APPLICATION OF ROCK MAGNETISM IN ESTIMATING THE AGE OF SOME NORWEGIAN DIKES

By

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Abstract. Directions of remanent magnetism are presented of two basic dike systems in South Norway: the diabase-lamprophyre association of the Ny-Hellesund area and the dolerites of the Egersund area. The Ny-Hellesund dikes show stable palaeomagnetic directions consistent with those derived from the Permian rocks of the Oslo area, thus enabling one to suggest that these dikes were intruded in Hercynian times. On the other hand, a Tertiary origin (connected with the general uplift of the western parts of the Scandinavian land mass at that time) of the Egersund dolerites seems to be the most likely interpretation of the directions for this dike formation; a result which is of special interest since the possibility of igneous activity in Norway younger than the Permian has not previously been seriously considered.

Introduction

Since the amount of palaeomagnetic data has increased, strong evidence is now available in favour of the geocentric axial dipole hypothesis. This fundamental concept means that the non-axial dipole components of the geomagnetic field will average out if observation spans a period of about 10,000 years, leaving a main dipole along the axis of spin. The palaeomagnetic poles, as calculated from the permanent magnetization of rocks, are therefore assumed to be geographic poles at the times considered if the geomagnetic secular variation has been cancelled out in the mean directions.

One of the most interesting results derived from palaeomagnetism is the indication of a slow change in attitude of the Earth's dipole axis relative to certain land masses, a movement which seems to have occurred through geological time as far back as the Precambrian. That a general polar wandering has taken place is suggested from the fact that the polar paths from different continents have a similar shape. On the other hand, the different curves are displaced relative to each other, so a continental drift is now considered more and more as a reality.

The polar wandering curves may obviously serve as a scale in age determination of rocks. But, unfortunately, the poles relative to Europe for the time prior to the Late Carboniferous are at present not well established. The discrepancy of results is probably mainly due to insufficient laboratory analysis of the permanent magnetization and to uncertainties about the time at which certain rocks acquired their remanence. However, there exist some reliable data from British rocks of Lower Carboniferous and Devonian age (EVERITT and BELSHÉ 1960, WILSON and EVERITT 1963, CHAMALAUN and CREER 1964) which together with data from later periods are indicative of a gradual polar shift of about 90 degrees of latitude since the Devonian.

As to the accuracy of palaeomagnetic dating, this method can generally only be applied to the study of relatively large age differ-

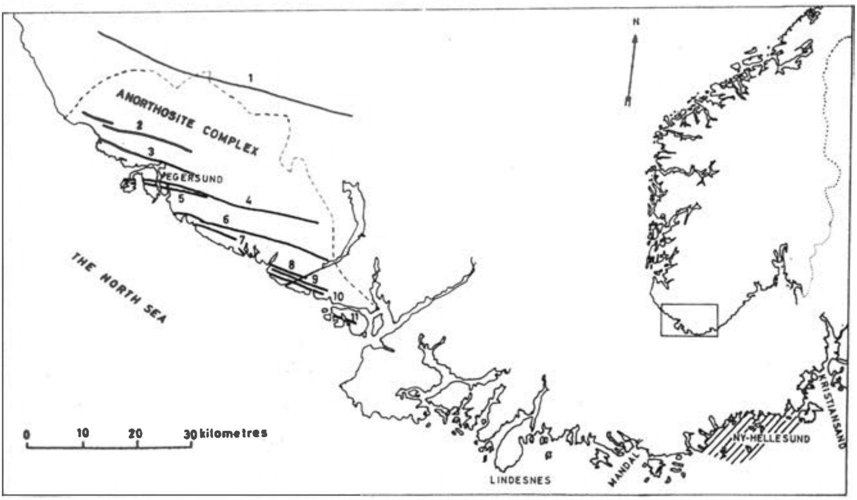

Fig. 1. Sketch map showing the situation of the discussed dike systems: the dolerites of the Egersund area and the lamprophyre-diabase association of the Ny-Hellesund area. Map area indicated on key map of Southern Norway.

ences (under normal conditions, say of the order of 50 million years); therefore, it is generally less accurate than radioisotope determinations. In certain cases, however, dating of subdivisions of geological periods may be achieved. A case in which the magnetic method ought to be able to be applied with especially great profit (and where radiogenic dating does not work) is in unfossiliferous sediments.

Palaeomagnetic dating has so far not been extensively used, but where it has been tried it seems to have been highly successful—at least where radioactive dating has also been applied the results of the two methods show good agreement (BOESEN, IRVING, and ROBERTSON 1961, LAROCHELLE 1961).

For consideration of the age problem, a palaeomagnetic survey of undated Norwegian dikes has been undertaken, and this paper presents results obtained on younger basic dikes from two different areas on the southern coast (Fig. 1).

The Ny-Hellesund area. The younger generation of lamprophyres and diabases

Geological investigations of these rocks have been carried out by BARTH (1943) and CARSTENS (1959). The dikes have mostly intruded the surrounding granitic gneisses and migmatites (BARTH 1945) as flat-lying or gently dipping sheets never exceeding 3 m in thickness. At three sites, however, vertical diabases occur. Since the outcrops are interrupted by the sea, the number of separate dikes is not known.

The lamprophyres (vogesites) are considered to have been developed from an original basaltic magma through assimilation of the adjacent rocks.

Both diabases and lamprophyres show, in general, a rather fresh appearance of the minerals.

The lamprophyre-diabase associations on the southern coast of Norway represent the last magmatic activity of the area, and tectonic movements worth mentioning anterior to intrusion have not been revealed. The age of the dikes has been discussed by HJELMQUIST (1939), BARTH (1943), and MACGREGOR (1948); a Permian origin is suggested as the most likely.

So far, 31 oriented blocks, comprising normal labradorite diabases (both vertical and inclined) and lamprophyres, from several outcrops (in general 2 blocks from each) have been collected and investigated palaeomagnetically. All samples were subjected to thermal demagnetization experiments in order to determine the fossil components of the remanence by selectively destroying secondary magnetizations.

Nearly 60% of the rocks collected yielded results considered as reliable. In contrast to the diabases, of which about 90% possessed a well-defined high temperature direction, nearly all lamprophyres sampled showed pronounced instability. Measurements of the total natural remanence of most of these lamprophyres gave directions close to the present magnetic field, but on partial demagnetization the directions changed gradually towards the position of the diabases. The remanent magnetization of the lamprophyres is mostly associated with blockage temperatures lower than those in the diabases, and a complete cleaning of 'softer' components has generally not been obtained. Nevertheless, two samples (from the same site) were stable throughout nearly the whole range of temperatures (the main intensity of magnetization being blocked just below the Curie point of pure magnetite), and the directions agreed fairly well with those of the diabases. In any case, the magnetization of the lamprophyres is generally somewhat puzzling; it apparently lacks a total thermoremanence in most cases. Therefore, it is tentatively suggested that the temperature of the lamprophyric magma just before solidification was in general only a few hundred degrees centigrade. However, many more experiments are in progress on this interesting aspect of rock magnetism.

The site mean directions are shown in Fig. 2 b. As seen, the dike system is reversely magnetized, the mean direction being N 200° E/–29°. The semiangle of the circle of confidence at the 95% probability level (Fisher 1953) is 10 degrees.

The great divergence between the direction of fossil magnetization and the present field direction together with the fact that the stable remanence is very likely of thermal origin (suggested from heating experiments) must be taken as strong indications that the dikes (in particular the diabases) throughout their history have been able to retain the sense of acting geomagnetic field at the time of cooling.

The pole as calculated from the mean direction shows excellent agreement with the remarkably consistent Permian palaeomagnetic

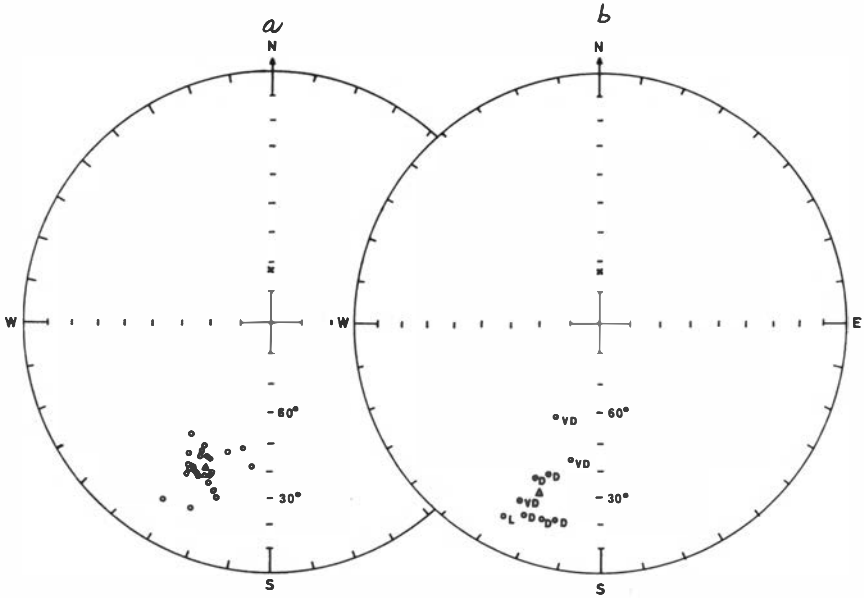

Fig. 2. Equal area nets showing palaeomagnetic directions deduced from the Permian rock complex of the Oslo area (a) and from the Ny-Hellesund dikes (b). Plots are north-seeking pole in upper hemisphere representing mean directions of rock units (lava flow, dike, etc.). Triangles show the overall mean direction of each formation. VD, vertical diabase dike; D, inclined or flat-lying dia-base dike; L, lamprophyre dike; x, present theoretical dipole field direction.

poles which are based on formations of Central and Northern Europe and Northern Asia. With the exception of certain red beds of the uppermost Permian (or lowermost Triassic) of the U.S.S.R. (KHRAMOV, quoted in KALASHNIKOV 1961), all rocks from this period so far studied are reversely magnetized.

The igneous complex of the Oslo area (of lower Permian age) has been subjected to a very detailed palaeomagnetic investigation by VAN EVERDINGEN (1960). His results are based on 26 geological units made up mainly of lava flows, but intrusives and a red bed are also represented. The mean direction of each unit has usually been based on several samples, and it is therefore reasonable to assume that the internal scatter has been averaged out in the mean directions, leaving in many cases a 'spot' reading of the ancient field. The time sequence involved is certainly also sufficiently long so that a reliable figure of the secular changes at that time may have been deduced (Fig. 2 a).

The mean direction of the Ny-Hellesund dikes and that of the Oslo complex are not significantly different, and the scatter of directions in the two formations is about the same. However, a more pertinent question is whether a dike system as here encountered may be expected to contain a full record of the secular variation. Since each dike certainly cooled very quickly and many of the different outcrops must be expected to be parts of the same intrusion, the answer is very probably no. It is thought that when more palaeomagnetic data are available (whereby the within dike dispersion is averaging out), a few readings of the ancient field will appear. However, it is undoubtedly safe to say that the considered palaeomagnetic directions most likely correspond to the time interval: Late Carboniferous–Triassic. At present, no reliable data can support a Caledonian age of the dikes, and the chance that the mean direction could belong to a reversed Tertiary field is statistically (FISHER 1953) much less than 1%. A connection with the Permian igneous activity of the Oslo area, as suggested by geologists, seems therefore to be a reasonable estimate of the age.

The Egersund area. The younger diabases

The younger diabases which dissect the Precambrian anorthosite complex of this area have been extensively studied geologically by ANTUN (1956). Eleven dikes, numbered 1 to 11 from north to south, were mapped and classified into the following three groups: dolerite (no. 6), trachydolerites (nos. 1, 2, 4, and 5) and porphyritic dolerites (nos. 3 and 7–11). Their attitude is about vertical, and the maximum thickness may be up to 30 m. With a general strike in the east—southeast direction, they can be followed over long distances. The dikes intersect all other rocks in the area and, apart from slight displacements where they cut some old fault zones, no evidence of tilting since emplacement has appeared.

All dikes are olivine-bearing, and the mineralogical state is generally very unaltered. Even glass (CHRISTIE 1959) may occur in the chilled margins and in apophyses.

According to Antun the dikes are surely post-Precambrian. Otherwise, no certain geological evidence of a better age establishment is present, although the glass content may indicate a rather recent age.

Twenty-two samples, or about 50% of the total rock collection, were considered reliable for the purpose of deriving the primary direction of magnetization.

Experimental results (STORETVEDT 1965) seem to indicate that the stable natural remanence has thermoremanent characteristics; therefore, its acquisition probably took place immediately after emplacement when the dikes cooled below the Curie points of the inherent iron-titanium oxide minerals.

The dike mean directions as based on all stable sample components are shown in Fig. 3. The overall mean direction, assigning unit weight to each dike, is N 085° E/+71°, and the radius of the circle of confidence at the 95% probability level is (as in the previous case) 10 degrees. Different from the Ny-Hellesund dikes, the Egersund dolerites possess normal polarity (as the present field) and a much higher inclination. Owing to the multiple nature of the dike system and the fact that each dike certainly contains a 'spot reading' of the geomagnetic field, the supposition that the mean direction should be that of an axial dipole at the time considered is probably not valid, and the calculated pole position does not correspond to any known reliable palaeomagnetic pole.

No Precambrian or Palaeozoic results fit the directions deduced from the Egersund dolerites. On the other hand, the remanent directions are representative of a geomagnetic field in geologically recent times (Late Mezosoic or younger), and the conclusion is therefore that the dike system seems most likely to be Tertiary in age.

Since the grain size distribution in the Eocene ash layers of Northern Jylland predicts an eruption centre in a direction towards the southern coast of Norway (NORIN 1940), a connection with the Egersund dolerites may exist. The large magnetic anomaly recently discovered in the sea south of Kristiansand is therefore perhaps the remnants of a Tertiary volcanic centre.

From geological considerations, it has been assumed that the intrusion act of the dike suite was of short duration (ANTUN 1956). If one supposes a Tertiary age of the dikes, the palaeomagnetic results would seem to support this suggestion, since the mean direction deviates significantly from the dipole field directions which may be calculated

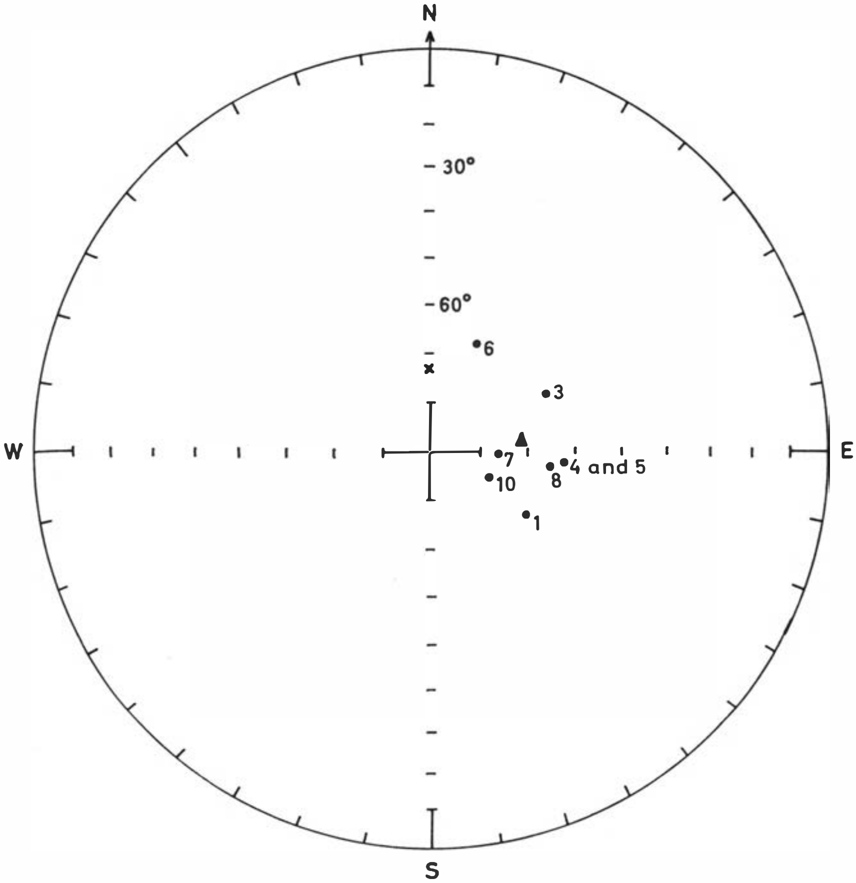

Fig. 3. Dike mean directions of the Egersund dolerites. Plots are north-seeking pole in lower hemisphere on an equal area projection. The triangle gives the estimated mean direction of the dike system. Dikes nos. 4 and 5 are identical, representing a bifurcating fissure, and are therefore treated together. Dikes no. 9 and no. 11 are not sampled and the collected site in dike no. 2 was affected by lightning. x, present theoretical dipole field direction.

for this time. Therefore, most intrusions probably took place in a very short time compared with the period of secular variation.

Whether all the different petrographic units represent a nearly single time reading of the field or whether there is a noticeable time break between the different intrusions (or groups of intrusions) can probably be answered palaeomagnetically, but, owing to the internal scatter displayed by most of these dikes, a very large rock collection is necessary for the solution of this problem.

Discussion

Although the majority of palaeomagnetic data so far available are not sufficiently detailed to serve as reliable observations of the secular variation scatter, the majority of the results seem to indicate a maximum variation of 20–30 degrees from the mean direction. It is obvious, therefore, that a certain deviation from the dipole direction can easily occur if only a few time readings are represented as a fossil record of the ancient field or if the entire time span investigated is short compared with the period of secular variation.

The paleomagnetism of some Norwegian red beds of Devonian Age have recently been investigated (STORETVEDT and GJELLESTAD 1966). The results show a marked deviation from the Permian direction but do not agree with the revised Devonian direction for Great Britain (CHAMALAUN and CREER 1964). At the time of writing, the author's attention was called to a recent study by NEUVONEN (1965) on the remanent directions of some Jotnian olivine dolerites of southwestern Finland. The pole calculated is situated at 158°E, 2°N, which is not very different from the revised Devonian pole for Great Britain (140°E, 10°S). Despite the uncertainties about the Devonian pole, there is therefore some evidence that the geomagnetic dipole axis might have been rather firmly trapped in the equatorial western Pacific in pre-Devonian times, perhaps covering a period of 500 million years. Therefore, palaeomagnetic dating in this time interval does not seem too promising at present. On the other hand, the polar shift since the middle of the Palaeozoic seems to have been so large that the palaeomagnetic method in many cases should add much information to the age determinations of our dike formations, even when the concept of an axial dipole field is unlikely to apply.

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