

THE PALAEOMAGNETISM OF THE KVAMSHESTEN OLD RED SEQUENCE, SOUTHWEST NORWAY

L. G. LIE, K. M. STORETVEDT & GURO GJELLESTAD

Geofysisk institutt, Universitetet i Bergen, Norway

LIE, L. G., STORETVEDT, K. M., GJELLESTAD, GURO: The palaeomagnetism of the Kvamshesten Old Red sequence, southwest Norway. *Norsk Geologisk Tidsskrift*, Vol. 49, pp. 241-249. Oslo 1969.

The inferred pole position (22°N, 170°E) for the Kvamshesten Old Red sequence is in fairly good harmony with other Old Red data of southern Norway. However, a deviation in declination of about 15° is thought to have arisen from a rotation (anti-clockwise) of this complex, a conclusion which is compatible with the geological observations. The stable remanence is considered as a moderate temperature viscous magnetization acquired during the time of diagenesis.

INTRODUCTION

The palaeomagnetic study of the Kvamshesten Old Red sequence formed part of a more extensive program — a palaeomagnetic investigation of Old Red Sandstone districts of southern Norway differently affected by post-depositional orogenic movements. There were two main aspects of these studies:

- 1) a possible contribution to the solution of the Devonian palaeomagnetic field problem, and
- 2) the study of possible differential rotations between Old Red sequences in different districts in Norway.

The results from the districts on the eastern edge of the Caledonian deformation, the Røragen complex and the Ringerike Sandstone, have been given elsewhere (Storetvedt & Gjellestad 1966, Storetvedt et al. 1968).

GEOLOGICAL SETTING

The Kvamshesten area, shown on the geological sketch map of Fig. 1, is situated between Dalsfjord and Fördefjord in the southwest of Norway, approximately 110 kilometres north of Bergen. It is one of six separated Devonian districts along a coastal range of about 100 kilometres.

Vertical tectonic movements, probably resulting in horst-graben features, appear to have been of essential importance during the evolution of these Old Red deposits; the present outcrop pattern is the result of uplift and denudation of the areas between the sedimentary basins.

The geology of the Kvamshesten area has been dealt with by C. F. Kol-

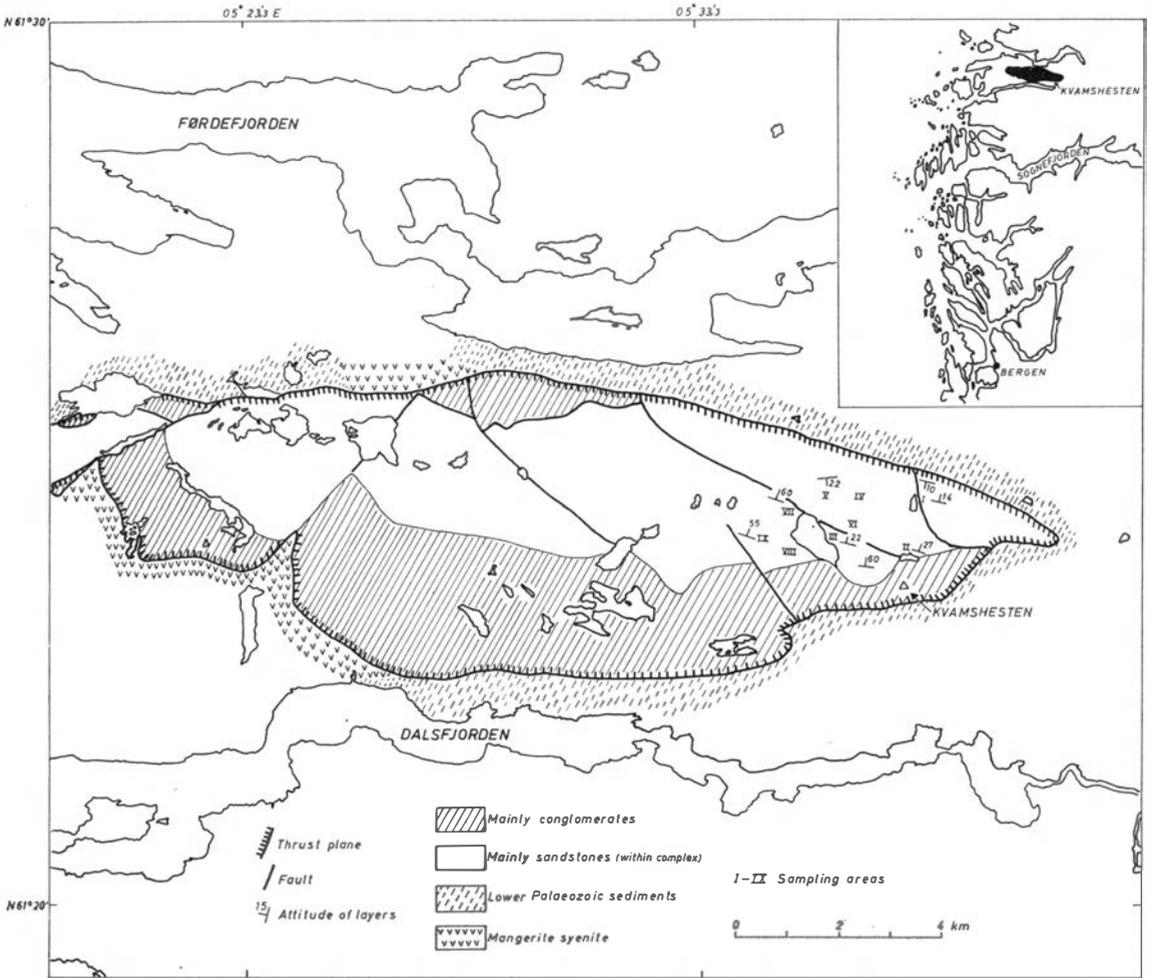


Fig. 1. Simplified geological map of the Kvamshesten Old Red complex. After Skjerlie (1968). Key map is of southwestern Norway.

derup (1923). Recent work by F. J. Skjerlie (1968, pers. comm.) has added much detailed information to the general understanding of the evolutionary history of this rock complex.

Because of a complicated tectonic structure, such as stratal repetition, it is difficult to estimate accurately the preserved stratigraphic thickness (less than 2,000 metres). However, it seems reasonable to suppose that the total thickness of sediments laid down amounts to several thousand metres. The sedimentary succession was initiated by breccia formation, passing into conglomerates with intercalated layers of green and red sandstones. The whole basin was deformed during late stages of orogenic disturbance (syn- and post-depositional to the Old Red sedimentation), resulting in faults, folds, and stratal plications. Thus the dip of layers may in certain cases

amount to about 60°. Furthermore, a marked mylonitic zone is developed at the boundary with the underlying Lower Palaeozoic sediments, and the basal conglomerate is lacking beneath the eastern tip of the area. Therefore, the whole complex must be considered as a nappe structure. Also, several faults subdivide the Old Red sequence, but they do not continue through the underlying schists. This indicates that the faults originated as the result of relative movements within the Devonian complex itself. It does not seem that the different sections thus created have rotated relative to each other by a significant amount, because the fold structure predominating along the northern half of the complex is only slightly disturbed.

As to the age of the Kvamshesten complex, there are only poorly preserved fossils in the area itself, but floral and faunal evidence from the nearby districts suggests a Middle or possibly early Upper Devonian age (Kolderup 1923, Kiær 1918, Jarvik 1949).

Ninety-seven geographically oriented samples of finegrained red sediments were collected from sites of varying attitude (cf. Fig. 1) in the eastern part of the complex. It was hoped that this sampling would throw some light upon the age of magnetization relative to the post-depositional deformation.

THE NATURAL REMANENT MAGNETISM (n. r. m.)

The measurements (of about 6 cylindrical specimens from each sample) were carried out on an astatic magnetometer.

In general the n. r. m. has a southerly direction, but a certain planar distribution through the direction of the present geomagnetic field is recognized. Remeasurements after 1½ years of random field storage often gave considerably greater variation than the estimated measuring errors ($\pm 2^\circ$ in direction and 5 % in intensity). Differences as large as 60° in direction and 30 % in intensity were recorded. The intensity of magnetization ranged mostly between 1×10^{-6} e.m.u./cm³ and 8×10^{-6} e.m.u./cm³.

THERMAL EXPERIMENTS

In order to remove the low stability components obviously present, thermal demagnetization tests were applied extensively.

The procedure during these experiments was as previously reported (Storetvedt et al. 1968). These demagnetizations were carried out before a more refined technique of zero field control during heating had been developed in our laboratory (Hummervoll 1969), and the average magnetic field in the space occupied by the specimens was about 35γ after cooling to room temperature. Even such a small field may introduce a thermoremanent

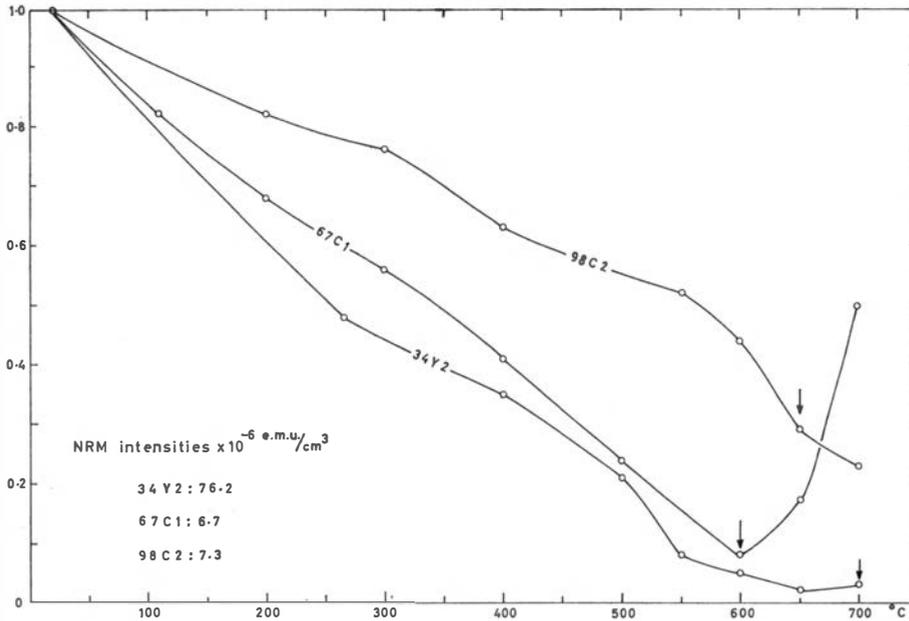


Fig. 2. Examples of remanence intensity as a function of temperature. Arrows indicate where anomalous magnetizations are being introduced.

moment of sufficient magnitude to limit the applicability of thermal demagnetization.

It was soon recognized that magnetic properties of these rocks were extremely sensitive to heat treatment, as the magnetic viscosity increased rapidly with temperature. Storage of the rock cylinders in approximately zero field before measurement was therefore one of the basic experimental requirements. Demagnetization of a series of pilot specimens from samples of varying n. r. m. characteristics showed that a large number of them — those of scattered n. r. m. direction or of weak n. r. m. intensity — failed to give a meaningful sample direction after heat treatment. Therefore, when dealing with the present problem, a demagnetization program to the whole rock collection appeared to be a waste of time and a primary rejection of samples was based on the following criteria:

- 1) All samples of magnetization intensity $\leq 3 \times 10^{-6}$ e.m.u./cm³.
- 2) All samples whose internal scatter gives a circle of confidence (α_{95}) greater than 40° .

In addition to rejections after later demagnetizations (see later), altogether 56 samples were considered inappropriate for further discussion. In the remaining samples, 41, a certain low stability component is removed when demagnetization is affected at approximately 400°C . The directional change

is always towards the south, away from the direction of the present field. The temperature of about 600°C appears to be a critical one for changes in magnetic properties, and normally the remanence direction is randomly scattered when demagnetized to these temperatures. Also, a rapid increase in magnetization intensity is associated with this scatter. However, in the cases where the progressive reduction of intensity could be followed up to 650°C, no new high temperature direction came to light. Typical intensity decay patterns are shown in Fig. 2.

The total artificial thermoremanent magnetization (t. r. m.) imposed on some test specimens is of the order of 10^{-3} e.m.u./cm³ implying that the maximum stray moments which are capable of being introduced during the thermal demagnetization experiments are of the same magnitude as the remanence to be analysed. It is thus conceivable that, beside the scatter caused by an increase in magnetic viscosity, scattered directions due to artificial t. r. m. moments may appear when demagnetization is affected at a sufficiently high temperature. The experiments also show that although there may exist a large difference between the n. r. m. intensities, those of the corresponding t. r. m.'s are practically identical. This observation tentatively suggests a fairly homogeneous distribution of type and quantity of the magnetic mineral content. Also the presence of a significant amount of unmagnetized material in these rocks appears to be a reasonable conclusion.

Thermal demagnetization of the artificial t. r. m. of two specimens suggest the presence of both magnetite and haematite, the remaining moment at 600°C constituting 5 % and 28 % of the initial value, respectively. The presence of two magnetic phases is also partly suggested by high field studies (translation and quartz spring balances), although most of these thermal curves are difficult to interpret owing to a pronounced linearity in shape and the extremely small moment remaining at around 600°C. The presence of magnetite is not evident from the thermal decay curves of the n. r. m. and the mineral mainly responsible for the stable remanence appears to lose its magnetism at a temperature corresponding to the Curie point of haematite. It is suggested therefore that any magnetite constituent present may be magnetically very indifferent, being either self-demagnetized or carrying perhaps the low stability component.

ALTERNATING FIELD TREATMENT

Specimens from 12 samples were subjected to treatment in stepwise increasing alternating fields. The equipment used is similar to that applied by Creer (1959). The results obtained agree with those observed by the thermal method. Where direction changes occur they are always away from the direction of the present geomagnetic field, but they often varied erratically, and no stable end point of the magnetization direction was obtained. However,

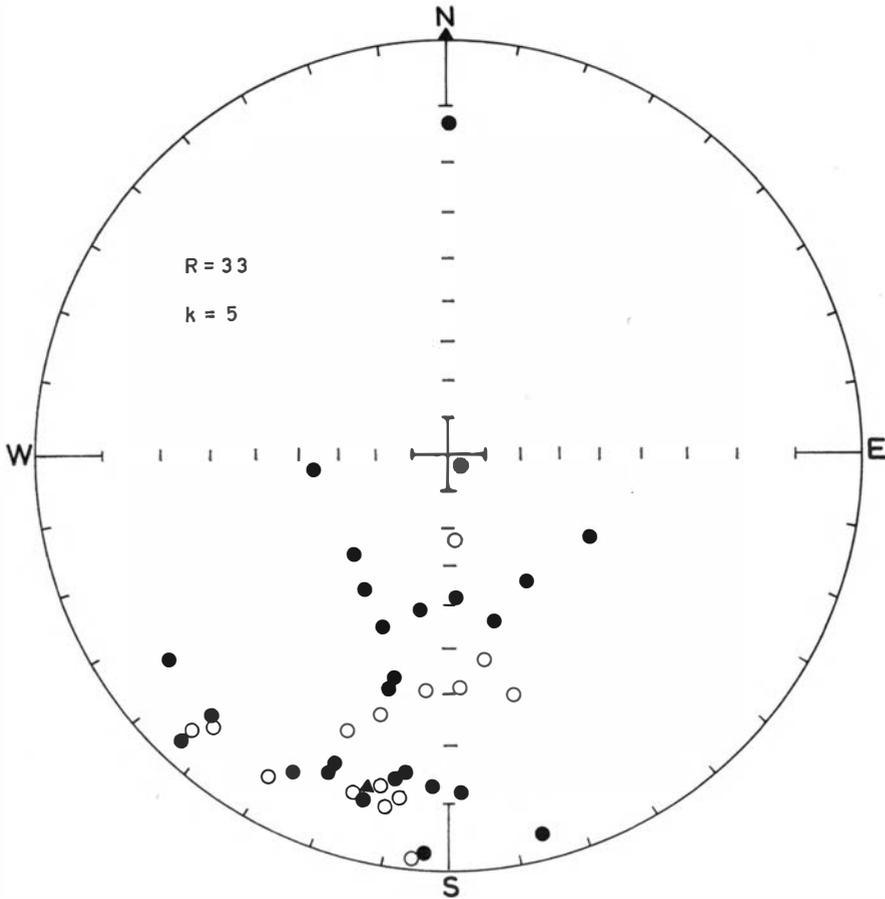


Fig. 3. Sample mean directions before correction for geological dip (stereographic projection). *Open circles* are points on the upper hemisphere and *full circles* are points on the lower hemisphere. The overall mean direction is shown by a *triangle*. R is the vector sum of all individual sample directions and k the precision parameter of Fisher's (1953) statistics.

where the low stability component was successfully removed, a good agreement of results from the two demagnetization methods was obtained. The scattered results introduced by alternating field treatment are well known in every palaeomagnetic laboratory. This scatter is most likely due to instrumental imperfection, and it appears to predominate in rocks containing a large proportion of low coercivity materials.

THE ACCEPTABLE DATA

The data accepted for palaeomagnetic discussion are those where the low stability component could be successfully removed. The a. c. results have been incorporated where of adequate reliability. With one exception the accept-

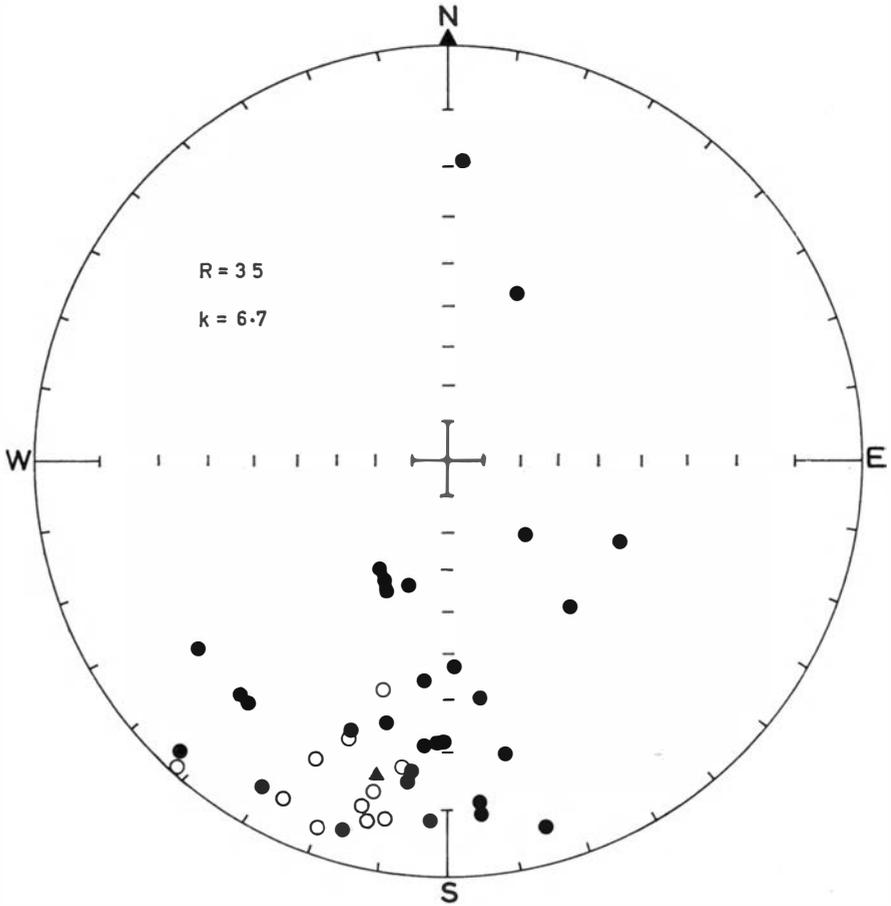


Fig. 4. Sample mean directions referred to the bedding plane. Key to Figure as in Fig. 3.

able data represent all sampling areas. For these data there is a reasonably good within-sample consistency. The sample means and the overall mean direction are shown in Fig. 3 when referred to the present horizontal, and in Fig. 4 when referred to the bedding plane. As shown from these figures there are only or two directions which have the same polarity as the present geomagnetic field. As, on the other hand, there is every reason to believe that in this weakly magnetized material a substantial fraction of the dispersion is due to other causes than field changes, one may reasonably conclude that the geomagnetic field was consistently reversed throughout the magnetization period. However, in estimating the overall mean directions of magnetization (unit weight on each sample) the normal directions have been changed by 180° .

When testing the correctness of fit to Fisher's (1953) distribution (before and after tilt correction), the χ^2 values computed are always smaller (some-

times considerably smaller) than the critical $X^2_{0.95}$ values, suggesting that both distributions are Fisherian to a sufficient approximation.

The angular difference between the overall mean directions of Fig. 3 and Fig. 4 is only 3° . The scatter is slightly reduced after correction for geological dip, but a comparison of direction dispersions (Watson & Irving 1957) shows that the fold test has no statistical significance at the 5 % probability level. By application of the mean direction of magnetization after geological tilt correction, 194° , $+12$, and assuming the geomagnetic field to be axial dipolar in average, a pole position at 22°N , 170°E results. The axes in the oval of confidence are 4.5 and 9.5 respectively.

DISCUSSION AND CONCLUSION

According to present views, the origin of red sediments is thought to arise from a variety of geological and climatic agencies affecting the parent rocks as well as the area of deposition. Also, the remanent magnetization of such rocks may have had a quite complicated birth. Thus, it seems rather doubtful in many cases whether magnetizations acquired at deposition or immediately thereafter (depositional and chemical remanences) are of great significance in palaeomagnetism. First of all, the unconsolidated sediment is likely to undergo continuous chemical changes through the action of penetrating solutions. Another point of greatest importance is the question of temperature increase due to deep burial and to tectonic processes as well. In the present case where the overburden may have been of the order of kilometres, it does not seem unrealistic to postulate temperatures of at least 200°C . As such elevated temperatures may have operated over millions of years, the process of acquiring viscous magnetization will be enhanced. Thus the hypothesis that the previous magnetization has, to a significant amount, been replaced by a moderate temperature viscous magnetization acquired at the time of diagenesis, seems to be based on reasonable assumptions. Also, the undetermined result of the fold test may indicate that folding was simultaneous to magnetization.

It has recently been pointed out (Storetvedt 1968) that the results from systematic thermal analysis of some Old Red formations (among which the Kvamshesten data are incorporated) indicate a gradual change in the magnetic polarity versus rock age, changing from a normal sense in early Old Red Sandstone time to a reversed one in late Old Red Sandstone time. This observation indicates that the assumption of a correspondance between physical rock age and magnetic age is valid to a sufficient approximation.

The pole position for the Kvamshesten formation shows a certain deviation from that of the other two Norwegian Old Red formations studied (Storetvedt 1967, 1968). Despite the statistical uncertainty about this difference it may, according to geological indications, easily be ascribed to a rotation of

this Old Red sequence. The amount of rotation required is about 15° anti-clockwise. This figure must be considered as a minimum value since any rotation prior to blockage of magnetization will of course remain undetected.

ACKNOWLEDGEMENTS

This work has in part been supported by the Norwegian Research Council for Science and the Humanities. Our sincere thanks are due to Dr. F. J. Skjerlie for valuable discussions throughout various stages of this investigation, and for reading the manuscript.

*Geofysisk Institutt, Avd. C,
Universitetet i Bergen,
5000 Bergen, Norway
3rd December 1968*

REFERENCES

- CREER, K. M. 1959: A. C. demagnetization of unstable Triassic Keuper Marls from S.W. England, *Geophys. J.* 2, 261-275.
- FISHER, R. A. 1953: Dispersion on a sphere. *Proc. Roy. Soc. London A* 217, 295-305.
- HUMMERVOLL, R. 1968: In preparation.
- JARVIK, E. 1949: On the Middle Devonian Crossopterygians from the Hornelen Field in Western Norway. *Bergens Museums Aarbok* 1948, No. 8.
- KIÆR, J. 1918: Fiskerester fra den devoniske sandsten paa Norges vestkyst, *Bergens Museums Aarbok* 1917-18 No. 7.
- KOLDERUP, C. F. 1923: Kvamshestens devonfelt. *Bergens Museums Aarbok* 1920-21 No. 4.
- SKJERLIE, F. J. 1968: Private communication.
- STORETVEDT, K. M. 1967: A synthesis of the Palaeozoic palaeomagnetic data for Europe. *Earth Planet. Sci. Letters* 3, 444-448.
- STORETVEDT, K. M. 1968: The Devonian palaeomagnetic field for Europe. In RUNCORN, S. K. (ed.) *Palaeogeophysics*, Academic Press, London (in press).
- STORETVEDT, K. M. & GJELLESTAD, GURO 1966: Palaeomagnetic investigation of an Old Red Sandstone formation of southern Norway. *Nature* 212, 59-61.
- STORETVEDT, K. M., HALVORSEN, E. & GJELLESTAD, GURO 1968: Thermal analysis of the natural remanent magnetism of some Upper Silurian red sandstones in the Oslo region. *Tectonophysics* 5, 413-426.
- WATSON, G. S. & IRVING, E. 1957: Statistical methods in rock magnetism. *Mon. Not. Roy. Astr. Soc. Geophys. Supp.* 7, 289-300.