since these data furnish an estimate of the irregularities and variations likely to be encountered in studies of past magnetic fields. This might be called the expected "signal to noise ratio" for paleomagnetic studies. The present field at the surface of the earth may be described in terms of three components: a relatively small component due to processes occurring above the earth's surface; a dipole component equivalent to the field of a magnetic dipole located at the center of the earth and inclined $11\frac{1}{2}°$ from the axis of rotation; and a nondipole component, which would remain if the externally produced field and dipole field were removed.

If the earth's magnetic field is represented by means of spherical harmonics, one may easily recognize and separate these three components. The first such analysis was made by Gauss in 1839 and has been repeated at various intervals since (Chapman and Bartels, 1940, p. 639). The results of the analysis are expressed as a series of terms, each a simple algebraic combi-

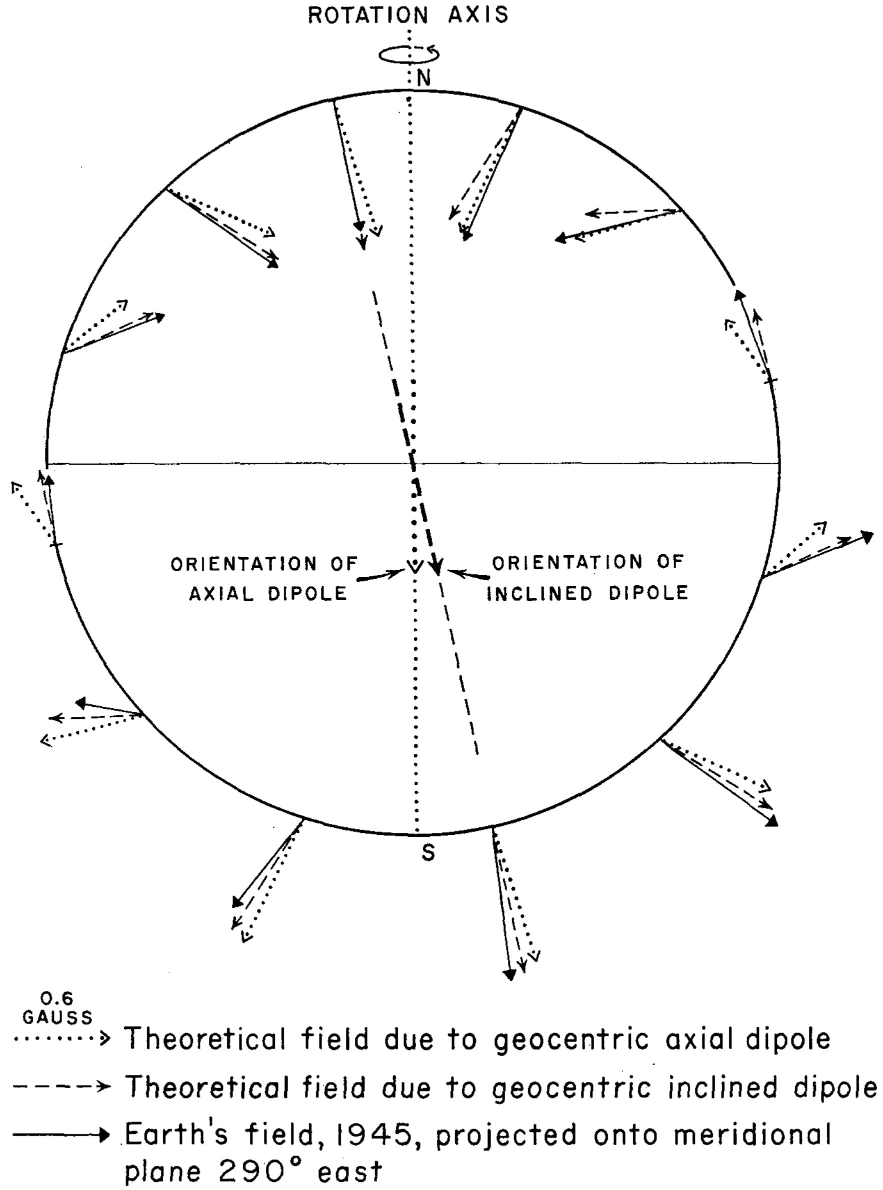

FIGURE 10.—THEORETICAL MAGNETIC FIELDS OF A GEOCENTRIC AXIAL DIPOLE AND A GEOCENTRIC INCLINED DIPOLE, WITH OBSERVED FIELD DIRECTIONS

Plane of projection passes through geomagnetic poles, and observed field is projected onto this plane. Observation points are at 30-degree intervals from geomagnetic pole.

nation of sin $m\phi$, cos $m\phi$, $P_n^m(\cos\theta)$, and appropriate constants, where ϕ is the longitude, θ the latitude, m and n are integers, and $P_n^m(\cos\theta)$ are associated spherical functions. Moreover, processes occurring above the earth are represented by terms that are mathematically distinguishable from those corresponding to processes occurring within the earth. The externally produced field, physically generated by movement of electrical charges in the ionosphere, fluctuates because of atmospheric tidal effects and sunspot activity. Although its magnitude during magnetic storms may exceed several per cent of the total field, the algebraic average is very small.

Of the terms representing the internally produced field, those for which $n = 1$ are collectively termed the first-order harmonic and those for which $n = 2, 3, \cdots$ are known as the higher-order harmonics. The nondipole component of the earth's field is represented by the higher-order harmonics, and the dipole component is completely described by the first-order harmonic. Therefore, if the earth's magnetic field were due solely to a dipole at the center of the earth, only the first-order harmonic would appear in the analysis, and conversely the first-order harmonic completely specifies the orientation and intensity of a geocentric dipole. Of all the dipoles that might, by various criteria, be chosen best to approximate the irregular field of the earth, the one that is inclined 11½° from the axis of rotation gives the best average fit, in the sense of least squares, over the entire surface of the earth. The point on the surface of the earth toward which this dipole points is, by definition, the geomagnetic pole, and its present co-ordinates are 78½° North Latitude and 69° West Longitude (Finch and Leaton, 1957, p. 316). The closeness of the fit is shown graphically in Figure 10. The present earth's field has been projected into the plane which passes through the geomagnetic pole and the earth's axis of rotation. The directions are shown at intervals of 30° from the geomagnetic pole. For comparison, the field directions caused by an axial dipole are also shown at these points.

Although theoretical considerations and paleomagnetic results suggest that the geomagnetic pole has not always been at its present location, it is important to note that there is no direct evidence that it has moved. It was not until the latter part of the nineteenth century that data adequate for an accurate determination of the geomagnetic pole became available, and since then it has remained within about half a degree of its present location (Bullard and others, 1950, p. 86).

Superimposed on this stable dipole field is the comparatively irregular, rapidly changing nondipole field represented by the higher-order harmonics. The nondipole field is made up of irregularly distributed regions of high and low field intensity which range in diameter from about 25° to 100° (Bullard and others, 1950, p. 70). Moreover, these regions wax and wane much as the centers of cyclonic activity in the atmosphere do, and present rates of change suggest an average life for an individual cell of the order of 100 years (Elsasser, 1956, p. 87). The movement of these nondipole features over the surface of the earth is not entirely random but shows a systematic westward drift, estimated by several methods at one-fifth degree of longitude per year. The movement is independent of the latitude of the feature (Bullard and others, 1950, p. 83).

The geomagnetic pole does not coincide with the magnetic dip pole, which is defined as the place where the horizontal component of the earth's field vanishes, because a horizontal component due to the nondipole field is present at the geomagnetic pole. At the magnetic dip pole, the nondipole horizontal component exactly cancels the horizontal component of the dipole field. Whereas the geomagnetic pole has not changed since adequate measurements were available, the position of the dip pole has changed relatively rapidly with changes in the nondipole component.

The description of the earth's field in terms of spherical harmonics is a purely mathematical procedure and carries no implication that each term (or group of terms) is physically significant in the sense that it corresponds to a separate physical event. However, other evidence shows that the external field (corresponding to certain of the harmonic terms) is physically different.

With respect to the terms of internal origin, the fact that the first term of the spherical harmonic analysis is predominant does not in itself imply that the dipole term has special or separate physical significance. At greater depths within the earth the higher-order terms become larger relative to the first, and at the core–mantle boundary the two are approximately equal (Elsasser, 1956, p. 87). The strongest evidence that the first term may correspond to a process different from the higher-order terms lies in the observation that their rates of movement relative to the surface during the past 75 years have been very different.

With the exception of the important work of Thellier and Thellier (1959) on the intensity of the earth's past magnetic field, most paleomagnetic data give the field direction only. Therefore, of the various methods of comparing the dipole and nondipole field components, the angular departure of the observed field from the field of a dipole is of most direct interest in paleomagnetism. Examples from four observatories of the angular departure of the observed field from that due to the inclined dipole field (and the axial dipole field) are shown in Figure 11 on an equal-area projection. The axial dipole field is that due to a magnetic dipole aligned along the axis of rotation of the earth and is of more interest in paleomagnetism than is the inclined field. The average departure between the observed field and the *axial* dipole field at the present time is 8.5° in the northern hemisphere and 17.3° in the southern (Cox, 1959, p. 11). The largest departure disclosed by most of the available observatory records is 29°.

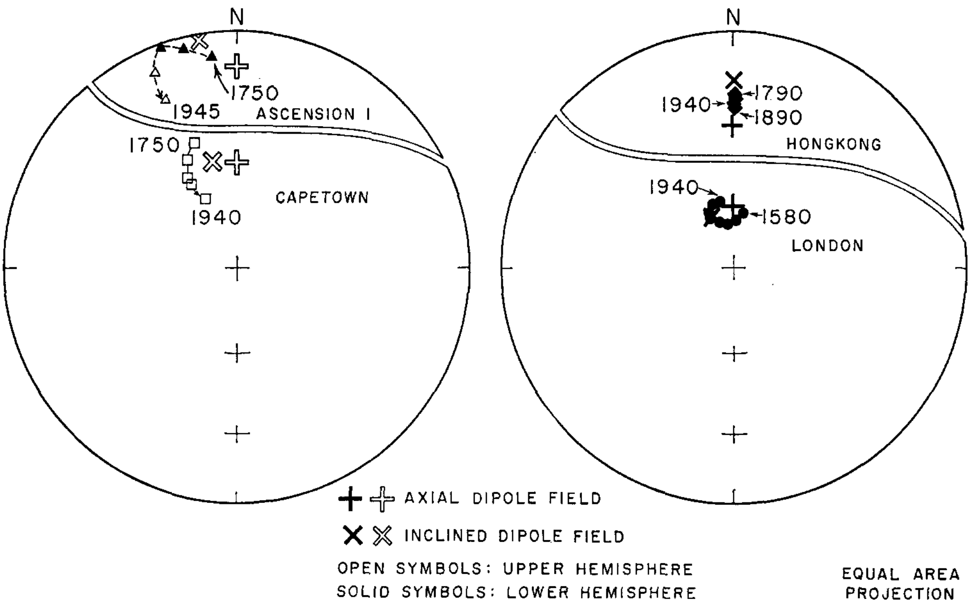

FIGURE 11.—CHANGES IN DIRECTIONS OF EARTH'S MAGNETIC FIELD WITH TIME, AT FOUR MAGNETIC OBSERVATORIES

Successive observations of the field direction are spaced 40–50 years apart. The axial and inclined dipole field directions shown for the four locations are computed from the present positions of the geographic and geomagnetic poles using equations (5) to (7).

It is often convenient in paleomagnetic studies to represent the data not in terms of the field direction measured, but rather in terms of the geocentric dipole that would produce the measured field direction. This is usually done by specifying the geographic co-ordinates of the geomagnetic pole that corresponds to the orientation of this inferred dipole. Given the declination and inclination of the field at an observatory (or as determined paleomagnetically), the position of the geomagnetic pole consistent with the observed direction may be found by the following relations:

$$\sin\theta' = \sin\theta\cos p + \cos\theta\sin p\cos D \quad (5)$$

$$\sin(\phi' - \phi) = (\sin p\sin D)/\cos\theta' \quad (6)$$

where p, the angular distance along the great circle from the observatory (or sampling site) to the geomagnetic pole, is given by the 'dipole" formula:

$$\cot p = \tfrac{1}{2}\tan I \quad (7)$$

Quantities θ' and ϕ' are the latitude and longitude of the geomagnetic pole; θ and ϕ are the latitude and longitude of the observatory; and D and I are the declination and inclination of the field at the observatory. The position of the geomagnetic pole consistent with a given field direction may also be found graphically by means of a Schmidt or Wulff projection. The relationships are shown graphically in Figure 12.

Equations (5), (6), and (7) establish a one-to-one mapping relation between all possible field directions at an observatory and their equivalent pole locations distributed over the earth's surface—given one quantity, the other is uniquely determined. "Poles" may thus be formally computed from any observed field direction whether due entirely to a geocentric dipole or not. Such poles will here be termed *virtual geomagnetic poles*. When non-dipole components are present, the virtual geomagnetic poles calculated at different

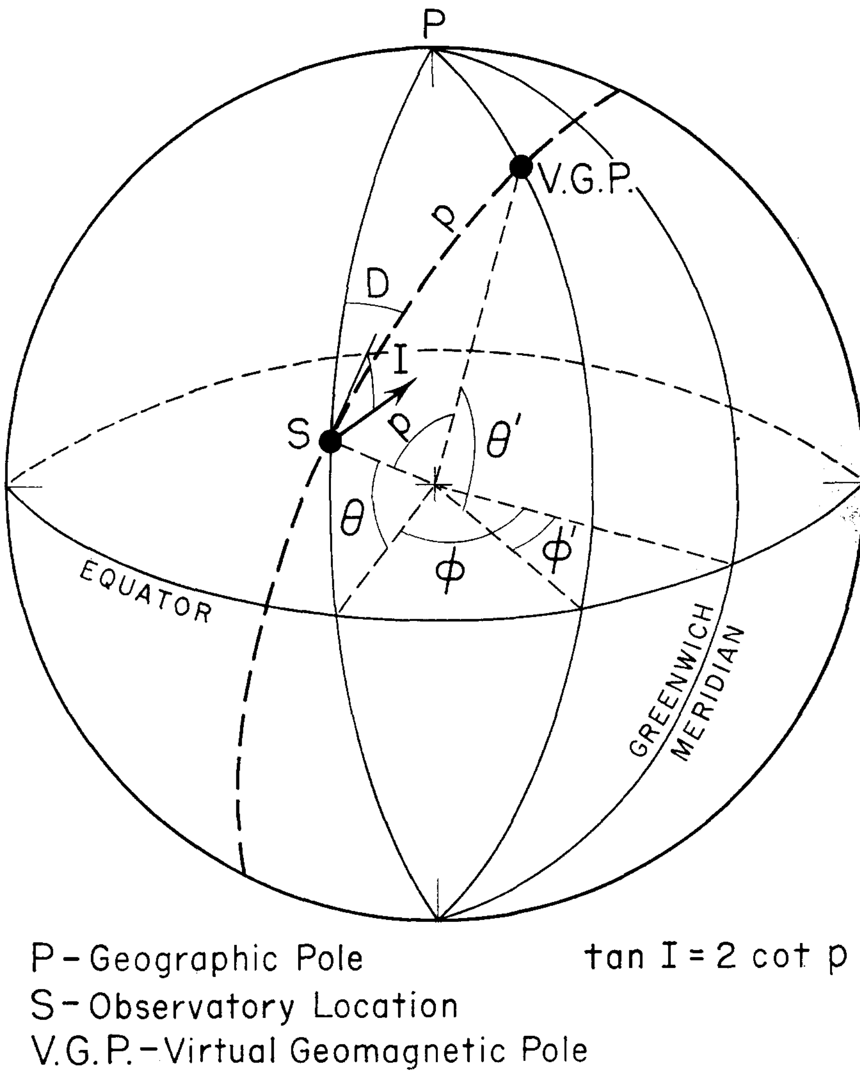

FIGURE 12.—RELATIONSHIPS BETWEEN LOCATION OF OBSERVATORY OR SAMPLING SITE, FIELD DIRECTION, AND VIRTUAL GEOMAGNETIC POLE

Calculation of virtual geomagnetic pole from field-direction data. θ is the latitude and ϕ the longitude of the observatory or site; θ' is the latitude and ϕ' the longitude of the virtual geomagnetic pole; D is the declination, and I the inclination of the field direction; p is the geomagnetic latitude as calculated from equation (7).

localities will not, in general, coincide, and their scatter may be taken as a measure of the departure of the observed field from an ideal dipole field. Figure 13 shows the present-day scatter in virtual geomagnetic poles calculated from the observed field directions at many observatories. Examples of the change in position of virtual geomagnetic poles with time are shown in Figure 14. These poles are calculated from the direction data shown in Figure 11. These figures might therefore suggest an order of magnitude for the "noise signal" to be expected in the determination of average poles by the paleomagnetic method.

Origin of the field.—The problem of the origin of the earth's internally produced magnetic field has long remained one of the least tractable in all of geophysics. Earlier theories suggesting that the field is due to the earth's remanent magnetization do not satisfy two very serious

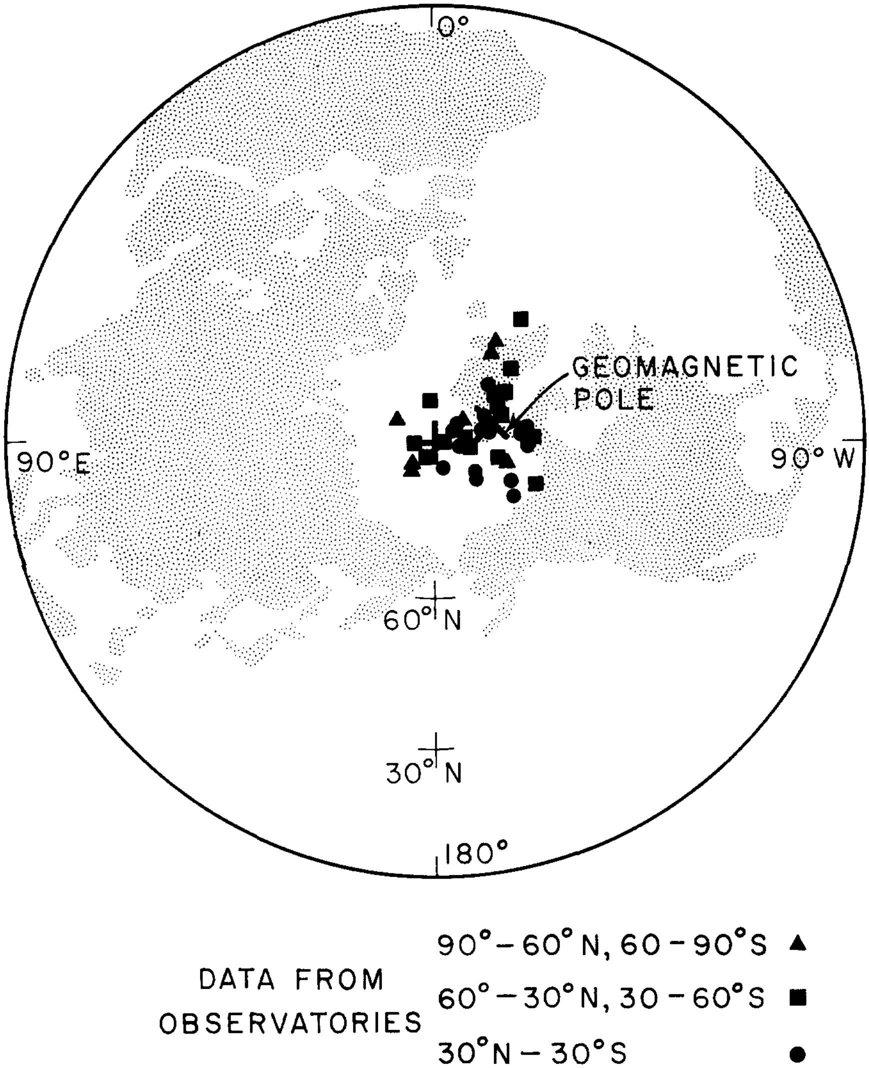

FIGURE 13.—VIRTUAL GEOMAGNETIC POLES CALCULATED FROM OBSERVATIONS AT VARIOUS LATITUDES IN 1945
Data from Vestine and others, 1947

objections. The high rate of change and westward drift of the nondipole field with velocities up to 20 km per year are difficult to explain as due to geologic processes in the mantle or crust. Such processes would certainly proceed at a much more leisurely pace. A further difficulty is that the earth probably does not contain enough ferromagnetic materials below their Curie temperatures to account for the intensity of the field. The Curie temperature of iron is 780° C, of nickel 350° C, and of magnetite 580° C; moreover, there is no evidence that these values increase significantly with pressure. Since the temperature in the earth at depths greater than 25 km is probably above 750° C (Jacobs, 1956, p. 219), it follows that only this outer region could possess a remanent magnetization. The required average intensity would be 6 emu/cc, and in the light of the present knowledge of crustal materials fulfillment of this requirement seems virtually impossible. Magnetite-rich igenous rocks may acquire remanent magnetizations as large as 0.6–1.8 emu/cc in magnetic fields of the order of 1000 oe (Nagata, 1953a, p. 107); however, their natural remanent magnetizations usually range between 0.001 and 0.05 emu/cc.

A theory that most nearly explains all the

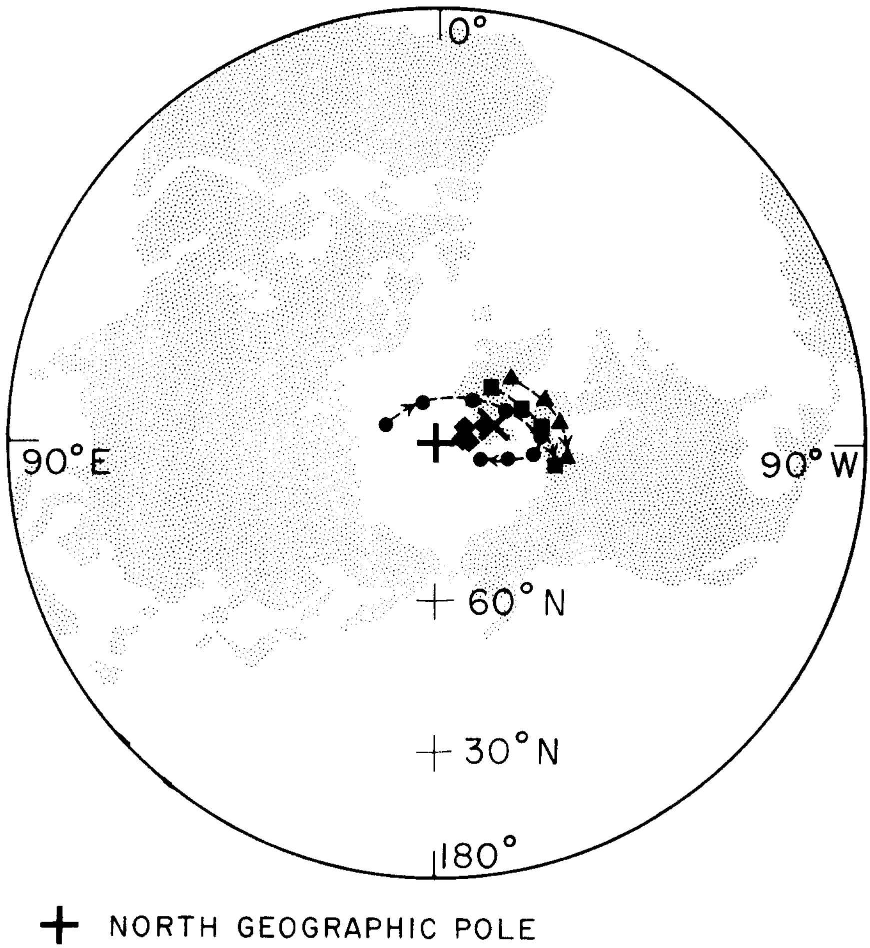

FIGURE 14.—CHANGES IN VIRTUAL GEOMAGNETIC POLES WITH TIME

Poles were calculated from the field-direction data at four observatories shown in Figure 11. Time between points is 40–50 years. (Symbols in Figures 11 and 14 correspond.)

observations is that the fluid core of the earth acts as a self-exciting dynamo (Elsasser, 1956, p. 88–90). In addition to the existence of an electrically conducting fluid the theory requires a source of energy to keep the fluid in convective motion. Moreover, it requires that the fluid be rotating so that order is established in the otherwise random convective motions. The earth's rotation fulfills the last requirement, and aside from transient effects the orientation of the magnetic field should be symmetrically related to the axis of rotation (Runcorn, 1954, p. 61). The rapid changes in the nondipole field are interpreted as the result of fluid eddies near the core–mantle boundary, and the westward drift as due to a smaller angular velocity in the outer layer of the core with respect to the mantle. If we accept this model of the earth's field, then, as a consequence of the relative motion of the core and mantle, the nonaxial components of both the dipole field and nondipole field should cancel when averaged over a sufficiently long time (Runcorn, 1959, p. 91). The dynamo theory requires that one layer in the core be rotating at the same velocity as the mantle, however, and this last argument would not apply to fields generated in that layer. Although the differential motions of the core and mantle, as well as the basic rotational requirement of the dynamo theory, lead to an average field with axial symmetry, it is not necessarily a dipole field—*i.e.*, the average declination may be zero, but the inclination need not show the dipolar variation with latitude.

The dynamo theory has had some success in explaining features of the magnetic fields of the sun and of some stars; moreover, as predicted by the theory, there appears to be a correlation between the sun's magnetic field and its axis of rotation (Elsasser, 1956, p. 101).

Statistical Analysis of Paleomagnetic Data

General statement.—The basic data obtained in paleomagnetic studies consist generally of many directions of magnetization measured in oriented rock samples. Although the samples are collected from areas never greater than a very small fraction of the earth's total surface, their stratigraphic distribution is often such that they represent directions of the earth's field over long periods of time. Paleomagnetic data might thus be compared with a long record from a single tide gauge in a harbor, whereas the data used in a contemporary spherical harmonic analysis are analogous to a topographic map of the water surface in the harbor at some particular instant. Different sorts of information can be obtained from the two approaches, and different mathematical techniques are necessary for their analyses.

Statistical analysis of sets of vectors or lines.—An analytical tool that has proved very useful for paleomagnetic interpretations is the statistical method developed by Fisher (1953). The method was originally developed for the analysis of paleomagnetic data; however, it is also appropriate for the analysis of other data consisting of sets of vectors or lines. Since Fisher's statistics are of primary importance in the interpretation of paleomagnetic data, and also because they could be applied to other geologic problems, the method will be reviewed in some detail. The analysis of a set of vectors will be considered first, and later the method will be extended to the case for lines.

The statistical method may be used repeatedly on different levels during a single study. For example, an analysis may be made of the directions of magnetization of specimens[2] from a single oriented sample, or of the average directions of magnetization of each oriented sample from a single lava flow or outcrop. An analysis could also be made of the mean directions of magnetization of lava flows from a single formation, or perhaps of the virtual geomagnetic poles corresponding to the mean directions of magnetization of the lava flows.

Since the method is concerned with an analysis of directions, each datum is given unit weight by representing it as a vector with unit length—there is no weighting in favor of more intensely magnetized specimens. An equivalent representation is to regard each datum, or vector, as a point on a sphere of unit radius. In order rigorously to justify the use of Fisher's statistics, the population from which the sample is drawn must satisfy two conditions: (1) the vectors in the population must be distributed with axial symmetry about their mean direction; (2) the density of the vectors in the population must decrease with increasing angular displacement ψ from the mean direction according to the probability density function

$$\mathcal{P} = \frac{\kappa}{4\pi \sinh \kappa} \exp (\kappa \cos \psi) \qquad (8)$$

Quantity κ is a constant called the ***precision parameter*** and describes the tightness of the group of vectors in the population about their mean direction. High values of κ indicate tight groups, and $\kappa = 0$ corresponds to a population uniformly distributed over the entire surface of the unit sphere. The probability density function $\mathcal{P}$ has the following meaning: given a small area of size δa on the unit sphere, at an angular distance ψ from the mean direction, the proportion of the total points expected in δa is $\mathcal{P}\delta a$. The quantity $(\kappa/4\pi \sinh \kappa)$ is merely a constant factor adjusted so that the integral of $\mathcal{P}$ over the sphere is equal to one. Equation (8) describes a distribution of points on a sphere which is closely analogous with a Gaussian distribution on a plane.

In geologic studies such as petrofabric analyses the density distribution of points on a sphere or hemisphere is often indicated by means of equal-density contour lines. Along each contour line the percentage $\mathfrak{D}$ of the total points included in a circular test area equal to 1 per cent of the area of the sphere or hemisphere

[2] The term *oriented sample* will be used to describe an individually oriented piece of rock; *specimen* will be used to describe pieces of rock cut from an oriented sample and used in the measuring apparatus; *sample* will be used in the usual statistical sense to refer to the data, consisting of a set of N vectors, drawn from a given population of vectors.

remains constant. In Figure 15, contours of equal 𝒫 are shown for a Fisher probability distribution with $\kappa = 10$. The density-contour diagram which would result if a large number of vectors from this same population were contoured using the usual 1 per cent test circle is shown in the same figure. As may be seen in the cross sections, the two representations are similar except for a slight leveling of the peak in the density-contour diagram owing to the finite size of the test circle.

Provided the conditions of the statistical model are satisfied, Fisher (1953, p. 296) shows that the direction of the vector sum of the N unit vectors of the sample is the best estimate of the true mean direction of the population. If the ith unit vector has declination or azimuth D_i, east of north, and inclination or plunge I_i below the horizontal, then the mean direction may be calculated from the relations:

$$Z = \sum_{i=1}^{N} \sin I_i \text{ (Downward component)} \tag{9}$$

$$X = \sum_{i=1}^{N} \cos I_i \cos D_i \text{ (North component)} \tag{10}$$

$$Y = \sum_{i=1}^{N} \cos I_i \sin D_i \text{ (East component)} \tag{11}$$

$$R = (X^2 + Y^2 + Z^2)^{1/2} \tag{12}$$

$$\sin I_R = Z/R \tag{13}$$

$$\tan D_R = Y/X \tag{14}$$

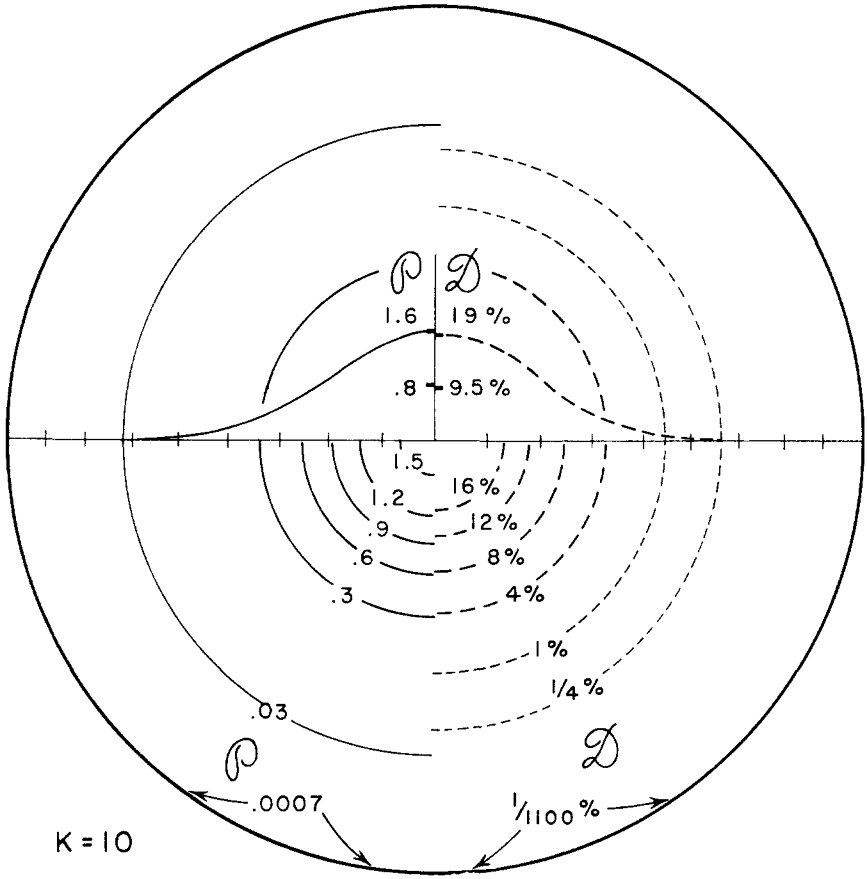

FIGURE 15.—PROBABILITY DENSITY FUNCTION P AND EQUIVALENT POINT-PERCENTAGE CONTOURS

The population of points shown has a symmetrical distribution with mean direction at the pole of the projection (*i.e.*, vertical). 𝒫 is the probability density function, 𝒟 is a function showing the distribution of point percentage contours for 1 per cent test areas. Cross sections of these functions are shown along the horizontal line.

where Z, X, and Y are the components of the resultant vector, R is its length, and D_R and I_R its declination and inclination, respectively. In paleomagnetic analyses, P is usually taken as 0.05, which means that there is 1 chance in 20 that the true mean direction of the popula-

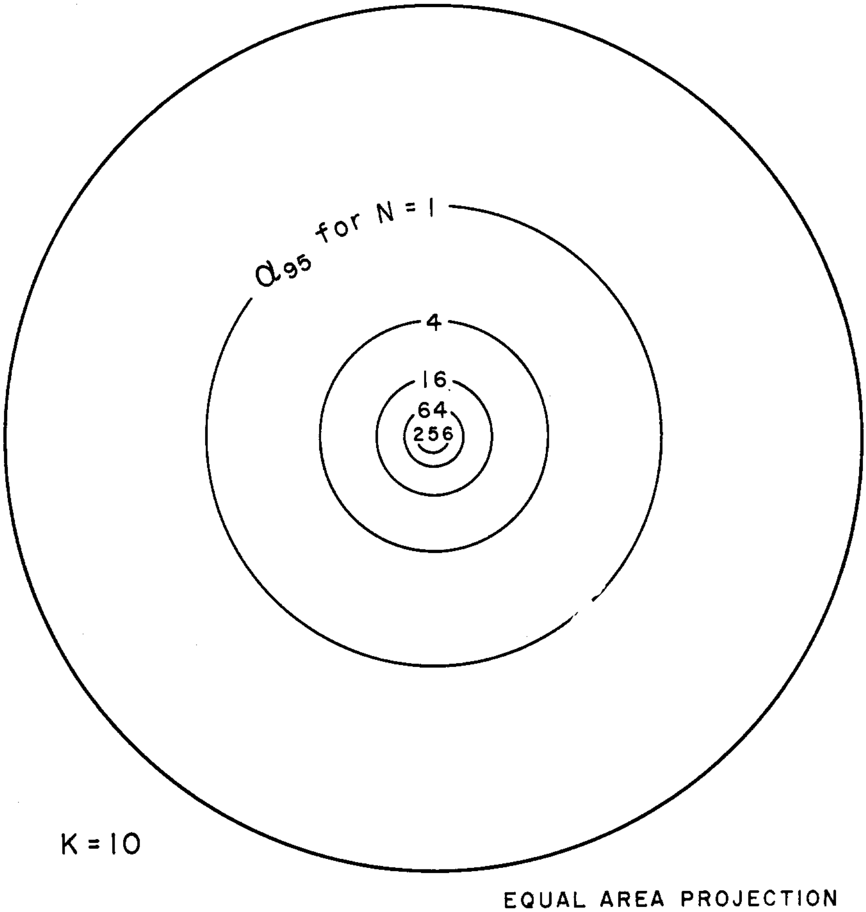

FIGURE 16.—DEPENDENCE OF CIRCLE OF CONFIDENCE ON NUMBER OF POINTS OR VECTORS
Population is same as in Figure 15

The best estimate, k, of the precision parameter κ is given (Fisher, 1953, p. 303), for $k > 3$, by

$$k = \frac{N - 1}{N - R} \qquad (15)$$

At a probability level of $(1 - P)$, the true mean direction of the population lies within a circular cone about the resultant vector R with a semivertical angle $\alpha_{(1-P)}$, given (Fisher, 1953, p. 303) for $\kappa > 3$, by

$$\cos \alpha_{(1-P)} = 1 - \frac{N - R}{R}\left\{\left(\frac{1}{P}\right)^{1/N-1} - 1\right\} \qquad (16)$$

tion lies outside the "cone of confidence" specified by α_{95} and the direction of R. Some approximate relationships, valid for small values of α, are

$$\alpha_{50} = \frac{67.5°}{\sqrt{kN}} \qquad (P = 0.5) \qquad (17)$$

$$\alpha_{95} = \frac{140°}{\sqrt{kN}} \qquad (P = .05). \qquad (18)$$

For a discussion of these and other useful relations, reference is made to Watson (1956) and Watson and Irving (1957, p. 289–293).

As the number of vectors included in the analysis increases without limit, k, the best estimate of the precision parameter, approaches the true value of κ, the precision parameter; on the other hand α becomes infinitely small as N becomes infinitely large. The relationship is shown graphically in Figure 16 for $\kappa = 10$. Thus, even for small values of κ, it is possible to determine the mean direction of a population with any desired degree of accuracy provided a sufficient number of independent measurements are made.

To determine whether the paleomagnetically determined mean direction differs significantly from some known direction such as the present earth's field at the sampling site, α may be used directly. The two directions are significantly different at the probability level used if the angle between them is greater than α. Fisher's statistical method may also be used to calculate α, k, and the mean position of virtual geomagnetic poles corresponding, for example, to the mean directions of lava flows. As is the case for directions, the mean position of the virtual geomagnetic poles differs significantly from some known position, such as the north geographic pole, if the distance between them exceeds α.

It is often desirable to compare one paleomagnetically determined field direction with another rather than with a known direction. A criterion sometimes used is that the two mean directions are significantly different if the two cones of confidence do not intersect, and conversely that they are not different if the cones do intersect. This criterion is not rigorously correct, and more exact significance tests are now available (Watson, 1956, p. 157; Watson and Irving, 1957, p. 293).

Sets of lines or axes rather than vectors are encountered in many geologic applications, and in paleomagnetic studies the problem arises when normal and reversed magnetizations are analyzed together. In this case the field is known to be parallel to a certain line, but the sense along that line is not specified.

If a set of lines or axes has axial symmetry about its mean direction and approximates the density distribution of equation (8), it may be analyzed using Fisher's statistics. However, it is first necessary to convert the lines to vectors—that is, to give an arbitrary sense to each line. This is most easily done by dividing the unit sphere into two hemispheres and regarding each line in one of the hemispheres as a positive unit vector. The vector sum is then calculated in the usual manner. The choice of the plane dividing the sphere is not arbitrary, however; if the vector sum is to be the true mean direction of the lines, it is necessary that it be normal to the dividing plane. In practice the proper plane may be found as follows: (1) a provisional mean direction is estimated and the sphere is divided by the plane normal to this direction, (2) the vector sum of the points in one hemisphere is computed yielding a more accurate mean direction, (3) the sphere may then be redivided by the plane normal to this new direction, and a second vector sum may be computed, (4) finally, the above steps may be reiterated until no change in the direction of the vector sum takes place. Quantity α has the same significance as for vectors, except that the cone defining the confidence interval is reflected in the plane perpendicular to the mean direction.

Ovals of confidence about virtual geomagnetic poles.—Equations (5), (6), and (7) establish a 1-to-1 mapping relationship between any mean field direction at a given locality and a corresponding mean virtual geomagnetic pole. The equations also map the circle of confidence about the field direction into a closed curve around the virtual geomagnetic pole which, because of the mapping function, is an oval rather than a circle. If α is the semivertical angle of the circle of confidence we may write

$$\alpha = dI = dD \cos I \qquad (19)$$

where I is the inclination of the mean field direction, and dI and dD are changes in inclination and declination, respectively. From equations (5), (6), and (7) we may then find the semiaxes δp and δm of the oval of confidence about the mean virtual geomagnetic pole from:

$$\delta p = \tfrac{1}{2}(1 + 3\cos^2 p)\, dI = c_1\alpha \qquad (20)$$

$$\delta m = \sin p\, dD = \sin p / \cos I = c_2\alpha \qquad (21)$$

where p is the distance from the sampling site to the virtual geomagnetic pole (Irving, 1956a, p. 26). The semiaxis δp lies along the great circle passing through the point of observation and the virtual geomagnetic pole, and the semiaxis δm is perpendicular to δp.

The constants c_1 and c_2, which determine the "ellipticity" of the oval of confidence, depend only on the inclination of the field and increase with increasing inclination. Quantity c_1 increases from a value of ½ for 0 inclination to 2 for vertical inclination, and c_2 increases from 1 to 2 over the same range. Thus, for vertical inclinations a circle of confidence about the mean field direction with radius α

maps into another circle about the pole with radius 2α, whereas for flat inclinations the semiaxes of the oval of confidence for the same circle are $\frac{1}{2}\alpha$ and α respectively.

If α is calculated for a probability of 95 per cent, there is a 95 per cent probability that the virtual geomagnetic pole lies within the oval determined from equations (20) and (21).

Sources of error.—Fisher's statistical methods, like others, can be incorrectly applied, and a review of the published data suggests to us that underestimates of α_{95} are not uncommon. Too small a value for α_{95} often results when the N vectors constituting the sample have not been randomly drawn from the same population. This error is analogous to that which would arise if, in finding the mean chemical composition of the Sierra Nevada batholith, five samples were collected at random, 20 separate chemical analyses performed on each sample, and the resultant data treated statistically as if 100 samples had been collected and a single chemical analysis made on each sample.

As a numerical example of the error that may arise in this way, suppose that the true mean directions of magnetization of five lava flows are scattered with a precision parameter κ_F. Let 15 oriented samples be collected from each flow with a between-sample precision parameter κ_{SA}, and let four specimens be measured from each sample with a between-specimen precision parameter κ_{SP}. The scatter in directions of magnetization within samples and within lava flows is usually much smaller than that between flows in the same formation; fairly typical values are $\kappa_F = 30$, $\kappa_{SA} = 200$, and $\kappa_{SP} = 1000$ (Cox, 1959, p. 76).

If each mean sample direction is first found by taking the mean of its four specimens, and if each mean flow direction is then found by a Fisher analysis of its 15 mean sample directions, the resulting estimated mean flow directions will deviate slightly from the true flow directions. Therefore, the estimated precision parameter k_F will be slightly smaller than that for the true mean flow directions, κ_F. However, for the values of κ_{SP}, κ_{SA}, and κ_F indicated, the difference is small, and it can be shown that k_F is equal to 29.7. The circle of confidence using this value is: $\alpha_{95} \cong 140°/\sqrt{29.7 \times 5} = 11\frac{1}{2}°$, by the approximate equation (18). This is a very close approximation to the smallest value of α_{95} that can correctly be calculated from these data.

An incorrect procedure is to analyze the 300 specimen measurements as if each had been chosen randomly from the same population. It can be shown that the "precision parameter" for the 300 vectors is about 25, given the above values for κ_{SP}, κ_{SA}, and κ_F. We may use this value in the approximate formula (18), with N equal to 300, to estimate the "circle of confidence" which would be found in this incorrect analysis; "α_{95}" $= 140°/\sqrt{25 \times 300} = 1\frac{1}{2}°$, which is too small by a factor of 7.

The same problem arises in a paleomagnetic study of sediments, where the different values of κ might describe the precision at different hierarchal levels in the sampling scheme such as the stratigraphic units in a formation, the sampling sites within a stratigraphic unit, or the oriented samples at a site.

When it can be established that a group of data at some level in the sampling scheme corresponds essentially to one point in time, as, for example, the group of measurements from one lava flow, then the variations with time of the earth's field set a lower limit to the value of α_{95} that can be obtained from N groups of data representing N points in time, no matter how many data are in each group. This lower limit for α_{95} may be estimated by the approximate formula (18):

$$\alpha_{95} = 140°/\sqrt{k'N} \qquad (22)$$

where k′ is the precision parameter corresponding to variations of the earth's field with time.

A rough estimate of k′ may be made by assuming that variations with time of the field at a locality are similar to the present variation of the field around the circle of latitude passing through the locality. Creer (1955) estimates that k′ at the equator is about 16 and that it increases poleward, reaching a value of about 70 in high latitudes. Cox (1959, p. 38), using a different method of analysis, finds a similar range of values with large irregularities in the latitude dependence. For the latitudes where most paleomagnetic sampling has been done 30 is a good average value for k′ to be used in equation (22). Using this value, a lower limit for the value of α_{95} obtainable from four lava flows is 12°. If the present irregularities in the earth's field existed in the past, some of the reported values of α_{95} based on a large number of samples collected from a few lava flows are probably too small.

One final note should be made concerning the use of Fisher's statistics. The vector population which is represented by the magnetic measurements should satisfy the density distribution given by equation (8) and have symmetry about the mean direction. Watson and Irving (1957, p. 293) have tested these requirements on two sets of stably magnetized rocks and one set of unstable rocks. To the extent allowed by the number of measurements available, the two stable magnetizations satisfied Fisher's requirements, whereas the unstable one did not.

Design of experiments.—The variation in directions of magnetization encountered in a paleomagnetic investigation may arise from many sources, and values of the corresponding precision parameters may differ by several orders of magnitude. Statistical methods are useful in designing sampling schemes and experiments so that the greatest accuracy can be obtained from the smallest possible number of measurements.

Watson and Irving (1957, p. 296) have considered the case of the two-level sampling scheme in some detail. If a total of N oriented samples are collected at B sites or from B lava flows, α_{95} is given by the approximate formula

$$\alpha_{95} \cong 140° \left(\frac{1}{\omega N} + \frac{1}{\beta B}\right)^{1/2} \tag{23}$$

where ω is the within-site precision parameter at *all* sites, and β is the between-site precision parameter. Watson and Irving conclude that, whatever the values of ω and β, the smallest number of samples needed to achieve a given α is made up of a single observation at each of the B sites, but that in practice two samples are desirable to test for gross experimental error and magnetic stability. If, as is often the case, the number of sampling sites is limited, a preliminary estimate of ω and β may be used in equation (23) to estimate the number of oriented samples which should be collected at each site. In the example cited by Watson and Irving (1957), the use of this method gave an α_{95} 8 per cent lower than that found using mean-site directions.

Frequently a small α is desired not only for the entire formation but also at each site for possible use in stratigraphic correlation or other geologic applications. From a preliminary estimate of the appropriate precision parameters an estimate of the number of samples required at each site can be made using equation (18).

Other statistical methods.—A measure of the dispersion of a set of vectors that makes no assumption about their density distribution is the angular standard or root mean square deviation $\delta_{r.m.s.}$ defined (Wilson, 1959, p. 755) as the root mean square of the angular distances δ_i of the unit vectors from the mean direction. Wilson (1959, p. 755) shows that

$$\delta_{r.m.s.} = \left\{ \sum_{i=1}^{N} \delta_i^2/N \right\}^{1/2} = \{2(N - R)/N\}^{1/2} \tag{24}$$

where N is the total number of vectors, and R is the length of the vector sum. If the distribution of the vector population is that of Fisher's model, then 63 per cent of the vectors will be within a cone with radius $\delta_{r.m.s.}$ (Creer and others, 1959, p. 316).

Paleomagnetic Data

General Statement

Paleomagnetic results are of interest in several fields of study, and an attempt has been made in Table 1 to assemble all the available basic data in as compressed and accessible a form of reference as feasible. All information available to us that could possibly be used for paleomagnetic purposes is here tabulated. No data have been excluded, even where there is no evidence for stability or where there are other reasons for rejection. It is our belief that sufficient basic data should be available to enable the critical reader to decide for himself whether individual determinations are sufficiently reliable for his purposes. Description of the number of samples collected, their lithology, the areal and stratigraphic extent of the sampling, possible stratigraphic uncertainties, and tests for paleomagnetic applicability are fully as important as a list of pole positions.

The numerical data presented include the co-ordinates of the sampling locality, the direction of magnetization after correcting for tilt of the strata, and the co-ordinates of the corresponding geomagnetic pole. Confidence limits about the magnetic direction and pole position are also included. In many paleomagnetic studies not all these quantities are given, frequently because the appropriate statistical techniques were not available when the study was made, and in other cases because the original author did not intend that "poles" be calculated from the data. Because of this, separate entries are used for each source of data in Table 1. Extensive use has been made of previous reviews, notably those of Hospers (1955), Creer and others (1954), Runcorn (1955a), Irving (1956a), Creer and others (1957), and Irving (1959). In general, a review is cited only if it lists data which did not appear in the original source or if there is a difference in the numerical values cited.

The quantities listed in entries designated by an asterisk were found by us in the following ways. The co-ordinates of sampling sites, when not listed in original sources, were located in standard atlases and are reported to the nearest half degree. When the original source lists directions of magnetization with no mean direction or pole position we have made a Fisher statistical analysis of the data, and the results are listed to the nearest half degree. Frequently, directions of magnetization are shown only on stereographic or equal-area projections, and we have scaled the magnetization directions from these diagrams. Since some of the diagrams are small, errors may arise during the scaling process; however, other workers have used this procedure in earlier reviews (*e.g.*, Irving, 1956a, Tables 1, 2, 3; Irving, 1959, Table 1), and it is encouraging to note that the different determinations usually agree to within 1–2 degrees. Several examples showing our values and those of previous reviewers are listed in the tables.

Virtual geomagnetic pole positions can be found from locality co-ordinates and mean directions of magnetization by using equations (5) through (7) or, alternately, by using a stereographic or equal-area projection. The pole positions in Table 1 attributed to the present authors were calculated on a Schmidt equal-area projection 20 cm in diameter. These pole positions were read to the nearest half degree, but because of a slight distortion in the projection used they are probably accurate only to about 1 degree.

Occasionally pole positions but not mean directions of magnetization are listed in original sources. Although it would be possible to recalculate the original direction data from the pole position and sampling-locality co-ordinates using equations (5) to (7), we have preferred to scale the original individual directions of magnetization from diagrams and compute mean field directions from them. The virtual geomagnetic poles calculated from these mean field directions usually differ by only 1–2 degrees from the pole position listed in the original source, again indicating that analyses based on data scaled from small diagrams can be quite accurate. Where this procedure has been employed we have listed the virtual geomagnetic pole corresponding to the mean field direction calculated by us so that the two will be consistent. A pole position calculated by us and differing by 1–2 degrees from that in the original reference is intended as a verification rather than a correction of the earlier result.

In a few cases it has not been possible to reconcile sampling-area co-ordinates, field directions, and pole positions listed in original sources with our computational methods. We have attempted to reach the authors concerned, stating the methods we have used, so that the reasons for the differences might be determined. Where this has not been possible we have used the methods discussed in this paper with the available data so that all results would be as nearly consistent as possible.

The proper application of statistical methods is especially important when paleomagnetic results are interpreted in terms of continental drift and polar wandering, and errors arising from the treatment of each specimen measurement as an independent datum were discussed in the section on statistics. Where adequate data have been given in original sources, and where, in our view, confidence intervals are too low, new analyses have been made for Table 1. In all these cases both the original values and the procedures used by us are described. Even in the absence of complete data, it occasionally has been possible to make realistic estimates of confidence intervals. For example, when specimen measurements have been made on samples from a few lava flows, the secular variation of the earth's field and the number of flows sets a lower limit to α_{95}. (*See* equation (22).) In Table 1 numerous confidence intervals have been recalculated using this equation. For sediments it is usually difficult to judge what level in the sampling scheme represents an independent point in time, and, therefore, few such changes have been made in the statistical data for sediments. However, when the statistical analysis has been applied to many individual specimen measurements made from only a few oriented samples, it is possible that the resulting circle of confidence is too small.

Values of k, the precision parameter describing variations in the observed directions of magnetization, are listed, where possible, for each entry in Table 1 because of the importance of this quantity in evaluating paleomagnetic data. As discussed previously, the present irregularities in the earth's magnetic field in moderate latitudes may be described by a value for k of approximately 30. If this value is taken as a measure of the variations of the field at one locality over an interval of time in the past, then a set of paleomagnetic data in which each datum corresponds to an individual point in time would be expected to have a similar value of k. Values of k considerably lower than 30 indicate a variation larger than that presently observed in the earth's field and may be due to a greater amount of variation in the past field, to experimental error in measurement, or possibly to the presence of anomalous components of magnetization in the rocks. On the other hand, higher values of k may arise in two different ways. If each specimen measured has effectively averaged the earth's field direction over a long interval of time, then each sample will have a direction close to the mean field direction, and k will be large; alternatively, if many of the samples measured were magnetized at the same time, the mean direction of the group will not be parallel to the average direction of the field, but the scatter will be small, and k will again be large.

The stratigraphic subdivisions of Table 1 are somewhat arbitrary and simply reflect the order in which the data will be discussed. Since many rocks giving consistent paleomagnetic results are poorly dated geologically, the assignment of a particular paleomagnetic investigation to one of the subdivisions in Table 1 has sometimes been difficult. In several instances stratigraphic assignments different from those in previous reviews have been made. In these cases we have noted the original stratigraphic assignment and have, where possible, given some indication of the stratigraphic uncertainty. We feel ourselves unqualified to pursue this problem further, and, for additional information concerning ages, reference is made to the original sources. No stratigraphic ordering is implied by the order of listing in each section of the table.

In evaluating the reliability of individual studies listed in Table 1, the following questions should be carefully considered: (1) Do field and laboratory tests indicate that the magnetization is stable and parallel to the field in which it developed? (2) Do the samples represent enough time to insure that rapid variations in the earth's field have been averaged out? (3) Have appropriate statistical methods been applied, and is the value of α_{95} realistic considering probable variations in the earth's field? (4) Has a sufficiently large geographical area been sampled to insure that the direction of magnetization has not been influenced by local effects such as magnetic field anomalies or small, undetected tectonic movements? (5) Are the geological structure and history sufficiently well known to allow proper bedding corrections to be made and to eliminate the possibility of remagnetization during metamorphism or other alteration? (6) To what geological interval of time and what geographical region do these results apply? (Rather extensive sampling is necessary before a pole position can be regarded as representing, say, "the Carboniferous of Asia").

Key to Table 1

The data are arranged in three sections: the numerical data, a list of references from which these data were obtained, and relevant remarks. Each entry is designated by a serial number and contains data from one source only; there is no significance in the ordering of the entries. The entries in boldface type are those from which the text figures in the next section were made and include values in all columns if these were available or could be calculated from data in the original reference.

Rocks sampled.—The formation name or other descriptive designation from the original reference is given here, together with an indication of what petrologic type is represented. Within each section the results from a given continent are grouped together.

No.—This column contains a number for each entry. In each section numbers begin with 1, and the complete serial designation of an entry is understood to be the letter describing the table subsection followed by the entry number—for example **A 3** and **D 4**.

Locality.—The two columns under this heading give the latitude and longitude of the place where the samples were collected. The latitude (Lat) is given in degrees north (N) or south (S) of the equator, and the longitude (Long) in degrees east (E) or west (W) of Greenwich.

Magnetic direction.—The columns under this heading give the magnetic direction and statistical data. The declination of the average magnetic direction (Decl) is given in degrees east of geographic north, and the inclination of the average magnetic direction (Incl) is given in degrees below the horizontal or above the horizontal (the latter is indicated by a minus sign). Correction has been made for tilt of the strata. The statistical data listed are the circle of confidence in degrees at a probability level of 95 per cent (α_{95}), the precision parameter (k), and the number of vectors (N) used in obtaining these values. Values of k and N apply to magnetic field directions for all those entries which list values for the magnetic direction. In other entries k and N apply to statistical analyses of sets of pole positions.

Pole position.—These columns give the location of the pole of the theoretical geocentric dipole (the virtual geomagnetic pole) consistent with the co-ordinates of the sampling locality and the mean direction of magnetization. The location is given by the values in columns (Lat) and (Long), with the same conventions as for the sampling locality. Each magnetic dipole has a north and a south pole, and the pole listed is the one that falls in the northern hemisphere. In column (P) which designates the polarity of the pole, the letter S is used if the direction of magnetization corresponds to a magnetic south pole in the northern hemisphere (the present magnetic field is of this type), and the letter N is used if it corresponds to a magnetic north pole in the northern hemisphere. Poles calculated from sets of samples having approximately opposing or reversed polarities are designated (M). (δm) and (δp) are the values in degrees of the semimajor and semiminor axes, respectively, of the 95 per cent confidence oval about the mean pole position, corresponding to the value of α_{95} about the mean magnetic direction in each entry. Quantity δp is measured along the great circle passing through the sampling site and the mean pole position, and δm along the great circle at right angles to the first circle.

The last column in the numerical data section, (S), indicates the publication source from which the data in that entry were obtained. Lowercase letters refer to the references listed in the next column, and an asterisk (*) indicates that some of the values have not appeared in previous entries and were calculated by us.

References.—For each item tabulated the name in italics is, to the best of our knowledge, that of the worker who made the measurements. The references corresponding to the letters in column (S) are then keyed by author and year.

Remarks.—Information concerning the age of the rocks is listed here, together with information of value in assessing the reliability of the results for paleomagnetic purposes. The absence of any remarks under the following headings indicates that this particular information was not available.

(1) *Age*—If no specific reference is given for the statements, the age specified was obtained from the principal reference listed in the previous column.

(2) *Sampling*—The remarks under this heading give the areal and stratigraphic extent of the sampling as well as the manner in which statistics were applied to the data.

(3) *Stability*—Any field or laboratory tests that indicate stability or instability are noted here. If no entry is present, no specific test for stability has been reported. Even if a stable component of magnetization is indicated, it does not necessarily follow that the results have paleomagnetic applicability.

(4) *Reversals*—For those studies that show mixed polarities, remarks concerning the number of samples in each group, their stratigraphic relationship, and other relevant observations are noted.

(5) *Other*—Remarks that do not come under the above headings are listed here.

ПОЯСНЕНИЕ К ТАБЛИЦАМ

Приведенньіе таблицьі состоят из трех частей: числовьіх даньіх, списка литературьі из каторой эти данньі почеркнутьі, и соответствующих примечаний. Каждое исследованьіе помечено серийньім номером и содержит данньіе по обрасцу толко из одного источника; порядок последовательности номеров значения не имеет. Подчеркньітьіе данньіе представляют материял из которого бьіли взятьі числовьіе величиньі, помещенньіе в тексте следующей части; они дают числовьіе величиньі для каждаго столбца, кагда эти величиньі приведеньі или могут бьіть вьічисленьі по данньім источника. Ниже дается детальное пояснение что находится под заголовком в каждом столбце.

Rocks sampled.—Названиие формации или её иное описателное обозначение, вместе с указанием на представленньій петрологический тип, даньі в этом столбце. Результатьі по данному континенту сгрупированьі в кеждой секции вместе, причем названия континентов набраньі жирнбім шрифтом.

No.—В этом стольце дается номер для даннЬіх по каждому обрасцу. В каждом разделе таблици номера начинается сначала. Таким образом, полное серийное обозначение цифровьіх даннЬіх по образцу состоит из заглавной буквбі, обозначающей раздел талицбі и следующего за буквой номера, на пример **А 3** и **D 4**.

Locality.—В двух колонках под этим обозначением дана географическая жирота и долгота места отбора обрасцов. жирота (*Lat.*) дана в градусах к северу (*N*) или к югу (*S*) от экватора, а долгота (*Long.*) к востоку (*E*) или запасу (*W*) от Гринвича.

Magnetic direction.—В этом столбце дается направление намагничености и статистиче ьские данныя. Значение склонения среднего направления намагничености (*Decl.*) дается в градусах на восток од географического меридиана, а значение наклонения среднего направления намагничености (*Incl.*) в градусах от горизонтали, со знаком минус для направления вверх от неё. Введена поправка за наклонение пласта. Приведенные статистические даннья указивают "круг сходимости" каторий содержит в себя положение средней точки с вероятности 95% (α_{95}), мера точности (k) и число единичных векторов (*N*), использованых при вычислении этих величины. Величины k и N относятся к направлениям магиитного поля всех тех данных, каторые указывают значения направления намагничености. В остальных случаях данные k и N относятся к статистическому анализу групи положений полюса.

Pole position.—В этих столбцах даны положения полюсов теоретического геоцентрического диполя (виртуальный магнетный полюс) соответствующий координатам места отбора образцов и среднему значению направления намагничености. Положения полюсов даны в колонках (*Lat.*) и (*Long.*), так же как это было сделано в стольце для координат места отьора образцов. у каждаго магнитного диполя имеется северный и южныи полюс а данныя в столбце односятся к полюсу находящему в северному полушарю. В столбце (*P*) каторий дает значения поларности полюса, буква *S* обозначает направление намагничености, соответствующее южному магнитному полюсу в северном полушарии (современое магнитное поле этого типа), а буква *N* указивает, что направление намагничености соответствует северному магнитному полюсу в северном полушарии. Полюса, вычисленные из данных по образцам имеющие приблизительно противположные или обращенные полярности обозначены буквой (*M*).

(δm) и (δp) обозначают, соотвественно, величину в градусах, болшой и малой полуосей 95-ти процентного овала доверия, относительного среднего положения полюоса, соответствующего величине α_{95} относительно среднего магнитного направления по каждому определению. δ_p измеряется по окрушности болжого круга, проходящего через место отборки образца и среднее положение полюса, а δ_m вдоль окружности большого круга перпендикуларного к первому кругу. В последней колонке (*S*) числовыи данных указан источник, из каторого были взяты числовые данные. Строчные буквы относятся к источникам указанным в следующей колонке, а символ (*) обозначает что некаторые из величин указанные в предидущем столбце не были даны источником, а были вычислены нами.

References.—имя, набраное курсивом относится, согласно наиболее доставерным сведениим, каторые мы могли достать, к работнику, производившему измерения. Затем даны есылки соглпасно буквам в столбце (*S*).

Remarks.—В этом столбце даны сведения, относящиеся к возрасту пород, вместе с оценком достоверности этих сведений для целей палеомагнетизма. Отсуствие примечаний под следующим заглавками указивает на отсуствие источников, из каторых нужные сведения могли быть почеркнуты.

(*1*) *Age.*—Здесь данны замечания о возрасте изучаемых пород. Отсуствие таковых замечаний означает, что данные о возрасте были получены из гловного источника, указаного в предидущем столбце.

(*2*) *Sampling.*—Замечания под этим загаловком дают ареал и стратиграфические указания отобранных образцов, а такше и метод статистической обработки данных.

(*3*) *Stability.*—Здесь указаны полевые или лабораторные иследования магнитной стаьилности. Отсуствие данных по иследованию на стабильность указывает, что сведений по этому новоду не имеется. Даже, если указан устоичивый компонент намагниченности, это ещо не значит что результаты имеют палеоматнетную значимость.

(*4*) *Reversals.*—Здесь даны замечания относительно образцов в каждой групе, их стратиграфические взаимоотощения и другие, относящиеся к делу наблюдения для случаев смешанной поларности.

(*5*) *Other.*—Заметки и примечания, каторые не входят в предыдущие столбцы.

TABLE 1.—PALEOMAGNETIC DATA

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION A POST EOCENE																
EUROPE																
MT. ETNA LAVAS	1	37½N	15 E	4½	56	2	—	11	—	—	S	—	—	a	*Chevallier*	*Age:* 394 B.C. to A.D. 1911
	2	**37½N**	**15 E**	**4½**	**56**	**6½**	**50**	**11**	**86 N**	**126 E**	**S**	**9½**	**7**	*	a Hospers, 1955	*Sampling:* 3 to 9 oriented samples were taken from 11 historic lava flows. The last 2 directions agree with observatory data.
	3	—	—	—	—	—	—	11	86½N	125½E	S	10	7½	b	b Irving, 1959	
															c Chevallier, 1925	
CARTHAGE FIRED CLAYS	**4**	**37 N**	**10 E**	**359**	**54½**	—	—	—	**88 N**	**155 W**	**S**	—	—	*	*Thellier and Thellier* a Thellier and Thellier, 1951	*Age:* 2 dates, 146 B.C. and 300 A.D. *Sampling:* 9 oriented samples from 2 kilns (146 B.C.) and 9 oriented samples from one kiln (300 A.D.) were measured. Values in entry (4) are based on the average declination and inclination given on p. 1478, Ref. a. *Other:* $N = 2$ is not sufficient for calculating Fisher statistics.
PRÄSTMON VARVES	5	63 N	17½E	357½	73½	3½	—	46	—	—	S	—	—	a	*Bancroft*	*Age:* 0 to A.D. 1000
	6	**63 N**	**17½E**	**357½**	**73½**	**3½**	**42**	**46**	**86 N**	**150 W**	**S**	**6**	**5½**	*	a Hospers, 1955	*Sampling:* 46 "groups" of specimens were measured.
															b Bancroft, 1951	
BRITISH FIRED CLAYS	**7**	**52 N**	**0 E**	**0**	**66½**	**2½**	**242**	**14**	**87 N**	**180 E**	**S**	**4**	**3½**	*	*Cook and Belshé* a Cook and Belshé, 1958	*Age:* First to 15th centuries A.D. *Sampling:* 10 archaeological fired clays were measured from the 1st through 4th centuries and 4 from the 12th, 13th, and 15th centuries. Values for entry (7) are based on data scaled from Fig. 3, Ref. a, which gives declination and inclination values corrected to Cambridge, England. *Other:* Statistical values have no rigorous significance because individual measurements do not represent independent points in time.
ÅNGERMAN RIVER VARVES	**8**	**63 N**	**17½E**	**2**	**74½**	**4½**	**34**	**29**	**88 N**	**150 E**	**S**	**8**	**7½**	*	*Griffiths*	*Age:* 1100 B.C. to A.D. 750, based on Liden's varve chronology
	9	—	—	—	—	—	—	—	88½N	160 E	S	13	12	b	a Griffiths, 1955	*Sampling:* About 150 samples from two localities a few kilometers apart were measured. These were averaged into 29 groups, each representing about 100 years. Data for the calculations of entry (8) were scaled from Fig. 3(b), Ref. a.
															b Irving, 1959	

ICELAND LAVAS	**10**	**—**	**—**	**—**	**—**	**6**	**31**	**21**	**89½N**	**54 E**	**S**	**6**	**6**	*	*Brynjólfsson* a Brynjólfsson, 1957	*Age:* Postglacial (3400 B.C. to 1950 A.D.) *Sampling:* 21 flows were sampled covering about 5000 years. Entry (10) is based on pole-position data for each flow scaled from Fig. 3, Ref. a. *Stability:* The samples were partially demagnetized in 140 oersted A.C. fields before measurement.
ICELAND LAVAS	11	—	—	1	74	8	—	8	—	—	S	—	—	a	*Hospers*	*Age:* Postglacial *Sampling:* 8 flows were measured covering a period of at least 4000 years. The value of *k* for entry (12) was calculated by the approximate formula.
	12	**64 N**	**19 W**	**1**	**74**	**8**	**36**	**8**	**86½N**	**153 E**	**S**	**15**	**13½**	*	a Hospers, 1955	
SWEDISH VARVES	**13**	**—**	**—**	**—**	**—**	**12½**	**16**	**10**	**86 N**	**98 W**	**S**	**12½**	**12½**	*	*Granar* a Granar, 1959	*Age:* Glacial and postglacial *Sampling:* 10 varve sections were sampled over a lateral distance of 800 km. Fisher statistics were applied to the pole positions calculated from magnetic direction and locality data on p. 27, Ref. a.
CHAINE DES PUYS LAVAS	14	—	—	353	62	—	—	10	84 N	50 W	S	—	—	a	*Roche*	*Age:* late Pleistocene *Sampling:* 10 flows were sampled.
	15	**45½N**	**3 E**	**353**	**62**	**—**	**—**	**10**	**84½N**	**106 W**	**S**	**—**	**—**	*	a Roche, 1958	
ICELAND LAVAS	16	64½N	22 W	181	−75	7	—	51	—	—	N	—	—	a	*Hospers*	*Age:* early Quaternary *Sampling:* The samples were collected over a lateral extent of 125 km.
	17	**64½N**	**22 W**	**181**	**−75**	**7**	**9**	**51**	**87½N**	**150 E**	**N**	**13**	**11½**	*	a Hospers, 1955	
PLATEAUX BASALTS	18	—	—	206	−63½	—	—	8	72 N	100 E	N	—	—	a	*Roche*	*Age:* early Quaternary *Sampling:* 8 flows were sampled.
	19	**45½N**	**3 E**	**206**	**−63½**	**—**	**—**	**8**	**71½N**	**84 E**	**N**	**—**	**—**	*	a Roche, 1958	
FRENCH LAVAS	20	45 N	3½E	197	−62½	13	—	6	—	—	N	—	—	b	*Roche*	*Age:* Pliocene and Pleistocene. The oldest flows are Villafranchien. *Sampling:* 6 flows were sampled.
	21	**45 N**	**3½E**	**197**	**−62½**	**13**	**28**	**6**	**78½N**	**93 E**	**N**	**20**	**15½**	*	a Roche, 1951 b Hospers, 1955	
ICELAND LAVAS	22	—	—	—	—	—	19	33	77½N	74 E	S	—	—	a	*Sigurgeirsson*	*Age:* Pliocene and Pleistocene *Sampling:* 33 lava flows from three normally magnetized groups and 26 flows from three reversely magnetized groups were sampled. Fisher statistics were applied to the pole positions calculated from each flow. The values of α_{95} for entries (23) and (25) were calculated by the approximate formula. *Stability:* A.C. demagnetization of 110 oersted reduced the scatter in the determinations, especially in the reversed groups.
	23	**—**	**—**	**—**	**—**	**5½**	**19**	**33**	**77½N**	**74 E**	**S**	**5½**	**5½**	*	a Sigurgeirsson, 1957	
	24	—	—	—	—	—	15	26	88 N	149 E	N	—	—	a		
	25	**—**	**—**	**—**	**—**	**7**	**15**	**26**	**88 N**	**149 E**	**N**	**7**	**7**	*		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	*k*	*N*	Lat.	Long.	*P*	δm	δp	*S*		
								SECTION A—*Continued*								
CHELEKAN SEDIMENTS	26	—	—	12	37	—	—	—	—	—	S	—	—	a	*Khramov*	*Age:* Pliocene and Pleistocene
	27	**39 N**	**53 E**	**12**	**37**	**—**	**—**	**—**	**69 N**	**161 W**	**S**	**—**	**—**	*	a Khramov, 1957	*Sampling:* 650 oriented samples were measured from localities as far as 170 km from each other.
	28	—	—	196	−30	—	—	—	—	—	N	—	—	a		
	29	**39 N**	**53 E**	**196**	**−30**	**—**	**—**	**—**	**63 N**	**163 W**	**N**	**—**	**—**	*		*Other:* In 4 bore holes 2–4 km apart, transition from north-seeking to south-seeking magnetizations occurs at the same level. Samples from several "normal" and "reversed" zones are included in the average directions cited. Additional details appear in Khramov, 1958.
FRENCH LAVAS	30	45½N	3 E	176½	−51	14	—	5	—	—	N	—	—	b	*Roche*	*Age:* Miocene and Pliocene. The oldest flows are Pontian.
	31	**45½N**	**3 E**	**176½**	**−51**	**14**	**27**	**5**	**76 N**	**164 W**	**N**	**19**	**12½**	*	a Roche, 1951	
	32	—	—	—	—	—	—	5	73 N	167½W	N	19	13½	c	b Hospers, 1955	*Sampling:* 5 flows were sampled.
															c Irving, 1959	
ICELAND LAVAS	33	65 N	20 W	1½	78	5½	—	102	—	—	M	—	—	a	*Hospers*	*Age:* Miocene
	34	**65 N**	**20 W**	**1½**	**78**	**5½**	**7**	**102**	**88 N**	**10 W**	**M**	**10½**	**10**	*	a Hospers, 1955	*Sampling:* An average of 25 flows from each of 4 normal and reversed zones were measured.
VOGELSBERG BASALTS															*Angenheister*	*Age:* Cited as Miocene
															a Angenheister, 1956	*Sampling:* More than 200 oriented samples were collected from 42 flows. The values of *k* for entries (36), (38), and (40) were calculated by the approximate formula.
Normal flows	35	—	—	8	57	8	—	29	—	—	S	—	—	a		
	36	50½N	9½E	8	57	8	11	29	76 N	163½	S	11½	8	*		
Reversed flows	37	—	—	188½	−60	15	—	13	—	—	N	—	—	a		
	38	50½N	9½E	188½	−60	15	7	13	79 N	155 E	N	22	17	*		
All flows	39	—	—	8½	57½	6	—	42	—	—	M	—	—	a		
	40	**50½N**	**9½E**	**8½**	**57½**	**6**	**13**	**42**	**76½N**	**160 E**	**M**	**8½**	**6½**	*		
ENGLISH NORTH WEST DYKES	**41**	**55½N**	**3 W**	**179½**	**−73**	**15½**	**16**	**7**	**87 N**	**8 W**	**N**	**28**	**25**	*	*Bruckshaw and Robertson*	*Age:* Cited as Oligocene or Miocene in Refs. a and b
	42	55½N	3 W	174½	−73½	15½	—	7	—	—	N	—	—	b		*Sampling:* The samples were collected from 4 dikes at 7 sites. The sites covered an area of about 50 by 140 miles. Values for entry (41) were based on data scaled from Fig. 7B, Ref. a.
	43	—	—	—	—	—	—	7	86 N	76 W	N	25	21	c	a Bruckshaw and Robertson, 1949	
															b Hospers, 1955	
															c Irving, 1959	
LIMAGNE BASALT	44	—	—	180	−73	—	—	—	—	—	N	—	—	a	*Roche*	*Age:* Cited as Aquitanian (lower Miocene)
	45	—	—	—	—	—	—	—	77 N	3 E	N	—	—	b	a Roche, 1950b	*Sampling:* One locality was sampled.
	46	**46 N**	**3 E**	**180**	**−73**	**—**	**—**	**—**	**77 N**	**3 E**	**N**	**—**	**—**	*	b Irving, 1959	
FRENCH INTRUSIVE ROCKS	47	46 N	3 E	201	−57	11	—	9	—	—	N	—	—	a	*Roche*	*Age:* Cited as Oligocene in Ref. a
	48	**46 N**	**3 E**	**201**	**−57**	**11**	**24**	**9**	**72 N**	**114 E**	**N**	**15½**	**11½**	*	a Hospers, 1955	
	49	—	—	—	—	—	—	—	73 N	119 E	N	16	12	c	b Roche, 1950a	
															c Irving, 1959	

NORTH AMERICA																
New England Varves	50	43 N	72½W	355½	51½	10	—	6	—	—	S	—	—	a	*Johnson, Murphy, and Torreson* a Hospers, 1955 b Irving, 1959 c Johnson, Murphy, and Torreson, 1948	*Age:* 13,000 to 7000 B.C. *Sampling:* The measurements were averaged into 6 groups, each representing 1000 years, and the calculations were based on the average directions for these 6 groups.
	51	**43 N**	**72½W**	**355½**	**51½**	**10**	**50**	**6**	**79 N**	**127 E**	**S**	**13½**	**9**	*		
	52	—	—	—	—	—	—	—	80½	132 E	S	13½	9½	b		
Canadian Basalts	53	—	—	348½	75	4	28	46	—	—	M	—	—	a	*Du Bois* a Du Bois, 1959a	*Age:* Cited as late Tertiary in Ref. a *Sampling:* 29 samples were collected at 60½ N, 135 W; 9 at 60 N, 130½ W; 6 at 63 N, 138 W; and 4 at 59½ N, 134 W; 2 widely divergent samples from the second group were discarded. There is no indication of the number of flows sampled. Location data for entry (54) are averages of the above 4 localities. *Reversals:* All the samples from the first and third groups were reversed with respect to the present field direction.
	54	**61 N**	**134½W**	**348½**	**75**	**4**	**28**	**46**	**85 N**	**145 E**	**M**	**6½**	**7½**	*		
Neroly Formation (sediments)	55	—	—	7	58	3	—	29	—	—	S	—	—	a	*Doell* a Doell, 1955a b Doell, 1956	*Age:* Magnetization is parallel before correcting for post early Pleistocene folding with dips of 50°; therefore the magnetization was acquired post early Pleistocene, although the rocks were deposited in late Miocene time. *Sampling:* 29 oriented samples were collected from 3 areas about 50 miles apart. The value of *k* for entry (56) was calculated using the approximate formula. *Stability:* Partial heat demagnetization to 100°C. decreased the scatter in directions.
	56	**37½N**	**122 W**	**7**	**58**	**3**	**89**	**29**	**85 N**	**42 W**	**S**	**4**	**3**	*		
Payette Formation (sediments)	**57**	**43 N**	**115½W**	**1½**	**62½**	**2½**	**258**	**13**	**88½N**	**60 W**	**S**	**4**	**3**	*	*Torreson et al.* a Torreson, Murphy, and Graham, 1949	*Age:* Cited as Pliocene in Ref. a although now regarded by U. S. Geological Survey as Miocene and Pliocene(?) *Sampling:* 13 oriented samples were collected at one site. Entry (57) was based on data given in Table 4, Ref. a.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION A—*Continued*																
COLUMBIA RIVER BASALTS															*Campbell and Runcorn* a Campbell and Runcorn, 1956 b Irving, 1959	*Age:* Miocene *Sampling:* 73 separate flows are included in the calculations out of a total of 114 examined in the area. 7 localities were sampled over an area of 300 by 200 miles. Values for entry (62) were obtained by averaging the values for declination, inclination, and k given in entries (58) and (60). The value for α_{95} was then calculated by the approximate formula.
Normal flows	58	—	—	11½	73½	7½	5	44	—	—	S	—	—	a		
	59	46½N	120 W	11½	73½	7½	5	44	75½N	97 W	S	13½	12½	*		
Reversed flows	60	—	—	177	−66	10½	4	29	—	—	N	—	—	a		
	61	46½N	120 W	177	−66	10½	4	29	87 N	170 W	N	17½	14½	*		
All flows	**62**	**46½N**	**120 W**	**3½**	**69½**	**8**	**4**	**73**	**83 N**	**105 W**	**M**	**13½**	**11½**	*		
	63	—	—	—	—	—	—	—	87 N	40 E	M	4½	3½	b		
ELLENSBURG FORMATION (sediments)	64	46½N	120½W	4	66½	10½	11	19	86½N	73 W	S	17½	14	*	*Torreson et al.* a Torreson, Murphy, and Graham, 1949 b Graham, 1949	*Age:* Cited as Miocene in Ref. a. Now regarded as late Miocene and early Pliocene by U. S. Geological Survey. *Sampling:* 23 oriented samples were collected at one site. The calculations for entry (64) were based on data scaled from Fig. 11, Ref. b, and those for entry (65) were based on data given in Table 4, Ref. a. *Stability:* Stability is indicated by the application of Graham's conglomerate test. *Reversals:* One sample showed reversed polarity.
	65	**46½N**	**120½W**	**½**	**68½**	**9**	**12**	**23**	**85 N**	**115 W**	**S**	**15½**	**13**	*		
ARIKAREE FORMATION (sediments)	**66**	**44 N**	**103 W**	**66**	**69**	**25½**	**3**	**21**	**47 N**	**49 W**	**S**	**43½**	**37**	*	*Torreson et al.* a Torreson, Murphy, and Graham, 1949	*Age:* Cited as Miocene. *Sampling:* 21 oriented samples were collected at one site. Entry (66) was based on data given in Table 4, Ref. a. *Other:* The scatter in directions is extreme.
DUCHESNE RIVER FORMATION (sediments)	**67**	**40½ N**	**110 W**	**2**	**65**	**5**	**14**	**85**	**83 N**	**99 W**	**S**	**8**	**6**	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Tertiary. *Sampling:* 85 specimen measurements were made on 24 oriented samples.

SOUTH AMERICA NEUQUEN LAVAS															*Creer* a Creer, 1958 b Irving, 1959	*Age:* Cited as Quaternary. *Sampling:* In all these entries, N is the number of specimen measurements which were made on 20 oriented samples collected from 10 flows (both normal and reversed). Lateral sampling extent was about 200 by 400 km. Entry (74) was based on data scaled from plots in Ref. a. Entry (75) is based on the "secular variation precision" $k' = 30$ and the number of flows sampled, and α_{95} was calculated by the approximate formula. *Stability:* The scatter in directions was very greatly reduced by partial A.C. demagnetization at 250 oersted.
Normal flows	-68	—	—	350	−46	8	31	12	—	—	S	—	—	a		
	69	38 S	70 W	350	−46	8	31	12	76½N	112 W	S	10	6	*		
Reversed flows	-70	—	—	188	64	5	17	46	—	—	N	—	—	a		
	71	38 S	70 W	188	64	5	17	46	80½N	76 E	N	8½	6½	*		
All flows	72	—	—	1	−61	5	15	58	—	—	M	—	—	a		
	73	—	—	—	—	—	—	—	83 N	126 E	M	7	6	b		
	74	38 S	70 W	3	−69	3½	15	65	75 N	102 E	M	6	5	*		
	75	**38 S**	**70 W**	**3**	**−69**	**8**	k'	**10**	**75 N**	**102 E**	**M**	**13½**	**11½**	*		
AUSTRALIA NEWER VOLCANICS OF VICTORIA	76	38 S	143½E	8	−59½	8	35	13	—	—	S	—	—	a	*Irving and Green* a Irving and Green, 1957	*Age:* Pliocene to Recent *Sampling:* At least 2 oriented samples were collected at each of 32 sites covering an area of 50 by 150 miles. The values cited here for k are between-site precision parameters (see Watson and Irving, 1957, p. 296–297).
	77	38 S	143½E	177	60	6½	31	16	—	—	N	—	—	a		
	78	**38 S**	**143½E**	**3½**	**−60**	**5**	**37**	**32**	**86½N**	**78 W**	**M**	**7**	**5½**	a		
NEW ZEALAND IGNIMBRITES	79	—	—	—	—	—	—	—	79 N	35 E	S	—	—	b	*Hatherton* a Hatherton, 1954 b Irving, 1959	*Age:* Cited as Pliocene *Sampling:* 52 oriented samples were measured as well as 65 samples cut from vertical drill cores. Values for entry (80) were based on the inclination and declination data given in Table 3, Ref. a. Lateral sampling extent was 10 miles.
	80	**37½S**	**175 E**	**351**	**−65**	—	—	—	**79 N**	**26 E**	**S**	—	—	*		
ASIA JAPANESE FIRED CLAYS	**81**	**35½N**	**140 E**	**358**	**52**	**3**	**58**	**45**	**86½**	**5 W**	**S**	**4**	**3**	*	*Watanabe* a Watanabe, 1958	*Age:* From 5600 to 4400 B.C. and 300 to 1800 A.D. *Sampling:* Data from 43 archaeological fired clays and 2 dated lava flows were reported, 22 in the period 300 to 1800 A.D. and 23 in the period 5600 to 4400 B.C. Values for entry (81) were based on data scaled from Figs. 1 and 2, and cited in Table 1, Ref. a.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION A—*Continued*																
NORTH IZU AND HAKONE VOLCANIC ROCKS	**82**	—	—	—	—	**7**	**11**	**42**	**78 N**	**45½E**	**M**	**7**	**7**	*	*Nagata et al.*	*Age:* Quaternary
	83	—	—	—	—	—	—	—	76½N	37½E	M	10½	7	b	a Nagata, Akimoto, Uyeda, Shimizu, Ozima, Kobayashi, and Kuno, 1957 b Irving, 1959	*Sampling:* 42 flows were measured more or less uniformly throughout the Quaternary. The calculations for entry (82) are in the form of a Fisher analysis on the pole positions for each group of flows cited in Table 2, Ref. a. Since values of α_{95} for the 42 sets of data vary widely, the overall value of α_{95} listed has no rigorous statistical significance. *Stability:* Stability was established by extensive and elaborate laboratory tests. *Reversals:* 9 flows near the bottom of the Quaternary show reversed polarity.
JAPAN VOLCANIC ROCKS	**84**	**36 N**	**138 E**	**11**	**61½**	**11**	**5**	**39**	**79½N**	**173 W**	**M**	**17**	**13**	*	*Matuyama* a Matuyama, 1929	*Age:* The rocks sampled are Tertiary and younger. *Sampling:* 39 oriented samples were collected at 35 localities in Honsyû, Kyûsyû, Tyôsen, and Manchuria, the majority being collected in Honsyû. The data used in the calculations for entry (84) were scaled from a figure on p. 204, Ref. a. The latitude & longitude of the sampling area are an average for Honsyû; thus there may be somewhat more dispersion in the values given than there would have been at a single sampling area. *Reversals:* About half the samples measured showed reversed polarity.
JAPAN VOLCANIC ROCKS	**85**	**36 N**	**138 E**	**359**	**47½**	**11**	**18**	**11**	**82½N**	**35 W**	**S**	**14½**	**9½**	*	*Kumagai et al.* a Kumagai, Kawai, and Nagata, 1950	*Age:* Pleistocene to Recent *Sampling:* 11 lava flows were sampled. Data for the calculation of entry (85) were taken from Tables I and II, Ref. a (nos. 1, 2, 3, 5, 6, 7, 17, 18, 19, 20, 21). The Narita bed, no. 4, is stated by Kawai (1954, p. 209) to be unstable and was not included here. Coordinates for the sampling area are averages.

JAPAN VOLCANIC ROCKS	86	36 N	138 E	349½	48	12⅓	37	7	79 N	13 E	M	16	10½	*	*Kumagai et al.* a Kumagai, Kawai, and Nagata, 1950	*Age:* Late Tertiary *Sampling:* 7 lava flows were sampled. Data for the calculation of entry (86) were taken from Table I, Ref. a. Nos. 9 through 15 were used. No. 8 was discarded because of instability (Kawai, 1954, p. 209). Co-ordinates for the sampling area are averages. *Reversals:* One of these flows showed reversed polarity.
KAWAJIRI BASALT	87	—	—	—	—	—	—	—	80 N	49 E	N	—	—	a	*Asami* a Irving, 1959 b Asami, 1954a c Asami, 1954b	*Age:* early Pleistocene *Sampling:* One flow was sampled. *Other:* Normal and intermediate directions of magnetization were found in closely associated lavas (Ref. c, p. 151).
JAPAN VOLCANIC ROCKS															*Nagata et al.* a Nagata, Akimoto, Shimizu, Kobayashi, and Kuno, 1959	*Age:* late and early Pliocene *Sampling:* 2 basalt lavas were sampled from the upper Pliocene and 2 andesite lavas from the lower Pliocene. Values for calculation of entry (90) are based on direction data given in Table II, Ref. a, and the localities cited in Table 1, Ref. a. Fisher statistics were applied to the 4 pole positions calculated from these data.
upper Pliocene	88	—	—	3	42	2	—	12	79 N	57 W	S	3	2	a		
lower Pliocene	89	—	—	14	52	4	—	10	77 N	109 W	S	6	4	a		
combined	90	—	—	—	—	10	82	4	79½N	88½W	S	10	10	*		
JAPAN VOLCANIC ROCKS															*Nagata et al.* a Nagata, Akimoto, Shimizu, Kobayashi, and Kuno, 1959	*Age:* late, middle, and early Miocene *Sampling:* A dolerite sheet, andesite sheet, and 2 andesite lavas were sampled from the upper and middle Miocene and a dolerite sheet and 2 andesite lavas from the lower Miocene. Values for calculation of entry (93) are based on direction data given in Table II, Ref. a, and the localities cited in Table I, Ref. a. Fisher statistics were applied to the 7 pole positions calculated from these data. *Reversals:* 2 units from the upper and middle Miocene and one from the lower Miocene had reversed polarity.
upper and middle Miocene	91	—	—	27	59	3	—	32	68 N	152 W	M	5	4	a		
lower Miocene	92	—	—	32	40	11	—	20	59 N	113 W	M	13	8	a		
combined	93	—	—	—	—	22	8	7	73 N	144 W	M	22	22	*		

TABLE 1.—*Continued*

SECTION B PRECAMBRIAN

Rocks Sampled	No.	Locality Lat.	Locality Long.	Magnetic Direction Decl.	Magnetic Direction Incl.	α_{95}	*k*	*N*	Pole Position Lat.	Pole Position Long.	*P*	δm	δp	*S*
EUROPE TORRIDONIAN SANDSTONE Upper	1	—	—	295	−34	—	—	—	—	—	—	—	—	a
	2	58 N	6 W	295	−34	—	—	—	3 N	53 E	N	—	—	*
	3	58 N	6 W	294	−28	9	9	28	—	—	—	—	—	e
	4	58 N	6 W	294	−28	9	9	28	1 N	56 E	N	10	5½	*
	5	—	—	127	52	—	—	—	—	—	—	—	—	a
	6	58 N	6 W	127	52	—	—	—	11½N	37 E	S	—	—	*
	7	58 N	6 W	129	51	5	15	53	—	—	—	—	—	e
	8	58 N	6 W	129	51	5	15	53	10 N	36 E	S	6½	4½	*
	9	—	—	304	−38	—	—	—	—	—	—	—	—	a
	10	58 N	6 W	304	−38	—	—	—	2 N	45 E	M	—	—	*
	11	—	—	—	—	—	—	—	5 N	49 E	—	8	5	b
	12	**—**	**—**	**123**	**44**	**5**	**12**	**81**	**6 N**	**43 E**	**M**	**6**	**4**	**f**
Lower	13	—	—	—	—	—	—	—	37 N	109 W	—	—	—	d
	14	—	—	307	34	7	40	—	—	—	—	—	—	c
	15	—	—	307	34	7	40	13	35 N	112 W	S	8	5	f
	16	**58 N**	**6 W**	**307**	**34**	**7**	**—**	**—**	**35 N**	**118 W**	**S**	**8**	**5**	**g**

References

Irving and Runcorn
a Creer, Irving, and Runcorn, 1954
b Runcorn, 1955b
c Runcorn, 1955a
d Day and Runcorn, 1955
e Irving and Runcorn, 1957
f Creer, Irving, and Runcorn, 1957
g Irving, 1957a

Remarks

Age: late Precambrian, overlying Lewis gneiss and overlain by Lower Cambrian rocks. Entries (1) through (12) are Aultbea, Applecross, and top Diabaig formations. Entries (13) through (16) are lower Diabaig. Aultbea overlies Applecross which overlies Diabaig.

Sampling: Lateral extent, 60 miles; vertical extent, 10,500 feet in upper Torridonian and 1,900 feet in lower Torridonian. *N* refers to the number of sampling sites; the mean direction at each site was used in the statistical analysis. 11 sites in the upper Torridonian were magnetized in directions oblique to the mean direction of the remaining 81 sites; these, as well as 6 sites with directions parallel to the present field, were not used in the statistical analysis. "Normal" and "reversed" groups of sites differ significantly in their mean directions but were combined in entry (12) for mean axial direction of magnetization.

Other: The change in magnetic direction between upper and lower Torridonian occurs stratigraphically in less than 300 feet with no evidence of unconformity.

Stability: Torridonian pebbles in conglomerates of later age have randomly oriented directions of magnetization. Directions of magnetization are scattered in beds showing penecontemporaneous deformation (Ref. e, p. 93). Directions of magnetization of samples collected from a fold of Caledonian age are parallel only after correcting for dip, indicating stability at least since the Caledonian (Ref. e, p. 92–93).

Reversals: About 16 zones in the upper Torridonian have magnetizations which alternately lie in approximately opposite directions. In two cases obliquely magnetized zones occur stratigraphically between two reversed zones. No reversals occur in the lower Torridonian.

LONGMYNDIAN (Sediments)	17	—	—	111	19	—	—	—	—	—	—	—	—	a	*Creer*	*Age:* late Precambrian, possibly equivalent to Torridonian
	18	53 N	3 W	111	19	—	—	—	4½N	115½W	M	—	—	*	a Creer, Irving, and Runcorn, 1954	*Sampling:* Lateral extent, 20 miles. Vertical extent, probably several thousand feet. 40 samples were collected at 12 sites. Statistical analysis apparently is of directions of individual samples, not of mean site directions (Ref. d).
	19	—	—	—	—	—	—	—	2 N	118 W	—	13	7	b	b Runcorn, 1955b	*Stability:* Magnetization unchanged in 300 oersted alternating field and also unchanged after 1 year's random orientation in the laboratory.
	20	—	—	114	29	12	5	40	2 N	120 W	M	13	7	c	c Creer, Irving, and Runcorn, 1957	*Reversals:* Present, but number of alternating zones not known.
	21	**53 N**	**3 W**	**114**	**29**	**12**	**5**	**40**	**1½N**	**121 W**	**M**	**13**	**7**	*	d Creer, 1957b	
NORTH AMERICA																
CHEQUAMEGON SANDSTONE	22	—	—	30	74	6	—	15	69 N	47 W	—	—	—	a	*Du Bois*	*Age:* late Keweenawan
	23	**47 N**	**88½W**	**30**	**74**	**6**	**36**	**15**	**68 N**	**47 W**	**S**	**11**	**10**	*	a Du Bois, 1957	*Sampling:* *N* is listed as number of "specimens." The value of *k* for entry (23) was calculated by the approximate formula.
JACOBSVILLE SANDSTONE	24	—	—	250	−11	13	—	15	14 N	10 E	N	—	—	a	*Du Bois*	*Age:* late Keweenawan, older than Chequamegon
	25	**47 N**	**88½W**	**250**	**−11**	**13**	**8**	**15**	**17½N**	**13 E**	**N**	**13**	**6½**	*	a Du Bois, 1957	*Sampling:* *N* is listed as number of "specimens." The value of *k* for entry (25) was calculated by the approximate formula.
FREDA SANDSTONE AND NONESUCH SHALE	26	—	—	—	—	—	—	—	20 N	165 E	—	—	—	a	*Du Bois*	*Age:* late Keweenawan, older than Jacobsville; conformable on Copper Harbor conglomerate
	27	—	—	285	−1	3	—	68	9 N	169 E	—	—	—	b	a Du Bois, 1955	*Sampling:* Lateral extent, probably about 100 miles. *N* is number of "specimens." Value of *k* for entry (28) was calculated by the approximate formula.
	28	**46½N**	**88½W**	**285**	**−1**	**3**	**32**	**68**	**10 N**	**170 E**	**S**	**3**	**1½**	*	b Du Bois, 1957	*Stability:* Fold tests indicate stability.
COPPER HARBOR (Sediments and Lava flows)	29	—	—	294	32	7	—	25	30 N	176 E	—	—	—	a	*Du Bois*	*Age:* late Keweenawan
	30	**47 N**	**88½W**	**294**	**32**	**7**	**16**	**25**	**29 N**	**176 E**	**S**	**8**	**4½**	*	a Du Bois, 1957	*Sampling:* 13 samples are from lava flows, and 12 are from sediments. The value of *k* for entry (30) was calculated by the approximate formula.
															b Du Bois, 1955	*Stability:* Copper Harbor(?) basalt and andesite-pebbles in Copper Harbor conglomerates are randomly magnetized. Thermal demagnetization curves (of basalts?) are similar to those for TRM. *Other:* Sediments have 10° smaller inclination than lavas above and below them (Ref. b, p. 507).

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
								SECTION B—*Continued*								
PORTAGE LAKE LAVA SERIES	31	—	—	282	41	4	—	31	25 N	170 W	—	—	—	a	*Du Bois*	*Age:* middle Keweenawan; conformably overlain by Copper Harbor *Sampling:* N is number of specimens. The value of k for entry (32) was calculated by the approximate formula. *Stability:* Thermal decay curves are similar to those for TRM.
	32	**47 N**	**88½W**	**282**	**41**	**4**	**40**	**31**	**25 N**	**170 W**	S	**5**	**3**	*	a Du Bois, 1957	
MICHIGAN DIABASE DIKES	**33**	**46½N**	**88½W**	**82**	**−86**	**1**	**82**	**36**	**45 N**	**99 W**	N	**2**	**2**	a	*Graham* a Creer, Irving, and Runcorn, 1957 b Graham, 1953	*Age:* late Precambrian. Overlain in adjacent localities by Jacobsville and by flat-lying Cambrian sediments. Probable age about 1100 million years (James, 1958, p. 40). *Sampling:* Statistical analysis is based on 36 samples from 2 dikes 8 miles apart. 20 samples from 1.8-foot thick dike span a distance of 3½ feet. 16 samples from 40-foot thick dike span a distance of 15 feet. Samples are from both chilled borders and coarse interiors. Several samples from a third dike agree with these directions; samples from two additional dikes are widely scattered in direction. *Stability:* One sample retained direction and 70% of intensity of magnetization in alternating magnetic field of 493 oersted. *Reversals:* Graham (1953, p. 252–254) believed dikes may have undergone self-reversal in field essentially parallel to present field, but laboratory evidence for self-reversal is not conclusive.

ADIRONDACK METAMORPHIC ROCKS	34	—	—	—	—	—	—	—	44 N	74 W	N	—	—	a	*Balsley and Buddington* a Du Bois, 1958 b Du Bois, 1957 c Balsley and Buddington, 1954	*Age:* Du Bois (Ref. a) believes remanent magnetization was acquired during metamorphism of Grenville age (ca. 1000 million years). *Other:* Pole entry (34) was calculated on the basis of the report by Balsley and Buddington (1954) that rocks containing titano-hematite as the principal magnetic constituent tend to be vertically and reversely polarized. Co-ordinates were scaled from Fig. 1, Ref. a. Balsley and Buddington (1958, p. 790–792) question the interpretation that the remanent magnetization of these rocks is simple TRM parallel to the field in which the rocks cooled.
GABBRO INTRUSIVE ROCKS, BANCROFT AREA, ONTARIO															*Hood* a Hood, 1958	*Age:* Precambrian (Grenville province). Radio-isotope ages of igneous rocks in this part of the Grenville province generally range between 1000 and 1200 million years (Shillibeer and Cumming, 1956, p. 56–57; Wilson, 1958, p. 762).
Boulter Intrusive	**35**	**45 N**	**77½W**	**297½**	**55**	**5**	**19**	**43**	**42½N**	**157 W**	**S**	**7**	**5**	**a**		*Sampling:* Statistical analysis is based on directions of 43 specimens from 8 oriented samples. *Stability:* Alternating field decreased scatter in directions of magnetization. *Other:* Gabbro is locally gneissic, approaching metagabbro. Laboratory observations suggest susceptibility anisotropy.
Umfraville Instrusive	36	45 N	78 W	115	42½	7	8	58	—	—	—	—	—	a		*Sampling:* Statistical analysis is based on 58 specimens from 12 oriented samples; anomalously magnetized specimens were not included in the analysis.
	37	45 N	78 W	115	42½	7	8	58	1 N	22 W	S	9	5½	*		*Other:* Umfraville intrusive is less metamorphosed than Boulter.
Thanet Intrusive	38	45 N	77½W	92½	62½	14½	5	28	—	—	—	—	—	a		*Sampling:* Statistics are based on 28 specimens from 6 oriented samples. Locality is 5 miles from Umfraville site.
	39	45 N	77½W	92½	62½	14½	5	28	28 N	23½W	S	22	18	*		*Stability:* Alternating magnetic field demagnetization decreased scatter in directions of magnetization.
Thanet and Umfraville	40	45 N	77½W	110	49	7	6	86	34 N	22 W	S	9	6	a		*Sampling:* Combination of two previous groups.
	41	**45 N**	**77½W**	**110**	**49**	**7**	**6**	**86**	**8½N**	**22 W**	**S**	**9**	**6**	*		
Tudor Intrusive	42	44½N	77½W	327½	11½	9	5	68	—	—	—	—	—	a		*Sampling:* Statistics are based on 68 specimens from 11 oriented samples. Tudor locality is 8 miles south of Thanet.
	43	**44½N**	**77½W**	**327½**	**11½**	**9**	**5**	**68**	**41½N**	**149 E**	**S**	**9**	**4½**	*		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION B—*Continued*																
SUDBURY INTRUSIVE															*Hood* a Hood, 1958	*Age:* Precambrian. Radio-isotope age of between 1200 and 1800 million years is generally assigned (Russell and others, 1954, p. 307–308; Wetherill and others, 1957, p. 412). Four localities (Azilda, Blezard, Garson, Creighton) spanning 16 miles were sampled on the south side of the Sudbury Basin. One locality (Levack) was sampled on the north side.
Levack	44	46½N	81½W	320½	70	5	20	41	64 N	140½W	S	9	8	a		*Sampling:* Statistics based on 41 specimens from 14 oriented samples; some anomalous specimens were not included.
Azilda	45	46½N	81 W	194½	66½	2½	67	45	—	—	—	—	—	a		*Sampling:* Statistical analysis is based on 45 specimens from 13 oriented samples. Lateral sampling extent is 1.6 miles.
Blezard	46	46½N	81 W	184	71½	1½	86	78	—	—	—	—	—	a		*Sampling:* Lateral sampling extent is 1.4 miles. Statistical analysis based on 78 specimens from 12 oriented samples. *Stability:* Partial demagnetization in 124 oersted A.C. field decreased scatter.
Garson	47	46½N	81 W	155½	59	10	44	6	—	—	—	—	—	a		*Sampling:* Statistical analysis is based on 6 specimens from 2 oriented samples.
Creighton	48	46½N	81 W	171½	57	4	47	26	—	—	—	—	—	a		*Sampling:* Statistics are based on 26 specimens from 6 oriented samples. *Stability:* 125 oersted alternating field had little effect on intensity or direction of magnetization.
South Range of Sudbury, combined	49	46½N	81 W	183	68	1½	49	155	7½N	94½W	S	3	2	a		*Sampling:* Entry (49) is based on all 155 specimens from 33 samples collected at all 4 sites. Entry (51) is based on the mean direction of magnetization at each of 4 sites.
	50	46½N	81 W	183	68	1½	49	155	7½N	82½W	S	3	2	*		
	51	46½N	81 W	174	64	11½	65	4	—	—	—	—	—	*		
Both sides of Sudbury Basin, combined	52	46½N	81 W	245½	82½	—	—	196	38½N	99½W	S	—	—	a		*Other:* The magnetic direction in entry (52) was chosen midway between the direction for Levack on the north rim of the basin and the average direction entry (49) for the sites on the south rim. Entry (53) is based on the following geologic considerations. Thomson (1956, p. 44–45) concludes that the gently dipping north limb and steeply dipping south limb of the Sudbury syncline were largely developed
	53	**46½N**	**81 W**	**300**	**78**	**11**	**—**	**—**	**53 N**	**115 W**	**S**	**21**	**20**	*		

																before intrusion; most of the post-intrusion folding was in the south limb. The magnetic evidence supports this view; accordingly the direction of the north range (Levack) is unfolded 10° about the axis of the syncline, and the mean direction of the south range is unfolded 35° about the same axis, which makes them coincide. The circle of confidence is estimated as that of entry (51).
HAKATAI SHALE, GRAND CANYON	54	—	—	—	—	—	—	—	30 N	148 W	—	10	9	a	*Runcorn* a Runcorn, 1955b b Runcorn, 1956a c Creer, Irving, and Runcorn, 1957	*Age:* Precambrian *Sampling:* Statistical analysis for entry (55) is based on 34 specimen measurements from 15 oriented samples collected at one locality. *Other:* Doell (1955b, p. 1167) incorrectly states that these values are not corrected for geologic dip.
	55	—	—	268	73	5½	22	34	30½N	148 W	S	9½	8½	b		
	56	—	—	268	73	5	22	—	31 N	150 W	S	10	9	c		
	57	**36 N**	**112 W**	**268**	**73**	**5**	**22**	**34**	**29½N**	**149 W**	**S**	**9½**	**8½**	*		
HAKATAI SHALE AND BASS LIMESTONE, GRAND CANYON	58	—	—	246	72	17½	—	—	18 N	144 W	S	—	—	a	*Doell* a Doell, 1955b b Creer, Irving, and Runcorn, 1957 c Doell, 1955a	*Age:* Precambrian. Bass limestone underlies the Hakatai shale; the contact is gradational. *Sampling:* 10 oriented samples from 1 locality span a stratigraphic interval of 450 feet. Locality is same as that of entries (54–57). *Stability:* α_{95} of directions of magnetization before correcting for individual geologic dips of beds is smaller than after dip correction (19° vs. 21°) indicating some instability. *Other:* Entry (58) was not corrected for geologic dip. Entry (59) corrects for regional dip. Entry (61) was recalculated from data in Ref. c, correcting direction of magnetization of each sample for local attitude of bed.
	59	—	—	215	76	18	—	—	21 N	130 W	S	—	—	b		
	60	36 N	112 W	215	76	18	—	—	13 N	127 W	S	—	—	*		
	61	**36 N**	**112 W**	**205**	**65**	**21**	**6**	**10**	**4 N**	**52 E**	**N**	**33½**	**27½**	*		
HAKATAI SHALE, GRAND CANYON	62	36 N	112 W	291	58	—	—	41	36 N	177 W	S	—	—	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian *Sampling:* Entry (62) is based on 41 specimen measurements from 14 oriented samples from a locality several miles from the site of the samples in entries (54–61). Directions of magnetization show streaking toward direction of present field; in entry (63) a mean direction was estimated excluding directions tending toward the present field direction.
	63	**36 N**	**112 W**	**245**	**31**	**—**	**—**	**—**	**9 N**	**6 E**	N	**—**	**—**	a		
BASS LIMESTONE, GRAND CANYON	64	36 N	112 W	232	52	5	23	43	6 N	26 E	N	6	3	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian; conformably overlain by Hakatai shale *Sampling:* Statistical analysis is based on 43 specimens from 13 oriented samples.
	65	**36 N**	**112 W**	**225**	**34**	**—**	**—**	**—**	**20 N**	**21 E**	N	**—**	**—**	a		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION B—*Continued*																
SHINUMO QUARTZITE, GRAND CANYON	66	36 N	112 W	288	65	—	—	61	37 N	166 W	S	—	—	a	*Collison and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian; overlies Hakatai shale *Sampling:* Entry (66) is based on 61 specimens from 14 oriented samples. Directions of magnetization show streaking toward direction of present field; in entry (67) a mean direction was estimated excluding directions tending toward the present field direction.
	67	**36 N**	**112 W**	**246**	**33**	**—**	**—**	**—**	**7 N**	**7 *E***	N	**—**	**—**	a		
HAZEL FORMATION (sediments)	68	—	—	—	—	—	—	—	49 N	175 W	S	—	—	a	*Howell, Martinez, and Statham* a Howell, Martinez, and Statham, 1958	*Age:* Precambrian *Sampling:* Entries (68, 69) are based on 15 samples from flat-lying beds exposed at 5 localities scattered over an area of 2 square miles. Entries (70, 71) based on 37 oriented samples from dipping beds from 9 localities scattered over 20 miles, correction for dip having been made. Entries (69) and (71) are based on data scaled from Fig. 3 and Fig. 4, respectively, in Ref. a. *Stability:* Directions of magnetization of some samples changed 2°–16° in several months. *Other:* Rocks may be slightly metamorphosed.
	69	**31 N**	**105 W**	**316**	**56½**	**6½**	**35**	**15**	**53 N**	**173 W**	**S**	**9½**	**7**	*		
	70	—	—	—	—	—	—	—	60 N	151 E	S	—	—	a		
	71	**31 N**	**105 W**	**328**	**37½**	**17**	**3**	**37**	**59½N**	**154 E**	**S**	**20**	**12**	*		
BELT SERIES McNamara Formation (sediments)	**72**	**47 N**	**114 W**	**26**	**−43**	**4**	**30**	**53**	**14 N**	**42 E**	**S**	**5**	**3**	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian *Sampling:* Statistics are based on 53 specimens from 20 oriented samples.
Miller Peak Formation (sediments)	**73**	**47 N**	**114 W**	**234**	**30**	**7**	**20**	**23**	**11 N**	**14 E**	N	**8**	**4**	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian *Sampling:* Statistics are based on 23 specimens from 14 oriented samples.
Spokane Shale	**75**	**47 N**	**112 W**	**232**	**55**	**4**	**18**	**71**	**5 N**	**152 W**	**S**	**6**	**4**	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian; younger than Grinell formation *Sampling:* Statistics are based on 71 specimens from 39 oriented samples.
	76	**49 N**	**114 W**	**206**	**39**	**8**	**10**	**19**	**16 N**	**41 E**	N	**10**	**6**	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian; younger than Grinell formation *Sampling:* Statistics are based on 19 specimens from 5 oriented samples.

Appekunny Argillite	77	49 N	113½ W	223	29	6	15	38	15 N	24 E	N	7	4	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian; younger than Appekunny argillite *Sampling:* Statistics are based on 38 specimens from 15 oriented samples.
Grinell Formation (sediments)	78	49 N	113½ W	225	48	6	15	42	3 N	28 E	N	8	5	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian *Sampling:* Statistics are based on 44 specimens from 16 oriented samples.
Bonito Canyon Quartzite	79	36 N	109 W	31	−25	4	19	74	33 N	34 E	S	4	2	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Precambrian *Sampling:* Statistics are based on 74 specimens from 16 oriented samples.
BLACKHEAD SANDSTONE, NEWFOUNDLAND	80 81	47 N 47 N	53 W 53 W	232 232	51 51	10 10	25 25	10 10	5 N 2 N	84 E 95 W	— S	13½ 13½	9 9	a *	*Nairn, Frost, and Light* a Nairn, Frost, and Light, 1959	*Age:* Precambrian *Sampling:* Statistical analysis is based on mean direction of each of 10 oriented samples from one locality. 4 specimen measurements were made on each oriented sample. *Other:* CCW rotation of Newfoundland of 20° is suggested in Ref. a in order to bring these results into closer agreement with results from Hakatai shale; "corrected" pole is then at 10° N 110° W.
SIGNAL HILL SANDSTONE OF NEWFOUNDLAND	82 83	47 N 47 N	53 W 53 W	283 283	20 20	11½ 11½	21 21	9 9	16 N 16½N	142 W 145 W	— S	12 12	6 6	a *	*Nairn, Frost, and Light* a Nairn, Frost, and Light, 1959	*Age:* Precambrian, possibly 8500 feet stratigraphically below Blackhead sandstone *Sampling:* Statistics are based on 9 oriented samples from one locality. 4 specimen measurements were made on each sample. *Stability:* Beds at the Signal Hill site dip steeply eastward, those at the Blackhead site dip less steeply; agreement between the two sites is presumably better after correction for dip. *Other:* Correction for hypothetical rotation of Newfoundland was made as in the case of the Blackhead sandstone. "Corrected" pole is at 29° N, 163° W.
BLACKHEAD AND SIGNAL HILL FORMATIONS, UNDIFFERENTIATED	84	47 N	53 W	262	39	13½	8	19	11 N	122 W	—	16	9½	a	*Nairn, Frost, and Light* a Nairn, Frost, and Light, 1959	*Sampling:* Analysis was made on entire 19 oriented samples of last entries.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
									SECTION B—*Continued*							
AUSTRALIA																
BULDIVA QUARTZITE	**85**	**14 S**	**132 E**	**243**	**38**	**12**	**—**	**—**	**30 N**	**121 W**	**N**	**14**	**8**	**a**	*Irving and Green* a Irving and Green, 1958	*Age:* latest Precambrian; contains fossils of primitive life
NULLAGINE LAVAS	**86**	**21 S**	**120 E**	**143**	**64**	**8**	**—**	**—**	**51 N**	**18 W**	**N**	**13**	**10**	**a**	*Irving and Green* a Irving and Green, 1958	*Age:* late Precambrian, part of Catherine River group; probably younger than the Edith River volcanic rocks
EDITH RIVER VOLCANIC ROCKS	**87**	**13 S**	**132 E**	**90**	**48**	**18**	**—**	**—**	**6 N**	**14 E**	**N**	**24**	**15**	**a**	*Irving and Green* a Irving and Green, 1958 b Irving, 1959	*Age:* earliest late Precambrian
	88	13 S	132 E	90	48	18	—	—	6 N	14 W	N	24	15	b		
AFRICA																
PILANSBERG DYKES	89	26 S	28 E	24	69½	—	—	—	7½N	42½E	S	—	—	a	*Gough* a Gough, 1956	*Age:* Generally regarded as pre-Karroo, post-Waterberg. Possibility of their being late Precambrian is mentioned in Ref. a. Recently determined radio-isotope age is 1290 m.y. (Schreiner, 1958, p. 1330). *Sampling:* Sampling sites span 54 miles. Vertical sampling extent varied, but usually was at least several hundred feet. Between 8 and 58 samples were collected from each dike studied, giving circles of confidence of 3.3° to 7°. Statistical analysis of entry (90) is based on the mean direction of magnetization of each of 5 dikes. A comparatively small number of randomly magnetized samples is not included in this analysis. *Stability:* Most specimens were stable in alternating fields of the order of 100 oersted.
	90	**26 S**	**28 E**	**24**	**69½**	**6**	**124**	**5**	**7½N**	**42½E**	**S**	**10**	**9**	*		
BUSHVELD GABBRO	91	25½S	28 E	—	—	—	—	5	23 N	36 E	S	—	—	a	*Gough and van Niekerk* a Gough and van Niekerk, 1959	*Age:* Concordant radio-isotope results indicate an age of 2.0 × 10^9 years. *Sampling:* Between 12 and 29 oriented samples were collected at 5 sites in the Main Gabbro zone of the complex. Lateral sampling extent is 150 miles.
	92	**25½S**	**28 E**	**—**	**—**	**12**	**40**	**5**	**23 N**	**36 E**	**S**	**12**	**12**	*		

Circles of confidence at the 99% level for the directions at each site range between 2° and 9.6°; all data were included in these calculations with the exception of 4 anomalous samples at one site. Scatter in mean site directions is reduced on correcting for pseudo-stratification in the gabbro. Statistics for entry (92) were applied to magnetic poles corresponding to corrected magnetic field directions at each of 5 sites.

Stability: Reduction of scatter in directions of magnetization upon correcting for pseudo-stratification of gabbro suggests deformation after cooling of the intrusive and stability since that deformation.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION C EARLY PALEOZOIC																
DEVONIAN																
EUROPE																
OLD RED SANDSTONE	1	52 N	2½W	233	−22	—	—	39	—	—	—	—	—	a	*Clegg, Almond, and Stubbs* a Clegg, Almond, and Stubbs, 1954a b Irving, 1959	*Age:* Devonian; Lower part of Old Red sandstone, Brownstone series from Mitcheldean in Gloucestershire *Sampling:* Measurements were made of 39 specimens from 3 oriented samples collected alt one locality. α_{95} (entry 2) was recalculated from vaue of α_{50} given in Ref. a; this is probably based on N = 39. The value of k was calculated by the approximate formula. *Stability:* Magnetizations were stable in D.C. fields of several oersted and in alternating fields of several hundred oersted.
	2	**52 N**	**2½W**	**233**	**−22**	**11½**	**4**	**39**	**31 N**	**111 E**	N	**12**	**6½**	*		
	3	—	—	—	—	—	—	—	25 N	102 E	N	—	—	b		
OLD RED SANDSTONE	4	—	—	199	−2	—	—	—	—	—	N	—	—	a	*Creer* a Creer, Irving, and Runcorn, 1954 b Runcorn, 1955a c Runcorn, 1955b d Creer, 1957b e Creer, Irving, and Runcorn, 1957	*Age:* Devonian; the Old Red sandstone of the Angleo Welsh cuvette is divided into an upper and lowr- unit; the lower unit consists of the Downtonian and the overlying Dittonian. Entries (6) and (7) refer to the Downtonian, entries (4) and (5) to the two overlying units, and all the other entries refer, presumably, to the entire section of Old Red sandstone. *Sampling:* Samples were collected at 17 localities with different amounts of folding. Only the samples from 6 localities with flat-lying strata gave consistent results. The statistical analysis of entries (11), (12), and (13) is based on 35 oriented samples from these 6 localities. The stratigraphic thicknesses sampled at these localities are 30, 80, 250, 0.5, 34, 0.5, and 1200 feet, respectively.
	5	52 N	3 W	199	−2	—	—	—	37 N	153 E	N	—	—	*		
	6	—	—	34	−2	—	—	—	—	—	S	—	—	a		
	7	52 N	3 W	34	−2	—	—	—	31½N	136 E	S	—	—	*		
	8	—	—	—	—	—	—	—	34 N	156 E	M	—	—	a		
	9	—	—	198	−2	—	—	—	45 N	155 E	N	—	—	b		
	10	—	—	—	—	—	—	—	34 N	156 E	N	10	5	c		
	11	52 N	3 W	196	−4	5	19	35	—	—	—	—	—	d		
	12	—	—	196	−5	5	19	35	30 N	159 E	N	5	3	e		
	13	**52 N**	**3 W**	**196**	**−4**	**5**	**19**	**35**	**38½N**	**156 E**	N	**5**	**2½**	*		

																Stability: The lack of agreement between strata which have been folded by different amounts indicates that at least some of the magnetization is unstable. *Reversals:* Ref. d states that reversals are absent from the Old Red sandstone. However, in Ref. a, reversals were noted at two localities in the Downtonian.
NORTH AMERICA																
ONONDAGA LIMESTONE	**14**	**42½N**	**74 W**	**177**	**79**	**4**	**19**	**65**	**21 N**	**73 W**	**S**	**7½**	**7**	*	*Graham* a Graham, 1956	*Age:* Top of lower or bottom of Early or Middle Devonian (late Ulsterian) *Sampling:* 65 oriented samples were collected at 2 localities. Analysis of entry (14) is based on data scaled from Fig. 3 of Ref. a. *Stability:* Directions of magnetization are approximately parallel throughout both stratiform beds and beds showing penecontemporaneous deformation, indicating that remanent magnetization is post-depositional.
AUSTRALIA																
AINSLIE VOLCANIC ROCKS	**15**	**35 S**	**149 E**	**17**	**−30**	**12**	**—**	**—**	**66 N**	**168 W**	**S**	**13**	**7**	**a**	*Irving and Green* a Irving and Green, 1958 b Irving, 1959	*Age:* There is some uncertainty as to whether the volcanic rocks are Devonian or Silurian (Ref. b).
SILURIAN																
EUROPE																
LUDLOW SERIES	16	—	—	205	−16	—	—	—	40 N	140 E	N	—	—	a	*Creer* a Creer, Irving, and Runcorn, 1954	*Age:* The Ludlow series at Pembrokeshire is Late Silurian.
	17	**52 N**	**5 W**	**205**	**−16**	**—**	**—**	**—**	**41 N**	**141 E**	**N**	**—**	**—**	*		
URAL PERIDOTITES	**18**	**67 N**	**66 E**	**98**	**38**	**—**	**—**	**—**	**16 N**	**140 E**	**S**	**—**	**—**	**a**	*Komarov* a Komarov, 1959	*Age:* Silurian *Sampling:* 6 samples were collected at one quarry.
NORTH AMERICA																
ROSE HILL FORMATION OF SWARTZ, 1923 (Sediments)	19	40 N	78 W	322	−39	5	—	—	19 N	138 E	S	6	4	b	*Graham* a Graham, 1949 b Irving, 1956a c Creer, Irving, and Runcorn, 1957	*Age:* early Middle Silurian (lower Niagara series) *Sampling:* 35 oriented samples were collected at 6 localities spanning a distance of 32 miles. Entry (21) was based on data scaled from Figs. 18, 20, and 22 of Ref. a. *Stability:* Samples were collected on limbs of small
	20	—	—	322	−39	5	27	—	19 N	138 E	S	6	4	c		
	21	**39½N**	**79 W**	**321**	**−40**	**6½**	**16**	**35**	**18 N**	**138½E**	**S**	**8**	**5**	*		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION C—*Continued*																
																folds at 2 localities and on steep limbs of large fold-at the remaining localities. Directions of magnes tization are widely scattered before correction for dip. All but 3 samples have nearly parallel directions after dip correction. Deformation was near the end of the Paleozoic, indicating magnetic stability for at least 200 million years. *Reversals:* Of the 3 aberrant samples, 2 that are stratigraphically adjacent have directions of magnetization approximately opposed to the mean direction for the entire group.
CLINTON IRON ORE	22	—	—	—	—	—	—	—	35 N	138 E	N	—	—	a	*Howell et al.*	*Age:* Middle Siluvian (Niagaran series)
	23	**33½N**	**86½W**	**143**	**19½**	**11½**	**107**	**16**	**34 N**	**139 E**	N	**12**	**6½**	*	a Howell, Martinez, and Statham, 1958	*Sampling:* 16 specimens were measured from 7 oriented samples. Lateral sampling extent: 300 feet. Analysis (entry 23) is based on data scaled from Fig. 1 of Ref. a. Since specimen rather than sample directions are used, α_{95} may be too small. *Other:* Planes of maximum susceptibility tend to lie in bedding plane.
AUSTRALIA																
MUGA PORPHYRY	24	35 S	149 E	26	−30	22	—	—	60 N	157 W	S	24	14	a	*Irving and Green*	*Age:* Late Silurian (Ref. a)
	25	**35 S**	**149 E**	**26**	**−30**	**22**	**—**	**—**	**60 N**	**153 W**	**S**	**24**	**14**	*	a Irving and Green, 1958	
ASIA																
RED SILTSTONES FROM YUMEN	26	—	—	293½	55½	8½	—	17	49 N	12 E	S	—	—	a	*Chang Wen-You and Nairn*	*Age:* Middle Silurian
	27	**40 N**	**97 E**	**293½**	**55½**	**8½**	**16**	**17**	**38½N**	**25½E**	**S**	**12**	**8½**	*	a Chang Wen-you and Nairn, 1959	*Sampling:* Analysis of Ref. a is based on measurements of 17 specimens from 3 oriented samples. Collecting site is described as southern part of Yumen, Kansu province.

ORDOVICIAN																
EUROPE																
UKRAINIAN BASALTS	28	51 N	26 E	140	75	—	—	—	28 N	46 E	S	—	—	a	*Komarov*	*Age:* Shown as Ordovician(?) in Table 2 of Ref. a, but Komarov (1959) believes European polar-wandering curve suggests Cambrian age for entries (28, 29) and Ordovician age for entries (30, 31).
	29	**51 N**	**26 E**	**140**	**74½**	**10½**	**40**	**6**	**27½N**	**46 E**	**S**	**19½**	**17½**	*	a Komarov, 1959	*Sampling:* 6 samples collected in a quarry were reported for entries (28) and (29), and 8 samples from 2 quarries for entries (30) and (31). Data for calculating entries (29) and (31) were taken from Table 1, Ref. a.
	30	51 N	26 E	255	58	—	—	—	21 N	27 W	S	—	—	a		
	31	**51 N**	**26 E**	**255**	**56½**	**11½**	**23**	**8**	**20 N**	**29 W**	**S**	**16½**	**12**	*		
RED SANDS AND BROWN CLAYS NEAR LENINGRAD	32	60 N	30 E	211	−35	—	—	—	—	—	N	—	—	a	*Khramov*	*Age:* Early Ordovician
	33	60 N	30 E	27	58	—	—	—	—	—	S	—	—	a	a Khramov, 1958	*Sampling:* 29 oriented samples were collected over a stratigraphic thickness of 10 meters. Entry (34) is an estimate that excludes an unstable component in entry (33). Entry (35) is from Table 25, Ref. a, and entry (36) is the mean of the poles in entries (32) and (34).
	34	60 N	30 E	38	41	—	—	—	—	—	S	—	—	a		
	35	60 N	30 E	—	—	18½	—	—	42 N	169 E	M	—	—	a		
	36	**60 N**	**30 E**	**—**	**—**	**18½**	**—**	**—**	**44 N**	**162 E**	**M**	**22**	**13**	*		
NORTH AMERICA																
TRENTON GROUP (sediments)																
Sprakers, New York	**37**	**42½N**	**75 W**	**177½**	**71**	**5½**	**23**	**28**	**8½N**	**74 W**	**S**	**9½**	**8**	*	*Graham* a Graham, 1956	*Age:* Middle Ordovician *Sampling:* 28 oriented samples were collected, presumably at 1 locality; samples are from different cobbles in a limestone conglomerate. Data for entry (37) are based on values scaled from Fig. 2 of Ref. a. *Stability:* Agreement in directions of magnetization in different cobbles indicates that the remanent magnetization is not that of the parent limestone body but was acquired after the deposition of the Trenton group.
Trenton Falls, New York	**38**	**43½N**	**75 W**	**179**	**82**	**5**	**23**	**45**	**27½N**	**75 W**	**S**	**10**	**9½**	*	b Graham, 1954	*Sampling:* Data for entry (38) were scaled from Fig. 5 of Ref. b showing 35 measurements from flat-lying beds and 10 from a local deformed bed after correcting for dip. *Stability:* Flat-lying beds have well-grouped directions of magnetization. A distorted zone enclosed by flat-lying beds has scattered directions, which tend to move toward the other group on correcting for dip; significant stability since deposition is thus indicated (Graham, 1954, p. 219).

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
									SECTION C—*Continued*							
JUNIATA FORMATION (sediments)	**40**	**40 N**	**78½W**	**131**	**26**	**8**	**6**	**56**	**20 N**	**153 E**	N	**9**	**5**	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Late Ordovician *Sampling:* Statistical analysis is based on 56 specimens from 12 oriented samples.
CAMBRIAN																
EUROPE																
CAERBWDY SANDSTONE	41	—	—	187	39	—	—	—	15 N	173 E	N	—	—	a	*Creer* a Creer, Irving, and Runcorn, 1954 b Runcorn, 1955a c Irving, 1956a d Creer, Irving, and Runcorn, 1957 e Creer, 1957b	*Age:* Cambrian. Caerbwdy sandstone is in the lower part of the Cambrian Caerfai series. *Sampling:* 12 samples span a stratigraphic interval of 350 feet. *Other:* Values cited in entry (41) also appear in Ref. b. Details appear in Ref. e, p. 123–124.
	42	—	—	191	41	—	—	—	15 N	170 E	N	—	—	b		
	43	52 N	5 W	187	39	8	—	—	15 N	173 E	—	10	7	c		
	44	—	—	187	39	8	32	12	15 N	173 E	N	10	8	d		
	45	**52 N**	**5 W**	**187**	**39**	**8**	**32**	**12**	**15½N**	**168½E**	N	**9½**	**5½**	*		
NORTH AMERICA																
TAPEATS SANDSTONE, GRAND CANYON	46	—	—	—	—	—	—	—	22 N	27 E	—	—	—	a	*Runcorn* a Day and Runcorn, 1955 b Creer, Irving, and Runcorn, 1957	*Age:* Early Cambrian *Other:* No other data about this research are available. According to Ref. b, the pole of Ref. a is based on inadequate data and should be disregarded.
WILBERNS FORMATION (sediments)	**47**	**30½N**	**99 W**	**98**	**24½**	—	—	—	**0**	**158 E**	N	—	—	a	*Howell and Martinez* a Howell and Martinez, 1957	*Age:* Late Cambrian; Point Peak shale member of Wilberns formation, Llano uplift area *Sampling:* 185 samples were collected at 10 localities spanning a distance of 55 miles. Statistical analysis was not made of this data because directions of magnetization show "streaking" toward direction of present field. Values for declination and inclination indicated are for the group of measurements farthest from the present field direction; they were scaled from Fig. 5, Ref. a, and do not exactly correspond to the pole position cited.

																Stability: "Streaking" indicates partial instability. A single locality with steeply dipping beds shows wide scatter in directions of magnetization after correcting for dip. *Reversals:* No systematic reversals occur, but some widely scattered points are on the upper hemisphere.
SAWATCH "QUARTZITE" SANDY DOLOMITE	48	—	—	—	—	—	—	—	49 N	125 E	N	—	—	b	*Howell and Martinez* a Howell and Martinez, 1957 b Howell, Martinez, and Statham, 1958	*Age:* Late Cambrian; magnetization may be post depositional *Sampling:* 36 samples were collected at 2 localities. Analysis for entry (49) was based on data scaled from Fig. 7 of Ref. a, omitting 5 samples with directions parallel to present field. *Stability:* 5 of the 36 samples have directions of magnetization parallel to the present field; 31 have tight grouping approximately perpendicular to the present field. *Other:* Remanent magnetization may have been acquired at time of dolomitization, possibly in the late Paleozoic, Ref. a, p. 391.
	49	**39 N**	**106½W**	**148**	**−15**	**4**	**44**	**31**	**47 N**	**125 E**	N	**4**	**2**	*		
LODORE FORMATION (sediments)	50	41 N	109½ W	59	4	8	14	26	—	—	—	—	—	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Cambrian *Sampling:* Based on 33 specimens from 11 oriented samples. *Reversals:* Entry (50) is reversed with respect to (51). Stratigraphic distribution of samples in these two groups is not known.
	51	41 N	109½ W	234	13	13	25	7	—	—	—	—	—	a		
	52	**41 N**	**109½ W**	**—**	**—**	**—**	**—**	**—**	**23 N**	**6 E**	M	**7**	**4**	a		
DEADWOOD FORMATION (sediments)	**53**	**42 N**	**107½ W**	**151**	**−14**	**7**	**15**	**34**	**47 N**	**117 E**	N	**7**	**4**	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Cambrian. Ref. a cites a possible Mississippian age. However, it is definitely regarded as Cambrian by U. S. Geological Survey. *Sampling:* 34 specimen measurements were made on 7 oriented samples.
AUSTRALIA																
ELDER MOUNTAIN SANDSTONE	54	16 S	126 E	231	−15	10	—	—	34 N	172 W	N	10	5	a	*Irving and Green* a Irving and Green, 1958	*Age:* Middle Cambrian (Ref. a)
	55	**16 S**	**126 E**	**231**	**−15**	**10**	**—**	**—**	**34 N**	**165 W**	N	**10**	**5**	*		
ANTRIM PLATEAU BASALTS	**56**	**16 S**	**126 E**	**53**	**−2**	**12**	**—**	**—**	**36 N**	**154 W**	M	**12**	**6**	a	*Irving and Green* a Irving and Green, 1958 b Irving, 1959	*Age:* Early Cambrian, possibly latest Precambrian (Ref. b) *Reversals:* Reversals are indicated in Ref. b, but no details are given.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION D CARBONIFEROUS																
EUROPE																
GLOUCHESTER PENNANT SANDSTONE	1	—	—	33	35	—	—	14	—	—	S	—	—	a	*Clegg et al.*	*Age:* late Carboniferous (late Coal Measures) *Sampling:* 14 specimen measurements were made on 1 oriented sample. Calculations for α_{95} and k in entry (2) were based on α_{50} = 5, cited in Ref. a. *Stability:* The magnetization of the specimens was unchanged after application of fields of several hundred oersted A.C.
	2	**51½N**	**2½W**	**33**	**35**	**10½**	**13**	**14**	**48½N**	**126½E**	**S**	**12**	**6½**	*	a Clegg, Almond, and Stubbs, 1954a	
	3	—	—	—	—	—	—	—	43 N	114 E	S	—	—	b	b Irving, 1959	
CLEE HILL SEDIMENTS AND IGNEOUS ROCKS	4	—	—	200	15	—	—	45	—	—	N	—	—	a	*Clegg et al.*	*Age:* Probably late Carboniferous *Sampling:* Samples were collected at 6 sites over a lateral extent of 30 miles. It is not known whether N is the number of oriented samples or specimen measurements. Calculations for entry (5) were based on data scaled from Fig. 1, Ref. a. Igneous and sedimentary samples could not be distinguished in this plot. *Stability:* Stability is suggested by the tight grouping of the baked sediments compared with scattered directions and lower intensity of nearby unbaked sediments.
	5	**52½N**	**2 W**	**200**	**15**	**3½**	**36**	**45**	**27½N**	**156 E**	N	**3½**	**2**	*	a Clegg, Deutsch, Everitt, and Stubbs, 1957	
	6	—	—	—	—	—	—	—	27 N	155 E	N	—	—	b	b Irving, 1959	
TIDESWELLDALE BAKED SEDIMENTS	7	—	—	218	36	—	—	5	—	—	—	—	—	a	*Clegg et al.*	*Age:* These sediments were baked by an intrusive of late Carboniferous age. *Sampling:* It is not known whether N is the number of oriented samples or specimen measurements. Calculations for entry (8) were based on data scaled from Fig. 1, Ref. a.
	8	**53½N**	**2 W**	**219**	**41**	**8**	**61**	**5**	**6½N**	**142½E**	N	**9½**	**6**	*	a Clegg, Deutsch, Everitt, and Stubbs, 1957	
	9	—	—	—	—	—	—	—	5 N	143 E	N	—	—	b	b Irving, 1959	
LANCASHIRE PENDLE MONOCLINE	**10**	**54 N**	**3 W**	**24½**	**23½**	**4**	**64**	**19**	**44 N**	**142½E**	**S**	**4**	**2**	*	*Belshé* a Belshé, 1957	*Age:* Carboniferous *Sampling:* 19 oriented samples were collected at 3 sites from the lower Coal Measures, Dandy Rock and Old Lawrence Rock. Calculations for entry (10) were based on data scaled from Fig. 3, Ref. a. *Stability:* Application of Graham's fold test indicates that the magnetization is stable and was imparted to the rocks before late Carboniferous folding.

LANCASHIRE ROCKS	**11**	**54 N**	**3 W**	**27**	**24**	**6**	**29**	**18**	**43 N**	**139 E**	**S**	**6½**	**3½**	*	*Belshé* a Belshé, 1957	*Age:* late(?) Carboniferous *Sampling:* Calculations for entry (11) were based on data scaled from Fig. 2, Ref. a. This figure shows the directions of magnetization for 40 (out of a reported 49) samples. These 18 samples form 1 group and the 13 used for the following entry (12) form another group. 9 scattered directions were excluded from these calculations.
LANCASHIRE MILLSTONE GRIT	**12**	**54 N**	**3 W**	**188½**	**9½**	**3**	**176**	**13**	**30½N**	**167 E**	**N**	**3**	**1½**	*	*Belshé* a Belshé, 1957	*Age:* early late Carboniferous *Sampling:* Calculations for entry (12) were based on data scaled from Fig. 2, Ref. a. Also see remarks for entry (11) above.
DERBYSHIRE SANDSTONE AND SILTSTONE	13	—	—	26	37	—	—	—	—	—	S	—	—	a	*Belshé* a Runcorn, 1955a b Runcorn, 1955b c Belshé, 1957 d Irving, 1956a	*Age:* early and late Carboniferous *Sampling:* 103 oriented samples were collected from 14 sites. *Stability:* Stability is suggested by remeasurement after 6 months with no change in the magnetization. *Other:* A later study cited in Ref. c of 142 samples from 34 localities showed much greater scatter.
	14	—	—	—	—	—	—	—	36 N	137 E	S	—	—	b		
	15	—	—	27	36	—	—	103	—	—	S	—	—	c		
	16	**53 N**	**1½W**	**27**	**36**	**—**	**—**	**103**	**50½N**	**136 E**	**S**	**—**	**—**	*		
	17	53 N	1½W	26	37	—	—	—	51 N	143 E	S	—	—	d		
DERBYSHIRE TOADSTONES	18	53 N	1½W	26	43	—	—	—	55 N	148 E	S	—	—	a	*Belshé* a Irving, 1956a b Belshé, 1957	*Age:* The lavas are interbedded with sediments of early Carboniferous age and are probably pre-Millstone Grit (Evans, 1918, p. 172). *Sampling:* 9 oriented samples were obtained from 3 interbedded units. Calculations in entry (20) were based on data scaled from Fig. 1, Ref. b.
	19	—	—	48	47	13	—	9	—	—	—	—	—	b		
	20	**53 N**	**1½W**	**48**	**47**	**13**	**13**	**9**	**47 N**	**105 E**	**S**	**17**	**11**	*		
KINGHORN LAVAS															*Clegg et al.* a Clegg, Deutsch, Everitt, and Stubbs, 1957 b Irving, 1959	*Age:* early Carboniferous (pre-Millstone Grit) *Sampling:* The sequence of flows is as indicated, with 65 uppermost. Calculations for entries (27) and (29) (flows 50–54 and 41–46) were based on data scaled from Fig. 2, Ref. a. Data for flows 64–65 and 48–49 were not given. Entry (31) is a Fisher statistical treatment of the pole positions given in entries (22), (25), and (27).
Flows 64–65	21	56 N	3½W	20	15	—	—	—	—	—	—	—	—	a		
	22	56 N	3½W	20	15	—	—	—	39 N	150½E	S	—	—	*		
	23	—	—	—	—	—	—	—	42 N	150 E	S	—	—	b		
Flows 48–54	24	56 N	3½W	200	38	—	—	—	—	—	—	—	—	a		
	25	56 N	3½W	200	38	—	—	—	10½N	157½E	N	—	—	*		
	26	—	—	—	—	—	—	—	12 N	157½E	N	—	—	b		
Flows 50–54	27	56 N	3½W	202½	34	5½	23	27	13 N	154½E	N	6½	3½	*		
Flows 41–46	28	56 N	3½W	26	−42	—	—	18	—	—	—	—	—	a		
	29	56 N	3½W	26	−42	3	156	18	6½N	153 E	S	4	2½	*		
	30	—	—	—	—	—	—	—	8 N	153 E	S	—	—	b		
Kinghorn Average	**31**	**—**	**—**	**—**	**—**	**28**	**21**	**3**	**18½N**	**154 E**	**M**	**28**	**28**	*		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
								SECTION D—*Continued*								
SHATTERFORD INTRUSION	32	—	—	—	—	—	—	—	32 N	137 E	M	—	—	b	*Clegg et al.*	*Age:* Cited as Carboniferous (undifferentiated) in Ref. b
	33	**52½N**	**2 W**	**31½**	**3**	**4**	**63**	**21**	**32½N**	**139½E**	**M**	**4**	**2**	*	a Clegg, Deutsch, Everitt, and Stubbs, 1957 b Irving, 1959	*Sampling:* The samples were collected at 2 sites 200 yards apart; it is not known whether N is the number of oriented samples or specimen measurements. Calculations in entry (33) were based on data scaled from Fig. 3, Ref. a. *Reversals:* 11 of the 21 samples were oppositely polarized from the other 10.
LUNDY GRANITES	34	—	—	175	−9	27	—	5	—	—	—	—	—	a	*Blundell*	*Age:* Cited as Permian and Carboniferous in Ref. a and as late Carboniferous in Ref. b.
	35	—	—	—	—	—	—	—	43 N	180 E	N	—	—	b	a Blundell, 1957	*Sampling:* 10 specimen measurements were made on 5 oriented samples. The value of k for entry (36) was calculated by the approximate formula.
	36	**51 N**	**4½W**	**175**	**−9**	**27**	**5**	**5**	**43 N**	**177 W**	**N**	**27**	**13½**	*	b Irving, 1959	
NORTH AMERICA																
NACO FORMATION															*Runcorn*	*Age:* Pennsylvanian
Carizzo Creek (sediments)	37	36 N	113 W	149½	−3½	4	40	31	48½N	120 E	N	4	4	a	a Runcorn, 1956a	*Sampling:* Entries (37)–(39) are based on measurements of 31 specimens from 8 oriented samples collected at 1 site with a stratigraphic extent of 200 feet. Entry (40) is from a later collection of 9 oriented samples made at Fossil Creek.
	38	**36 N**	**113 W**	**149½**	**−3½**	**4**	**40**	**31**	**45½N**	**114 E**	**N**	**4**	**2**	*	b Irving, 1959	
	39	—	—	—	—	—	—	—	41 N	120 E	N	8	4	b		
Fossil Creek (limestone)	**40**	**34½ N**	**111½ W**	**125**	**16**	**7**	**22**	**20**	**23 N**	**130 E**	**N**	**7**	**4**	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	
BARNETT FORMATION (sediments)	41	31 N	99 W	—	—	—	—	—	39 N	124 E	N	—	—	a	*Howell and Martinez*	*Age:* Mississippian
	42	31 N	99 W	—	—	—	—	—	41 N	128 E	N	—	—	b		*Sampling:* 60 oriented samples from 8 sites (N poles) and 8 oriented samples from 1 site (S poles) were collected over a lateral extent of 73 miles. Calculations for entries (43) and (45) were based on data scaled from Fig. 3, Ref. b.
	43	**31 N**	**99 W**	**148½**	**19**	**5½**	**11**	**60**	**39 N**	**122½E**	**N**	**6½**	**3**	*	a Martinez and Howell, 1956	
	44	31 N	99 W	—	—	—	—	—	42 N	142 E	S	—	—	a		
	45	**31 N**	**99 W**	**319**	**8**	**3½**	**200**	**8**	**42½N**	**144 E**	**S**	**3½**	**2**	*	b Howell and Martinez, 1957	

CODROY GROUP (sediments)	46	48 N	59 W	166	8	8½	38	9	43 N	139 E	N	8½	4½	a	*Nairn et al.*	*Age:* Cited as Mississippian in Ref. a
	47	**48 N**	**59 W**	**166**	**8**	**8½**	**38**	**9**	**36½N**	**139 E**	N	**8½**	**4½**	*	a Nairn, Frost, and Light, 1959	*Sampling:* 36 specimen measurements were made on 9 oriented samples.
BONAVENTURE, KENNEBECASIS and BATHURST FORMATIONS (sediments)	48	48 N	66 W	163½	19½	5	—	46	—	—	—	—	—	a	*Du Bois*	*Age:* Carboniferous; Bonaventure is Late Mississippian or Early Pennsylvanian, Kennebecasis is Pennsylvanian (Ref. a)
	49	**48 N**	**66 W**	**163½**	**19½**	**5**	**17**	**46**	**30 N**	**133 E**	N	**5**	**2½**	*	a Du Bois, 1959b	*Sampling:* 22, 14, and 10 oriented samples were collected from these 3 formations from groups of sites spanning 250 miles. The mean direction of 2 specimen measurements from each sample was reduced to the common mean locality cited, and a statistical analysis was made on the resulting directions. α_{95} may be too low because mean site or formation directions were not used in the analysis. The value of k for entry (49) was calculated by the approximate formula.
AUSTRALIA																
KATTUNG VARVOID SEDIMENTS	**50**	**33 S**	**151 E**	**90**	**84**	**6**	**—**	**75**	**32 N**	**15 W**	**M**	**12**	**12**	**a**	*Irving* a Irving, 1957b b Irving and Green, 1958	*Age:* Age cited as late Carboniferous in Ref. b *Sampling:* 75 oriented samples were collected at 4 localities. *Stability:* Application of Graham's fold test indicates stability. *Reversals:* The direction of magnetization of samples from one locality was reversed to that at the other 3 localities.
KATTUNG LAVAS	**51**	**33 S**	**151 E**	**5**	**−85**	**8**	**—**	**—**	**43 N**	**30 W**	**S**	**16**	**16**	**a**	*Irving and Green* a Irving and Green, 1958	*Age:* Cited as late Carboniferous in Ref. a
AFRICA																
DWYKA VARVED CLAYS	**52**	**18 S**	**29 E**	**360**	**−81**	**5½**	**84**	**10**	**36 N**	**151 W**	**S**	**10**	**10**	**a**	*Nairn*	*Age:* Cited as late Carboniferous in Ref. a
	53	18 S	29 E	333	76	7	57	9	7 N	17 E	—	13	12	a	a Creer, Irving, Nairn, and Runcorn, 1958	*Sampling:* The 19 specimen measurements (including "normal" and "reversed" groups) were made on 4 oriented samples.
	54	**18 S**	**29 E**	**333**	**76**	**7**	**57**	**9**	**5½N**	**17½E**	**S**	**13**	**12**	*		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION E PERMIAN																
EUROPE																
EXETER VOLCANIC SERIES	1	—	—	189	−9	—	—	—	47 N	147 E	N	—	—	a	*Creer*	*Age:* Cited as Permian
	2	—	—	—	—	—	—	—	48 N	168 E	N	—	—	c	a Creer, Irving, and Runcorn, 1954	*Sampling:* 34 oriented samples were collected from 5 flows. Pole position cited from Ref. a was scaled from Fig. 1. This figure also appears in Ref. b. Values cited for Ref. c were also scaled from a map. Data for the individual flow directions are given in Ref. e. The dispersion within flows is much less than that between flows.
	3	—	—	189	−9	20	15	5	43 N	164 E	N	20	10	f	b Runcorn, 1955a	
	4	**51 N**	**4 W**	**189**	**−9**	**20**	**—**	**5**	**43 N**	**164 E**	**N**	**20**	**10**	**d**	c Runcorn, 1956a d Irving, 1956a e Creer, 1957b f Creer, Irving, and Runcorn, 1957	
MAUCHLINE SEDIMENTS	5	—	—	187	−6	12	—	26	37 N	163 E	N	—	—	a	*Du Bois*	*Age:* Cited as Permian
	6	**55½N**	**4½W**	**187**	**−6**	**12**	**5**	**26**	**37 N**	**166½E**	**N**	**12**	**6**	*	a Du Bois, 1957	*Sampling:* 26 is the number of specimen measuree ments; number of samples is not known. The valu[ə] of k for entry (6) was calculated by the approximat- formula.
MAUCHLINE LAVAS	7	—	—	180	−4	8	—	34	36 N	175 E	N	—	—	a	*Du Bois*	*Age:* Cited as Permian
	8	**55½N**	**4½W**	**180**	**−4**	**8**	**9**	**34**	**36 N**	**175 E**	**N**	**8**	**4**	*	a Du Bois, 1957	*Sampling:* 34 is the number of specimen measurements. The number of flows sampled is not given. The value of k for entry (8) was calculated by the approximate formula.
ESTEREL VOLCANIC ROCKS																*Age:* Cited as Permian
Pyromeride R4	9	—	—	210	−16	—	—	5	—	—	—	—	—	a	*Roche*	*Sampling:* The samples were collected "several dozen meters apart and from different levels." The value of α_{95} for entry (10) is a minimum value which assumes that the 5 samples all came from different flows and is based on the "secular variation precision" $k' = 30$. The value of α_{95} for entry (13) is based on the sample data cited on page 2953, Ref. a, and is greater than
	10	**43½N**	**7 E**	**210**	**−16**	**11½**	**k'**	**5**	**46 N**	**142 E**	**N**	**12**	**6½**	*	a Roche, 1957	
	11	—	—	—	—	—	—	—	46 N	141 E	N	—	—	b	b Irving 1959	
Dolerite	12	—	—	175	−13	—	—	3	—	—	—	—	—	a		
	13	**43½N**	**7 E**	**175**	**−13**	**18**	**20**	**3**	**52½N**	**165 W**	**N**	**18**	**9**	*		
	14	—	—	—	—	—	—	—	53 N	165 W	N	—	—	b		

																the minimum value based on the "secular variation precision." *Stability:* The magnetization of the samples was not changed by heating to 300°C. and cooling in zero applied field.
Rhyolite	15	43½N	7 E	217	−22½	4½	—	14	45 N	130½E	N	—	—	a	*Rutten et al.*	*Sampling:* The 14 samples were all collected from a single flow. Since only one point in time was sampled the circle of confidence does not have the usual significance. The value of *k* for entry (16) was calculated by the approximate formula.
	16	**43½N**	**7 E**	**217**	**−22½**	**4½**	**69**	**14**	**45 N**	**130½E**	N	**4½**	**2½**	*	a Rutten, van Everdingen, and Zijderveld, 1957	
Undifferentiated	17	—	—	—	—	—	—	14	47 N	144 E	—	—	—	a	*As and Zijderveld*	*Sampling:* These samples contain dolerites, rhyolites, pelites, and arkoses. Statistical analysis for entry (18) is based on data scaled from Fig. 6(d), Ref. a. *Stability:* Partial demagnetization at 150°C. and 300 oersted A.C. field decreases scatter. Application of Graham's fold test also indicates stability.
	18	**43½N**	**7 E**	**207½**	**−16**	**5**	**59**	**14**	**47 N**	**145 E**	N	**5½**	**3**	*	a As and Zijderveld, 1958	
Oslo Graben Trachyandesite	19	60 N	10½E	201½	−33	9½	—	12	45½N	165 E	N	—	—	a	*Rutten et al.*	*Sampling:* 3 flows and 12 "rhomboporphyries" were sampled over a lateral extent of 30 by 15 km and a stratigraphic thickness of 750 m. The value of *k* for entry (20) was calculated by the approximate formula. *Stability:* Stability was checked by inverting the samples in the laboratory and remeasuring. 12 stable samples were used for the calculations.
	20	**60 N**	**10½E**	**201½**	**−33**	**9½**	**18**	**12**	**45 N**	**160½E**	N	**11**	**6**	*	a Rutten, van Everdingen, and Zijderveld, 1957	
Ayrshire Kylites	21	54 N	4½W	181	7	—	—	7	—	—	N	—	—	a	*Armstrong*	*Age:* The Kylites intrude Coal Measures and are cut by Permian volcanic necks. They are suggested as equivalent to the Mauchline Lavas in Ref. a. *Sampling:* Entry (21) is based on Kylite samples from 5 localities plus 2 other Permian localities. Entry (22) is based on the data for the Kylite samples only. *Stability:* Partial demagnetization was used to decrease the scatter.
	22	**54 N**	**4½W**	**190**	**1½**	**12**	**5**	**5**	**34 N**	**163½E**	N	**12**	**6**	*	a Armstrong, 1957	
Niedeck Porphyre	23	—	—	193	−7	4½	22	49	43 N	168 E	N	—	—	a	*Nairn*	*Age:* Saxonian(?), middle Permian *Sampling:* 49 specimen measurements were made on 14 oriented samples. *Other:* Locality is in the Vosges of France; exact locality could not be determined.
	24	**—**	**—**	**193**	**−7**	**4½**	**22**	**49**	**43 N**	**168 E**	N	**4½**	**2½**	*	a Nairn, 1957b	
Montcenis Sediments	25	—	—	197	6	4	93	14	38 N	162 E	N	—	—	a	*Nairn*	*Age:* Cited as Saxonian, middle Permian *Sampling:* 14 specimen measurements were made on 3 oriented samples. Some specimens were not included in the statistical analysis because they were believed to be unstable.
	26	**46½N**	**4½E**	**197**	**6**	**4**	**93**	**14**	**38 N**	**162 E**	N	**4**	**2**	*	a Nairn 1957b	

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
								SECTION E—*Continued*								
SAINT-WENDEL	27	—	—	181	−9	3½	27	27	45 N	175 W	N	—	—	a	*Nairn*	*Age:* Cited as Autunian, early Permian
SEDIMENTS	**28**	**49½N**	**7 E**	**181**	**−9**	**3½**	**27**	**27**	**45 N**	**175 W**	N	**3½**	**2**	*	a Nairn, 1957b	*Sampling:* 27 specimen measurements were made on 5 oriented samples.
UFIMSKIJ AND	29	58 N	56 E	221	−40	15½	—	—	45 N	178 E	N	—	—	a	*Khramov*	*Age:* late Permian
KAZANSKIJ SEDIMENTS	**30**	**58 N**	**56 E**	**221**	**−40**	**15½**	**—**	**—**	**45 N**	**178 E**	N	**18½**	**11½**	*	a Khramov, 1958	*Sampling:* 16 oriented samples were collected from Ufimskij over a lateral extent of 100 km and a thickness of 70 m, and 24 were collected from Kazanskij over a lateral extent of 100 km and a thickness of 90 m. Data for entry (29) are an estimate which excludes "partially" stable samples. *Other:* A large amount of scatter is present in the plotted measurements.
TARTARSKIJ SEDIMENTS	**31**	**59 N**	**50 E**	**—**	**—**	**10**	**—**	**—**	**52 N**	**176 E**	**17**	**—**	**—**	a	*Khramov* a Khramov, 1958	*Age:* late Permian *Sampling:* 74 oriented samples were collected over a lateral extent of 100 km and a thickness of 485 m. Khramov states that two groups are present, centering at 38 E, plus 57 and 254 E, plus 42. He states that the latter group has a stable component at 211 E, minus 38. *Other:* A plot of some of these data shows very extreme scatter.
NORTH AMERICA																
CUTLER FORMATION (sediments)															*Graham* a Graham, 1955	*Age:* Permian
Glenwood Springs, Colo.	32	39½N	107½W	—	—	—	—	2	36 N	122 E	N	—	—	a		*Sampling:* 2 samples were collected 50 feet apart laterally and 1 foot apart stratigraphically. Entry (32) values were scaled from a map on p. 343, Ref. a. Entry (33) is based on data scaled from Fig. 7, Ref. a. (N = 2 is not sufficient to calculate α_{95} or k.)
	33	39½N	107½W	140	6	—	—	2	33½N	123 E	N	—	—	*		
Monument Valley, Utah	34	37 N	110 W	161	32½	9½	96	4	33 N	92 E	N	11	6	*		*Sampling:* 12 samples were collected over a stratigraphic thickness of 200 feet and a lateral extent of ¼ mile. Entry (34) is based on data scaled from Fig. 7, Ref. a, for 4 samples, which form a group away from the present field direction.

CUTLER, AVERAGE	**35**	—	—	—	—	**13**	—	**2**	**34 N**	**107 E**	N	**13**	**13**	*		*Sampling:* This pole is midway between the poles of entries (33) and (34); 13° is the distance to either pole and has no statistical significance.
SUPAI FORMATION																*Age:* Permian and Pennsylvanian
Upper Supai Oak Creek, Arizona	37	35 N	112 W	161	10	8	13	32	46 N	96 E	N	8	4	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* Statistical analysis is based on 32 specimen measurements on 14 oriented samples.
Oak Creek, Arizona	38	35 N	111½W	—	—	—	—	—	43 N	122 E	N	—	—	a	*Graham*	*Sampling:* 52 specimen measurements were made on 17 oriented samples spanning 1.4 miles laterally and 100 feet stratigraphically. Specimens from conglomerates had rather scattered directions. 11 specimens from flat-lying sediments show streaking toward the present field. The analysis of entry (39) is based on the remaining 24 specimens from flat-lying sediments. Entry (38) was scaled from Fig. 6 of Ref. a.
	39	35 N	111½W	143½	9½	7½	17	24	37½N	117 E	N	7½	4	*	a Graham, 1955 b Irving, 1956a c Irving, 1959	
Carizzo Creek, Arizona	40	34 N	110½W	—	—	—	—	—	50 N	104 E	N	—	—	a		*Sampling:* Statistical analysis of entry (41) is based on 59 specimen measurements made on 30 oriented samples collected over a lateral distance of 10 miles and a stratigraphic thickness of 1000 feet. Entry (40) was scaled from Fig. 6 of Ref. a.
	41	34 N	110½W	159	2	3	33	59	50 N	103 E	N	3	1½	*		
Supai Combined	42	35 N	104 W	150	3	5	—	—	37 N	107 E	—	5	3	b		*Sampling:* Described in Ref. b as Supai Beds, Arizona and New Mexico.
	43	—	—	—	—	—	—	—	41 N	117 E	N	—	—	c		
Grand Canyon and Colorado Plateau	44	—	—	—	—	—	—	—	23 N	119 E	N	8	6	a	*Runcorn*	*Sampling:* 31 samples were collected over a lateral distance of 75 miles and a stratigraphic thickness of 500 feet. 21 specimen measurements from 6 samples were smeared toward the present pole. The calculations were based on the remaining 34 specimen measurements from 25 oriented samples.
	45	36 N	112 W	132½	23	7½	16	34	26 N	119 E	N	8	6½	b	a Runcorn, 1955b	
	46	36 N	112 W	132½	23	7½	16	34	24½N	120 E	N	8	4	*	b Runcorn, 1956a	
	47	36 N	113 W	133	23	8	—	—	26 N	121 E	N	9	5	c	c Irving, 1956a	
Grand Canyon, Arizona	48	—	—	146	8	7	—	—	39 N	115 E	N	—	—	b	*Doell*	*Sampling:* 42 oriented samples were collected over a lateral extent of 2 miles and a stratigraphic thickness of 500 feet. 24 of the samples showed agreement between 2 or more specimen measurements. 12 of these were smeared toward the present pole, and the calculations were based on the remaining 12 (Ref. a).
	49	36 N	112 W	146	8	7	33	12	39 N	114 E	N	7	3½	*	a Doell, 1955a b Doell, 1955b	
Hunter's Point	51	35½ N	109 W	164	5	5	32	24	50 N	96 E	N	5	3	a	*Collinson and Runcorn*	*Sampling:* 24 specimen measurements were made on 7 oriented samples.
Lower Supai, Oak Creek, Arizona	52	35 N	112 W	141	18	4	25	55	33 N	116 E	N	4	2	a	a Collinson and Runcorn, 1960	*Sampling:* 55 specimen measurements were made from 16 oriented samples.
SUPAI AVERAGE	**53**	—	—	—	—	**9**	**45**	**7**	**40½N**	**110 E**	N	**9**	**9**	*		*Sampling:* This mean pole position was found by applying Fisher statistics to the pole positions cited for entries (37), (39), (41), (46), (49), (51), and (52) above.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
									SECTION E—*Continued*							
YESO FORMATION (sediments)	54	35½N	105½W	—	—	—	—	22	41 N	127 E	N	—	—	a	*Graham*	*Age:* Permian (Leonard)
	55	**35½N**	**105½W**	**143**	**−1**	**3**	**99**	**22**	**41 N**	**127 E**	N	**3**	**1½**	*	a Graham, 1955	*Sampling:* 26 oriented samples were collected over a lateral extent of 200 feet and a stratigraphic thickness of 36 feet. The pole position for entry (54) was scaled from Fig. 6 of Ref. a. Entry (55) was based on data scaled from Fig. 7, Ref. a; 4 widely scattered samples were excluded from the calculations.
ABO FORMATION (sediments)															*Graham*	*Age:* early Permian
Abo Canyon	56	34½N	106½W	—	—	—	—	8	44 N	120 E	N	—	—	a	a Graham, 1955	*Sampling:* 11 oriented samples were collected over a lateral distance of 400 feet and a stratigraphic thickness of 50 feet. 8 of the 20 specimen measurements made from these samples form a group and were used to give the pole position of entry (56) which was scaled from Fig. 6 of Ref. a. Entry (57) is based on data scaled from Fig. 7 of Ref. a, excluding 3 of the 20 specimen measurements.
	57	34½N	106½W	149	8	17½	5	17	42 N	117 E	N	17½	9	*		
Zuni Mts.	58	35½N	108½W	160½	55	12	7	25	17 N	87½E	N	17	12	*		*Sampling:* 13 oriented samples were collected over a lateral extent of 150 feet and a stratigraphic thickness of 25 feet. Entry (58) is based on directions of all specimens as scaled from Fig. 7, Ref. a.
ABO AVERAGE	**59**	**35 N**	**107½W**	—	—	—	—	—	**30 N**	**100 E**	N	**18**	**18**	*		*Sampling:* Average of pole positions of entries (57) and (58) is listed. 18° is the distance from average position to either pole and has no further significance.
SANGRE DE CRISTO FORMATION (sediments)	**60**	**35½N**	**105½W**	**175½**	**30½**	**11**	**9**	**19**	**38 N**	**80½E**	N	**11**	**6½**	*	*Graham* a Graham, 1955	*Age:* early Permian and Middle or Late Pennsylvanian *Sampling:* 19 oriented samples were collected over a lateral extent of 100 feet and a stratigraphic thickness of 10 feet. Entry (60) was based on data scaled from Fig. 7, Ref. a.
AUSTRALIA																
UPPER MARINE VOLCANIC SERIES	**61**	**35 S**	**151 E**	**67**	**81**	**11**	—	—	**27 N**	**11 W**	N	**21**	**21**	a	*Irving and Green* a Irving and Green, 1958 b Irving, 1959	*Age:* Cited as Permian in Ref. a *Sampling:* Ref. b states that 3 flows were sampled.

LOWER MARINE VOLCANIC SERIES	**62**	**33 S**	**151 E**	**110**	**80**	—	—	—	**38 N**	**6 W**	N	—	—	a	*Irving and Green* a Irving and Green, 1958 b Irving, 1959	*Age:* Cited as Permian in Ref. a *Sampling:* Ref. b states that 1 flow was sampled.
AFRICA																
MAJI YA CHUMVI FORMATION (sediments)	**63**	**3 S**	**39 E**	**267**	**38**	**11½**	**9**	**5**	**4 N**	**150 E**	N	**13½**	**8**	a	*Nairn* a Creer, Irving, Nairn, and Runcorn, 1958	*Age:* Cited as late Permian *Sampling:* 21 specimen measurements were made on 5 oriented samples.
TARU GRIT	**64**	**3 S**	**39 E**	**87**	**61**	**16½**	**23**	**8**	**0 N**	**87 E**	S	**25**	**19½**	a	*Nairn* a Creer, Irving, Nairn, and Runcorn, 1958	*Age:* Cited as early Permian *Sampling:* 32 specimen measurements were made on 8 oriented samples. *Other:* Values cited for N, α_{95}, and k are inconsistent in entries (63) and (64), and it is impossible to deduce whether specimen measurements or mean sample measurements were used in computing the statistics.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION F TRIASSIC																
EUROPE																
KEUPER MARLES															*Clegg et al.* a Clegg, Almond, and Sutbbs, 1954a b Runcorn, 1955a c Runcorn, 1955b d Runcorn, 1956a e Irving, 1956a f Day and Runcorn, 1955	*Age:* Late Triassic; sandstones sampled are close to base of Keuper Marle series
Normal sites	1	—	—	29	34	10	58	—	—	—	S	—	—	b		*Sampling:* 12, 2, 6, 3, and 2 samples, respectively, were collected at each of 5 sites over a lateral distance of 140 miles. Values from Ref. b (citing an analysis of Creer, 1955) are from p. 272 and p. 284, respectively. Calculations for entry (3) were based on mean site directions cited in Table 1, Ref. a.
	2	—	—	26	28	—	—	—	—	—	S	—	—	b		*Stability:* The magnetization was not changed after random orientation in the earth's field for several weeks, nor by the application of a 300-oersted A.C. field. Graham's fold test on dips of 15° and less also indicate stability.
	3	53 N	2 W	26½	34½	13½	34	5	50½N	137½E	S	15½	9	*		
Reversed sites	4	—	—	219	−16	27	13	—	—	—	N	—	—	b		*Sampling:* 6, 2, 2, and 8 samples, respectively, were collected at each of 4 sites over a lateral distance of 180 miles. For basis of entry (6) see remark above for entry (3).
	5	—	—	214	−28	—	—	—	—	—	N	—	—	b		*Stability:* See previous remark about stability.
	6	53 N	2 W	218	−16	27	13	4	35½N	129½E	N	28½	15	*		
Average of Normal and Reversed	7	—	—	—	—	—	—	—	48 N	155 E	M	—	—	b		*Sampling:* Values for entry (9) were scaled from Fig. 9 in Ref. d. Entry (12) was based on average directions at normal and reversed sites (Table 1, Ref. a). All entries are presumably based on these same data.
	8	—	—	—	—	—	—	—	47 N	122 E	—	13	7	c		
	9	—	—	—	—	—	—	—	46 N	131 E	—	13	7	d		
	10	53 N	2 W	33	27	12	—	—	43 N	131 E	—	12	7	e		
	11	—	—	—	—	—	—	—	47 N	133 E	—	—	—	f		*Other:* A detailed study of unstable Keuper Marles from another locality is given by Creer (1957a).
	12	**53 N**	**2 W**	**32**	**26**	**13**	**16**	**9**	**43 N**	**133 E**	**M**	**14**	**8**	*		
VOSGES SANDSTONE	**13**	**48 N**	**6 E**	**218**	**10**	**12**	**2**	**61**	**27½N**	**142 E**	N	**12**	**6**	*	*Clegg et al.* a Clegg, Deutsch, Everitt, and Stubbs, 1957 b Irving, 1959	*Age:* Cited as Early Triassic in Ref. a *Sampling:* 61 specimens or samples (?) were collected at 7 sites. Entry (13) was based on data scaled from Fig. 5, Ref. a.
	14	—	—	—	—	—	—	—	28 N	143 E	N	12	6	b		
VILLAVICIOSA SANDSTONE	**15**	**43½N**	**5½W**	**4**	**56**	**2**	**80**	**87**	**82 N**	**150 E**	**S**	**2½**	**2**	*	*Clegg et al.* a Clegg, Deutsch, Everitt, and Stubbs, 1957	*Age:* Cited as Triassic in Ref. a *Sampling:* It is not known whether 87 is the number of oriented samples or specimen measurements. Entry (15) was based on data scaled from Fig. 6, Ref. a.

																Stability: Stability is suggested by the tightness of the group which *in situ* (*i.e.*, before correction for geologic dip) has a direction 30° from the present field direction. Of 7 sites sampled in this region, only Villaviciosa, Alcolea, and Aguilar had consistency of directions of magnetization.
ALCOLEA AND AGUILAR SANDSTONE	**16**	**41 N**	**2½W**	**349½**	**51½**	**5½**	**50**	**16**	**78 N**	**135 W**	**S**	**7½**	**5½**	*	*Clegg et al.* a Clegg, Deutsch, Everitt, and Stubbs, 1957	*Age:* Cited as Triassic in Ref. a *Sampling:* 16 samples or specimens (?) were collected at 2 sites. Entry (16) was based on data scaled from Fig. 7, Ref. a.
VETLUJSKIJ SEDIMENTS	17	59 N	50 E	235	21	—	—	9	—	—	—	—	—	a	*Khramov* a Khramov, 1958	*Age:* Early Triassic *Sampling:* 9 oriented samples were collected over a lateral extent of 100 km and a thickness of 40 m. Entries (19) and (20) refer to the direction of the "stable" (Ref. a) component. Much scatter is present in the plotted data.
	18	59 N	50 E	235	21	—	—	9	7½N	176 E	N	—	—	*		
	19	59 N	50 E	222	−19	—	—	—	—	—	—	—	—	a		
	20	**59 N**	**50 E**	**222**	**−19**	**—**	**—**	**—**	**31 N**	**179½E**	**N**	**—**	**—**	*		
NORTH AMERICA																
SPRINGDALE SANDSTONE MEMBER OF MOENAVE FORMATION	21	37½N	113 W	350	39	8½	17	18	—	—	S	—	—	a	*Runcorn* a Runcorn, 1956a b Runcorn, 1955b	*Age:* Late Triassic (?) *Sampling:* 8 oriented samples were collected at 1 locality. The statistical analysis of entry (21) is based on 18 specimens from 7 of these samples. The pole position cited in entry (24) is suggested (Ref. a) as more probable owing to "smearing" toward the present pole.
	22	**37½N**	**113 W**	**350**	**39**	**8½**	**17**	**18**	**72½**	**98 E**	**S**	**10**	**6**	*		
	23	—	—	—	—	—	—	—	60 N	110 E	S	—	—	b		
	24	—	—	338	16	—	—	—	55 N	107 E	S	—	—	a		
REDONDA FORMATION (sediments)	25	35 N	104 W	16½	55½	4½	57	20	77 N	23 W	S	6½	4½	*	*Graham* a Graham, 1955	*Age:* Late Triassic, equivalent to the upper part of the Chinle *Sampling:* 20 specimen measurements were made on 17 oriented samples collected over a lateral extent of ½ mile and a stratigraphic thickness of 150 feet. Calculations for entry (25) were based on data scaled from Fig. 7, Ref. a.
CHINLE FORMATION (sediments)																*Age:* Late Triassic. The Chinle includes the Redonda formation (upper portion) and the Shinarump member of the Chinle formation (lower portion).
Romeroville, New Mexico	26	35½N	105 W	15½	9	9	14	16	56 N	47 E	M	9	4½	*	*Graham* a Graham, 1955	*Sampling:* 16 oriented samples collected at 1 site over a horizontal distance of 100 feet and a vertical thickness of 15 feet. Entry (26) was based on data scaled from Fig. 7, Ref. a. *Reversals:* 1 specimen is reversely magnetized.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
									SECTION F—*Continued*							
Las Vegas, New Mexico	27	35½ N	105 W	48	32	—	—	—	—	—	—	—	—	b	*Graham* a Graham, 1955 b Kintzinger, 1957	*Sampling:* 8 specimen measurements were made on 6 oriented samples. Lateral sampling extent is 100 feet, vertical sampling extent is 5 feet. Entry (28) is based on data scaled from Fig. 7 of Ref. a.
	28	35½	105 W	33	47½	16½	12	8	61 N	10 W	S	21½	14	*		
Site 1, Moab, Utah	29	38⅔ N	109⅔ W	160	44	—	—	39	23 N	90 E	N	—	—	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* 39 specimen measurements were made on 14 oriented samples. *Stability:* Because of "smearing" these samples are considered to be only partially stable; entry (30) is an estimate (Ref. a) of the stable component of magnetization.
	30	38⅔ N	109⅔ W	156	−8	—	—	39	49 N	109 E	N	—	—	a		
Site 2, Moab, Utah	31	38⅔ N	109⅔ W	59	73	—	—	60	48 N	66 W	S	—	—	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* 60 specimen measurements were made on 10 oriented samples. *Stability:* Because of "smearing" these samples are considered to be only partially stable; entry (32) is an estimate (Ref. a) of the stable component of magnetization.
	32	38⅔ N	109⅔ W	160	10	—	—	60	50 N	114 E	N	—	—	a		
Site 1, Colo. National Monument	33	39 N	108⅔ W	356	66	5	25	29	—	—	—	—	—	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* 29 specimen measurements were made on 6 oriented samples. *Stability:* Cited as unstable (Ref. a)
	34	39 N	109 W	356	66	5	25	29	80½N	125 W	S	8½	7	*		
Site 2, Colo. National Monument	35	39 N	108⅔ W	34	60	7	14	31	—	—	—	—	—	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* 31 specimen measurements were made on 7 oriented samples. *Stability:* Cited as unstable (Ref. a)
	36	39 N	108⅔ W	34	60	7	14	31	64 N	35 W	S	10½	8	*		
SHINARUMP MEMBER OF CHINLE FORMATION (sediments)	37	36 N	111½W	355	43	6½	27	17	78½N	90 E	M	8	5	*	*Graham* a Graham, 1955 b Kintzinger, 1957	*Age:* Late Triassic *Sampling:* 20 specimen measurements were made on 17 oriented samples taken over a lateral extent of 20 feet and a stratigraphic thickness of 5 feet. Entry (37) was based on data scaled from Fig. 7, Ref. a. 3 widely scattered specimen measurements were excluded. *Reversals:* 4 specimens are reversely magnetized.
	38	36 N	111½W	356	33	—	—	17	—	—	—	—	—	b		

CHINLE AVERAGE	**39**	—	—	—	—	**27½**	**5**	**8**	**78 N**	**16 E**	**M**	**27½**	**27½**	*		*Sampling:* These values were calculated by applying Fisher statistics to the pole positions cited in entries (25), (26), (28), (30), (32), (34), (36), and (37). These include the poles for the equivalent Redonda formation and the Shinarump member of the Chinle formation. *Other:* Owing to "smearing" and instability at some sites (see above) the mean pole position cited here is probably too far north. The confidence intervals for the data used in this computation vary widely, and the value of α_{95} listed is therefore of doubtful significance.
CHUGWATER FORMATION (sediments)															*Collinson and Runcorn*	*Age:* Cited as Triassic in Ref. a; generally taken as Triassic and Permian
Troublesome Creek, Wyoming	41	42 N	106½ W	134	−12	7	10	43	36 N	135 E	N	7	4	a	a Collinson and Runcorn, 1960	*Sampling:* 43 specimen measurements were made on 10 oriented samples.
Alcova Reservoir, Wyoming	42	42½ N	107 W	152	−18	8	10	48	49 N	118 E	N	8	4	a		*Sampling:* 48 specimen measurements were made on 10 oriented samples.
Sheep Mtn., Wyoming	43	44½ N	108 W	148	−6	3	58	35	40 N	115 E	N	3	2	a		*Sampling:* 35 specimen measurements were made on 9 oriented samples.
Shell, Wyoming	44	44½ N	107½ W	155	−23	7	16	16	—	—	N	—	—	a		*Sampling:* 5 specimen measurements for the normal group were made on 1 oriented sample. 16 specimen measurements for the reversed group were made on 4 oriented samples. Entry (48) is an average for the normal and reversed groups.
	45	44½ N	107½ W	155	−23	7	16	16	50½N	113 E	N	8	4	*		
	46	44½ N	107½ W	340	36	—	—	5	—	—	S	—	—	a		
	47	44½ N	107½ W	340	36	—	—	5	60 N	110½E	S	—	—	*		
	48	44½ N	107½ W	—	—	—	—	—	56 N	113 E	M	8	4	a		
Fort Washakie, Wyoming	49	43 N	109 W	146	6	5	34	28	—	—	N	—	—	a		*Sampling:* 25 specimen measurements for the normal group were made on 6 oriented samples. 28 specimen measurements for the reversed group were made on 5 oriented samples. Entry (53) is an average for the normal and reversed groups.
	50	43 N	109 W	146	6	5	34	28	34½N	114 E	N	4½	2½	*		
	51	43 N	109 W	346	14	6	22	25	—	—	S	—	—	a		
	52	43 N	109 W	346	14	6	22	25	51½N	94½E	S	6½	3½	*		
	53	43 N	109 W	—	—	—	—	—	44 N	105 E	M	5	3	a		
Dinwoody Lake, Wyoming	54	43½ N	109½ W	154	−20	7	17	22	—	—	N	—	—	a		*Sampling:* The 22 specimen measurements for the reversed group were made on 6 oriented samples. The 20 specimen measurements for the normal group were made on 4 oriented samples. Entry (58) is an average for the normal and reversed groups.
	55	43½ N	109½ W	154	−20	7	17	22	50 N	112 E	N	8	4	*		
	56	43½ N	109½ W	339	25	6	30	20	—	—	S	—	—	a		
	57	43½ N	109½ W	339	25	6	30	20	55 N	107½E	S	6½	3½	*		
	58	43½ N	109½ W	—	—	—	—	—	52 N	110 E	M	5	3	a		
Lander, Wyoming	59	42½ N	108½ W	157	15	9	8	37	—	—	N	—	—	a		*Sampling:* The 37 specimen measurements for the reversed group were made on 8 oriented samples. The 12 specimen measurements for the normal group were made on 2 oriented samples. Entry (63) is an average for the normal and reversed groups.
	60	42½ N	108½ W	157	15	9	8	37	35 N	99 E	N	9½	4½	*		
	61	42½ N	108½ W	344	27	4	55	12	—	—	S	—	—	a		
	62	42½ N	108½ W	344	27	4	55	12	58 N	101 E	S	5	2½	*		
	63	42½ N	108½ W	—	—	—	—	—	47 N	100 E	M	8	4	a		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
									SECTION F—*Continued*							
Thermopolis, Wyoming	64	43½ N	108 W	170	−19	11	13	15	—	—	N	—	—	a		*Sampling:* 18 specimen measurements for the normal group were made on 3 oriented samples. 15 specimen measurements for the reversal group were made on 3 oriented samples. Entry (68) is an average for the normal and reversed groups.
	65	43½ N	108 W	170	−19	11	13	15	54½N	90 E	N	11½	6	*		
	66	43½ N	108 W	332	16	5	56	18	—	—	S	—	—	a		
	67	43½ N	108 W	332	16	5	56	18	46½N	114 E	S	5½	3	*		
	68	43½ N	108 W	—	—	—	—	—	52 N	103 E	M	7	4	a		
Rawlins, Wyoming	69	42 N	107½ W	149	−19	6	25	21	—	—	N	—	—	a		*Sampling:* 21 specimen measurements for the reversed group were made on 6 oriented samples. 12 specimen measurements for the normal group were made on 3 oriented samples. Entry (73) is an average for the normal and reversed groups.
	70	42 N	107½ W	149	−19	6	25	21	47½N	122 E	N	7	3½	*		
	71	42 N	107½ W	328	12	4	43	12	—	—	S	—	—	a		
	72	42 N	107½ W	328	12	4	43	12	44 N	120½E	S	3½	2	*		
	73	42 N	107½ W	—	—	—	—	—	46 N	121 E	M	5	3	a		
Red Mtn., Wyoming	74	41 N	106 W	151	−6	6	12	52	—	—	N	—	—	a		*Sampling:* 52 specimen measurements for the reversed group were made on 13 oriented samples. 16 specimen measurements for the normal group were made on 3 oriented samples. 2 samples were not used in the calculations. Entry (78) is an average for the normal and reversed groups.
	75	41 N	106 W	151	−6	6	12	52	44 N	116 E	N	6	3	*		
	76	41 N	106 W	335	15	6	30	16	—	—	S	—	—	a		
	77	41 N	106 W	335	15	6	30	16	50 N	114 E	S	6½	3	*		
	78	41 N	106 W	—	—	—	—	—	47 N	116 E	M	5	3	a		
CHUGWATER AVERAGE	**79**	**—**	**—**	**—**	**—**	**5**	**57**	**17**	**48 N**	**112½E**	**M**	**5**	**5**	*		*Sampling:* These calculations were made by applying Fisher statistics to the pole positions given for each site; reversed groups are considered as separate sites. The 17 entries used are (41), (42), (43), (45), (47), (50), (52), (55), (57), (60), (62), (65), (67), (70), (72), (75), and (77).
MOENKOPI FORMATION (Sediments)																*Age:* Early to Middle (?) Triassic
Zion Nat. Park	80	36 N	111½W	0	27½	—	—	—	—	—	—	—	—	a	*Runcorn*	*Sampling:* 18 oriented samples were collected over a lateral extent of 250 miles. Entry (81) was based on mean directions of 16 samples (Table 6, Ref. a); two samples with widely divergent directions were not included.
	81	36 N	111½W	1½	28	13	9	16	69 N	64 E	S	14½	8	*	a Runcorn, 1956a	

Marble Canyon	82	37 N	111½W	325	35	—	—	11	—	—	—	—	—	a	*Kintzinger*	*Sampling:* 11 oriented samples were collected over a lateral extent of 1 mile and a stratigraphic thickness of 230 feet. The values cited for entries (82) and (83) appear in a table and were scaled from Fig. 1, respectively, in Ref. a. Entry (84) was based on data scaled from Fig. 1 in Ref. a.
	83	37 N	111½W	340	28	—	—	11	—	—	—	—	—	a	a Kintzinger, 1957	
	84	37 N	111½W	345	29½	15½	11	11	65 N	105 E	S	17	9½	*		
Echo Cliffs, Arizona	86	37 N	111½ W	349	28	6	17	42	66 N	95 E	S	6	4	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* The statistical analysis was based on 42 specimen measurements made on 18 oriented samples; 6 specimen measurements on 4 samples were discarded.
Poverty Tank, Arizona	87	36 N	111½ W	337	36	7	22	27	64 N	127 E	S	8	5	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* The statistical analysis was based on 27 specimen measurements made on 10 oriented samples; 3 specimen measurements from 1 sample discarded.
Vernal, Utah	88	40½ N	109½ W	158	−4	6	18	38	46 N	103 E	N	6	3	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* The statistical analysis was based on 38 specimen measurements made on 8 oriented samples. 3 specimen measurements from 1 sample were discarded.
Split Mtn., Colorado	89	40½ N	109 W	156	−4	6	28	23	46 N	106 E	N	6	3	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* 23 specimen measurements were made on 5 oriented samples.
Sand Canyon, Colorado	90	40½ N	109 W	148	−7	9	10	27	43 N	118 E	N	9	4	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* The statistical analysis was based on 27 specimen measurements made on 7 oriented samples. 3 specimen measurements from 1 sample were discarded.
MOENKOPI AVERAGE	**91**	**—**	**—**	**—**	**—**	**12½**	**20**	**8**	**62 N**	**103 E**	**M**	**12½**	**12½**	*		*Sampling:* These calculations were made by applying Fisher statistics to the pole positions of entries (81), (84), (86), (87), (88), (89), and (90). Data on partially unstable Capitol Reef outcrop (Ref. a) not included.
CONNECTICUT VALLEY MASSACHUSETTS LAVAS	92	42 N	73 W	10	14	11	—	8	54 N	90 E	S	8	6	a	*Du Bois et al.*	*Age:* Cited as Triassic
	93	**42 N**	**72½W**	**10**	**14**	**15**	**k'**	**3**	**54 N**	**90 E**	**S**	**15**	**7½**	*	a Du Bois, Irving, Opdyke, Runcorn, and Banks, 1957	*Sampling:* 8 oriented samples were collected from 3 flows. Entry (93) is a minimum value of α_{95} based on 3 points in time (3 flows) and a "secular variation precision" $k' = 30$.
CONNECTICUT LAVAS AND SEDIMENTS	94	42 N	73 W	12	14	15	—	12	55 N	88 E	—	15	8	a	*Du Bois et al.*	*Age:* Cited as Triassic in Ref. a
	95	—	—	12	14	3	—	32	41 N	91 E	M	—	—	b	a Du Bois, Irving Opbyke, Runcorn, and Banks, 1957	*Sampling:* 12 oriented samples were collected (Ref. a); 32 specimens were measured (Ref. b). The value of k for entry (96) was calculated by the approximate formula.
	96	**42 N**	**73 W**	**12**	**14**	**15**	**7**	**12**	**53 N**	**86 E**	**M**	**15**	**7½**	*	d Du Bois, 1957	*Reversals:* A plot in Ref. b shows that about half the specimens are reversed.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION F—*Continued*																
BRUNSWICKIAN FORMATION* (sediments)	97	41 N	75 W	6	28	3	—	71	63 N	93 E	S	6	3	a	*Du Bois et al.* a Du Bois, Irving, Opdyke, Runcorn, and Banks, 1957 b Collinson and Runcorn, 1960	*Age:* Late Triassic, top of the Newark group; referred to as "Newark formation" in Ref. b. *Sampling:* 71 specimen measurements were made on 21 oriented samples (Ref. a).
	98	**40½N**	**75 W**	**2**	**22**	**3**	**86**	**70**	**61 N**	**102 E**	**S**	**3**	**2**	b		
NEW OXFORD FORMATION (sediments)	99	39½N	77½W	—	—	—	—	—	63 N	158 E	S	—	—	a	*Graham* a Graham, 1955	*Age:* Late (?) Triassic, bottom of the Newark group *Sampling:* 13 oriented samples were collected over a lateral distance of 300 feet and a stratigraphic thickness of 20 feet. Values for entry (100) were based on data scaled from Fig. 7, Ref. a. One sample is not included. The pole position for entry (99) was scaled from Fig. 6, Ref. a.
	100	**39½N**	**77½W**	**334**	**48**	**6½**	**36**	**13**	**66 N**	**174 E**	**S**	**8½**	**5½**	*		
NOVA SCOTIA LAVAS	101	—	—	—	—	5½	—	74	77½N	72 E	—	5½	5½	a	*Bowker* a Bowker, 1959 (letter of Nov. 16, 1959 to Doell)	*Age:* Cited as Triassic in Ref. a *Sampling:* 217 specimen measurements were made on 74 oriented samples collected at 12 sites. The values for entry (102) were based on averages for each site. In both entries, the statistical calculations were made on pole positions rather than magnetic directions. *Stability:* A.C. partial demagnetization decreased the scatter.
	102	**—**	**—**	**—**	**—**	**11½**	**14**	**12**	**77 N**	**75½E**	**—**	**11½**	**11½**	*		
DINOSAUR CANYON SANDSTONE MEMBER OF THE MOENAVE FORMATION	103	37 N	111½W	21	30	—	—	—	—	—	—	—	—	a	*Kintzinger* a Kintzinger, 1957	*Age:* Late Triassic (?); younger than the Chinle formation *Sampling:* Sampling extent was over 1 mile laterally and 80 feet stratigraphically. Values for entry (103) are from the table in Ref. a, and entry (104) was scaled from the plot in the same Ref. Entry (105) is based on individual sample data scaled from Fig. 1 in Ref. a.
	104	37 N	111½W	13½	27	—	—	—	—	—	—	—	—	a		
	105	**37 N**	**111½W**	**17**	**31**	**11**	**12**	**17**	**65 N**	**28 E**	**S**	**12**	**6½**	*		

* *Editor's Note:* Data for No. 98 withdrawn from Ref. b in final version of manuscript.

AUSTRALIA																
Tasmanian Volcanic Tuffs	**106**	**42 S**	**147 E**	**—**	**−81½**	**—**	**—**	**17**	**42 N**	**33 W**	**M**	**>16**	**>16**	*	*Almond et al.* a Almond, Clegg, and Jaeger, 1956	*Age:* The tuffs underlie the Tasmanian dolerite and are Triassic(?) *Sampling:* 20 feet of azimuthally unoriented core was sampled. The inclination indicated is an average of data in Table 4, Ref. a. *Other:* Since $I = 81\frac{1}{2}°$ corresponds to latitude 74°, the pole should be roughly 16° away from the sampling area. *Reversals:* 2 of the 17 samples have reversed polarity.
Brisbane Tuff	**107**	**27½S**	**153½E**	**35**	**−83**	**—**	**—**	**—**	**39 N**	**37 W**	**M**	**—**	**—**	a	*Irving and Green* a Irving and Green, 1958	*Age:* Cited as probably Early Triassic *Reversals:* Reversals are noted, but no details are given.
AFRICA																
Bechuanaland Cave Sandstone	108	—	—	326	−16	9½	6	44	54 N	79 W	S	—	—	a	*Nairn* a Nairn, 1957a b Creer, Irving, Nairn and Runcorn, 1958	*Age:* Late Triassic, immediately underlying the Karroo basalts (Du Toit, 1953, p. 301) *Sampling:* 44 specimen measurements were made on 8 oriented samples. *Other:* Contemporaneous sediments from adjacent regions have scattered directions.
	109	**23 S**	**27 E**	**326**	**−16**	**9½**	**6**	**44**	**54 N**	**44 W**	**S**	**10**	**5**	b		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION G JURASSIC																
EUROPE																
NORTH YORKSHIRE SEDIMENTS	1	—	—	3½	67	2½	88	36	—	—	—	—	—	a	*Nairn*	*Age:* Early Jurassic (middle Lias–lower Corallian) *Sampling:* 36 specimen measurements were made on 6 oriented samples. These were later rejected as unstable (Ref. b), because α_{95} changed from 4.7 to 6.7 after 18 months storage. The mean was little affected. *Stability:* Since the circle of confidence includes the present pole there is no evidence for stability.
	2	**54 N**	**1 W**	**3½**	**67**	**4½**	**88**	**36**	**85 N**	**150 E**	S	**7½**	**6**	*	a Nairn, 1956	
															b Nairn, 1957c	
SEDIMENTS OF SCOTLAND	3	—	—	234½	−66	6½	33	14	56 N	76 E	N	—	—	a	*Nairn*	*Age:* Cited as Early Jurassic *Sampling:* Entry (3) was based on 14 specimen measurements made on 4 oriented samples, 3 from the limestone of the Estuarine beds and 1 from the Brora Arenaceous series; these samples had reversed magnetizations. Entry (5) was based on average sample directions of the 4 samples plus an additional 2 samples from the Lias limestones, one of which is normal and the other reversed (Table III, Ref. a).
	4	—	—	226	−65	6½	33	14	—	—	—	—	—	b	a Nairn, 1957c	
	5	**57½N**	**5 W**	**220½**	**−71**	**18**	**14**	**6**	**68 N**	**73 E**	M	**31½**	**27**	*	b Nairn, 1957a	
MIDFORD SANDS	**6**	**51½N**	**2½W**	**103½**	**70**	**7½**	**10**	**42**	**33 N**	**41 E**	S	**13**	**11**	a	*Girdler* a Girdler, 1960	*Age:* Early Jurassic (upper Lias) *Sampling:* 42 specimen measurements were made on 20 oriented samples collected at 3 sites separated by more than 1 mile. *Stability:* Scatter was reduced by application of Graham's fold test. Specimens were remeasured after 6 months with no change in magnetization. *Other:* Samples at nearby sites were unstable.
COTSWOLD SEDIMENTS	**7**	**51½N**	**2½W**	**262½**	**−64**	**10**	**7**	**38**	**38 N**	**59½ E**	N	**15½**	**12½**	a	*Girdler* a Girdler, 1960	*Age:* Early Jurassic (upper Lias); older than the Midford sands *Sampling:* 38 specimen measurements were made on 17 oriented samples collected at 2 sites. *Stability:* Specimens were remeasured after 6 months with no change in magnetization.

PYRENEES VOLCANIC ROCKS	**8**	**43 N**	**1½E**	**55**	**60**	**6**	**17**	**38**	**49 N**	**76½E**	**S**	**8½**	**6½**	a	*Girdler* a Girdler, 1960	*Age:* Early Jurassic (lower Lias), on the basis of intercolated limestone beds *Sampling:* 38 specimen measurements were made on 18 oriented samples collected from 4 sites separated by more than 1 mile. *Stability:* Correction for rather uniform dips up to 40° did not significantly reduce the scatter. *Other:* The value of α_{95} is probably too high because individual specimen measurements were used.
ALPINE RADIOLARITE	9	47½N	12½E	36½	48	5½	100	21	58½N	128 E	S	—	—	a	*Hargraves and Fischer* a Hargraves and Fischer, 1959	*Age:* Cited as Middle Jurassic *Sampling:* 21 specimen measurements were made on 15 oriented samples taken at one site over a stratigraphic thickness of 7 meters.
	10	**47½N**	**12½E**	**36½**	**48**	**5½**	**100**	**21**	**56 N**	**122½E**	**S**	**7**	**4½**	*		
ALPINE LIMESTONE	11	47½N	12½E	48	50½	6½	71	30	53 N	112 E	S	—	—	a	*Hargraves and Fischer* a Hargraves and Fischer, 1959	*Age:* Cited as Early Jurassic *Sampling:* 30 specimen measurements were made on 16 oriented samples taken at 1 site over a stratigraphic thickness of 4 m.
	12	**47½N**	**12½E**	**48**	**50½**	**6½**	**71**	**30**	**50 N**	**109½E**	**S**	**9**	**6**	*		
NORTH AMERICA																
KAYENTA FORMATION																*Age:* The Kayenta is Early Jurassic (?) (Glen Canyon group).
Central Arizona	13	—	—	353	43½	9½	50	6	—	—	S	—	—	a	*Runcorn* a Nairn, 1956	
	14	35 N	111 W	353	43½	9½	50	6	79 N	102 E	S	12	7½	*		
Kayenta Arizona	15	36½ N	110½ W	20	50	6	14	43	72 N	6 W	S	8	6	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* 43 specimen measurements were made on 8 oriented samples.
Echo Cliffs, Arizona	16	37 N	111½ W	14	43	6	14	43	73 N	19 E	S	7	5	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* 43 specimen measurements were made on 14 oriented samples.
Navajo National Monument	17	36½ N	111 W	335	50	11	7	27	—	—	S	—	—	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* 27 specimen measurements were made on 7 oriented samples.
	18	36½ N	111 W	335	50	11	7	27	68½ N	151 E	S	15	10	*		
Kanab, Utah	19	37 N	112½ W	4	53	9	12	33	85 N	23 E	S	13	9	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Sampling:* The statistical analysis was based on 33 specimen measurements on 8 oriented samples. 6 specimen measurements from 2 oriented samples were discarded. The circle of confidence includes the present dipole direction.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
									SECTION G—*Continued*							
KAYENTA AVERAGE	20	—	—	—	—	21	20	4	83 N	63 E	S	21	21	*		*Sampling:* These values were computed by applying Fisher statistics to the pole positions for entries (14), (15), (16), (18), and (19).
CARMEL FORMATION (sediments)	21	38½ N	109½ W	349	63	9	10	31	80 N	160 W	S	14	11	a	*Collinson and Runcorn* a Collinson and Runcorn, 1960	*Age:* Cited as Jurassic in Ref. a *Sampling:* 31 specimen measurements were made on 9 oriented samples.
AFRICA																
KARROO DOLERITES															*Graham and Hales* a Graham and Hales, 1957	*Age:* The dolerites were emplaced during and somewhat after extrusion of the Karroo basalts (Du Toit, 1953, p. 369). Age is Late Triassic (Walker and Poldervaart, 1949, p. 598-599) or Early Jurassic (Du Toit, 1953, p. 370).
Winkelhaak Upper sill	22	26½S	29 E	173	58	5	—	17	77 N	127 W	N	7	6	a		*Sampling:* 17 oriented samples were taken in mine shafts. A 75-foot thickness of the sill was sampled at 4 sites a maximum of 1 mile apart.
Winkelhaak Lower sill	23	26½S	29 E	307	−63	12	—	8	44 N	98 W	S	18	14	a		*Sampling:* 8 oriented samples were taken in mine shafts. A 50-foot section of the sill was sampled at 4 sites a maximum of 1 mile apart.
Estcourt reversed dolerite	24	29 S	30 E	167	51	6	—	15	77 N	90 W	N	8	6	a		*Sampling:* 15 oriented samples were collected in a tunnel about 1 mile long.
	25	29 S	30 E	167	51	6	—	15	79 N	79 W	N	8	6	*		
Estcourt normal dolerite	26	29 S	30 E	331	−64	8	—	9	67 N	86 W	S	12	10	a		*Sampling:* 9 oriented samples were collected in a tunnel about 1 mile long.
	27	29 S	30 E	331	−64	8	—	9	62 N	105 W	S	13	10	*		
DOLERITE AVERAGE	28	—	—	—	—	20	23	4	66 N	101½W	M	20	20	*		*Sampling:* These values were computed by applying Fisher statistics to the pole positions of entries (22), (23), (25), and (27).

ESTCOURT BAKED SEDIMENTS															*Graham and Hales*	*Sampling:* These samples were baked by the reversed and normal dolerites at Estcourt, respectively, and were collected in the same tunnel. They are in good agreement with the dolerite samples in both cases.
Reversed	29	29 S	30 E	180	55	11	—	8	—	—	—	—	—	a	a Graham and Hales, 1957	
Normal	30	29 S	30 E	324	−62	7	—	7	—	—	—	—	—	a		
KARROO SURFACE SAMPLES	**31**	**30½S**	**28½E**	**352**	**−62**	**12**	**—**	**33**	**76 N**	**128 W**	**M**	**19**	**14**	**a**	*Graham and Hales* a Graham and Hales, 1957	*Sampling:* 33 oriented samples were collected over an area 250 by 400 miles. *Reversals:* 8 of the 33 samples had reversed polarity.
KARROO BASALTS	32	—	—	330	−40½	4½	19	44	61 N	76 W	S	—	—	a	*Nairn*	*Age:* The Karroo basalts are the top of the Stormberg series immediately overlying the Cave sandstone. The age is Late Triassic (Walker and Poldervaart, 1949, p. 598–599) or Early Jurassic (Du Toit, 1953, p. 370).
	33	—	—	332	−40	4½	19	44	—	—	—	—	—	b	a Nairn, 1956	*Sampling:* 44 specimen measurements were made on 11 oriented samples collected from 6 or 7 flows. Values for entry (36) are based on the "secular variation precision" $k' = 30$ and $N = 7$, the number of flows.
	34	18 S	26 E	332	−40	5	19	44	63 N	78 W	S	6	2½	c	b Nairn, 1957a	*Other:* The pole position at latitude 2 N, longitude 8 W mentioned in Ref. b apparently is a misprint.
	35	18 S	26 E	328	−40	4½	19	44	60 N	77 W	S	5½	3	d	c Creer, 1958	
	36	**18 S**	**26 E**	**332**	**−40**	**9½**	**k'**	**7**	**63½ N**	**79 W**	**S**	**11½**	**7**	*	d Creer, Irving, Nairn, and Runcorn, 1958	
SOUTH AMERICA																
PARANA BASIN BASALTS															*Creer* a Creer, 1958	*Age:* Exact age within the Mesozoic is not known
Normal group	37	29 S	57 W	348	−47	2	233	22	—	—	—	—	—	a		*Sampling:* The 48 specimen measurements (normal and reversed) were made on 12 oriented samples collected at 4 sites.
	38	29 S	57 W	348	−47	2	233	22	80 N	146 W	S	2½	1½	*		*Stability:* The scatter in directions was considerably decreased by partial demagnetization in A.C. fields of 250 oersted.
Reversed group	39	29 S	57 W	174	39	7	18	26	—	—	—	—	—	a		
	40	29 S	57 W	174	39	7	18	26	81 N	96 W	N	8½	5	*		
Basalt average	41	29 S	57 W	351	−42	2	82	48	—	—	—	—	—	a		
	42	29 S	57 W	351	−42	2	82	48	81 N	118 W	M	2½	1½	*		
TACUAREMBO BAKED SANDSTONE															*Creer* a Creer, 1958	*Age:* These sandstones were baked by the Parana Basin basalts. Thus the age of their magnetization within the Mesozoic is not known.
Normal group	43	29 S	57 W	357	−42	3	25	71	—	—	—	—	—	a		*Sampling:* The 81 specimen measurements (normal and reversed) were made on 12 oriented samples collected at 4 sites.
	44	29 S	57 W	357	−42	3	25	71	84 N	96 W	S	4	2	*		
Reversed group	45	29 S	57 W	176	43	14½	12	10	—	—	—	—	—	a		
	46	29 S	57 W	176	43	14½	12	10	77 N	132 W	N	18	11	*		
Sandstone Average	47	29 S	57 W	356	−43	3½	22	81	—	—	—	—	—	a		
	48	29 S	57 W	356	−43	3½	22	81	84½ N	102 W	M	4	2½	*		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION G—*Continued*																
PARANA BASALT AND SANDSTONE	49	29 S	57 W	354	−43	2½	24	129	83 N	126 W	M	3	1½	a	*Creer* a Creer, 1958	*Sampling:* For entry (49) Fisher statistics were applied to the 129 specimen measurements (basalts and sandstones) made on the 24 oriented samples (Ref. a). Entries (50), (51), and (52) are based on the "secular variation precision" k' = 30 and the 3 following assumptions about the number of different points in time that were sampled. Entry (50): the 12 sandstone samples were baked by 12 different flows, and in addition 12 other lava flows were also sampled. Entry (51): the sandstone samples were baked by 12 different flows, and in all cases both a flow and its baked sediment were sampled. Entry (52): only 1 lava flow and its associated baked sediment were sampled at each of the 4 sites. Ref. a does not specify the number of flows sampled.
	50	29 S	57 W	354	−43	5	k′	24	83½ N	112 W	M	6½	4	*		
	51	29 S	57 W	354	−43	7½	k′	12	83½ N	112 W	M	9	5½	*		
	52	**29 S**	**57 W**	**354**	**−43**	**12½**	**k′**	**4**	**83½ N**	**112 W**	**M**	**16**	**9½**	*		
SECTION H CRETACEOUS																
EUROPE																
WEALDEN SEDIMENTS	1	—	—	345	63	—	—	—	—	—	—	—	—	a	*Wilson* a Wilson, 1959	*Age:* Early Cretaceous *Sampling:* 97 specimen measurements on 19 oriented samples collected over a lateral extent of 4 miles were made. Mean sample directions were used in the statistical analysis, and the data for entry (2) were calculated from other statistical parameters reported in Ref. a. *Stability:* Correction for small-amplitude folding reduced scatter. Partial A.C. demagnetization at 180 oersted reduced scatter. Sands and clays of different lithology and different intensities had closely parallel directions. *Other:* 27 additional cretaceous samples were rejected as unstable.
	2	**50½N**	**1½W**	**345**	**63**	**2**	**260**	**19**	**79 N**	**117 W**	**S**	**3**	**2**	*		

NORTH AMERICA																
DAKOTA SAND-STONE	3	34 N	110 W	164	−62	—	—	10	76½	127 E	N	11	8½	a	*Runcorn*	*Age:* Lies above the Trinity group; Early(?) and Late Cretaceous *Sampling:* 6 samples were collected over a lateral distance of about 1 mile. The analysis of entry (3) is based on 10 specimen measurements made on 3 of the 6 oriented samples collected; all 10 specimens have reversed polarity. Values for entry (4) are based on average sample-direction data obtained from Table 8, Ref. a; one divergent sample was discarded.
	4	**34 N**	**110 W**	**169**	**−57**	**15**	**17**	**5**	**80 N**	**176 W**	**M**	**21½**	**16**	*	a Runcorn, 1956a	
AUSTRALIA																
TASMANIAN DOLERITES																*Age:* The dolerite sills cut Late Triassic (possibly Early Jurassic) rocks and are involved in early Tertiary faulting; they therefore are Jurassic or Cretaceous. Assignment to the Jurassic is favored in Ref. b.
Surface samples	**5**	**42 S**	**147 E**	**325**	**−85**	**4**	**48**	**30**	**50 N**	**23 W**	**S**	**8**	**8**	a	*Irving* a Irving, 1956b b Irving, 1959	*Sampling:* 2 samples were collected at each of 30 sites covering an area of more than 9000 square miles. The mean site directions were used in the analysis. *Stability:* Stability is indicated by the application of Graham's conglomerate test to Tertiary breccia containing fragments of the dolerite.
Core samples	6	42 S	147 E	—	−85½	—	—	57	—	—	M	—	—	a	*Almond et al.*	*Sampling:* 3 cores were sampled over the depths 1–947 feet, 8–152 feet, and 500–636 feet, respectively. The cores were vertical, but azimuthally unoriented. *Other:* Since $I = 85½°$ is appropriate to latitude 81°, the pole should be roughtly 9° from the sampling area. *Reversals:* About one-fifth of the samples near the bottom of one core had reversed polarity.
	7	**42 S**	**147 E**	**—**	**−85½**	**—**	**—**	**57**	**42 N**	**33 W**	**M**	**>9**	**>9**	*	a Almond, Clegg, and Jaeger, 1956	

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
									SECTION H—*Continued*							
INDIA																
UPPER RAJMAHAL TRAPS	8	25 N	88 E	328	−64	—	—	33	13 N	70 W	S	—	—	a	*Clegg et al.*	*Age:* The lower Rajmahal traps are interbedded with sediments of Early to Middle Jurassic age (Krishnan, 1956, p. 273). The upper part of the traps are undated but petrologically similar to post-lower Cretaceous Deccan traps (Hobson, quoted in Pascoe, 1929, p. 146). Assignment to the Jurassic is favored in Ref. a *Sampling:* The samples came from the upper 250 feet of the traps. 33 oriented samples were collected from 3 quarries about 20 miles apart. Samples from 2 additional badly weathered outcrops had scattered directions of magnetization. Entry (9) is based on data scaled from Fig. 1, Ref. a. Entry (10) is based on the "secular-variation precision" k' = 30 and an estimate of the number of flows.
	9	25 N	88 E	327	−64	4	36	33	13 N	69 W	S	6½	5	*	a Clegg, Radakrishnamurty, and Sahasrabudhe, 1958	
	10	**25 N**	**88 E**	**327**	**−64**	**10½**	**k'**	**6**	**13 N**	**69 W**	**S**	**17**	**13**	*		
AFRICA																
MADAGASCAR LAVAS AND DYKES	11	—	—	—	—	13½	32	5	58½N	162½W	S	13½	13½	*	*Roche et al.*	*Age:* Cited as Turonian stage of the Cretaceous *Sampling:* Entry (11) was obtained by a Fisher statistical analysis of 5 pole positions calculated from mean directions of magnetization of 5 sites (p. 2923, Ref. a). The 5 sites span a distance of 500 miles. Entry (13) was based on pole positions corresponding to the mean directions at 10 sites (p. 1050, Ref. b); these include (?) the data given in Ref. a. Entry (12) was found by grouping the results according to sampling area and averaging the results. *Stability:* Stability was checked by repeated measurements (Thellier's test) and by partial heat demagnetization.
	12	—	—	—	—	—	—	—	68 N	168 W	S	—	—	b	a Roche, Cattala, and Boulanger, 1958	
	13	**—**	**—**	**—**	**—**	**9**	**31**	**10**	**66½N**	**163½W**	**S**	**9**	**9**	*	b Roche and Cattala, 1959	

SECTION H—*Continued*

JAPAN																
INKSTONE RED SHALES															*Nagata et al.* a Nagata, Akimoto, Shimizu, Kobayashi, and Kuno, 1959	*Age:* Cited as Middle to Early Cretaceous *Sampling:* 24, 15, and 23 oriented samples were collected at Okoti, Imoziya, and Okuhu, respectively. *Other:* The between-site dispersion is much greater than within sites. The value of α_{95} cited in entry (20) is therefore probably much too small. The value of *k* for entries (15), (17), and (19) was calculated by the approximate formula.
Okoti	14	—	—	81	54	4	—	24	—	—	S	—	—	a		
	15	34½N	131½E	81	54	4	51	24	25½N	164½W	S	5½	4	*		
Imoziya	16	—	—	50	46	4	—	15	—	—	S	—	—	a		
	17	34½N	131½E	50	46	4	82	15	47 N	143½W	S	5	3	*		
Ohuku	18	—	—	43	46	7	—	23	—	—	—	—	—	a		
	19	34½N	131½E	43	46	7	17	23	52½N	139½W	S	9	5½	*		
Combined	**20**	**—**	**—**	**58**	**50**	**2**	**—**	**62**	**42 N**	**153 W**	**S**	**3**	**2**	**a**		

SECTION I EOCENE

EUROPE																
LUNDY DYKES	1	—	—	197	−59	—	—	8	—	—	—	—	—	a	*Blundell* a Blundell, 1957	*Age:* Not known but assigned to the early Tertiary (Ref. a) because the magnetic direction is similar to that for other lower Tertiary rocks from the British Isles *Sampling:* At least 2 samples were taken from each of 13 dikes and 2 dike contact rocks. 5 dikes and the 3 contact rocks were stable. Entry (2) was based on data from Table 1, Ref. a. *Stability:* Directions of magnetization were remeasured after 1 month and had not changed.
	2	**51 N**	**4½W**	**194**	**−59**	**7**	**64**	**8**	**75 N**	**129½ E**	**N**	**10½**	**7½**	*		
ARRAN DYKES	**3**	**—**	**—**	**—**	**—**	**—**	**—**	**10**	**79 N**	**154 E**	**M**	**15**	**12**	**a**	*Leng* a Irving, 1959	*Age:* Cited as early Tertiary in Ref. a
MULL INTRUSIVE ROCKS	**4**	**56½N**	**6 W**	**½**	**58**	**14**	**20**	**7**	**72 N**	**173 E**	**M**	**21**	**15½**	*	*Vincenz* a Vincenz, 1954 b Irving, 1959	*Age:* Early Tertiary, post Mull lavas and pre-Northwest Dikes *Sampling:* An average of about 9 samples was taken from each of 12 intrusive bodies. Only 7 of these bodies could be shown to possess a stable magnetization. The maximum separation of the sites was about 6 miles. Data for entry (4) were taken from Table I, Ref. a. *Reversals:* 2 of the 7 stable bodies showed reversed polarity.
	5	—	—	—	—	—	—	—	72 N	139 E	M	14	11	b		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
								SECTION I—*Continued*								
MULL LAVAS	6	56½N	6 W	137	−78	23½	—	16	—	—	—	—	—	b	*Bruckshaw and Vincenz* a Bruckshaw and Vincenz, 1954 b Hospers, 1955 c Irving, 1959	*Age:* Early Tertiary, probably Eocene (Ref. a) but may be Oligocene or even Miocene (Ref. b). *Sampling:* An average of about 7 samples was taken from each of 16 flows at 3 sites. 8 of the 16 flows could be shown to have stable magnetizations, and the data for entry (7) were for these stable flows, cited in Table I, Ref. a. Entry (6) is based on the data for both stable and unstable flows.
	7	**56½N**	**6 W**	**154½**	**−73½**	**17½**	**11**	**8**	**76½ N**	**74 W**	N	**31½**	**28½**	*		
	8	—	—	—	—	—	—	8	82 N	71 W	N	31	28	c		
ANTRIM BASALTS	9	55 N	6½W	194	−60	5½	—	24	—	—	N	—	—	a	*Hospers and Charlesworth* a Hospers, 1955 b Creer, Irving, and Runcorn, 1954 c Irving, 1956a d Hospers and Charlesworth, 1954	*Age:* The interbasaltic zone covering these basalts is "probably Eocene or Oligocene but may be later" (Charlesworth, as reported in Ref. a). Simpson (reported in Ref. a) considers this zone to be late Miocene or early Pliocene. *Sampling:* 6 flows at each of 3 sites and 5 at a fourth site were sampled; 2 to 4 samples were taken from each flow. The sites were about 30 miles apart (Ref. d).
	10	**55 N**	**6½W**	**194**	**−60**	**5½**	**31**	**24**	**73 N**	**135 E**	N	**8½**	**6½**	*		
	11	—	—	194	−60	—	—	—	75 N	118 E	N	—	—	b		
	12	55 N	6 W	194	−60	5	—	—	74 N	133 E	—	8	6	c		
ANTRIM BASALTS															*Wilson* a Wilson, 1959	*Age:* Generally regarded as Eocene, but comparison of Scottish and Irish pollens suggests (Ref. a) an age as young as Miocene *Sampling:* Ninety samples were collected from 57 igneous bodies at 47 sites spanning about 75 miles. The remanent magnetizations of one core from each sample and of the entire sample were both measured, and the mean of these two directions used in the statistical analysis. Three groups of basalt were studied: older "lower" olivine basalts (19 flows, entries 13 and 14); younger "middle" tholeiitic basalts (6 flows, entries 15 and 16); and intrusive rocks of unknown relative age (16 igneous bodies, entries 17 and 18). Entries (19) and (20) combine all these data. Statistical data were calculated from other statistical parameters reported in Ref. a.
Lower olivine basalts	13	—	—	173	−64½	—	—	—	—	—	—	—	—	a		
	14	55 N	6 W	173	−64½	9½	13	19	80 N	162 W	N	15	12	*		
Middle tholeiitic basalts	15	—	—	206	−62	—	—	—	—	—	—	—	—	a		
	16	55 N	6 W	206	−62	16	18	6	69½ N	108 E	N	25	19	*		
Intrusive bodies	17	—	—	184	−63½	—	—	—	—	—	—	—	—	a		
	18	55 N	6 W	184	−63½	8½	20	16	79½ N	157 E	N	13	10½	*		
Combined	19	—	—	183	−64	—	—	—	—	—	—	—	—	a		
	20	**55 N**	**6 W**	**183**	**−64**	**6**	**16**	**41**	**80½ N**	**162 E**	N	**9½**	**7½**	*		

NORTH AMERICA																
SILETZ RIVER VOLCANIC ROCKS	21	—	—	70	55	7	—	8	37 N	50 W	M	—	—	a	*Cox*	*Age:* Early middle to early Eocene age established by interbedded fossiliferous sediments *Sampling:* 57 samples were taken from 8 flows over a lateral distance of 38 miles; the value of *k* was estimated by the approximate formula. *Stability:* Heat demagnetization and application of Graham's fold test decrease scatter. *Reversals:* 5 flows indicate normal (S) poles, and 3 indicate reversed (N) poles.
	22	**45 N**	**123½ W**	**70**	**55**	**7**	**50**	**8**	**37 N**	**49 W**	**M**	**10**	**7**	*	a Cox, 1957	
LANEY SHALE MEMBER OF GREEN RIVER FORMATION	23	—	—	—	—	—	—	—	86 N	164 W	S	10	8	b	*Torreson et al.*	*Age:* Cited as Eocene in Ref. a *Sampling:* 21 oriented samples were collected. 2 of these were too weakly magnetized to measure. Data for entry (24) were taken from Table 4, Ref. a. *Stability:* The circle of confidence includes the presen pole, thus there is no indication of stability.
	24	**41½N**	**109½W**	**353½**	**62½**	**6**	**30**	**19**	**85 N**	**170 W**	**S**	**9½**	**7½**	*	a Torreson, Murphy, and Graham, 1949 b Irving, 1959	
GREEN RIVER FORMATION (sediments)	**25**	**39½N**	**108 W**	**345½**	**65**	**4½**	**168**	**7**	**77½ N**	**158 W**	**S**	**7**	**6**	*	*Torreson et al.* a Torreson, Murphy, and Graham, 1949	*Age:* Cited as Eocene in Ref. a *Sampling:* 7 out of 9 oriented samples collected were strong enough to be measured. Data for entry (25) were taken from Table 4, Ref. a.
WASATCH FORMATION (sediments)	**26**	**44½N**	**109 W**	**351½**	**63½**	**17**	**30**	**4**	**84½ N**	**180 E**	**S**	**26½**	**21**	*	*Torreson et al.* a Torreson, Murphy, and Graham, 1949	*Age:* Cited as Eocene in Ref. a *Sampling:* 4 oriented samples were collected. Entry (26) is based on data from Table 4, Ref. a. *Stability:* No stability is indicated since circle of confidence includes present pole. *Other:* 5 additional samples from the Wasatch at Gardner, Colorado, showed random directions.
AUSTRALIA																
OLDER VOLCANIC ROCKS OF VICTORIA	**27**	**38 S**	**145½E**	**17**	**−73**	**7**	**35**	**15**	**67 N**	**57 W**	**M**	**12**	**11**	a	*Irving and Green* a Irving and Green, 1957	*Age:* Cited as early Tertiary and probably Eocene in Ref. a *Sampling:* 3 oriented samples at each of 15 sites were collected. The sites cover an area of approximately 5000 square miles. *Reversals:* 9 sites are normal (S poles), 4 sites are reversed (N poles), and 2 sites are mixed.

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION I—*Continued*																
TASMANIAN BASALTS	**28**	**42 S**	**147 E**	—	**−83**	—	—	**8**	**42 N**	**33 W**	**S**	**>13½**	**>13½**	*	*Almond et al.* a Almond, Clegg, and Jaeger, 1956	*Age:* Cited as early Miocene or Oligocene on basis of sediments associated with basalts (Ref. a); however, Banks (1958, personal communication) believes age may be Eocene. *Sampling:* 8 cores not oriented with respect to azimuth from 2 borings span a stratigraphic interval of 339 and 53 feet, respectively and penetrate a number of flows. The cores have an average inclination of 83°. *Other:* Since $I = 83°$ corresponds to latitude 76½°, the pole should be roughly 13½° from the sampling locality. *Reversals:* One sample is reversely magnetized, but this core may have been inverted (Ref. a).
INDIA																
DECCAN TRAPS																*Age:* Generally considered Cretaceous to Eocene
Undiffer-entiated	29	18 N	74 E	149	56	10	—	7	28 N	78 W	M	15	10	a	*Irving*	*Sampling:* 7 samples were collected at different levels at sites spanning some 200 miles. The data for the calculations of entry (30) were taken from the appendix of Ref. a. *Reversals:* 5 of the 7 samples showed reversed polarity (N poles) from the other 2.
	30	**18 N**	**74 E**	**149**	**56**	**13½**	**21**	**7**	**28 N**	**78 W**	**M**	**19½**	**14**	*	a Irving, 1956a	
Linga Area	31	22 N	79 E	164	48	—	—	195	—	—	—	—	—	a	*Clegg et al.*	*Sampling:* The 195 oriented samples or specimen measurements (?) were taken from 4 flows which were sampled over an area of some 50 square miles. The lowest of these flows is considered to be the bottom of the Deccan trap sequence. Values for α_{95} and k for entry (32) were calculated by the approximate formulas from α_{50} given in Ref. a.
	32	22 N	79 E	164	48	2	25	195	36½ N	83 W	N	2½	2	*	a Clegg, Deutsch, and Griffiths, 1956	
Khandala Area	33	18½N	73½E	147	58	—	—	233	—	—	—	—	—	a		*Sampling:* 233 specimen measurements were made on 139 oriented samples from "numerous flows" collected at 20 sites. About 40 anomalous specimen measurements were not included. The flows are considered to be younger than those at Linga. Values of α_{95} and k for entry (34) were obtained in the manner outlined for entry (32) using data in Ref. a.
	34	18½N	73½E	147	58	3	9	233	25 N	78 W	N	4½	3½	*		

Linga and Khandala combined	35	—	—	155	53	—	—	—	28 N	85 W	N	—	—	a		*Sampling:* Average of Linga and Khandala results.
Kambatki Area	36	17½N	74 E	176	60	—	—	5	—	—	—	—	—	a	*Clegg et al. and Deutsch et al.*	*Sampling:* Of the 2 flows exposed at this area only 1 was stable, and the 5 oriented samples were from this flow. This flow is considered (Ref. b) to be near the bottom of the sequence. Values of *k* and α_{95} for entry (37) were obtained in the manner outlined for entry (32) using data in Ref. a. Since only one point in time was sampled, α_{95} as a measure of the average field direction should be larger.
	37	17½N	74 E	176	60	5	150	5	31 N	102 W	N	8	6	*	a Clegg, Deutsch, Everitt, and Stubbs, 1957	
Igatpuri Area	38	19½N	73½E	161	51	—	—	—	—	—	—	—	—	b	b Deutsch, Radakrishnamurty and Sahasrabudhe, 1959	*Sampling:* 4 samples were taken from each of 4 flows (Ref. b). One flow was unstable.
	39	19½N	73½E	161	51	—	—	—	35 N	86½W	N	—	—	*		
Nipani Area, Lower flows	40	16½N	74½E	170	57	—	—	44	—	—	—	—	—	a		*Sampling:* One flow was sampled at two sites (Ref. b). 4 anomalous specimens from 1 sample were excluded. Values of α_{95} and *k* for entry (42) were obtained as outlined for entry (32) using data in Table 2 of Ref. a.
	41	16½N	74½E	168	60	—	—	44	—	—	—	—	—	b		
	42	16½N	74½E	168	60	4	29	44	31½N	95 W	N	6	4½	*		
Nipani Area, Upper flows	43	16½N	74½E	340	−30	—	—	59	—	—	—	—	—	a		*Sampling:* At least 3 distinct flows spanning a stratigraphic thickness of 200 feet were sampled at 5 localities. These flows probably overlie the lower Nipani flows. Values of α_{95} and *k* for entry (45) were obtained as outlined for entry (32) using data in Ref. b.
	44	16½N	74½E	338	−32	—	—	74	—	—	—	—	—	b		
	45	16½N	74½E	338	−32	4	14	74	50 N	71½W	S	4½	2½	*		
Amba Area, Lower flows	46	17 N	74 E	141	59	—	—	54	—	—	—	—	—	a		*Sampling:* At least 5 flows were sampled at 8 sites in the Amba area; the results from the 5 lowest sites are combined here. Several samples with widely divergent directions were not used in the statistical analysis. Values of α_{95} and *k* for entry (48) were obtained as outlined for entry (32) using data in Ref. b.
	47	17 N	74 E	144	60	—	—	109	—	—	—	—	—	b		
	48	17 N	74 E	144	60	4	10	109	23 N	77 W	N	6	4½	*		
Amba Area, Upper flows	49	17 N	74 E	335	−23	—	—	34	—	—	—	—	—	a		*Sampling:* The results from the highest 3 of the 8 Amba sites are combined here; at least 5 flows were sampled at the 8 Amba sites. Values of α_{95} and *k* for entry (51) were obtained as outlined for entry (32) using data in Ref. b.
	50	17 N	74 E	335	−26	—	—	54	—	—	—	—	—	b		
	51	17 N	74 E	335	−26	7	8	54	50½N	66 W	S	7½	4	*		

TABLE 1.—*Continued*

Rocks Sampled	No.	Locality		Magnetic Direction					Pole Position						References	Remarks
		Lat.	Long.	Decl.	Incl.	α_{95}	k	N	Lat.	Long.	P	δm	δp	S		
SECTION I—*Continued*																
Pavagadh Area, Lower flows	52	22½N	71½E	348	−12	—	—	41	—	—	—	—	—	a		*Sampling:* 8 basic flows lying below an elevation of 2425 feet on Mt. Pavagadh were sampled. Values of α_{95} and k for entry (54) were obtained as outlined for entry (32) using data in Ref. b.
	53	22½N	71½E	351	−16	—	—	69	—	—	—	—	—	b		
	54	22½N	71½E	351	−16	7	5	69	58 N	91 W	S	7½	4	*		
Pavagadh Area, acid tuffs	55	22½N	71½E	357	15	—	—	17	—	—	—	—	—	a		*Sampling:* 15 specimen measurements were made on 8 samples of acid tuff collected at an elevation above 2490 feet on Mt. Pavagadh. They are post Deccan traps and may be post Eocene. Values of α_{95} and k for entry (57) were calculated as outlined for entry (32) using data in Ref. b. *Other:* Associated rhyolite flows show random directions, and laboratory tests indicate that these flows are unstable.
	56	22½N	71½E	355	17	—	—	15	—	—	—	-		b		
	57	**22½N**	**71½E**	**355**	**17**	**7**	**26**	**15**	**75½N**	**88 W**	**S**	**7½**	**4**	*		
UPPER DECCAN TRAPS AVERAGE	**58**	—	—	—	—	**13½**	**82**	**3**	**53 N**	**75½W**	**S**	**13½**	**13½**	*		*Sampling:* These values were computed by applying Fisher statistics to the upper Amba (51), upper Nipani (45), and lower Pavagadh (54) pole positions. There is no independent stratigraphic evidence correlating all these units, but the occurrence at several localities of normally magnetized flows overlying reversely magnetized flows has been interpreted (Ref. b) as supporting the correlation of all the normal flows and all the reversed flows.
LOWER DECCAN TRAPS AVERAGE	**59**	—	—	—	—	**8½**	**65**	**6**	**30½N**	**87 W**	N	**8½**	**8½**	*		*Sampling:* These values were computed by applying Fisher statistics to the lower Amba (48), lower Nipani (42), Igatpuri (39), Kambatki (37), Khandala (34), and Linga (32) pole positions. See also previous note.

Discussion of Results

General Statement

An attempt is here made to separate a discussion of the paleomagnetic data from a discussion of the conclusions that have been drawn from these studies. Individual paleomagnetic studies are briefly described first, emphasizing tests for stability and paleomagnetic applicability. All the virtual geomagnetic poles printed in boldface type in Table 1 are shown in the figures that accompany this section, and, since the reliability of the determinations varies widely, frequent reference to the data tables is recommended. The symbols used in the illustrations are explained in Table 2.

The sequence we have used for presenting the data places the post-Eocene first; this was done because these results are relatively simple and furnish a norm for comparison with the older results. The rest of the stratigraphic column is then discussed in sequence, beginning with the Precambrian. The section concludes with a discussion of the applications of paleomagnetic results to hypotheses such as polar wandering and continental drift.

Table 2.—Key to Figures 17, 20, 22–31, 35

ТАБЛИЦА 2.—УСЛОВНЫЕ ОБОЗНАЧЕНИЯ К РИСУНКАМ 17, 20, 22–32 и 35

VIRTUAL GEOMAGNETIC POLES

ИСТИННЫЕ ГЕОМАГНИТНЫЕ ПОЛЮСЫ

○	EUROPEAN ЕВРОПЕЙСКИЕ
□	NORTH AMERICAN СЕВЕРО-АМЕРИКАНСКИЕ
△	AUSTRALIAN АВСТРАЛИЙСКИЕ
▽	INDIAN ИНДИЙСКИЕ
▭	SOUTH AMERICAN ЮЖНО-АМЕРИКАНСКИЕ
◇	AFRICAN АФРИКАНСКИЕ
▯	ASIAN АЗИАТСКИЕ

POLARITY SYMBOLISM (APPLIES TO ALL SHAPES ABOVE AND NOT MERELY TO CIRCLES)
СИМВОЛЫ ПОЛЯРНОСТИ /ОТНОСЯТСЯ НЕ ТОЛЬКО К КРУЖКАМ, НО И КО ВСЕМ ВЫШЕПРИВЕДЕННЫМ УСЛОВНЫМ ОБОЗНАЧЕНИЯМ/

●	SOUTH MAGNETIC POLES ("NORMAL" POLARITY). ЮЖНЫЕ МАГНИТНЫЕ ПОЛЮСЫ/"НОРМАЛЬНАЯ" ПОЛЯРНОСТЬ/
○	NORTH MAGNETIC POLES ("REVERSED" POLARITY). СЕВЕРНЫЕ МАГНИТНЫЕ ПОЛЮСЫ/"ОБРАТНАЯ" ПОЛЯРНОСТЬ/
◑	POLES FROM MEASUREMENTS WITH MIXED POLARITY. ПОЛЮСЫ, ПОЛОЖЕНИЕ КОТОРЫХ ВЫСЧИТАНО ПО ИЗМЕРЕНИЯМ СМЕШАННОЙ ПОЛЯРНОСТИ
(dashed circle)	95 PER CENT CONFIDENCE LIMITS ГРАНИЦА 95% ТОЧНОСТИ

Post Eocene

Late Pleistocene and Recent.—The virtual geomagnetic pole positions for the data from this period are given in Section A of Table 1 and are shown graphically in Figure 17. The total sampling area represented is large, since two of the determinations are from North America, two are from Asia, and the remaining nine

European studies were made in areas as far apart as Iceland, Sicily, and Northern Sweden. The Sicilian measurements (**A 2**) (Chevallier, 1925, p. 146–158) were made on 11 lava flows from Mt. Etna extruded over a period of about 2300 years, the last one in 1911. The last two flows have average directions agreeing with nearby observatory measurements of the field, but there is no evidence of stability, other than the fact that the older flows have directions different from the present field direction. The Prästmon varves (**A 6**) (Bancroft, 1951) cover the period from 0 to A.D. 1000 and come from an area some 25 degrees north of the Sicilian lavas.

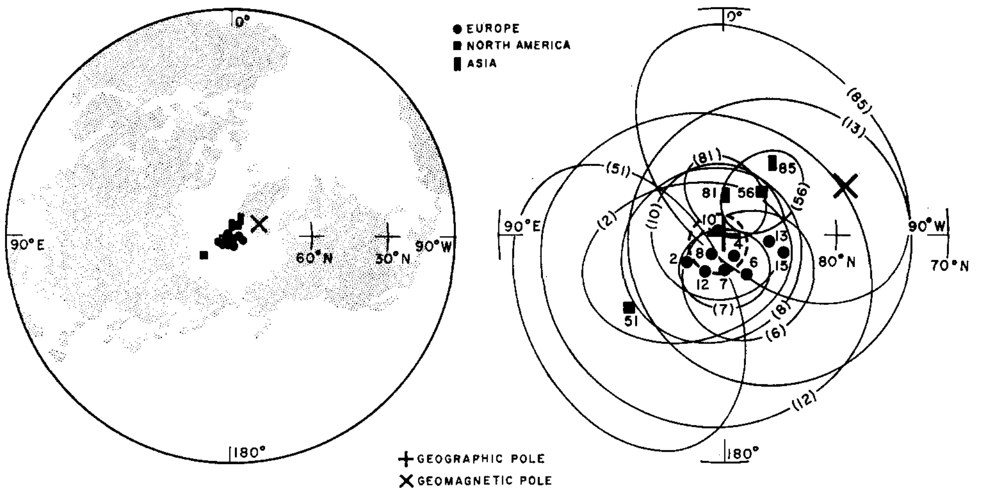

FIGURE 17.—LATE PLEISTOCENE AND RECENT VIRTUAL GEOMAGNETIC POLES (TABLE 1, SEC. A)
Mean poles and 95 per cent confidence intervals in region north of 70° N. Lat. are shown on the right. Heavy dashed circle is "α_{95}" calculated from mean pole positions but has no rigorous statistical significance. Numbers refer to entries in section A, Table 1.

Measurements of the remanent magnetism of kilns from Carthage have been reported by Thellier and Thellier (1951, p. 1477) (**A 4**). Two of the kilns were last fired in 146 B.C., and the third in 300 A.D., so that only two points in time are represented, and no statistical calculations can be made. Measurements on 14 archaeological specimens of fired clay (**A 7**) have been reported by Cook and Belshé (1958, p. 174). These specimens were all collected from Great Britain and are from the Roman period (first–fourth centuries) and the Middle Ages (twelfth, thirteenth, and fifteenth centuries). The measurements from the Middle Ages show easterly declinations, in agreement with direct observatory measurements made in London in 1600, but the earlier Roman measurements have westerly declinations.

Measurements on 150 samples from the Ångerman River varves (Griffiths, 1955, p. 108) collected at two localities a few kilometers apart were averaged into 29 groups each representing about 100 years; the mean value for each group was then used in the statistical analysis to compute pole **A 8**. The period covered is from 1100 B.C. to A.D. 750.

Brynjólfsson (1957, p. 252) has measured the direction of magnetization in 21 post-glacial lava flows from Iceland (**A 10**). Specimens from these flows, which cover the period from 3400 B.C. to A.D. 1950, were partially demagnetized in A.C. fields of 140 oersted before measurement, indicating that the reported directions were determined from magnetic components having high coercivities. Post-glacial lava flows from Iceland have also been measured by Hospers (1955, p. 63) (**A 12**). The consistency of both Bryjólfsson's and Hosper's measurements is good, k = 36 and k = 34, respectively.

Granar (1959, p. 27) sampled 10 sections of Swedish glacial and post-glacial varves over a lateral extent of some 800 km (**A 13**). Measurements on 10 upper Pleistocene lava flows from France (Roche, 1958, p. 3365) give the average pole numbered **A 15**. (Data necessary for a Fisher analysis were not available.)

Some of the first remanent magnetic measurements made on rocks from North America were those of Johnson and others (1948, p. 366) on glacial varves from several localities in New England (**A 51**). These measurements were grouped into sets representing about 1000 years each, covering the period from 13,000 to 7000 B.C. The average virtual geomagnetic pole is displaced from the geographic pole, and inclination errors such as those observed in artificially deposited varves (King, 1955, p. 121) would cause such a pole displacement in the observed direction, as Johnson and others (1948, p. 358) suggested. The magnetization direction in the varves thus probably does not represent the field direction at the time they were deposited, even though a fold test demonstrated the magnetic stability of at least some New England varves (Graham, 1949, p. 137–143).

The other measurements from North America are those on the Neroly formation of California (**A 56**) (Doell, 1956, p. 158). Although the rocks were deposited much earlier, it was shown that the magnetization was acquired after folding of post early Pleistocene age because application of Graham's fold test causes considerable scatter in the directions (the *in situ* directions are consistent). Partial demagnetization by heating to 100°C and cooling in zero field did not alter the magnetization, suggesting stability.

Measurements on 11 lava flows of Pleistocene to Recent age from Japan are given by Kumagai and others (1950, p. 62) (**A 85**). Watanabe (1958, p. 383–384) has reported magnetic directions for 45 archaeological fired clays and also two historically dated lava flows from Japan (**A 81**). These measurements cover the periods from 300 to 1800 A.D. and from about 5600 to 4400 B.C.; thus, some 2700 years has been sampled.

Several other groups of measurements which contain rocks from both this and preceding Tertiary time are discussed in the section on Oligocene through early Pleistocene measurements.

In summary, each of the 13 average geomagnetic poles calculated for late Pleistocene and Recent time were calculated from sets of samples that were probably magnetized over a period of several thousand years. (One possible exception is the Neroly formation (**A 56**); the magnetic history of this rock is somewhat obscure.) These poles are very tightly grouped, and a comparison with Figure 13 indicates, in fact, a much higher precision than for the virtual geomagnetic poles calculated from present field directions. This initially surprising result is easily explained, however, because each of the 13 paleomagnetically determined poles represents an average of several points in time. The nondipole components, which cause scatter in the present field, apparently have tended to cancel each other out. These paleomagnetic results are of great significance, since they clearly indicate that the basic configuration of the earth's field was that of a dipole with a fixed axis during the time these groups of rocks were magnetized. The tight grouping of virtual geomagnetic poles would not occur if the earth's field were not dipolar, nor if the average dipolar axis had moved between the times the different groups were magnetized.

In discussing historic observations of the earth's field we noted that there is little direct evidence that the earth's inclined dipolar axis has moved. If this axis had also been in its present inclined position throughout late Pleistocene and Recent time, we should expect to find the poles in Figure 17 grouped about the present geomagnetic pole rather than about the earth's *geographic* pole. Values of α_{95} should also be considered in evaluating the significance of this grouping, and from the correlation diagram (Fig. 18) it can be seen that two ovals of confidence encircle both poles, two ovals (from the Neroly formation and the New England varves) encircle neither pole, no oval includes the geomagnetic but not the geographic pole, and seven include the geographic pole but exclude the geomagnetic pole. There is thus very strong paleomagnetic evidence that throughout late Pleistocene and Recent time the earth's field, when averaged over a few thousand years, has been that of a dipole parallel to the present axis of rotation.

The reversal problem.—In contrast with the late Pleistocene and Recent results, about half the older post-Eocene rocks have magnetizations about 180° removed from the present direction of the earth's field. Before considering these results in detail, it is necessary, therefore, to consider briefly the problem of reversals. As noted before there are two interpretations of this phenomenon, one that the earth's field periodically reverses its polarity or, alternatively, that the rocks having reversed polarity possess a self-reversal mechanism. Although the problem is not completely resolved, it appears to us that some reversals are due to self-reversal and others to a reversal of the field. The investigation of the Haruna dacite by Uyeda (1958, p. 29–48) clearly shows that rocks can be self-reversing, and the correlation between inclination and mineralogy found by Balsley and Buddington (1954, p. 180) in metamorphic rocks strongly suggests a self-reversal. However, in thick sequences of alternating normal and reversed lava flows such as those in Iceland the reversals are not associated with changes in lithology (Einarsson, 1957, p. 233), and the PTRM curves for the reversed flows give no indication of a self-reversal mechanism (Hospers, 1953–1954, p. 487). Evidence given by Roche (1953, p. 108) also favors a reversal of the field; he found that four subjacent clays baked by reversely magnetized lava flows were also reversely magnetized. It seems improbable that in all four cases the subjacent clays as well as the lavas themselves would possess a self-reversal property. Einarsson and Sigurgeirsson (1955, p. 892) have also found numerous similar baked zones in Iceland; the baked rocks all have the same direction of magnetization as the baking flow (Fig. 19).

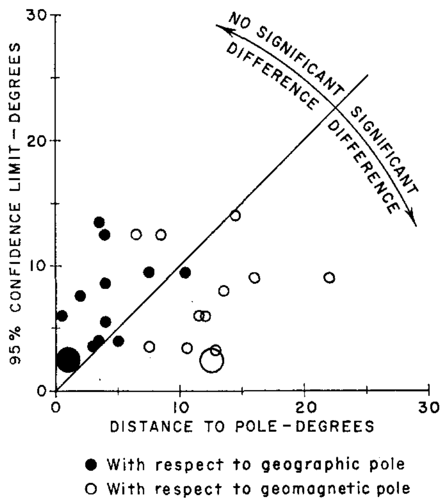

FIGURE 18.—CORRELATION DIAGRAM FOR LATE PLEISTOCENE AND RECENT POLES

Two points are plotted for each virtual geomagnetic pole (VGP); the abscissae of the two points are the lengths of the lines from the VGP to the geographic and geomagnetic poles respectively, and the ordinates are the semiaxes of the oval of confidence along these two lines. A point in the lower "significant difference" field thus indicates the pole lies outside the confidence interval. Large circles are for mean VGP position shown by heavy dashes in Figure 17.

The youngest reversely magnetized rocks are early Pleistocene or very late Pliocene in all the regions where reversely magnetized rocks have been found, including Japan (Nagata and others, 1957, p. 32), Iceland (Einarsson and Sigurgeirsson, 1955, p. 892; Hospers, 1953–1954, p. 475), France (Roche, 1953, p. 109; 1956, p. 814), and Russia (Khramov, 1957, p. 851). Although the exact ages of the rocks in most of these studies are subject to some uncertainty, the stratigraphic control is adequate to indicate that none of the late Pleistocene or Recent rocks which have been studied paleomagnetically are reversely magnetized. (The Haruna dacite samples were collected from a tuff for which there are no paleomagnetic data, but a young flow of this rock would presumably be reversed.) The last appearance of reversely magnetized rocks at about the same time in such widely separated areas suggests field reversal.

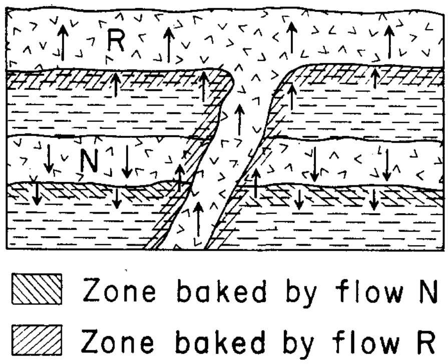

FIGURE 19.—MAGNETIC DIRECTIONS IN BAKED ZONES

Oligocene through early Pleistocene.—The virtual geomagnetic poles from paleomagnetic studies on Oligocene through early Pleistocene rocks are also given in Section A of Table 1. Thirteen of the 28 studies are from Europe, and the remainder from other continents. The most notable feature of these data in comparison with the late Pleistocene and Recent data is the large number of reversed magnetizations. Nine are of mixed polarity, 11 are consistently reversed, and 7 are entirely of normal polarity (Fig. 20).

Results from Icelandic lava flows of early Quaternary and Miocene age are given by Hospers (1955, p. 65, 68) and of Pliocene and Pleistocene age by Sigurgeirsson (1957, p. 243). The Quaternary flows studied by Hospers (**A 17**) all show reversed polarity, and although the precision is not high (k = 9) the reversed nature of the magnetization indicates stability. The Miocene flows (102 in number) (**A 34**) show about equal numbers of normal and reversed polarizations, occurring in four alternately reversed and normal zones. The consistency-of-reversals test indicates stability, and, because of the large number of flows measured, α_{95} is small despite the low value of k. Sigurgeirsson's studies, in which the samples were "cleaned" in A.C. fields of 110 oersted, resulted in much larger values for k. The mean pole for the reversely magnetized flows (**A 25**) is not significantly different from the geographic pole, but that for the normally magnetized flows (**A 23**) is, an effect which Sigurgeirsson (1957, p. 243) attributes to the small number of flows sampled in one part of the normal sequence.

Five determinations of the remanent magnetization of lava flows and intrusives from France, ranging in age from Oligocene to early Quaternary, have been reported by Roche (1958, p. 3365; 1951, p. 1133; 1950b, p. 1604; 1950a, p. 114). Six flows of Pliocene and Pleistocene age (**A 21**) have an average direction not significantly different from the geographic pole. However, five flows of Miocene and Pliocene age (**A 31**) and nine determinations on Oliogene intrusives (**A 48**) have circles of confidence that do not include the present geographic pole. Statistical data for the Limagne basalt (**A 46**) and eight flows of early Quaternary age (**A 19**) were not available. All the samples studied in these five determinations had reversed polarity.

Khramov (1957, p. 850) (**A 27** and **A 29**) studied 650 oriented samples of Pliocene and Pleistocene sediments from the Chelekan Peninsula. The samples show both normal and reversed polarity and indicate pole positions relatively far from the geographic pole. Because statistical data were not given a confidence interval could not be calculated.

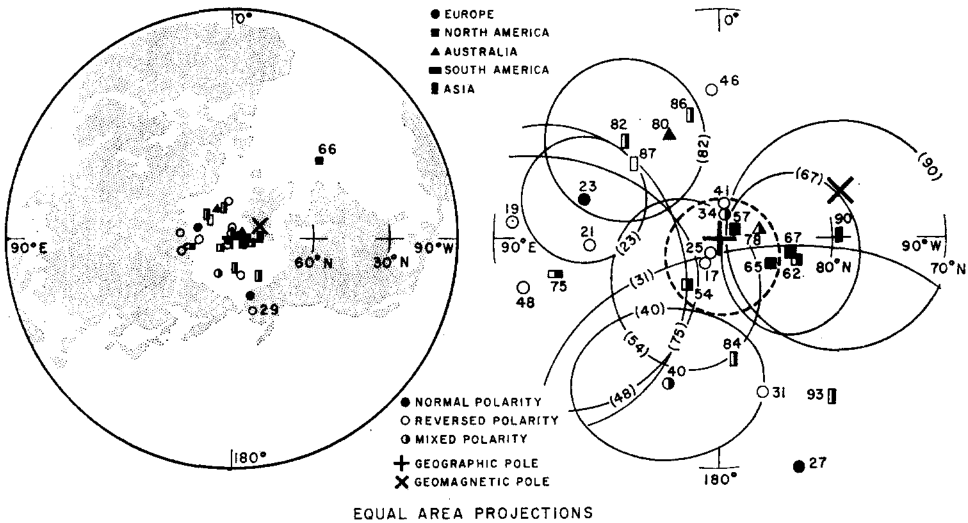

FIGURE 20.—OLIGOCENE THROUGH EARLY PLEISTOCENE VIRTUAL GEOMAGNETIC POLES (TABLE 1, SEC. A)
Mean poles in region north of 70° N. Lat. are shown on the right. Ovals of confidence are shown for only those poles significantly different from the geographic pole. Heavy dashed circle is "α_{95}" calculated from mean pole positions but has no rigorous significance. Numbers refer to those in section A, Table 1.

The circle of confidence calculated from the directions of magnetization of 42 lava flows from the Vogelsberg (**A 40**) (Angenheister, 1956, p. 190–191) includes neither the present geographic pole nor the geomagnetic pole. Thirteen of the flows have reversed polarity, and, treated separately, the reversed and normal flows do not have exactly the same average direction, indicating the presence of a secondary component of magnetization by the consistency-of-reversals test.

Bruckshaw and Robertson (1949, p. 316) found that all the samples from the North West Dikes of England (**A 41**) had directions of magnetization roughly opposed to the present field direction.

In contrast with the European measurements which, except for the Russian results, were all made on igneous rocks, most of the determinations from North America were made on sedimentary rocks. Twenty three oriented samples from the Ellensburg formation of late Miocene and early Pliocene age and 21 from the Arikaree formation of Miocene age studied by Torreson and others (1949, p. 125) yield poles **A 65** and **A 66** respectively. The poles are not significantly different from the geomagnetic pole, and there is no indication of stability. Torreson and others (1949, p. 125) also measured 13 oriented samples from the Payette formation of Miocene and

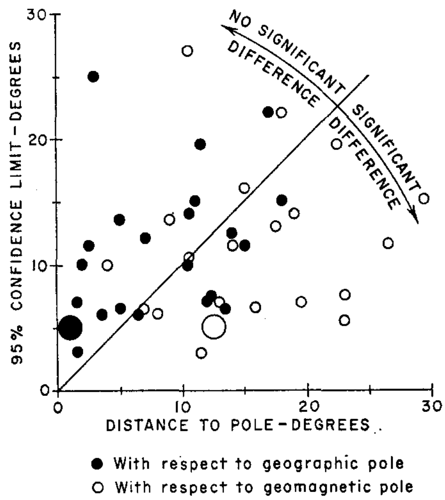

FIGURE 21.—CORRELATION DIAGRAM FOR OLIGOCENE THROUGH EARLY PLEISTOCENE POLES
See caption for Figure 18

Pliocene(?) age (**A 57**). These are all normally magnetized and have an unusually high precision parameter (k = 258). Collinson and Runcorn (1960) measured 24 samples of the Duchesne River formation from Utah (**A 67**). Like the other Tertiary sediments from North America these are all normally polarized. Du Bois (1959a, p. 1618) measured 46 samples collected from lava flows in northwestern Canada at four very widely separated localities (**A 54**). The direction of magnetization at two of the localities was reversed. The Columbia River basalt of Miocene age was extensively sampled by Campbell and Runcorn (1956, p. 450) (**A 62**). Twenty nine of the 73 flows sampled had reversed polarity.

Ten Quaternary lava flows from South America (**A 75**) have been studied by Creer (1958, p. 381). Some flows are normally, and some reversely polarized. The samples were all partially demagnetized in fields of 250 oersted A.C. before measurement so that the magnetizations reported are those of the higher coercive force magnetic constituents.

Two measurements are available from the southwest Pacific, one on the New Zealand ignimbrites (**A 80**) (Hatherton, 1954, p. 429), and the other on the Newer volcanics of Victoria (**A 78**) (Irving and Green, 1957, p. 351). Data necessary for computing Fisher statistics for the Pliocene ignimbrites were not available. The Newer volcanics of Victoria, sampled at 32 widely separated sites, range in age from Pliocene to Recent; 16 of these sites yielded samples with reversed polarity.

Six determinations from Japan are available for this interval—all made on volcanic rocks, and all but one including reversely magnetized samples. The oldest measurements are those of Matuyama (1929, p. 204) on lavas of Tertiary and younger ages collected at 36 localities throughout Japan and Manchuria (**A 84**). About half the samples have reversed polarity, and the scatter is probably somewhat increased because average co-ordinates for a sampling site had to be used.

Forty-two lava flows extruded more or less uniformly throughout the Quaternary are reported by Nagata and others (1957, Table 2) (**A 82**). Nine of the flows near the bottom of the sequence showed reversed polarities; the origin and stability of the magnetization measured in these lavas were very carefully studied by means of several laboratory tests.

Of the seven lava flows of late Tertiary age described by Kumagai and others (1950, p. 62) (**A 86**) only one has reversed polarity. One reversely magnetized lava flow of early Pleistocene age from Kawajiri was measured by Asami (1954a) giving pole **A 87**.

Two dolerite sheets, an andesite sheet, and four andesite lavas of Miocene age and two andesite lavas and two basalt lavas of Pliocene age have been studied by Nagata and others (1959, p. 380–381). The Pliocene flows (**A 90**) all have normal polarities, but three of the Miocene units (**A 93**) have reversed polarities.

In addition to the above studies, six lava flows stratigraphically between normally and reversely magnetized flows have intermediate directions of magnetization (Momose, 1958, p. 18); the data in this preliminary description are insufficient for the calculation of confidence limits.

Except for the occurrence of reversals and somewhat greater scatter in the virtual geomagnetic poles, the results from Oligocene through early Pleistocene time are very similar to those for the late Pleistocene and Recent. Only those ovals of confidence which do not encircle the present geographic pole are plotted in Figure 20; Figures 20 and 21 show that the poles farthest from the geographic pole generally have the largest ovals of confidence. Some of the ovals of confidence which do not encircle the geographic pole appear, for statistical reasons, to be too small (Table 1). As may be seen in the poles are shown in Figure 22 with their respective ovals of confidence; each oval is indicated by eight dashes around the virtual geomagnetic

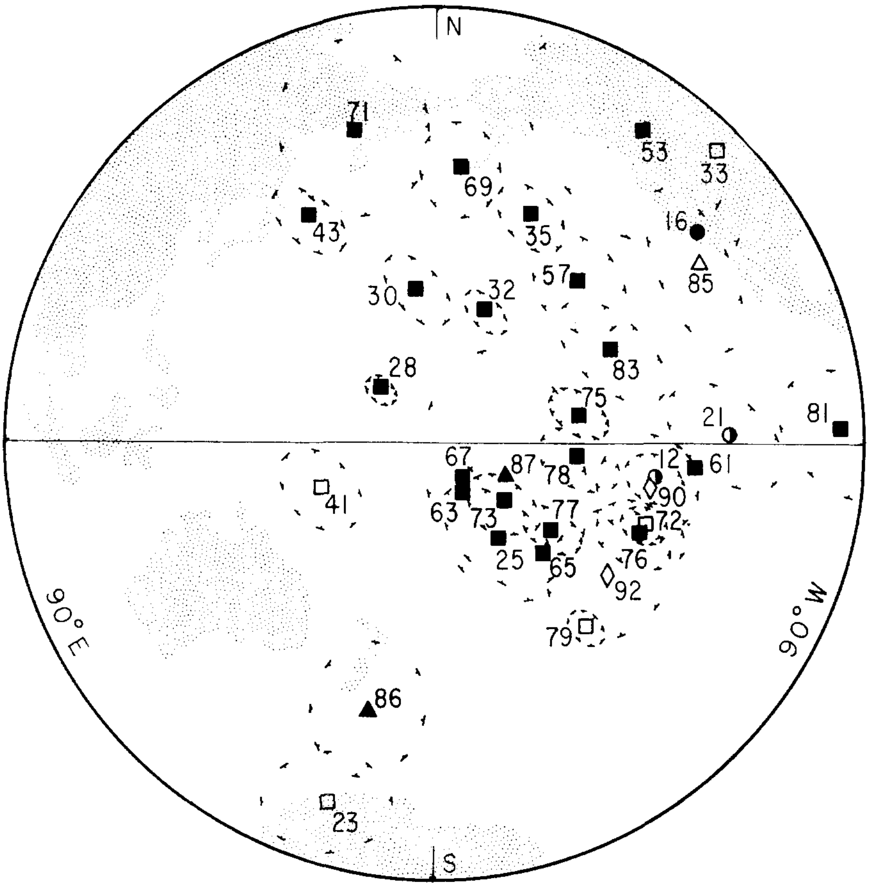

FIGURE 22.—PRECAMBRIAN VIRTUAL GEOMAGNETIC POLES (TABLE 1, SEC. B)

correlation diagram, the poles definitely group about the geographic pole rather than the geomagnetic pole, and it appears that, within somewhat broader limits than indicated for the late Pleistocene and Recent, the earth's average magnetic field throughout post-Eocene time was that of a dipole parallel to the present axis of rotation.

Precambrian

In striking contrast with results from the upper Tertiary, virtual geomagnetic poles calculated from all reported remanent magnetizations of rocks of Precambrian age are significantly different from the present geographic and geomagnetic poles. These virtual geomagnetic pole, a device introduced to avoid giving undue weight to data with large confidence intervals.

Two paleomagnetic studies have been made on British rocks of Precambrian age. From a paleomagnetic point of view the Torridonian sandstone (**B 12** and **B 16**) (Irving and Runcorn, 1957, p. 88) has been studied as carefully as any formation. Four hundred oriented samples were collected over a wide area and through a thick stratigraphic sequence, and the field tests indicating magnetic stability are very impressive. In conglomerates containing very fine-grained Torridonian pebbles, the directions of magnetization within pebbles are uniform, whereas those between pebbles are random; directions of magnetization in the beds are widely scattered before correcting for Caledonian folding but are nearly parallel after the correction. Only a relatively small proportion of the samples show evidence of instability, and the balance of the evidence certainly favors a field significantly different from the present field at the time these rocks were magnetized, which was before Caledonian time and probably in the Precambrian.

In the upper Torridonian (pole **B 12**) magnetizations fall into two groups which are approximately reversed with respect to each other; since the axes of the "normal" and "reversed" directions of magnetization differ significantly, the statistical combination of these two may have resulted in too low a value for α_{95}. The lower Torridonian sequence (**B 16**) has a direction *significantly different from that of the* upper, and in contrast has no reversals.

Stability of the late Precambrian Longmyndian formation (**B 21**) (Creer, 1957b, p. 126) is suggested by A.C. demagnetization experiments and Thellier's test (that is, there was no change in magnetic directions on remeasurement after storage in the earth's field). The pole lies between those for the upper and lower Torridonian (**B 12** and **B 16**).

Of the Canadian Keweenawan rocks studied by Du Bois (1957, p. 178) (**B 23, B 25, B 28, B 30**, and **B 32**) only the Freda sandstone and the Nonesuch shale (**B 28**) are folded and satisfy Graham's fold test. These data were shown in Figure 6 as an example of a fold test. The Copper Harbour formation (**B 30**) includes both sediments and lava flows; the sediments have an inclination 10° smaller than the intercalated lava flows, which is much smaller than the 63° difference between the mean direction of remanent magnetization and the present direction of the earth's field. Random directions of magnetization in pebbles of Copper Harbour lava in conglomerates also suggest stability. Two sedimentary formations from Newfoundland studied by Nairn and others (1959, p. 596) give the pole positions **B 81** and **B 83**.

The gabbro intrusives from southeastern Canada (**B 35, B 41, B 43**) (Hood, 1958) show some evidence of metamorphism. The gabbro is locally gneissic, and laboratory results strongly suggest susceptibility anisotropy so that these measurements may not be suitable for paleomagnetic purposes, even though A.C. demagnetization usually decreased the scatter in directions. A stronger case exists for the stability of magnetization of the Sudbury intrusive. The mean directions of magnetization of sets of samples collected on the north and south rims of this body lie on a small circle having, as its axis, the fold axis of the Sudbury basin. The simplest interpretation is that the magnetization predates the folding; the appropriate fold correction has been made in calculating pole **B 53**.

Stability of the magnetization of the Michigan diabase dikes (**B 33**) (Graham, 1953, p. 246) is indicated by their stability in A.C. magnetic fields up to 493 oersted, but other laboratory tests suggest that the present magnetization may have been acquired during chemical or phase changes after cooling (Graham, 1953, p. 252–254). The confidence interval about the pole position is artificially small because at *most only two points in time* are represented.

The pole for the Adirondack metamorphic rocks has not been plotted because the original workers (Balsley and Buddington, 1958, p. 790–792) have given convincing evidence that the directions of magnetization in these metamorphic rocks are controlled by the mineralogy and hence are not applicable to paleomagnetic interpretations.

The Hakatai shale has been sampled at two localities about 1° apart (**B 57** and **B 63**) (Runcorn, 1956a, 309; Collinson and Rundorn, 1960). Pole **B 65** is based on measurements by Collinson and Runcorn (1960) of samples from the underlying Bass limestone, which has a gradational contact with the Hakatai. Combined results from these two units based on measurements by Doell (1955a) (**B 61**) have a large oval of confidence which intersects the oval for pole **B 57** but not that of pole **B 65**. The Shinumo quartzite (**B 67**) (Collinson and Runcorn, 1960) overlies the Hakatai shale. The pole positions for these related formations, while scattered, show some measure of consistency. However, the differences emphasize the need for extensive sampling before pole positions can legitimately be regarded as representative of a given continent and geologic period.

The results for flat-lying beds (**B 69**) from the Hazel formation (Howell and others, 1958, p. 291) and for dipping beds after correction for dip (**B 71**) are not significantly different in mean direction, but differ considerably in amounts of scatter (k = 35 for flat lying, k = 3 for tilted beds), suggesting the presence of an unstable component of magnetization. The rocks may be slightly metamorphosed and hence unsuited for paleomagnetic applications.

The Belt series (**B 72, B 73, B 75, B 76, B 77, B 78**, and **B 79**) has been sampled over a wide region by Collinson and Runcorn (1960). The virtual geomagnetic poles from this series form a remarkably tight group in the vicinity of 10° S. and 150° W., and it would be very difficult to regard this grouping near the present equator as random. The mean directions of magnetization at two sites (**B 73** and **B 85**) are approximately reversed with respect to the others, satisfying the consistency-of-reversals stability test.

Results are available from three Australian formations (Irving and Green, 1958, p. 66): the Buldiva quartzite (**B 85**), the Nullagine lavas (**B 86**), and the Edith River volcanics (**B 87**) which are probably younger than the Nullagine lavas.

The Pilansberg dikes (**B 90**) were sampled at widely spaced localities and show excellent consistency of magnetizations (Gough, 1956, p. 206). Moreover, stability is suggested by the small changes of magnetization in alternating fields of 100 oersted. The Bushveld gabbro (**B 92**) was also sampled over a wide area (Gough and van Niekerk, 1959, p. 131), and its stability of magnetization is suggested by a considerable reduction in scatter on correcting for geologic dip, as inferred from pseudostratification in the gabbro. If a preferred orientation or layering of ferromagnetic grains accompanies the stratification, however, the original direction of TRM may not have been parallel to the applied field; Graham's fold test does not eliminate this possibility, and measurements of susceptibility anisotropy would be desirable (Girdler, 1959). Recently determined radio-isotope ages for these two bodies are 1290 m.y. for the Pilansberg (Schreiner, 1958, p. 1330) and 2000 m.y. for the Bushveld (Gough and van Niekerk, 1959, p. 127). In view of the large difference in age, the small distance between the poles (18°) is remarkable.

In summary, all the paleomagnetically studied Precambrian formations are magnetized in directions significantly different from that of the present field. Although there are grounds for reasonable doubt about the paleomagnetic applicability of some of the formations described, many of them satisfy the classic tests for stability. These tests are Graham's fold and conglomerate tests, Thellier's test for change of direction in the laboratory, stability of magnetization in A.C. fields, concurrent results from igneous and sedimentary rocks, consistency of directions different from that of the present field over wide sampling areas, and consistency of reversals. The balance of the evidence strongly suggests that the earth's field was not parallel to its present direction throughout Precambrian time.

The distribution and polarity of the virtual geomagnetic poles calculated for Precambrian formations from all continents do not appear to be entirely random. Most of the poles fall in a region covering about one-third of the hemisphere, and a concentration appears near the equator in the vicinity of 160° W. Some of the poles considerably removed from this region, however, are based on excellent data (for example, poles **B 16** and **B 28**).

Early Paleozoic

Because of the scarcity of results from the Cambrian through Devonian formations, they are grouped together, and the virtual geomagnetic poles are shown in Figure 23. One Cambrian formation from Europe has been studied, the Caerbwdy sandstone from South Wales (**C 45**) (Creer, 1957b, p. 123–124).

The directions of magnetization of the North American Wilberns formation, which was sampled at 10 localities spanning 55 miles, are distributed along a plane passing through the present direction of the earth's field (Howell and Martinez, 1957, p. 390–391). This indicates the presence of varying amounts of a magnetization parallel to the present field, and Howell and Martinez (1957, p. 391) calculate a pole position (**C 47**) from the group of measurements farthest removed from the present field direction. The Sawatch "quartzite" (**C 49**), a sandy dolomite, may have acquired its magnetization during a post-depositional dolomitization, and thus the pole may correspond to the earth's field in post-Cambrian time (Howell and Martinez, 1957, p. 391). A reversal occurs in the Lodore formation (**C 52**) (Collinson and Runcorn, 1960), satisfying the consistency-of-reversals stability test. The Deadwood formation (**C 53**) is cited as Mississippian by Collinson and Runcorn (1960); however, it contains unequivocal late Cambrian fossils at its type locality and is therefore listed here.

Two sets of Cambrian data are available from Australia, one from the Elder Mountain sandstone (**C 55**) and one from the igneous Antrim Plateau basalts (**C 56**) (both from Irving and Green, 1958, p. 66). Details of the sampling and evidence for stability have not been published; concordant results from igneous and sedimentary rocks like these, however, carry much more weight than either result would separately.

Two widely separated poles (**C 29** and **C 31**), based on measurements of Ukranian basalts (Komarov, 1959, p. 1221), are cited as probably Ordovician in age. However, Komarov (1959, p. 1223) states that they may not be the same age, but are both within the lower Paleozoic. Early Ordovician sediments near Leningrad have been sampled by Khramov (1958, p. 185). Pole **C 36** is the mean of a reversed (N) pole and a normal (S) pole that has been "corrected" for an unstable component. Pole position **C 38** (Graham, 1954, p. 219) is based on 45 samples from rocks of the Middle Ordovician Trenton group from New York. Thirty-five of the samples are from undisturbed flat-lying beds and have well-grouped directions of magnetization significantly different from the present field. Ten samples from a distorted zone, enclosed by stratiform beds, have much more scattered directions. However, most of the directions move toward the other group on

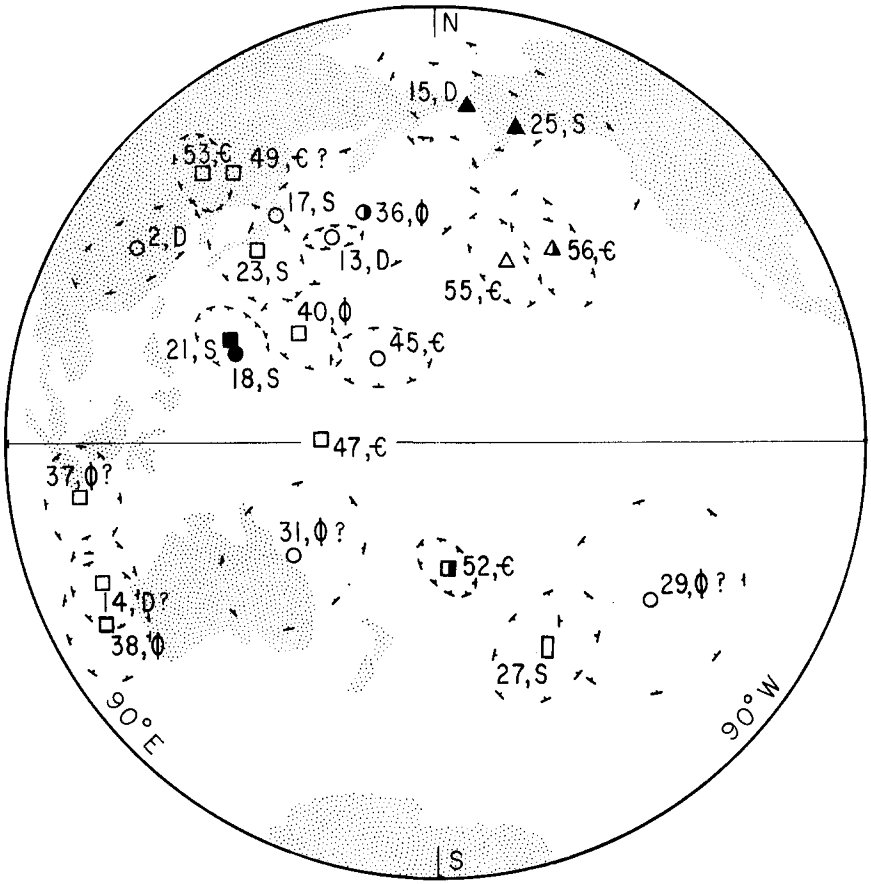

FIGURE 23.—EARLY PALEOZOIC VIRTUAL GEOMAGNETIC POLES (TABLE 1, SEC. C)

correcting for dip, and Graham (1954, p. 219) concludes that the magnetization has significant stability. Pole **C 37** is based on directions of magnetization in limestone cobbles of Trenton age in a conglomerate (Graham 1956, p. 738). Since the directions of magnetization are uniform from cobble to cobble, the magnetization must be post-depositional. Agreement with the previous results suggests, however, that not much time elapsed between deposition and magnetization. Pole position **C 40** is based on measurements of red beds in the North American Juniata formation of Late Ordovician age (Collinson and Runcorn, 1960).

The two Silurian units from Europe that have been studied are the Ludlow series (**C 17**) (Creer and others, 1954, p. 165) and the Ural peridotites (**C 18**) (Komarov, 1959, p. 1222) for which no confidence intervals or other details are available.

Two Middle Silurian formations from North America have been investigated, the Rose Hill formation of Swartz (1923) (**C 21**) (Graham, 1949, p. 148–154) and the Clinton iron ore (**C 23**) (Howell and others, 1958, p. 287–289). The Rose Hill determination is based on 35 oriented samples collected at 6 localities spanning 32 miles. At two localities the samples were collected on the limbs of small folds and at the remaining localities on the limbs of large folds. Directions of magnetization are widely scattered before correcting for dip and, except for three sample directions, are nearly parallel after the dip correction. The deformation occurred near the end of the Paleozoic, and Graham (1949, p. 151) concludes that the magnetization took place before the Permian and very probably at the time of deposition. The Clinton iron ore data are from a sampling area regarded by Howell and others (1958, p. 287) as too small to give a reliable pole position. The rocks have susceptibility anisotropy with the plane of maximum susceptibility nearly in the bedding plane, and the remanent magnetization associated with such a susceptibility anisotropy will probably have a smaller inclination than that of the earth's field in which it developed. The Clinton formation and the Rose Hill formation of Swartz (1923) are both of Middle Silurian age, so that, if the earth's field at this time was that of a dipole consistent with the Rose Hill paleomagnetic results, the field at the Clinton site would have been D = 320, I = −28, or D = 140, I = 28, depending on whether the "normal" or "reversed" sense is taken. The average direction of magnetization of the Clinton rocks is D = 140°, I = 19½°. Since the difference in inclination is in the direction anticipated on the basis of the susceptibility anisotropy, this careful laboratory study by Howell and others supports the results obtained from the study of the Rose Hill formation.

Details of the investigation of the Mugga porphyry from Australia (**C 25**) (Irving and Green, 1958, p. 66) have not been published. The data for the Silurian Red siltstones from China (**C 27**) consist of measurements of specimens from only three oriented samples and, as Chang Wen-You and Nairn (1959, p. 254) state, should be regarded as provisional.

The British Old Red sandstone of Devonian age has been the subject of two independent studies. Clegg and others (1954a, p. 587–588) examined specimens from three oriented samples collected at a single locality (**C 2**) and found that the magnetization was stable in weak D.C. and in strong A.C. magnetic fields. Creer (1957b, p. 113–123) sampled much more widely and noted that flat-lying beds gave consistent results (**C 13**), whereas the directions from folded beds after correcting for tilt were widely scattered, indicating the presence of an unstable component.

The paleomagnetism of one North American formation of Devonian age, the Onondaga limestone, has been studied (**C 14**) (Graham, 1956, p. 738). Directions of magnetization are parallel throughout both layered beds and beds showing penecontemporaneous deformation, indicating post-depositional remanent magnetization. Although the consistency of the results and their divergence from the present field direction point to some stability, the age and origin of the magnetization are uncertain.

The Ainslie volcanic rocks from Australia (**C 15**) (Irving and Green, 1958, p. 66) are probably Devonian but may be Silurian.

In addition, Graham (1954, p. 216) has measured 182 samples from 14 exposures of Ordovician to Permian age in the northeastern United States, with emphasis on the older rocks. Most of these have polarizations within about 30° of the present direction of the earth's field, and there is evidence that some of them are stable and some partially stable. Separate data for each formation are not given (with the exception of that for pole **C 38**), so individual poles could not be computed.

Carboniferous

Many data are available from lava flows, intrusive rocks, sediments, and baked sediments of Carboniferous age from Great Britain. Virtual geomagnetic poles and associated confidence limits for these and other Carboniferous studies are shown in Figure 24. Igneous rocks, probably of late Carboniferous age, and sediments baked by them were sampled at six sites in England spanning 30 miles (**D 5**) (Clegg and others, 1957, p. 220). Samples from adjacent unbaked sediments have random directions of magnetization, whereas the baked sediments have closely parallel directions and intensities of magnetization 100 times larger than those of the unbaked rocks. Pole position **D 8** is from another set of sediments baked by an intrusive of late Carboniferous age (Clegg and others, 1957, p. 220).

Unbaked sediments from Great Britain that Wales has widely scattered directions and no correlation with the above results (Belshé, 1957, p. 188).

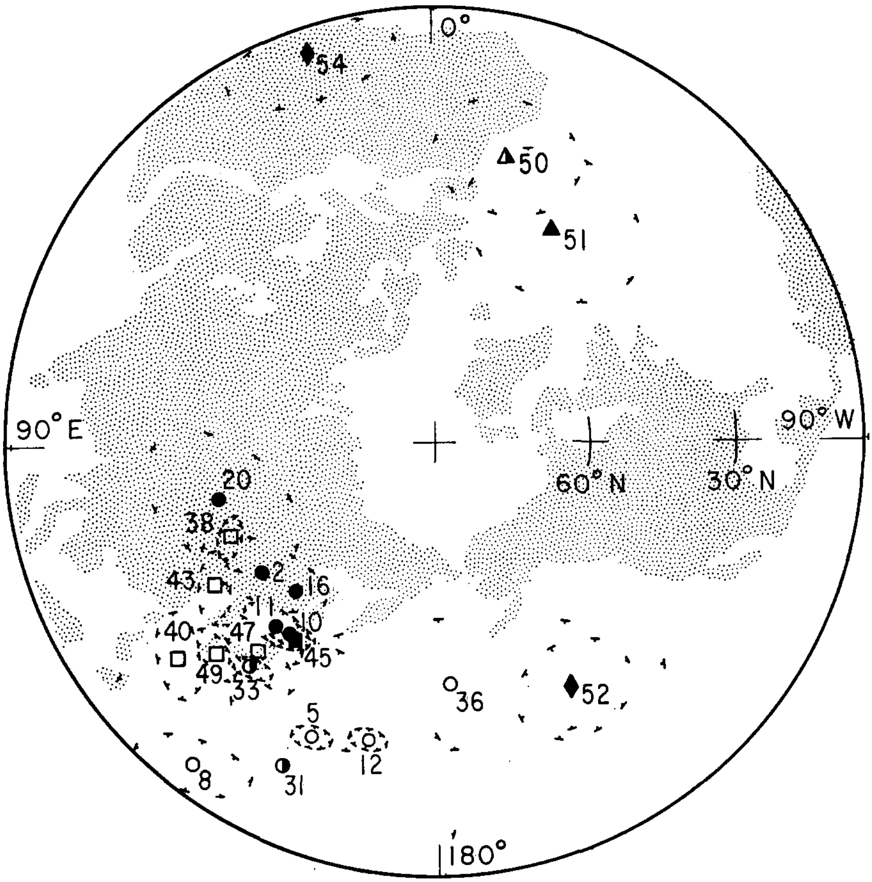

FIGURE 24.—CARBONIFEROUS VIRTUAL GEOMAGNETIC POLES (TABLE 1, SEC. D)

have been studied paleomagnetically include the Gloucester Pennant sandstone (**D 2**) (Clegg and others, 1954a, p. 588), the Pendle Monocline sediments of Lancashire (**D 10**), the Millstone Grit of Lancashire (**D 12**), other Lancashire sediments (**D 11**), and sandstones and siltstones from Derbyshire (**D 16**); the last four are from Belshé's (1957) data. The magnetizations of the 14 specimens from one oriented sample that constituted the data for pole position **D 2** were stable in A.C. fields of several hundred oersted. Stability for the magnetization corresponding to pole position **D 10** is supported by a fold test. The data for the other pole positions (**D 11, D 12,** and **D 16**) show considerable scatter, and an additional set of 50 Carboniferous sediment samples from

Interbedded with the Derbyshire sediments (**D 16**) are three volcanic units (**D 20**) with well-grouped directions of magnetization which are not significantly different from the direction of the sediment (Belshé, 1957, p. 188). A sequence of 15 lava flows of early Carboniferous age from Scotland falls into three stratigraphic groups, two with approximately parallel magnetizations separated by one with approximately opposed magnetization (Clegg and others, 1957, p. 221). The mean directions of magnetization of these three groups have been used by the present authors to calculate pole position **D 31**.

Samples from two sites 200 yards apart in the Shatterford intrusion (**D 33**), and undoubtedly from the same intrusive unit, have tightly grouped directions of magnetization almost exactly 180° apart, satisfying the consistency-of-reversals stability test (Clegg and others, 1957, p. 222). Five samples from the Lundy granite, studied by Blundell (1957, p. 191) (**D 36**), are weakly magnetized; however, application of Thellier's test after a month in the laboratory indicates some magnetic stability.

All the paleomagnetic determinations for the Carboniferous of North America are on sedimentary rocks. The Naco formation of Pennsylvanian age was sampled at two localities yielding poles **D 38** (Runcorn, 1956a, p. 309) and **D 40**, (Collinson and Runcorn, 1960). The angular difference between the mean directions of magnetization of these two localities is much less than the difference of either from the present field direction; however, the confidence intervals for these two determinations do not intersect, illustrating the importance of regarding the results from a single sampling site as applying to that site only and not necessarily to the entire formation. The mean directions of magnetization of eight sites spanning 73 miles in the Barnett formation of Mississippian age (**D 43**) are approximately reversed with respect to the mean direction of a ninth site (**D 45**) (Howell and Martinez, 1957, p. 385–388). The magnetization appears to be chemical in origin, and the fair agreement in direction between normal and reversed sites gives evidence of magnetic stability. Pole position **D 47** (Nairn and others, 1959, p. 596) is based on data from the Codroy group of sediments from Newfoundland, and pole **D 49** on combined measurements from the Bonaventure, Kennebacasis, and Bathurst formations of southeastern Canada (Du Bois, 1959b, p. 63).

Two sets of data are available from Australia. Irving (1957b) collected 75 oriented samples from the Kattung varved sediments at four sites (**D 50**). The mean directions of magnetization are very widely scattered before correcting for Permian folding, but are in striking agreement after correcting for dip; moreover, samples from one site are reversely magnetized with respect to those at the other three. Thus both the fold test and consistency-of-reversals test for magnetic stability are satisfied. Pole position **D 51** for the Kattung lavas (Irving and Green, 1958, p. 66) does not differ significantly from that for the varves, and the agreement between the results from igneous rocks and those from sediments also points to stability.

The only results from Africa (**D 52** and **D 54**) (Creer and others, 1948, p. 495) are based on measurements of 19 specimens from four oriented samples which fall into two groups with mean directions 157° apart. In the absence of stability tests, these poles should be viewed with some reservation.

In summary, the virtual geomagnetic poles calculated for the sedimentary formations of Carboniferous age from North America show a remarkable grouping in the vicinity of 36°N., 115°E. The virtual geomagnetic poles calculated from English rocks also fall in this general region but may be subdivided into two groups, one of which agrees very closely with the North American results (poles **D 20**, **D 2**, **D 16**, **D 11**, **D 10**, and **D 33**) and one of which does not (poles **D 8**, **D 31**, **D 5**, **D 12**, and **D 36**). Two determinations from the latter group (**D 31** and **D 36**) have large ovals of confidence, and the significance of their deviations from the other British group is doubtful. The remaining virtual geomagnetic poles, especially **D 5** and **D 8**, based on intrusive rocks and associated baked sediments, are undoubtedly significantly different. Among several possible interpretations of these two groups of poles, Clegg and others (1957, p. 221–222) considered the following: (a) These rocks may have been magnetized after the Carboniferous; this appears unlikely in view of the evidence relating the magnetization in the baked sediments to the Carboniferous intrusives. (b) The original magnetization may not have been parallel to the earth's field. (c) The earth's field may not have been that of a dipole which remained relatively fixed with respect to the mantle during the Carboniferous. We have tried to fit these data to an axial quadrupole field (*see* Creer and others, 1957, p. 148), for equations of this field) without success. A considerable interval of time is covered by these determinations, however, and it is therefore unlikely that the virtual geomagnetic poles calculated from the North American results, with sampling sites as far apart as Arizona and Newfoundland, would be so well grouped if the earth's field were nondipolar, or if it were changing rapidly during this period. The inconsistency between these two groups of European paleomagnetic poles remains an important unsolved problem.

Viewing the Carboniferous data on a somewhat larger scale, it would be difficult not to recognize that there is excellent evidence for a magnetic field in Carboniferous times different from the present one. Virtual geomagnetic poles calculated from English and American paleomagnetic directions form a group which is far from random, and the Australian poles, calculated from concordant results from igneous rocks and sediments and with several indications of stability, are certainly significantly different from the North American and European group.

Permian

Paleomagnetic results are available from volcanic, intrusive, and sedimentary rocks of Permian age from Great Britain and continental Europe; Figure 25 shows the virtual geomagnetic poles computed from these data. Pole position **E 4** is based on the mean direction of five lava flows from the Exeter volcanic series (Creer, 1957b, p. 112–113). Pole **E 8** is based on data from the Mauchline lavas, and **E 6** on data from the associated Mauchline sedimentary rocks (Du Bois, 1957, p. 178). The Ayrshire kylites (**E 22**) (Armstrong 1957, p. 1277), which intrude the Coal Measures and are cut by Permian volcanic necks, were sampled at five sites.

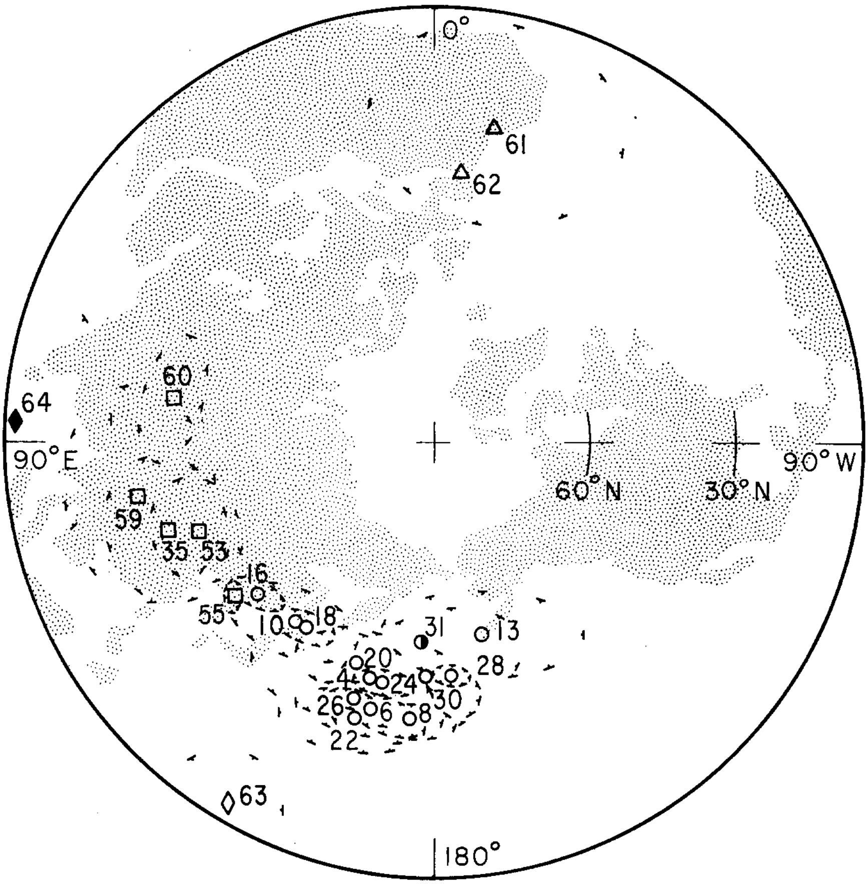

FIGURE 25.—PERMIAN VIRTUAL GEOMAGNETIC POLES (TABLE 1, SEC. E)

Poles **E 16**, **E 10**, **E 13**, and **E 18** are based on studies of several units in the Esterel volcanic rocks of southeastern France (Rutten and others, 1957, p. 195; Roche, 1957, p. 2953; As and Zijderveld, 1958, p. 317). **E 16** is based on 14 samples from a single flow and hence a single point in time, and, therefore, the small value of α_{95} does not have the usual paleomagnetic significance. Stability is indicated for the Esterel rocks (pole **E 18**) by the reduction of scatter in directions on partial demagnetization at 150°C. and in an A.C. field of 300 oersted, and also by a fold test.

Two other determinations from European igneous rocks are pole **E 24**, based on measurements of samples from the middle Permian Niedeck porphyry from France (Nairn, 1957b, p. 722), and pole **E 20** based on a number of separate igneous units sampled in the Oslo graben (Rutten and others, 1957b, p. 195).

only reversals in all reported Permian paleomagnetic data—the scatter in the measurements is so extreme as to leave this suggestion unsubstantiated.

The individual virtual geomagnetic poles

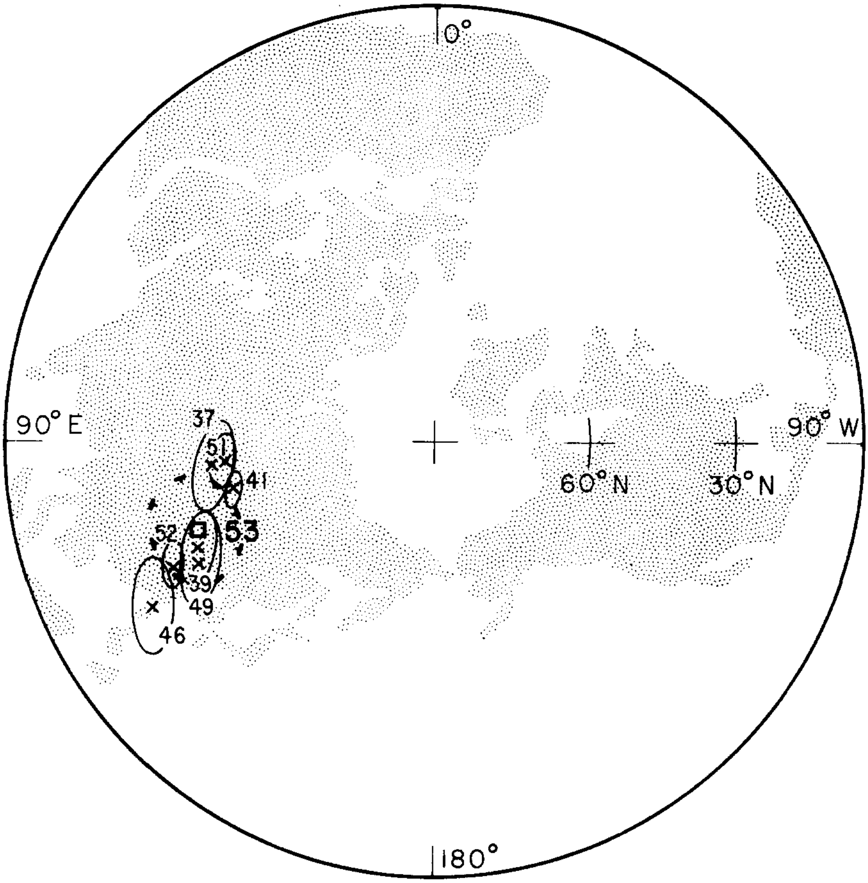

FIGURE 26.—POLES AND CONFIDENCE INTERVALS FOR THE SUPAI FORMATION

Virtual geomagnetic poles corresponding to mean directions at different sampling sites are indicated by X. Numbers refer to entries in section E, Table 1.

Two sedimentary formations from France, the Montcenis and the Saint-Wendel, give poles **E 26** and **E 28**. Twenty-two additional samples from the Montcenis and other sedimentary formations (Nairn, 1957b, p. 722) have directions of magnetization which are either scattered or roughly parallel to the present field; Nairn (1957b, p. 722) regards these as unstable. Late Permian sediments have been sampled at two localities in Central Russia (**E 30** and **E 31**) by Khramov (1958, p. 187). Although reversed magnetizations are suggested for the Tartarskij sediments—the

corresponding to seven separate studies of the North American Supai formation (Permian and Pennsylvanian) at sampling sites spanning several hundred miles are plotted in Figure 26, together with the mean pole position **E 53**. Poles **E 37** (Collinson and Runcorn, 1960) and **E 39** (Graham, 1955, p. 343) correspond to sets of samples collected at about the same locality. Poles **E 46** (Runcorn, 1955b, p. 505) and **E 49** (Doell, 1955b, p. 1167) are based on samples collected at a different locality.

The variations in the pole positions computed from the Supai data give some idea of the expectable variations in paleomagnetic studies of sediments and indicate that different populations of magnetic directions have probably been sampled at the different sites. Such differences between two undisplaced points within a formation are entirely normal and possibly are due to their having acquired magnetizations at different times. Again these studies emphasize the importance of not interpreting the results of a statistical analysis of measurements from one sampling site as necessarily applying to the entire formation, geologic period, or continent in which the sampling site is situated.

As one views these results from the Supai formation on a somewhat larger scale, the consistency between the average directions of magnetization is more impressive than the differences. Three groups of workers collected oriented samples independently at widely separated sites, transported them in different ways to different laboratories, machined cubes, cylinders, or discs from the samples, and measured the remanent moments using several types of spinner and astatic magnetometers. Thus the variations observed between different sets of data from the Supai include the effects of experimental errors as well as the actual variations in direction of magnetization between sampling sites.

The mean pole position for the Supai formation (**E 53**) is the result of a Fisher statistical analysis of the seven mean poles. Since these individual data have different values of α_{95}, no rigorous statistical significance should be attached to the circle of confidence calculated for pole **E 53**.

The Cutler formation was sampled at two localities by Graham (1955, Fig. 7) and by Collinson and Runcorn (1960). Pole **E 35** is midway between the two mean poles for these sets of data; "α_{95}" is taken as half the angular distance between the two poles but has no other significance. The Abo formation (**E 59**) is similarly based on data from two sites, and the Yeso formation (**E 55**) and the Sangre de Cristo formation (**E 60**) are each based on samples from a single site (all calculated from data of Graham, 1955, Fig. 7). The Sangre de Cristo formation includes rocks of middle or late Pennsylvanian age as well as early Permian age.

The two Australian virtual geomagnetic poles are based on samples from three lava flows from the Upper Marine volcanic series (**E 61**) and one flow from the Lower Marine volcanic series (**E 62**) (Irving and Green, 1958, p. 66). The two widely spaced poles from Africa are based on sediments of late Permian (**E 63**) and early Permian (**E 64**) age (Creer and others, 1958, p. 495).

A striking feature of the Permian paleomagnetic results is the separation of European from North American virtual geomagnetic poles. The results from European igneous rocks (poles **E 4**, **E 8**, **E 10**, **E 13**, **E 18**, **E 20**, **E 22**, **E 24**) show no systematic difference from those of the European sediments (poles **E 6**, **E 26**, **E 28**) However, the group of poles calculated from North American sediments is quite probably significantly different.

A possible explanation of the separation of these two sets of data is that the earth's field was not dipolar during the Permian. As noted in the section on the earth's field, the relative motion between core and mantle leads to an average field symmetrical with respect to the axis of rotation (Runcorn, 1959, p. 91). To test the hypothesis of an axial, nondipole field, three sets of data from three widely spaced localities would, in general, be required; intersection at a point P of the three great circles lying along the directions of the horizontal field components at the three localities would constitute support for the hypothesis.

In the special case where results from only two sampling areas are available but the areas happen to be equidistant from the point of intersection P, the hypothesis may also be tested, inasmuch as axial symmetry of the field requires that the sampling areas have the same average inclination. The mean Permian sampling areas in Europe and North America are both about 62° away from the corresponding point of intersection P (Fig. 27). The two sets of inclinations are:

Europe:	−9°, −6°, −4°, −16°, −13°, −22½°, −16°, −33°, +1½°, −7°, +6°, −9°
North America:	+6°, +32½°, +10°, +9½°, +2°, +23°, +8°, +5°, +18°, −1°, +8°, +55°, +30½°

These differences in inclination between Europe and North America appear to be systematic, and therefore an axially symmetrical nondipole field does not appear to be a suitable explanation for the differences between European and North American virtual geomagnetic poles.

A second striking feature of the North American and European Permian results is that all the field directions have the same polarity—

there are no "reversals." (The Tartarskij sediments may be an exception.) If the field-reversal hypothesis is incorrect, the interpretation that must be made is that mineral assemblages necessary for self-reversal are abundant in Carboniferous and Triassic rocks since both these periods have many reversals, but are missing in all (or almost all) Permian rocks studied to date. The interpretation of this feature on the basis of the field-reversal hypothesis is that oscillations in the polarity of the earth's field have been intermittent. The latter interpretation appears to us somewhat more plausible.

The two results from the Permian of Australia are consistent with each other but not with the general grouping of results from North America and Europe. Although these Australian results are based on estimates of the field at only four points in time during the Permian, they are consistent with the excellent Australian Carboniferous data.

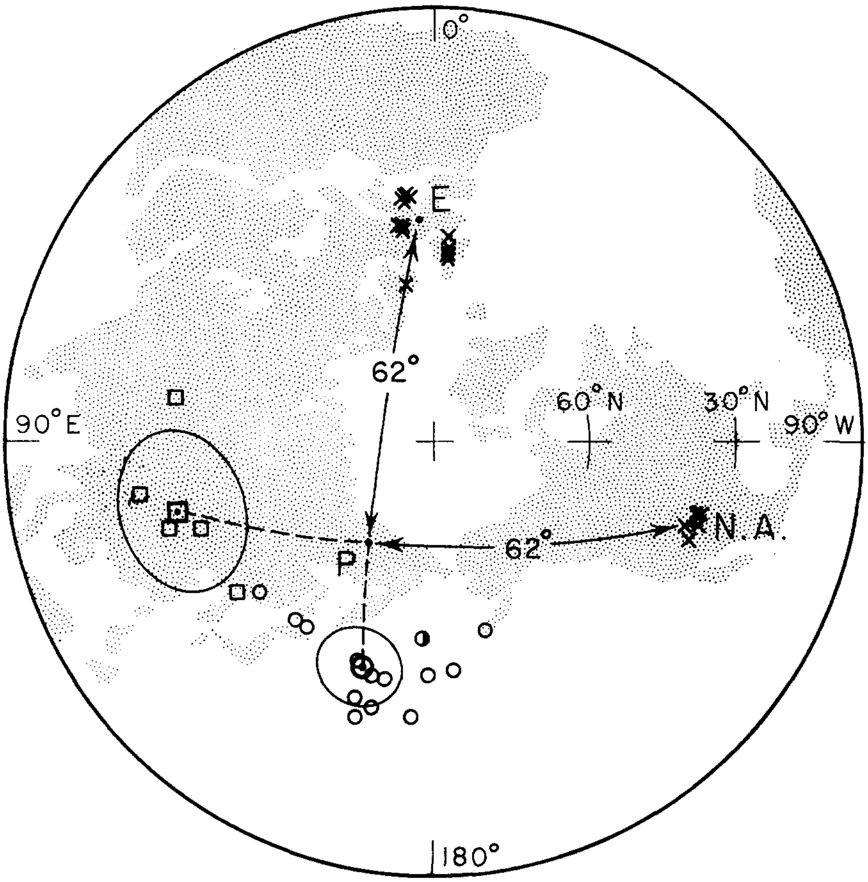

FIGURE 27.—TEST FOR AXIAL, NONDIPOLE FIELD

P is the intersection of great circles connecting mean sampling sites and mean virtual geomagnetic poles, as indicated by a heavy square (North America) and a heavy circle (Europe).

Triassic

The Triassic poles are plotted in Figure 28. The nine sampling sites in the Keuper Marl sandstones from England (Clegg and others, 1954a; 1954b, p. 195) fall into two groups which have directions of magnetization approximately reversed with respect to each other. These sediments are stable in weak D.C. fields and in strong A.C. fields and satisfy a fold test for rather shallow dips. Pole **F 12** is based on the nine mean site directions as listed in the original paper. Creer (1957a, p. 136) showed that Keuper Marl samples collected at many other localities have two components of magnetization, one stable, the other unstable; the stable one is essentially parallel to that described by Clegg.

Pole **F 13** combines the results of measurements on sediments of early Triassic age from seven sites in the Vosges region of France. There is considerable scatter in directions of magnetization, which has been interpreted by Clegg and others (1957, p. 225) to be indicative of partial instability. Of the seven localities in Spain where sedimentary samples were collected, only three localities had consistent directions of magnetization (**F 15** and **F 16**) (Clegg and others, 1957, p. 225–226). Pole (**F 16**) combines data from two sites. Data for the Vetlujskij sediments (**F 20**) are given by Khramov (1958, p. 187).

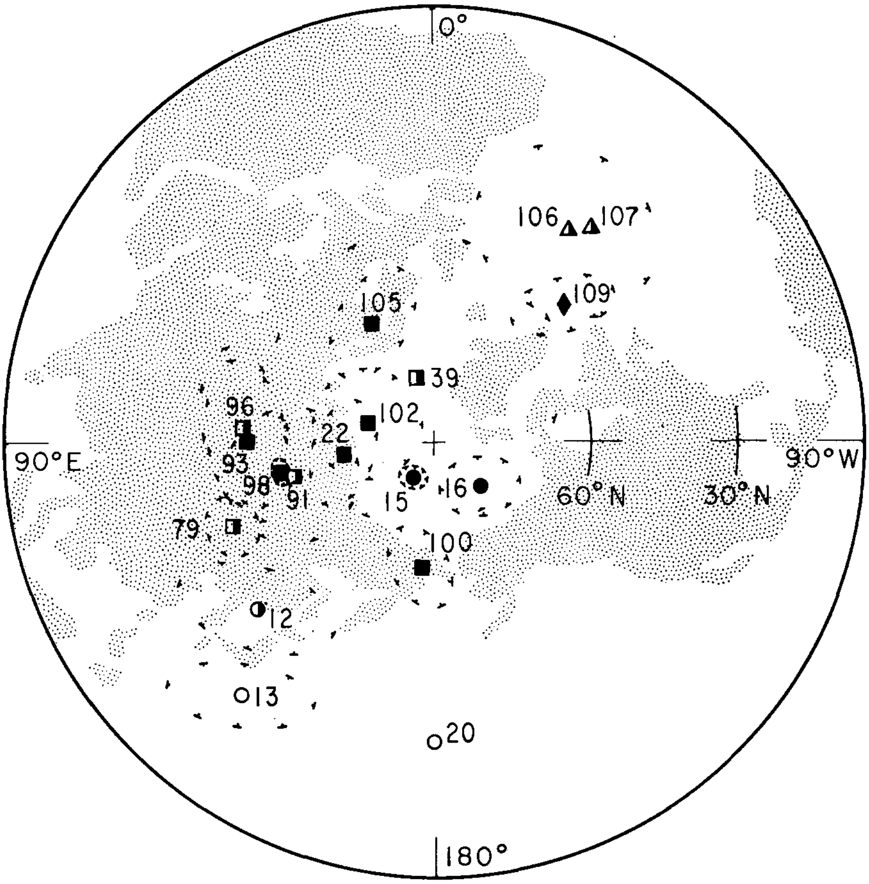

Figure 28.—Triassic Virtual Geomagnetic Poles (Table 1, Sec. F)*

Several Triassic formations from North America have been sampled extensively at a large number of sites, and in order to present all the data on a single plot only one mean pole position is shown for each formation; for intraformational details the reader is referred to Section F of Table 1. Pole **F 39** is based on work by several workers at eight sampling sites in the Chinle formation or formations of equivalent Late Triassic age (Graham, 1955, Fig. 7; Collinson and Runcorn, 1960). At some of the sites an unstable component of magnetization is probably present (Collinson and Runcorn, 1960), and our use of the actual measured directions in the statistical analysis rather than the direction of an inferred stable component may have resulted in a position too far north for pole **F 39**. Five of the sites are normally magnetized, one site is probably reversed, and at two sites most of the samples are normal, but several are reversed.

Pole **F 79** is based on a very extensive sampling of the Chugwater formation by Collinson and Runcorn (1960). At 7 of the 10 widely spaced sampling sites both normal and reversed groups of magnetizations were encountered; in the statistical calculations for pole **F 79** each group, whether normal or reversed, was treated as a separate measurement. The scatter of poles corresponding to the mean site directions is unusually small (k = 57), and these data show excellent stability by the consistency-of-reversals test.

The Moenkopi formation of Early and Middle (?) Triassic age (**F 91**) has been sampled at seven sites by Runcorn (1956a, p. 311–312), Kintzinger (1957, p. 931), and Collinson and Runcorn (1960). The four normally magnetized and the three reversely magnetized sites appear to form two separate groups; the poles of the normal group are north of the others. Thus the consistency-of-reversals test is not satisfied, indicating the presence of a comparatively small unstable component of magnetization. However, as pointed out by Creer and others (1957, p. 151), the average position of the two groups probably corresponds reasonably well to the stable component of magnetization. The Springdale sandstone member of the Moenave formation (**F 22**) (Runcorn, 1956a, p. 312–314) was sampled at one site and is probably partially unstable.

Poles **F 93** and **F 96** are based respectively on the magnetizations of lava flows and on those of sediments and lava flows combined, all from the Connecticut Valley (Du Bois and others, 1957, p. 1186). Pole **F 98** (Du Bois and others, 1957, p. 1186) is based on data from sediments at the top of the Newark group, and pole **F 100** (Graham, 1955, Fig. 7) on sediments from the bottom of this same group. Lavas from Nova Scotia were sampled at 12 sites by Bowker (letter of November 16, 1959, to Doell), and pole **F 102** is the mean of the virtual geomagnetic poles calculated for each of the 12 sites. The Dinosaur Canyon sandstone member of the Moenave formation, studied by Kintzinger (1957, p. 931) (**F 105**), is Late Triassic(?).

Pole **F 106** was calculated from measurements of the average inclination of unoriented vertical core samples from Tasmanian volcanic tuffs (Almond and others, 1956, p. 775); the steep inclination of 81½° implies a virtual geomagnetic pole within 16° of the sampling site. Deviations of the core hole from the vertical, a common occurrence, may contribute an additional uncertainty. Pole **F 107** (Irving and Green, 1958, p. 66) is based on measurements of oriented surface samples of the Brisbane tuff, and it is of interest to note that the pole inferred from the unoriented vertical core samples is in agreement with this pole. Pole **F 109** is based on sediments of Late Triassic age from Africa (Nairn, 1957a, p. 166–167); there is good internal consistency in this study, but contemporaneous sediments from adjacent localities have widely scattered directions.

All but one of the poles calculated from Triassic paleomagnetic measurements are significantly displaced from the present geographic pole. The North American poles are very roughly grouped at about 60° N. and 105° E., but many poles for individual formations are displaced considerably from this position. Reversals in both igneous and sedimentary formations are common.

Jurassic

Jurassic virtual geomagnetic poles are plotted in Figure 29. Pole **G 2** is based on results from English rocks which may be unstable (Nairn, 1957c, p. 311–312). Pole **G 5** is based on measurements of six oriented samples from several British Lower Jurassic formations; five of the six samples had reversed polarity (data are from Nairn, 1957a, p. 311–312). Poles **G 6** and **G 7** are based on two groups of sedimentary samples from the Early Jurassic (upper Lias) in Britain (Girdler, 1960, p. 358–359). One group is very nearly reversed with respect to the other, indicating stability by the consistency-of-reversals test. Samples from other nearby sites were unstable (Girdler, 1960, p. 354–355). Measurements on volcanics from the Pyrenees gave pole **G 8** (Girdler, 1960, p. 359–361). The flows are dated as Early Jurassic on the basis of intercalated limestone beds. Poles **G 10** and **G 12** are based, respectively, on measurements of radiolarite and limestone samples of Middle Jurassic age from the Alps (Hargraves and Fischer, 1959, p. 38).

From North America the Kayenta formation has been sampled at five sites (Collinson and Runcorn, 1960), and pole **G 20** is the mean of the virtual geomagnetic poles for each site. The Carmel formation (**G 21**) (Collinson and Runcorn, 1960) was sampled at one locality.

The Karroo dolerites were sampled extensively both in tunnels and mines (**G 28**) and on the surface (**G 31**) (Graham and Hales, 1957, p. 155). The surface samples have more scat-

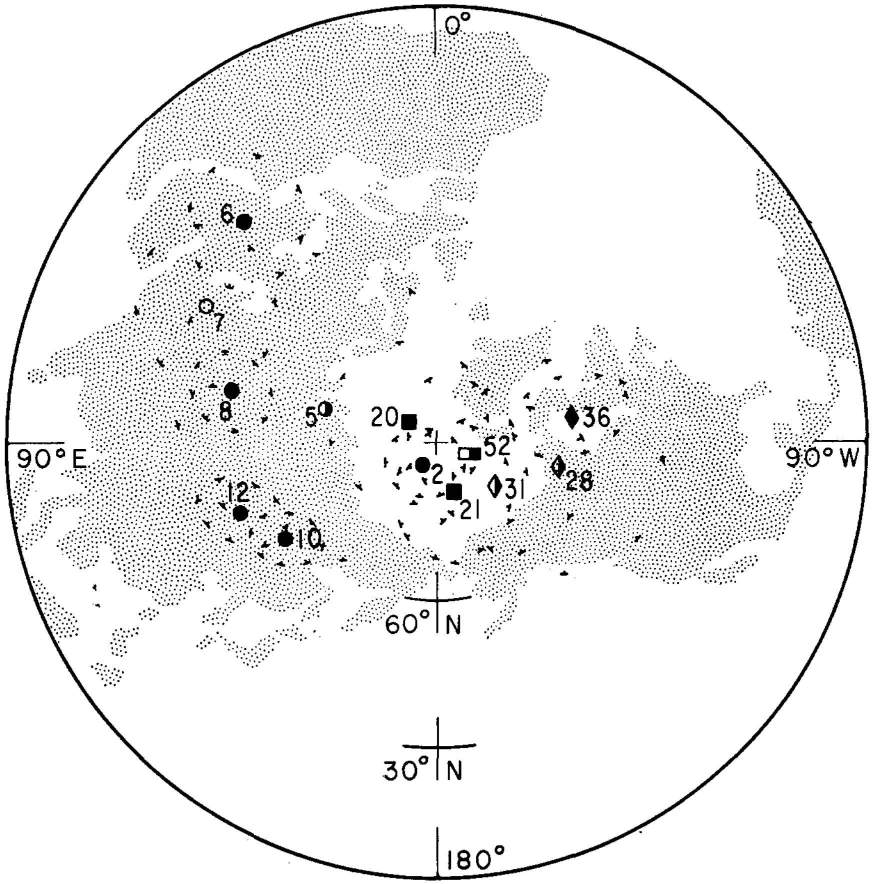

FIGURE 29.—JURASSIC VIRTUAL GEOMAGNETIC POLES (TABLE 1, SEC. G)
Poles H 5, H 7, and H 10 (shown in Fig. 30) may also be Jurassic and possibly should be included here.

tered directions of magnetization, but the mean directions for both groups agree. Some of the underground sills are magnetized reversely with respect to the others, and associated baked sediments are invariably magnetized in the same direction as the sill that baked them. Such a relationship points strongly to reversal of the earth's field. Pole **G 36** for the Karroo basalts (Nairn, 1956, p. 936; 1957a, p. 166), which are as old as the dolerites or slightly older, does not differ significantly from the pole for the dolerites.

Basalts from the Parana basin of South America, as well as sandstones baked by them, have been studied by Creer (1958, p. 377). The two sets of results agree with each other and have been combined in calculating pole **G 52**. The confidence interval of 3° by 1½° (Creer, 1958, p. 385) is probably too low, while the one shown in Figure 29 of 16° by 9½°, estimated by us, may be too large. The correct value depends on how many independent points in time (*i.e.*, separate lava flows) were sampled.

In addition to the points plotted in Figure 29, the Rajmahal traps of India (pole **H 10** in Fig. 30) and the Tasmanian dolerites (poles **H5** and **H 7** in Fig. 30) may also represent Jurassic field directions—the ages of these rocks are uncertain.

In addition to the Jurassic measurements reported above, four samples from the Summerville formation and three from the Carmel formation were measured by Torreson and others (1949, p. 125) in Utah. Because of the extreme scatter in the measured directions, no poles could be computed. The Jurassic virtual geomagnetic poles calculated for all continents show considerable scatter, and a relatively large number are not significantly different from the present geographic pole.

nearly parallel to the present field. Since no numerical data were given a pole could not be calculated.

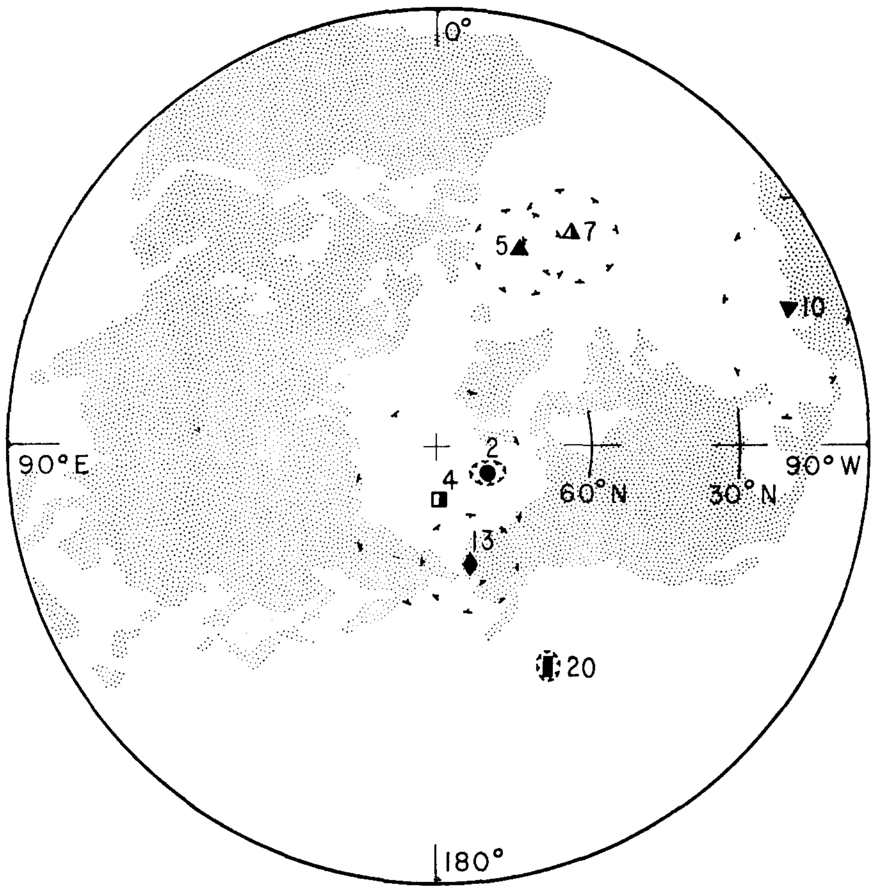

FIGURE 30.—CRETACEOUS VIRTUAL GEOMAGNETIC POLES (TABLE 1, SEC. H)
Poles H 5, H 7, and H 10 may be Jurassic

Cretaceous

Only one Cretaceous pole from Europe is available, that from the Wealden sediments of the Isle of Wright (**H 2**) (Wilson, 1959, p. 753). Several lines of evidence point to the existence of a stable component of magnetization about 4° from the present field direction. Nairn (1957c, p. 309) reports that the remanent magnetization of a red band 2–6 inches thick at the base of the Lower Cretaceous Gault Clay formation from England has both reversed and normal directions of magnetization which are

The only Cretaceous paleomagnetic data from North America for which a pole can be calculated consist of measurements made on 6 oriented samples from the Dakota sandstone from the Colorado Plateau (Runcorn, 1956a, p. 314–315). Three of the samples have magnetizations approximately reversed with respect to the direction of the present field, and 10 specimen measurements from these samples are the basis for the generally cited North American Cretaceous pole. For pole **H 4** (Fig. 30) we have used the mean sample directions for the three reversed and two normal samples; one obliquely magnetized sample has been excluded.

The Tasmanian dolerite sills cut Upper Triassic (or possibly Jurassic) rocks and are displaced by early Tertiary faults. Although they are thus no more closely dated than Late Triassic to early Eocene, the paleomagnetic results are usually plotted as Jurassic. We have taken the liberty of placing these virtual geomagnetic poles on the Cretaceous diagram to emphasize the uncertainty in their ages. The dolerites have been extensively sampled at surface outcrops (**H 5**) (Irving, 1956b, p. 166–167), and measurements have also been made on vertical well cores unoriented with respect to azimuth (Almond and others, 1956, p. 773). Since the inclination of the magnetization in the cores is $-85\frac{1}{2}°$, it follows that the virtual geomagnetic pole **H 7** lies within about 9° of the sampling site. This interpretation of the core measurements is supported by the agreement with the measurements of the oriented surface samples.

The lower Rajmahal traps of India are interbedded with sediments of Early to Middle Jurassic age (Krishnan, 1956, p. 273); the upper traps are petrologically similar to post Lower Cretaceous Deccan traps to the west (Hobson, quoted in Pascoe, 1929, p. 146) but otherwise appear to be undated. In paleomagnetic studies these results have usually been assigned to the Jurassic. However, we have plotted pole **H 10** for this formation as calculated from the measurements to Clegg and others (1958), on the Cretaceous diagram, again with a view to preventing data of uncertain age from becoming fixed in the paleomagnetic record.

Pole **H 13** is based on extensive investigations of lavas and dikes from Madagascar belonging to the Turonian stage of the Cretaceous (Roche and Cattala, 1959, p. 1050). Nagata and others (1959, p. 381) have calculated pole **H 20** from measurements on the Inkstone red shales of Middle to Early Cretaceous age from Japan.

Eocene

Most of the early Tertiary formations studied paleomagnetically are volcanic rocks that are imprecisely dated: an unfortunate circumstance, since paleomagnetic interpretation of these results depends on good stratigraphic control. Listed in Section I of Table 1 and shown in Figure 31 are all Tertiary results which have been described as Eocene, possibly Eocene, or early Tertiary, even though the balance of the evidence in some instances may favor assignment to a post-Eocene age. This procedure has undoubtedly resulted in the inclusion of some post-Eocene data in Section I and Figure 31, and therefore some of these virtual geomagnetic poles are expected to be near the present geographic pole, in agreement with the other post-Eocene results.

The age of the Lundy dikes (**I 2**) (Blundell, 1957, p. 191) is not known, but assignment to the early Tertiary has been suggested because the magnetization is similar to that of other lower Tertiary rocks from Britain. Thellier's stability test, with 1 month between measurements, and the consistency of this reversed magnetization point to stability. The Arran dikes (**I 3**) are described as early Tertiary by Irving (1959, p. 64). The Mull lavas (**I 7**) have been described as probably Eocene but possibly Oligocene or Miocene (Hospers and Charlesworth, 1954, p. 41–42; Hospers, 1955, p. 71); only flows showing some evidence of stability were used in calculating pole **I 7** (Bruckshaw and Vincent, 1954, p. 584–585). The Mull intrusive rocks (**I 4**) (Vincenz, 1954, p. 593) are younger than the lavas. The Antrim basalts are described as probably Eocene or Oligocene but possibly Miocene or early Pliocene (Hospers and Charlesworth, 1954, p. 41–42; Hospers, 1955, p. 71). Separate studies of these basalts have been made by Hospers and Charlesworth (1954, p. 40) (**I 10**) and by Wilson (1959, p. 752) (**I 20**).

The early Eocene age of the Siletz River volcanic series from the western United States (**I 22**) (Cox, 1957) is based on extensive fossil collections from sediments intercalated with the lava flows. Stability is indicated by the consistency-of-reversals test and by a reduction of scatter on correcting for folding which is mostly of late Eocene age. Irving (1959, p. 59) has calculated a pole for the Laney shale member of the Green River formation based on data of Torreson and others (1949, p. 125). We have recomputed this pole (**I 24**), and our results agree essentially with Irving's; in addition we have computed two other poles, **I 25** and **I 26**, from measurements on other sediments of Eocene age reported by Torreson and others (1949, p. 125). These three flat-lying units have magnetizations nearly parallel to the present field, with no reversals.

Pole **I 27** is based on an extensive sampling of the older volcanics of Victoria (Australia) which are of early Tertiary and probably Eocene age (Irving and Green, 1957, p. 351). The Tasmanian basalts have been described as Oligocene or Miocene by Almond and others (1956, p. 771), but Banks (1958, personal communication) believes they may be Eocene; vertical cores from a bore hole have an average inclination of −83°, indicating a virtual geomagnetic pole (**I 28**) within 13½° of the sampling site.

The Deccan traps of India have been studied independently by several workers. Pole **I 30** is based on seven oriented samples collected from different levels over a wide area (Irving, 1956a, p. 40). Clegg and others (1957, p. 227–230) and Deutsch and others (1959) have investigated the traps in great detail and have collected from several levels at seven sites covering a wide area. Results from horizons which are topographically and probably stratigraphically nearer the bottom of the sequence have been combined for pole **I 59**, and those from the upper horizons for pole **I 58**. Results from a post Deccan trap tuff form the basis for pole **I 57**.*

In addition to the Eocene measurements reported above, five samples from the Wasatch formation in Colorado and four from Wyoming have been measured by Torreson and others (1949, p. 125). The nine measurements were much too scattered to permit the calculation of a pole.

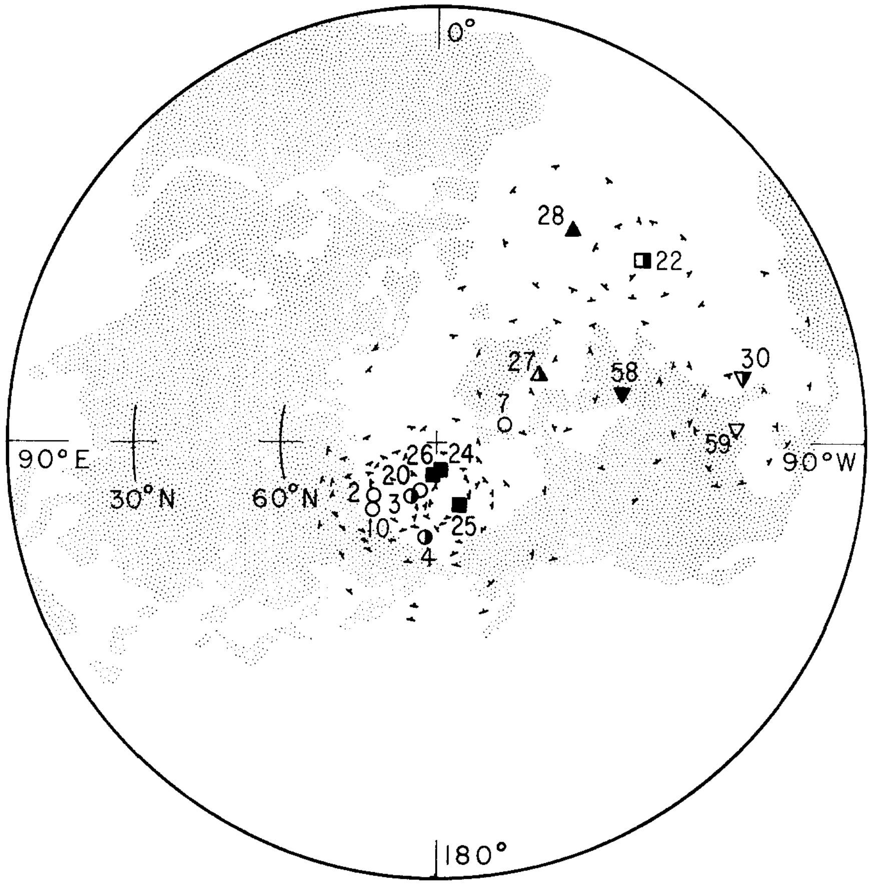

FIGURE 31.—EOCENE AND EOCENE (?) VIRTUAL GEOMAGNETIC POLES (TABLE 1, SEC. I)
Poles for all paleomagnetic studies of rocks described as Eocene, possibly Eocene, or early Tertiary are included. Some are almost certainly post-Eocene.

In summary, the virtual geomagnetic poles calculated from the magnetizations of rocks of Eocene (and probably younger) age fall into two groups, one near the present geographic pole and the other distributed north of lat 30° N. and within about 25° of the 300th meridian. Three poles in the first group correspond to sedimentary formations from North America having no evidence for stability, and the remaining poles in this group correspond to volcanic rocks of somewhat uncertain age from Europe.

* Pole I **57** was inadvertently not plotted.

Polar Wandering and Continental Drift

General statement.—Paleomagnetic measurements, which have been discussed in terms of their equivalent virtual geomagnetic poles, tell us only the direction of the earth's field at the time and place of formation of the rocks. If we are to apply these results to the problems of continental drift and polar wandering we must in some way relate the magnetic field to geographic configurations.

In order to interpret the results from some period in terms of continental drift we must first have enough data to know the configuration of the magnetic field during that period: was it, for example, essentially a dipole field as at present? It is further necessary to assess the expected variation between sampling areas that have not been displaced with respect to each other. Only then is it possible to infer that a departure in direction at some given sampling area indicates displacement of that area with respect to others. Polar-wandering interpretations require further that there be some connection between the magnetic-field configuration and the earth's axis of rotation. Continental-drift interpretations do not require such a connection, but they do require that the field configuration be changing at a rate which is small in comparison with the degree to which we can establish the contemporaneity of the formations compared.

Axial dipole theory.—The paleomagnetic evidence indicates, with a high degree of precision, that the earth's magnetic field, when averaged over a few thousand years, was dipolar in nature and parallel to the present axis of rotation throughout early Pleistocene and Recent time. It follows that the two axes were parallel during this time if we can establish that the earth's axis of rotation has also remained fixed. The distribution of the Pleistocene polar ice sheets defines rough limits for possible movements of the rotational axis during this time, but it is doubtful whether polar wandering of less than 10°–20° could be detected. Estimates of displacements of the rotational axis during the past several decades, as found from astronomical observations, indicate (Elsasser and Munk, 1958, p. 230) that the geographic pole moved at most 15 feet between 1900 and 1940. If the average rate of motion during the past half million years had been twice that amount, the total polar shift would have been only 1°. Since there is no other evidence to suggest that the axis of rotation differed significantly from the present one, the late Pleistocene and Recent paleomagnetic results constitute strong evidence in support of the dynamo theory for the origin of the earth's magnetic field.

It is, of course, possible that the coincidence of the paleomagnetically determined dipole axis and the present rotational axis is fortuitous. The earth's field may not have been dipolar or axial, and displacements of the sampling areas or of the entire crust may have been of exactly the right amount to compensate for such irregularities in the field. This, however, would be extremely unlikely.

Late Tertiary polar wandering and continental drift.—As noted earlier, the paleomagnetic results for Oligocene through early Pleistocene time are very similar to those for late Pleistocene and Recent except for the presence of reversals and somewhat greater scatter in mean pole positions. However, it is much more difficult to determine on geological or geophysical grounds what relationship the axis of rotation has had to the present continental configuration during this same interval. Large displacements of the pole have, in fact, been postulated by several workers. Polar-wandering curves of Kreichgauer (1902), Köppen and Wegener (1924), Milankovitch (1938), and Köppen (1940) as given by Gutenberg (1951, p. 202) are shown in Figure 32. (Note that only the paths of Kreichgauer and Milankovitch are in relation to the present continental configuration; those of Köppen and Wegener assume continental drift and are with respect to Africa only.) On the other hand, Chaney (1940, p. 486) and Durham (1950, p. 1260; 1952, p. 339) have cited paleoclimatological evidence to indicate that early Tertiary isoclimatic zones were parallel to present latitude lines. Further clarification of the paleobiogeographic picture during this interval is greatly to be desired. To the extent that we are willing to extrapolate the axial dipole model back into the past, the paleomagnetic evidence indicates that no large shift of the axis of rotation has occurred during the late Tertiary—a conclusion previously arrived at by Hospers (1955, p. 72–73) from analysis of fewer data.

Some recent theories calling for substantial shifts of the pole of rotation in late Tertiary time have cited paleomagnetic evidence in support of such shifts (Ewing and Donn, 1956, p. 1065; Hapgood, 1958, p. 308). Although some Oligocene to early Pleistocene virtual geomagnetic poles do, in fact, have ovals of confidence that do not include the present pole, there are several reasons why these probably do not indicate polar wandering or displacements of the

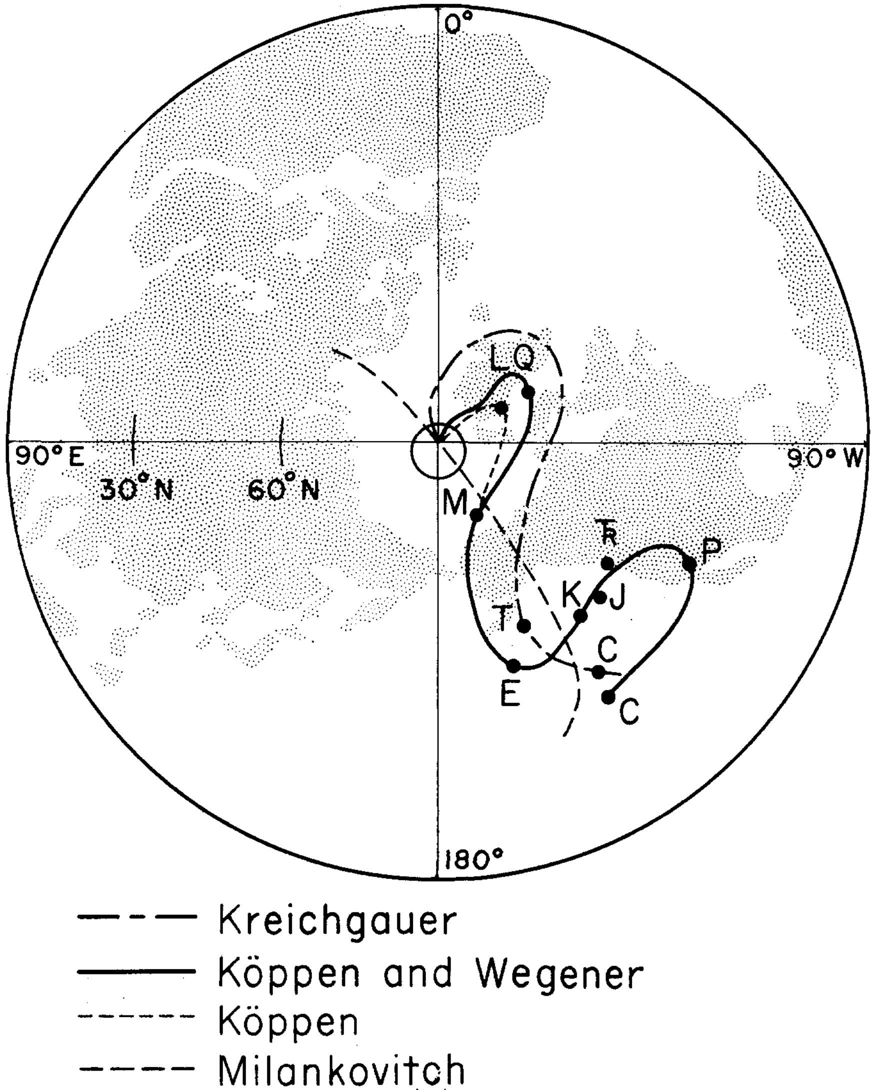

FIGURE 32.—POSTULATED TERTIARY POLAR-WANDERING PATHS

C—Carboniferous, P—Permian, T—Triassic, J—Jurassic, K—Cretaceous, E—Eocene, M—Miocene, LQ—lower Quaternary. (After Gutenberg, 1951)

sampling areas. For statistical reasons previously discussed, some of the confidence intervals may be too small. Pole **A 82**, for example, is based on data with widely varying confidence intervals, and a circle of confidence cannot be rigorously calculated from such data. Moreover, the virtual geomagnetic poles that are displaced from the present geographic pole are distributed throughout the time interval represented and are not confined to older rocks. This suggests that the effect may be random rather than systematic. One also expects, at the 95 per cent probability level used in these analyses, that 1 out of every 20 ovals of confidence will appear to be significantly different. Thus, although small amounts of polar wandering cannot be excluded, the paleomagnetic evidence appears to us to offer no support for theories requiring substantial late Tertiary polar wandering; on the contrary, it indicates that the pole has remained relatively fixed during this time.

Paleomagnetic polar wandering and continental drift.—Since the average magnetic dipole and rotational axes have been parallel in late Pleisto-

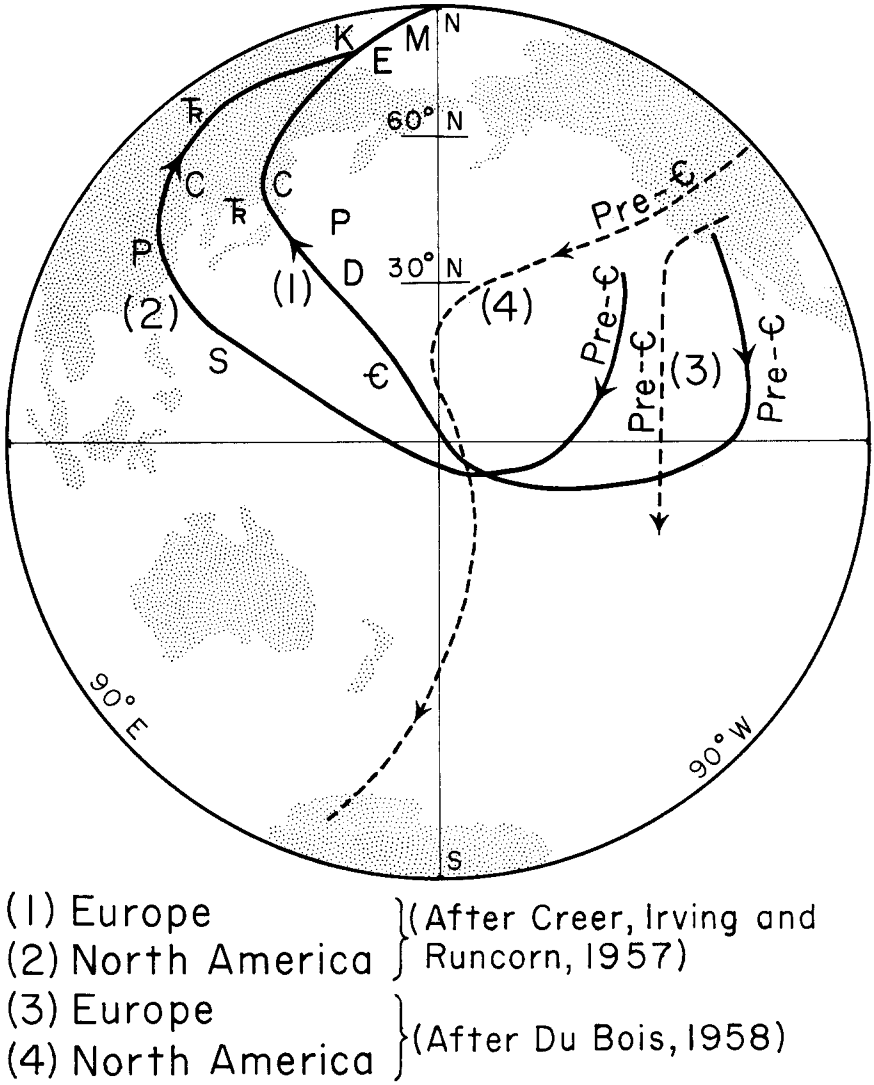

FIGURE 33.—POSTULATED PALEOMAGNETIC POLAR-WANDERING CURVES FOR EUROPE AND NORTH AMERICA

Pre-€—Precambrian, €—Cambrian, S—Silurian, D—Devonian, C—Carboniferous, P—Permian, T—Triassic, K—Cretaceous, E—Eocene, M—Miocene

cene through Recent time, and probably since the Oligocene, the principle of uniformitarianism suggests polar wandering and continental drift as possible interpretations for paleomagnetic results that do not agree with the present field configuration. Such an interpretation, in the form of a polar-wandering curve, was suggested by Creer and others (1954, p. 165) to explain pre-Tertiary paleomagnetic data from North America and Europe. When more data became available, the possibility of obtaining a better fit with separate paths for North America and Europe was pointed out by Irving (1956a, p. 39) and Runcorn (1956b, p. 82–83); these curves are shown in Figure 33 (after Creer and others, 1957, p. 147). The more westerly path inferred from the North American data was explained as due to a drift of North America of some 24° away from Europe prior to the middle Tertiary.

Du Bois has traced Precambrian paths of polar wandering for North America and Europe which cross the other paths nearly at right angles (Fig. 33); he interprets these and the later

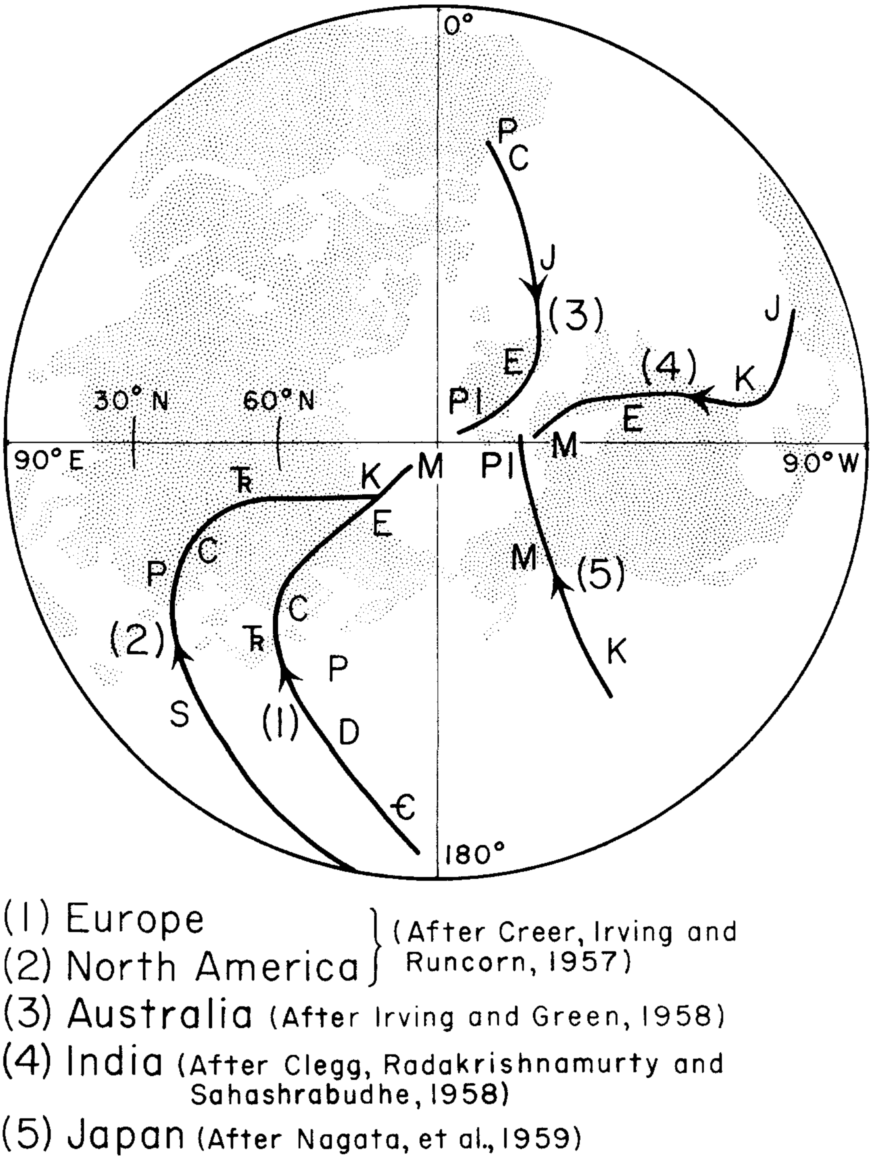

FIGURE 34.—POSTULATED PALEOMAGNETIC POLAR-WANDERING CURVES FOR EUROPE, NORTH AMERICA, AUSTRALIA, INDIA, AND JAPAN

€—Cambrian, S—Silurian, D—Devonian, C—Carboniferous, P—Permian, T—Triassic, J—Jurassic, K—Cretaceous, E—Eocene, M—Miocene, Pl—Pliocene

results as due to a westward drift of North America with respect to Europe of 45° (Du Bois, 1957, p. 179; 1958, p. 512).

Subsequent paleomagnetic data from India, Australia, and Japan have led many authors to postulate different polar-wandering curves for each of these regions. The Paleozoic and later portions of these curves are reproduced in Figure 34, and one may readily note that very large relative drifts and rotations are required to bring them into coincidence. The Indian studies, mostly on the Deccan traps, have been interpreted by a number of workers as indicating that India has rotated about 24° counterclockwise and has drifted 4000–5000 km with respect to North America and Europe since the

Eocene (Clegg and others, 1956, p. 430; Irving and Green, 1957, p. 358; Deutsch and others, 1959, p. 53–54).

The paleomagnetic results from Australia have also been interpreted as evidence for large displacements of Australia, again with respect to North America and Europe (Irving and Green, 1958, p. 71; Irving, 1959, p. 69–72). A suggested interpretation for the Japanese results is one of polar wandering along the path for North America and Europe, on which is superimposed the effects of a drift of Japan since the Cretaceous and a fairly large rotation since the Miocene (Nagata and others, 1959, p. 382–383).

Paleomagnetic evidence has also been cited in support of other rotations and displacements of land masses. Nairn and others (1959, p. 596) have suggested a 20-degree counterclockwise rotation of Newfoundland with respect to North America on the basis of a comparison between sets of Carboniferous and Precambrian virtual geomagnetic poles from these two areas. Creer (1958, p. 389) suggests a drift of South America with respect to Africa from a comparison of some Jurassic measurements from these continents, and Creer and others (1958, p. 497–501) have suggested a displacement of Africa with respect to Europe. The Triassic virtual geomagnetic poles from Europe have been cited in support of a rotation of Spain with respect to France and England (Clegg and others, 1957, p. 227). A 16-degree counterclockwise rotation of Japan has been suggested to explain Japanese results from Pleistocene to Holocene (Irving, 1959, p. 63). Finally, the large displacement of the Siletz River volcanic series' virtual geomagnetic pole from the usual North American polar-wandering curve has been suggested as possibly due to a large clockwise rotation of Oregon with respect to the rest of North America (Irving, 1959, p. 65).

Evaluation and interpretation of pre-Oligocene paleomagnetic data.—In analyzing the post-Eocene, and especially the post-early Pleistocene, paleomagnetic results, we found a dipolar field configuration and were able to make an estimate of the expected scatter in an individual measurement. With this information we could then discuss, with some confidence, the application of these paleomagnetic data to possible post-Eocene polar wandering and continental drift. In interpreting the pre-Oligocene data, is there any time for which we may also establish a field configuration and an estimate of the scatter?

The Permian and to some extent the Carboniferous are beginning to emerge as such times (Fig. 35) since there are now enough relatively consistent results from North America and Europe to establish an average pole region and to estimate the expected scatter. Even for these periods, however, the powers of resolution of the paleomagnetic method should not be overestimated. Displacements or rotations as small as 20°, such as have been suggested for Newfoundland (Nairn and others, 1959, p. 596), might well be due to expectable intraperiod variation rather than to displacements of land masses. A subsequent study of several Carboniferous formations from eastern Canada by Du Bois (1959b, p. B.A., 63) tends to confirm this conclusion.

Viewed on a larger scale, however, the consistency of the Permian and Carboniferous results from North America and Europe is most impressive and certainly indicates a magnetic-field configuration vastly different from the present configuration. If the earth's magnetic field was that of an axial dipole, as it probably was from Oligocene to early Pleistocene time and almost certainly was from late Pleistocene to Recent time, then these results constitute a strong case for polar wandering. This interpretation is also in accord with the axial-symmetry requirements of the dynamo theory.

An objection to this axial-dipole interpretation has been voiced by Öpik (1955, p. 236), however, who suggests that boundary conditions, such as temperature differences at the core–mantle boundary, rather than the earth's rotation might act to establish order in the convective core motions. The resulting external field would not be symmetrical with respect to the earth's axis of rotation, and, moreover, different rates of rotation of the core and mantle would not tend to give an average axial symmetry because the cold and hot spots causing the convective pattern would move with the mantle. This theory faces some obstacles, however. No analysis has, to our knowledge, been carried out to determine whether such temperature differences could exert a substantial influence on the convective pattern. Another obstacle to the theory is the axial-dipole nature of the earth's field for the past 30 million years. Either the temperature differences did not exist during this time, or they were fortuitously symmetrical with respect to the axis of rotation, or conceivably they were causally related to the rotation axis. Although the principle of uniformitarianism favors a polar-wandering interpretation for the Permian and Carboniferous paleomagnetic results, Öpik's objection should be kept in mind as a possible alternative explanation.

probably not accurate to better than 20 million years, and this certainly appears to be a reasonable estimate since most of the formations

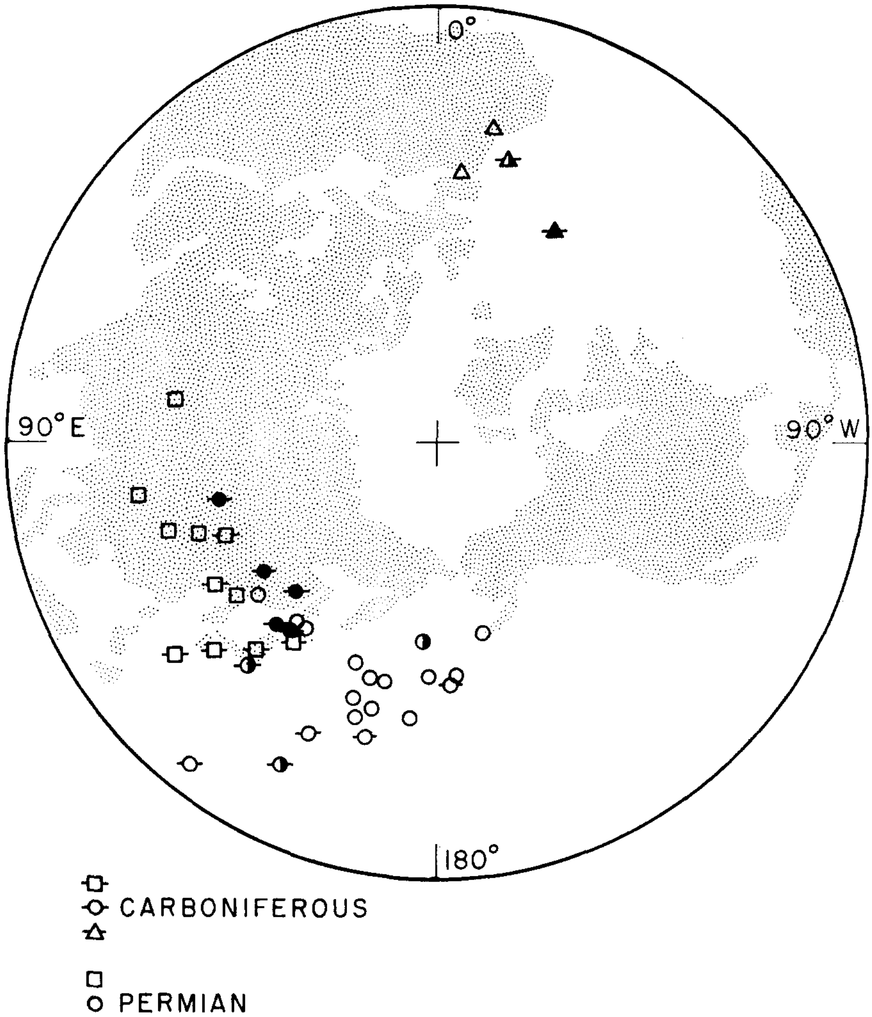

FIGURE 35.—PERMIAN AND CARBONIFERNOUS VIRTUAL GEOMAGNETIC POLES FROM EUROPE, NORTH AMERICA, AND AUSTRALIA

North America—squares, Europe—circles, Australia—triangles

studied are lava flows, intrusive rocks, and continental red beds, all subject to more than average age uncertainty. Using an estimate for the average rate of movement of the dipole axis during the Permian (Creer and others, 1957, p. 155), we can compute that an apparent displacement of 10° would result from a 20 million year discrepancy in stratigraphic correlation.

The Permian data also constitute the strongest evidence for a relative displacement between North America and Europe. An alternative explanation for the displacement of the virtual geomagnetic poles calculated from the two regions may lie in inaccuracies in the stratigraphic correlation for the Permian on the two sides of the Atlantic Ocean. In discussing and rejecting this possibility, Creer and others (1957, p. 151) state that the correlations are

Even assuming that there is no systematic difference in the age of the rocks from North

America and Europe listed as Permian, and assuming also that the field was dipolar, it is important to note that the two sets of Permian data from North America and Europe do not uniquely determine the relative positions of the two continents before a hypothetical displacement. The data from each continent must span enough time to delineate a segment along a path of polar wandering, and a very interesting problem emerges when the Permian and Carboniferous magnetic poles from Europe and North America are considered jointly. Between Carboniferous and Permian time the average geomagnetic pole position for North America appears to have moved roughly N. 85° W., while that for Europe moved roughly N. 40°–70° E. (Fig. 35). These two path segments cannot be brought into coincidence by postulating a simple westward movement of North America with respect to Europe since the Paleozoic, but would require, rather, a large post-Permian movement of North America *toward* Europe from the southeast. This is not intended as a serious interpretation, but points out difficulties that arise in attempting a unique solution for the data now available. (Geometrical techniques useful in experimenting with paleomagnetic reconstructions are given by Irving 1958, p. 227–229.)

The Australian Carboniferous and Permian paleomagnetic investigations, although few in number, include concordant results between sediments and volcanic rocks, with an excellent fold test for the sediments. However the virtual geomagnetic poles are quite significantly different from the poles for Europe and North America. If the axial-dipole hypothesis is valid for these periods, the Australian data constitute evidence for a relative displacement of Australia with respect to North America and Europe which cannot be ignored.

In general, there are relatively few measurements available from early Paleozoic rocks, and those that are available show a considerable range in pole positions (Fig. 23). Therefore, without sufficient data to determine a field configuration or to assess the expected scatter in the results, interpretations for these data involving continental drift or polar wandering are hazardous.

Many more Precambrian data are available, and, as might be expected from older rocks with large relative age differences, the scatter is large. As mentioned earlier, many of the virtual geomagnetic poles tend to lie in the eastern Pacific near the equator. Even if this group of poles represents an average field configuration, we must expect a rather large variation in any given measurement. Thus, as for the early Paleozoic, a large uncertainty exists in the basic data available for polar-wandering and continental-drift interpretations, and the paths shown in Figure 33 might best be regarded, at present, as working hypotheses.

Paleomagnetic measurements for the Mesozoic and early Tertiary present an interesting problem; although the preceding Permian and following post-Eocene results are each internally consistent, the geomagnetic pole positions from the Mesozoic and early Tertiary are quite scattered. Some impressively consistent results have been obtained for individual Triassic formations, and the distribution of results from North America and Europe to some extent suggests relative drift. However, the scatter between mean formation directions is quite large and weakens the conclusion that a relative displacement has taken place. The paleomagnetic results from the Jurassic are at least as scattered as those for the Triassic, and no conclusive statements concerning drift or wandering can be made. (Note also that poles **H5**, **H 7**, and **H 10** in Figure 30 are from formations of uncertain age and may be Jurassic.)

The paleomagnetic results from the Cretaceous and Eocene may profitably be considered together, inasmuch as large amounts of drift with respect to North America and Europe have been postulated for India, for Japan, and, to some extent, for Australia on the basis of geomagnetic data from rocks of these ages. Such interpretations are based on the conclusion that the Eocene and Cretaceous pole positions for North America and Europe were within 18° of the present geographic north pole and moved up to coincidence with it in the Tertiary, as shown in Figures 33 and 34. The paucity of paleomagnetic information for these time intervals has already been discussed. In this respect one of the most reliable virtual geomagnetic poles from the few available North American determinations (the Siletz River volcanic series) falls much closer to the Indian and Australian paleomagnetic poles than to the Cretaceous and Eocene points on the usual polar-wandering curves for North America and Europe. Thus, as for many of the other periods, the North American (and possibly European) field configurations for Cretaceous and Eocene time are far from certain, and, without such a well-defined reference position, the drift interpretations for Australian and Indian Cretaceous and Eocene results may be questioned.

An alternative explanation of the Cretaceous and Eocene measurements, and one that does not require simultaneous rotations of several tens of degrees for Oregon and India, would involve relatively rapid changes in the magnetic-field configuration during this period while maintaining the present continental configuration. The field may have been nondipolar or, alternatively, may have been that of a dipole undergoing somewhat rapid changes in direction. Such changes may or may not have been accompanied by rapid polar wandering.

This hypothesis poses many problems. It appears to us, however, to fit the available data at least as well as the drift hypotheses and it emphasizes the uncertainties connected with paleomagnetic interpretations at this time.

We have emphasized the tentative nature of some paleomagnetic interpretations. However, we would not like to conclude without emphasizing the contributions of paleomagnetism to geology. The post-Eocene results are impressive and offer very strong evidence for the dynamo theory and against substantial Tertiary polar wandering or continental drift. Although the nature of the Mesozoic and early Tertiary magnetic field is obscure, the consistency of the late Paleozoic studies, however, indicates that the paleomagnetic method is quite applicable to older rocks. It seems probable, therefore, that, with additional carefully studied and well-dated determinations from Mesozoic and pre-late Paleozoic time, a clear picture of the field configurations will evolve, opening the way for better evaluation of the hypotheses of continental drift and polar wandering.

Directions of Paleomagnetic Research

In concluding this review, we wish to suggest some lines of investigation in geology and geophysics that are of special interest to the worker in rock magnetism, and also to mention some important problems that remain for the paleomagnetist.

Paleobiogeographic studies probably rank first among those in other disciplines that are of interest in paleomagnetism. The paleomagnetic data from post-Eocene rocks indicate that the average geomagnetic pole was close to the present geographic pole throughout this time, and additional independent paleobiogeographic evidence to show that the geographic pole has also been in its present position throughout this period would give added support to the axial-dipole magnetic-field theory. Moreover, large discrepancies appear in the paleomagnetic data of the late Mesozoic and early Tertiary, and relevant paleobiogeographic evidence to indicate whether these discrepancies could be due to continental drift or polar wandering is needed. The Permian and Carboniferous periods are paleomagnetically very calm, and the measurements indicate a vastly different field configuration from the present one. Thus, Permian and Carboniferous formations should also be interesting subjects for paleobiogeographic studies. Recent paleobiogeographic studies of some relevance are those of Durham (1950; 1952), Stehli (1957), and Irving (1956a).

A further development of the dynamo theory for the earth's magnetic field is also highly desirable. The question of greatest interest concerns the axial-dipole requirements of the theory; the paleomagnetist would like to know if it is at all possible for a nonaxial dipole field to exist for a long period of time. Could stresses, such as might be provided by a local "hot spot" in the mantle, cause an ordering in core motions that would result in a magnetic field not symmetrical with the axis of rotation?

Other applications of rock-magnetism techniques to special geologic problems might be mentioned. Since the thermo-remanent magnetization of some rocks acquired in each temperature interval is independent of that acquired in adjacent temperature intervals, an application to unraveling the thermal histories of these rocks may be possible. Magnetic-anisotropy properties of rocks may also find important geologic applications. Techniques that permit a rapid measurement of the preferred orientation of ferromagnetic grains having either flat or elongate shapes or magnetocrystalline anisotropy are now available.

A field of paleomagnetic research that has been merely alluded to in this paper is that described by Thellier and Thellier (1959) in a review of their extensive work on the intensity of the earth's magnetic field during historic and Quaternary time. Their report should certainly excite more interest in this subject. Although directions of the field are of most use in continental-drift and polar-wandering interpretations, intensity data should be very useful in developing an expanded theory for the origin of the field and, hence, of considerable indirect interest to studies of drift and wandering.

In order to test properly the hypotheses of large-scale continental drifts since the Cretaceous and Eocene, it will be necessary to have additional paleomagnetic data from well-dated Cretaceous and Eocene rocks from all continents, especially from Europe and North America. Rocks of Permian and Carboniferous age from localities other than those already sampled in North America, Europe, and Australia should also be rewarding subjects for paleomagnetic studies.

In the paleomagnetic work completed, a relatively large number of studies from a given continent and interval of geologic time have been necessary before a clear picture of the field for that time and place has emerged; the Permian of North America and Europe are examples. Even with a large quantity of data, however, the picture may still be cloudy, as for example in the Triassic from North America and Europe. Future investigations may yield more and better information if they are able to satisfy the following conditions:

(1) The geologic formation to be studied should be well dated geologically and accessible at several sites over a relatively large sampling area.

(2) Careful consideration should be given to the sampling scheme so that a minimum of samples will be required, the requirements of the statistical method to be employed will be satisfied, and the earth's field over a large area and at several points in time is represented.

(3) Demagnetization and anisotropy studies of the samples should always be made in order to test the stability and paleomagnetic applicability of the measured magnetizations.

References Cited

Many of the data used in Table 1 and elsewhere are from unpublished theses. To avoid citing the same theses repeatedly in the text, they are listed in the References Cited. The year cited is the year of filing of the thesis.

Almond, M., Clegg, J. A., and Jaeger, J. C., 1956, Remanent magnetism of some dolerites, basalts, and volcanic tuffs from Tasmania: Philos. Mag., ser. 8, v. 1, p. 771–782

Angenheister, G., 1956, Über die magnetisierung der basalte des Volgelsberges: Akad. Wiss. Göttingen Nachr., Math.-phys. Kl., no. 9, p. 187–204

Armstrong, D., 1957, Dating of some minor intrusions of Ayrshire: Nature, v. 180, p. 1277

As, J. A., and Zijderveld, J. D. A., 1958, Magnetic cleaning of rocks in palaeomagnetic research: Royal Astron. Soc. Geophys. Jour., v. 1, p. 308–319

Asami, E., 1954a, On the reverse natural remanent magnetism of basalt of Cape Kawajiri, Yamaguchi Perfecture: Japan Acad. Proc., v. 30, p. 102–105

—— 1954b, Reverse and normal magnetization of the basaltic lavas at Kawajiri-misaki, Japan: Jour. Geomagnetism and Geoelectricity [Kyoto], v. 6, p. 145–152

Balsley, J. R., and Buddington, A. F., 1954, Correlation of reverse remanent magnetism and negative anomalies with certain minerals: Jour. Geomagnetism and Geoelectricity [Kyoto], v. 6, p. 176–181

—— 1958, Iron-titanium oxide minerals, rocks, and aeromagnetic anomalies of the Adirondack area, New York: Econ. Geology, v. 53, p. 777–805

Bancroft, A. M., 1951, The magnetic properties of varved clays: M. S. Thesis, Univ. of Birmingham, England

Belshé, J. C., 1957, Palaeomagnetic investigations of Carboniferous rocks in England and Wales: Advances in Physics, v. 6, p. 187–191

Blackett, P. M. S., 1952, A negative experiment relating to magnetism and the earth's rotation: Royal Soc. London Philos. Trans., ser. A, v. 245, p. 303–370

Blundell, D. J., 1957, A palaeomagnetic investigation of the Lundy dyke swarm: Geol. Mag. v. 94, p. 187–193

Bruckshaw, J. M., and Robertson, E. I., 1949, The magnetic properties of the tholeiite dykes of North England: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 5, p. 308–320

Bruckshaw, J. M., and Vincenz, S. A., 1954, The permanent magnetism of the Mull lavas: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 6, p. 579–589

Brynjólfsson, A., 1957, Studies of remanent magnetism and viscous magnetism in the basalts of Iceland: Advances in Physics, v. 6, p. 247–254

Bullard, E. C., Freedman, C., Gellman, H., and Nixon, J., 1950, The westward drift of the earth's magnetic field: Royal Soc. London Philos. Trans., ser. A, v. 243, p. 67–92

Campbell, C. D., and Runcorn, S. K., 1956, Magnetization of the Columbia River basalts in Washington and Northern Oregon: Jour. Geophys. Research, v. 61, p. 449–458

Chaney, R. W., 1940, Tertiary forests and continental history: Geol. Soc. America Bull., v. 51, p. 469–488

Chang Wen-You, and Nairn, A. E. M., 1959, Some palaeomagnetic investigations on Chinese rocks: Nature, v. 183, p. 254

Chapman, S., and Bartels, J., 1940, Geomagnetism: Oxford, England, Clarendon Press, 1049 p.

Chevallier, R., 1925, L'aimantation des lavas de l'Etna et l'orientation du champ terrestre en Sicile du 12e au 17e Siècle: Annales Physique [Paris], ser. 10, v. 4, p. 5–162

Clegg, J. A., Almond, M., and Stubbs, P. H. S., 1954a, The remanent magnetism of some sedimentary rocks in Britain: Philos. Mag., ser. 7, v. 45, p. 583–598

—— 1954b, Some recent studies of the pre-history of the earth's magnetic field: Jour. Geomagnetism and Geoelectricity [Kyoto], v. 6, p. 194–199

Clegg, J. A., Deutsch, E. R., and Griffiths, D. H., 1956, Rock magnetism in India: Philos. Mag., v. 1, p. 419–431

Clegg, J. A., Radakrishnamurty, C., and Sahasrabudhe, P. W., 1958, Remanent magnetism of the Rajmahal Traps of northeastern India: Nature, v. 181, p. 830–831

Clegg, J. A., Deutsch, E. R., Everitt, C. W. F., and Stubbs, P. H. S., 1957, Some recent palaeomagnetic measurements made at Imperial College, London: Advances in Physics, v. 6, p. 219–231

Collinson, D. W., and Runcorn, S. K., 1960, Further paleomagnetic observations in North America: Geol. Soc. America Bull., v. 71 (in press)
Cook, R. M., and Belshé, J. C., 1958, Archaeomagnetism: A preliminary report on Britain: Antiquity, v. 32, p. 167–178
Cox, Allan, 1957, Remanent magnetization of lower to middle Eocene basalt flows from Oregon: Nature, v. 179, p. 685–686
—— 1959, The remanent magnetization of some Cenozoic rocks: Unpublished Ph.D. Thesis, Univ. of Calif., Berkeley, Calif., 193 p.
Creer, K. M., 1955, A preliminary palaeomagnetic study of certain rocks in England and Wales: Unpublished Ph.D. Thesis, Cambridge Univ., England, 203 p.
—— 1957a, Palaeomagnetic investigations in Great Britain V, The remanent magnetization of unstable Keuper marls: Royal Soc. London Philos. Trans., ser. A, v. 250, p. 130–143
—— 1957b, Palaeomagnetic investigations in Great Britain IV, The natural remanent magnetization of certain stable rocks from Great Britain: Royal Soc. London Philos. Trans., ser. A, v. 250, p. 111–129
—— 1958, Preliminary palaeomagnetic measurements from South America: Annales Géophysique, v. 14, p. 373–390
Creer, K. M., Irving, E., and Nairn, A. E. M., 1959, Palaeomagnetism of the great Whin sill: Royal Astron. Soc. Geophys. Jour., v. 2, p. 306–323
Creer, K. M., Irving, E., and Runcorn, S. K., 1954, The direction of the geomagnetic field in remote epochs in Great Britain: Jour. Geomagnetism and Geoelectricity [Kyoto], v. 6, p. 163–168
—— 1957, Palaeomagnetic investigations in Great Britain VI, Geophysical interpretation of palaeomagnetic directions from Great Britain: Royal Soc. London Philos. Trans., ser. A, v. 250, p. 144–156
Creer, K. M., Irving, E., Nairn, A. E. M., and Runcorn, S. K., 1958, Palaeomagnetic results from different continents and their relation to the problem of continental drift: Annales Géophysique, v. 14, p. 492–501
Day, A. A., and Runcorn, S. K., 1955, Polar wandering: Nature, v. 176, p. 422–426
Deutsch, E. R., Radakrishnamurty, C., and Sahasrabudhe, P. W., 1959, Palaeomagnetism of the Deccan Traps: Annales Géophysique, v. 15, p. 39–59
Doell, R. R., 1955a, Remanent magnetism in sediments: Unpublished Ph.D. Thesis, Univ. of Calif., Berkeley, Calif., 156 p.
—— 1955b, Palaeomagnetic study of rocks from the Grand Canyon of the Colorado River: Nature, v. 176, p. 1167
—— 1956, Remanent magnetization of the upper-Miocene "blue" sandstones of California: Am. Geophys. Union Trans., v. 37, p. 156–167
Du Bois, P. M., 1955, Palaeomagnetic measurements of the Keweenawan: Nature, v. 176, p. 506–507
—— 1957, Comparison of palaeomagnetic results for selected rocks of Great Britain and North America: Advances in Physics, v. 6, p. 177–186
—— 1958, Palaeomagnetism and geological correlation: Annales Géophysique, v. 14, p. 509–514
—— 1959a, Late Tertiary geomagnetic field in northwestern Canada: Nature, v. 183, p. 1617–1618
—— 1959b, Palaeomagnetism and rotation of Newfoundland: Nature v. 184, p. B. A. 63–64
Du Bois, P. M., Irving, E., Opdyke, N. D., Runcorn, S. K., and Banks, M. R., 1957, The geomagnetic field in Upper Triassic times in the United States: Nature, v. 180, p. 1186–1187
Durham, J. W., 1950, Cenozoic marine climates of the Pacific Coast: Geol. Soc. America Bull., v. 61, p. 1243–1264
—— 1952, Early Tertiary marine faunas and continental drift: Am. Jour. Sci., v. 250, p. 321–343
Du Toit, A. L., 1953, Geology of South Africa: N. Y., Hafner Publ. Co., 611 p.
Einarsson, T., 1957, Magneto-geological mapping in Iceland with the use of a compass: Advances in Physics, v. 6, p. 232–239
Einarsson, T., and Sigurgeirsson, T., 1955, Rock magnetism in Iceland: Nature, v. 175, p. 892
Elsasser, W. M., 1955, Hydromagnetism I. A review: Am. Jour. Physics, v. 23, p. 590–609
—— 1956, Hydromagnetism II. A review: Am. Jour. Physics, v. 24, p. 85–110
Elsasser, W. M., and Munk, W., 1958, Geomagnetic drift and the rotation of the earth, p. 228–236, *in* Benioff, H., *et al., Editors*, Contributions in geophysics in honor of Beno Gutenberg, 1958: Pergamon Press, 244 p.
Evans, J. W., 1918 Geology of the British Isles: The Hague, Martinus Nijhoff, 354 p.
Ewing, M., and Donn, W. L., 1956, A theory of ice ages: Science, v. 123, p. 1061–1066
Finch, H. F., and Leaton, E. R., 1957, The earth's main magnetic field—epoch 1955.0: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 7, p. 314–317
Fisher, R. A., 1953, Dispersion on a sphere: Royal Soc. London Proc., ser. A, v. 217, p. 295–305
Girdler, R., 1959, Anisotropy of susceptibility of rocks: Unpublished Ph.D. Thesis, Cambridge Univ., England
—— 1960, A palaeomagnetic study of some lower Jurassic rocks of N. W. Europe: Royal Astron. Soc. Geophys. Jour., v. 2, p. 353–363
Gorter, E. W., and Schulkes, J. A., 1953, Reversal of spontaneous magnetization as a function of temperature in LiFeCr spinels: Physical Review, v. 90, p. 487–488
Gough, D. I., 1956, A study of the palaeomagnetism of the Pilansberg dykes: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 7, p. 196–213
Gough, D. I., and van Niekerk, C. B., 1959, A study of the palaeomagnetism of the Bushveld gabbro: Philos. Mag., v. 4, p. 126–136
Graham, J. W., 1949, The stability and significance of magnetism in sedimentary rocks: Jour. Geophys. Research, v. 54, p. 131–167
—— 1953, Changes of ferromagnetic minerals and their bearing on magnetic properties of rocks: Jour. Geophys. Research, v. 58, p. 243–260
—— 1954, Rock magnetism and the earths' magnetic field during Paleozoic time: Jour. Geophys. Research, v. 59, p. 215–222
—— 1955, Evidence of polar shift since Triassic time: Jour. Geophys. Research, v. 60, p. 329–347
—— 1956, Paleomagnetism and magnetostriction: Jour. Geophys. Research, v. 61, p. 735–739

Graham, J. W., Buddington, A. F., and Balsley, J. R., 1957, Stress-induced magnetizations of some rocks with analyzed magnetic minerals: Jour. Geophys. Research, v. 62, p. 465–474
—— 1959, Magnetostriction and paleomagnetism of igneous rocks: Nature, v. 183, p. 1318
Graham, K. W. T., and Hales, A. L., 1957, Palaeomagnetic measurements on Karroo dolerites: Advances in Physics, v. 6, p. 149–161
Granar, L., 1959, Magnetic measurements on Swedish varved sediments: Arkiv Geofysik, v. 3, p. 1–40
Griffiths, D. H., 1955, The remanent magnetism of varved clays from Sweden: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 7, p. 103–114
Gutenberg, B., 1951, Hypothesis on the development of the earth, p. 178–226 *in* Gutenberg, B., *Editor*, The internal constitution of the earth: N. Y., Dover Publ., 439 p.
Haigh, G., 1958, The process of magnetization by chemical change: Philos. Mag., v. 3, p. 267–286
Hapgood, C. H., 1958, Earth's shifting crust: N. Y., Pantheon Books, 438 p.
Hargraves, R. B., and Fischer, A. G., 1959, Remanent magnetism in Jurassic red limestones and radiolarites from the Alps: Royal Astron. Soc. Geophys. Jour., v. 2, p. 34–41
Hatherton, T., 1954, The magnetic properties of the Whakamaru ignimbrites: New Zealand Jour. Sci. and Tech., v. 35, p. 421–432
Hood, P. J., 1958, Paleomagnetic studies of some Precambrian rocks in Ontario: Unpublished Ph.D. Thesis, Univ. of Toronto, Canada, 200 p.
Hospers, J., 1951, Remanent magnetism of rocks and the history of the geomagnetic field: Nature, v. 168, p. 1111–1112
—— 1953–1954, Reversals of the main geomagnetic field: Koninkl. Nederlandse Akad. Wetensch. Proc. of the section of Sciences, Ser. B, Phys. Sci. Part I, v. 56 (1953), p. 467–476; Part II, v. 56 (1953), p. 477–491; Part III, v. 57 (1954), p. 112–121
—— 1955, Rock magnetism and polar wandering: Jour. Geology, v. 63, p. 59–74
Hospers, J., and Charlesworth, H. A. K., 1954, The natural permanent magnetization of the lower basalts of northern Ireland: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 7, p. 32–43
Howell, L. G., and Martinez, J. D., 1957, Polar movement as indicated by rock magnetism: Geophysics, v. 22, p. 384–397
Howell, L. G., Martinez, J. D., and Statham, E. H., 1958, Some observations on rock magnetism: Geophysics, v. 23, p. 285–298
Irving, E., 1956a, Palaeomagnetic and palaeoclimatological aspects of polar wandering: Geofisica Pura e Appl., v. 33, p. 23–41
—— 1956b, The magnetization of the Mesozoic dolerites of Tasmania: Royal Soc. Tasmania Papers and Proc., v. 90, p. 157–168
—— 1957a, Rock magnetism: A new approach to some palaeogeographic problems: Advances in Physics, v. 6, p. 194–218
—— 1957b, Directions of magnetization in the Carboniferous glacial varves of Australia: Nature, v. 180, p. 280–281
—— 1958, Palaeogeographic reconstruction from palaeomagnetism: Royal Astron. Soc. Geophys. Jour., v. 1, p. 224–237
—— 1959, Palaeomagnetic pole positions: A survey and analysis: Royal Astron. Soc. Geophys. Jour., v. 2, p. 51–79
Irving E., and Green, R., 1957, The palaeomagnetism of the Kainozoic basalts of Victoria: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 7, p. 347–359
—— 1958, Polar movement relative to Australia: Royal Astron. Soc. Geophys. Jour., v. 1, p. 64–72
Irving, E., and Runcorn, S. K., 1957, Palaeomagnetic investigations in Great Britain II. Analysis of the palaeomagnetism of the Torridonian sandstone series of Northwest Scotland. I: Royal Soc. London Philos. Trans., ser. A, v. 250, p. 83–99
Jacobs, J. A., 1956, The interior of the earth, p. 183–234, *in* Landsberg, H. E., *Editor*, Advances in geophysics, v. 3: N. Y., Academic Press, 378 p.
James, H. L., 1958, Stratigraphy of pre-Keweenawan rocks in parts of Northern Michigan: U. S. Geol. Survey Prof. Paper 314-C, 44 p.
Johnson, E. A., and McNish, A. G., 1938, An alternating-current apparatus for measuring small magnetic moments: Terrestrial Magnetism and Atmospheric Electricity, v. 43, p. 393–399
Johnson, E. A., Murphy, T., and Torreson, O. W., 1948, Pre-history of the earth's magnetic field: Terrestrial Magnetism and Atmospheric Electricity, v. 53, p. 349–372
Kawai, N., 1954, Instability of natural remanent magnetism of rocks: Jour. Geomagnetism and Geoelectricity, v. 6, p. 208–209
Khramov, A. N., 1957, Paleomagnetism—the basis of a new method of correlation and subdivision of sedimentary strata: Akad. Nauk SSSR Doklady ser. geol., v. 112, p. 849–852 (in Russian) (English translation Consultants Bureau, Inc., 1958)
—— 1958, Paleomagnetic correlation of sedimentary rocks: Leningrad, GOSTOPTEHIZDAT, 218 p.
King, R. F., 1955, The remanent magnetism of artificially deposited sediments: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 7, p. 115–134
Kintzinger, P. R., 1957, Paleomagnetic survey of Triassic rocks from Arizona: Geol. Soc. America Bull., v. 68, p. 931–932
Kobayashi, K., 1959, Chemical remanent magnetization of ferromagnetic minerals and its application to rock magnetism: Jour. Geomagnetism and Geoelectricity [Kyoto], v. 10, p. 99–117
Komarov, A. G., 1959, Paleomagnetic measurements on lower Paleozoic basalts from the Ukraine: Akad. Nauk SSSR Izv. ser. geofiz. no. 8, p. 1219–1225 (in Russian)
Köppen, W., 1940, Die Wanderung des Nordpols seit der Steinkohlenzeit: Meteorol. Zeitschr., v. 57, p. 106–110
Köppen, W., and Wegener, A., 1924, Die Klimate der geologischen Vorzeit: Berlin, Gebrüder Borntraeger, 225 p.
Kreichgauer, P. D., 1902, Die Äquatorfrage in der Geologie: Kaldenkirchen, Germany, Missionsdruckerei in Steyl, 394 p.
Krishnan, M. S., 1956, Geology of India and Burma: Madras, India, Higginbothams (Private) Ltd., 555 p.
Kumagai, N., Kawai, N., and Nagata, T., 1950,

Recent progress in palaeomagnetism in Japan: Jour. Geomagnetism and Geoelectricity [Kyoto], v. 2, p. 61–65
Martinez, J. D., and Howell, L. G., 1956, Palaeomagnetism of chemical sediments: Nature, v. 178, p. 204–205
Matuyama, M., 1929, On the direction of magnetization of basalt in Japan, Tyôsen, and Manchuria: Japan Acad. Proc., v. 5, p. 203–205
Mercanton, P. L., 1926, Aimantation de basaltes groenlandais: Acad. Sci. [Paris] Comptes Rendus, v. 182, p. 859–860
Milankovitch, M., 1938, Astronomische Mittel zur Erforschung der erdgeschichtlichen Klimate: Handbuch der Geophysik, v. 9, p. 593–698
Momose, K., 1958, Palaeomagnetic researches for the Pliocene volcanic rocks in central Japan: Jour. Geomagnetism and Geoelectricity [Kyoto], v. 10, p. 12–19
Nagata, T., 1953a, Rock magnetism: Tokyo, Japan, Maruzen Co. Ltd., 225 p.
—— 1953b, Self-reversal of thermo-remanent magnetization of igneous rocks: Nature, v. 172, p. 850–852
Nagata, T., Akasi, K., and Rikitaki, T., 1943, The natural remanent magnetism of sedimentary rocks (Preliminary note): Bull. Earthquake Research Inst., v. 21, p. 276–297
Nagata, T., Akimoto, S., and Uyeda, S., 1951, Reverse thermoremanent magnetism: Japan Acad. Proc., v. 27, p. 643–645
Nagata, T., Akimoto, S., Shimizu, Y., Kobayashi, K., and Kuno H., 1959, Palaeomagnetic studies on Tertiary and Cretaceous rocks in Japan: Japan Acad. Proc., v. 35, p. 378–383
Nagata, T., Akimoto, S., Uyeda, S., Momose, K., and Asami, E., 1954, Reverse magnetization of rocks and its connection with the geomagnetic field: Jour. Geomagnetism and Geoelectricity [Kyoto], v. 6, p. 182–193
Nagata, T., Akimoto, S., Uyeda, S., Shimizu, Y., Ozima, M., Kobayashi, K., and Kuno, H., 1957, Palaeomagnetic studies on a Quaternary volcanic region in Japan: Jour. Geomagnetism and Geoelectricity [Kyoto], v. 9, p. 23–41
Nairn, A. E. M., 1956, Relevance of palaeomagnetic studies of Jurassic rocks to continental drift: Nature, v. 178, p. 935–936
—— 1957a, Palaeomagnetic collections from Britain and South Africa illustrating two problems of weathering: Advances in Physics, v. 6, p. 162–168
—— 1957b, Observations paléomagnétiques en France: Roches Permiennes: Soc. Géol. France Bull., ser. 6, v. 7, p. 721–727
—— 1957c, A palaeomagnetic study of Jurassic and Cretaceous sediments: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 7, p. 308–313
Nairn, A. E. M., Frost, D. V., and Light, B. G., 1959, Palaeomagnetism of certain rocks from Newfoundland: Nature, v. 183, p. 596–597
Néel, L., 1951, L'inversion de l'aimantation permanente des roches: Annales Géophysique, v. 7, p. 90–102
—— 1955, Some theoretical aspects of rock-magnetism: Advances in Physics, v. 4, p. 191–243
Öpik, E. J., 1955, Palaeomagnetism, polar wandering, and continental drift: Irish Astron. Jour., v. 3, p. 234–236
Pascoe, E., 1929, General report for 1928: Geol. Survey India Records, v. 62, p. 1–184
Rimbert, F., 1956a, Sur la désaimantation par action de champs magnétiques alternatifs, de la magnétite et du sesquioxyde de fer$_\alpha$: Acad. Sci. [Paris] Comptes Rendus, v. 242, p. 890–893
—— 1956b, Sur l'action de champs alternatifs sur des roches portant une aimantation rémanente isotherme de viscosité: Acad. Sci. [Paris] Comptes Rendus, v. 242, p. 2536–2538
Roche, A., 1950a, Sur les caractères magnétiques du système éruptif de Gergovie: Acad. Sci. [Paris] Comptes Rendus, v. 230, p. 113–115
—— 1950b, Anomalies magnétiques accompagnant les massifs de pépérites de la Limagne d'Auvergne: Acad. Sci. [Paris] Comptes Rendus, v. 230, p. 1603–1604
—— 1951, Sur les inversions de l'aimantation rémanente des roches volcaniques dans les monts d'Auvergne: Acad. Sci. [Paris] Comptes Rendus, v. 230, p. 1132–1134
—— 1953, Sur l'origine des inversions d'aimantation constantées dans les roches d'Auvergne: Acad. Sci. [Paris] Comptes Rendus, v. 236, p. 107–109
—— 1956, Sur la date de la dernière inversion du champ magnétique terrestre: Acad. Sci. [Paris] Comptes Rendus, v. 243, p. 812–814
—— 1957, Sur l'aimantation des roches volcaniques de l'Estérel: Acad. Sci. [Paris] Comptes Rendus, v. 244, p. 2952–2954
—— 1958, Sur les variations de direction du champ magnétique terrestre au cours du Quaternaire: Acad. Sci. [Paris] Comptes Rendus, v. 246, p. 3364–3366
Roche, A., and Cattala, L., 1959, Remanent magnetism of the Cretaceous basalts of Madagascar: Nature, v. 183, p. 1049–1050
Roche, A., Cattala, L., and Boulanger, J., 1958, Sur l'aimantation de basaltes de Madagascar: Acad. Sci. [Paris] Comptes Rendus, v. 246, p. 2922–2924
Runcorn, S. K., 1954, The earth's core: Am Geophys. Union Trans., v. 35, p. 49–63
—— 1955a, Rock magnetism—geophysical aspects: Advances in Physics, v. 4, p. 244–291
—— 1955b, Palaeomagnetism of sediments from the Colorado Plateau: Nature, v. 176, p. 505–506
—— 1956a, Paleomagnetic survey in Arizona and Utah: Preliminary results: Geol. Soc. America Bull., v. 67, p. 301–316
—— 1956b, Palaeomagnetic comparisons between Europe and North America: Geol. Assoc. Canada Proc., v. 8, p. 77–85
—— 1959, On the theory of the geomagnetic secular variation: Annales Géophysique, v. 15, p. 87–92
Russell, R. D., Farquhar, R. M., Cumming, G. L., and Wilson, J. T., 1954, Dating galenas by means of their isotopic constitutions: Am. Geophys. Union Trans., v. 35, p. 301–308
Rutten, M. G., van Everdingen, R. O., and Zijderveld, J. D. A., 1957, Palaeomagnetism in the Permian of the Oslo graben (Norway) and of the Estérel (France): Geol. en Mijnb. N. s. 19e Jaarg. no. 6, p. 193–195
Schreiner, G. D. L., 1958, Age of a Pilansberg dyke of palaeomagnetic significance: Nature, v. 181, p. 1330–1331

Shillibeer, H. A., and Cumming, G. L., 1956, The bearing of age determination on the relation between the Keewatin and Grenville provinces: Royal Soc. Canada Special Pub. 1, p. 54–73

Sigurgeirsson, Th., 1957, Direction of magnetization in Icelandic basalts: Advances in Physics, v. 6, p. 240–246

Stehli, F. G., 1957, Possible Permian climatic zonation and its implications: Am. Jour. Sci., v. 255, p. 607–618

Stott, P. M., and Stacy, F. D., 1959, Magnetostriction and palaeomagnetism of igneous rocks: Nature, v. 183, p. 384–385

Swartz, C. K., 1923, Geologic relations and geographic distribution of the Silurian strata of Maryland, p. 19–52 *in* Maryland Geological Survery, Silurian: Baltimore, The Johns Hopkins Press, 794 p.

Thellier, É., 1951, Propriétés magnétiques des terres cuites et des roches: Jour. Physique et Radium, v. 12, 205–218

Thellier, É., and Rimbert, F., 1954, Sur l'analyse d'aimantations fossiles par action de champs magnétiques alternatifs: Acad. Sci. [Paris] Comptes Rendus, v. 239, p. 1399–1401

—— 1955, Sur l'utilisation, en paléomagnétisme, de la désaimantation par champs alternatifs: Acad. Sci. [Paris] Comptes Rendus, v. 240, p. 1404–1406

Thellier, É., and Thellier, O., 1951, Sur la direction du champ magnétique terrestre retrouvée sur des parois de fours des époques punique et romaine, à Carthage: Acad. Sci. [Paris] Comptes Rendus, v. 233, p. 1476–1478

—— 1959, Sur l'intensité du champ magnétique terrestre dans le passé historique et géologique: Annales Géophysique, v. 15, p. 285–376

Thomson, J. E., 1956, Geology of the Sudbury basin: Ontario Dept. Mines Report, v. 65, p. 1–56

Torreson, O. W., Murphy, T., and Graham, J. W., 1949, Magnetic polarization of sedimentary rocks and the earth's magnetic history: Jour. Geophys. Research, v. 54, p. 111–129

Uyeda, S., 1958, Thermo-remanent magnetism as a medium of palaeomagnetism, with special reference to reverse thermo-remanent magnetism: Japanese Jour. Geophysics, v. 2, p. 1–123

Verhoogen, J., 1956, Ionic ordering and self-reversal of magnetization in impure magnetites: Jour. Geophys. Research, v. 61, p. 201–209

—— 1959, The origin of thermo-remanent magnetization: Jour. Geophys. Research, v. 64, p. 2441–2449

Vestine, E. H., La Porte, L., Cooper, C., Lange, I., and Hendrix, W. C., 1947, Description of the earth's main magnetic field and its secular change, 1905–1945: Carnegie Inst. Washington Pub. 578, 532 p.

Vincenz, S. A., 1954, The magnetic properties of some Tertiary intrusives of the Isle of Mull: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 6, p. 590–603

Walker, F., and Poldervaart, A., 1949, Karroo dolerites of the Union of South Africa: Geol. Soc. America Bull., v. 60, p. 591–706

Watanabe, N., 1958, Secular variation in the direction of geomagnetism as the standard scale for geomagnetochronology in Japan: Nature, v. 182, p. 383–384

Watson, G. S., 1956, Analysis of dispersion on a sphere: Royal Astron. Soc. Monthly Notices, Geophys. Supp., v. 7, p. 153–159

Watson, G. S., and Irving, E., 1957, Statistical methods in rock magnetism: Royal Astron. Soc. Monthly Notices, Geophys. Supp. v. 7, p. 289–300

Wetherill, G. W., Davis G. L., and Aldrich, L. T., 1957, Age measurements on rocks north of Lake Huron: Am. Geophys. Union Trans., v. 38, p. 412

Wilson, M. E., 1958, Precambrian classification and correlation in the Canadian shield: Geol. Soc. America Bull., v. 69, p. 757–774

Wilson R. L., 1959, Remanent magnetism of late Secondary and early Tertiary British rocks: Philos. Mag., v. 4, p. 750–755

U. S. Geological Survey, Menlo Park, California

Manuscript Received February 1, 1960

Publication Authorized by the Director, U. S. Geological Survey