Tectonophysics, 98 (1983) 151–164
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

PALAEOMAGNETIC RE-EXAMINATION OF THE BASAL CAITHNESS OLD RED SANDSTONE; ASPECTS OF LOCAL AND REGIONAL TECTONICS

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(Received March 25, 1983)

ABSTRACT

Storetvedt, K.M. and Torsvik, T.H., 1983. Palaeomagnetic re-examination of the basal Caithness Old Red Sandstone; aspects of local and regional tectonics. In: E. McClelland Brown and J. VandenBerg (Editors), Palaeomagnetism of Orogenic Belts. *Tectonophysics*, 98: 151–164.

A palaeomagnetic re-examination of the basal strata of the Caithness Old Red Sandstone has given results that are fully compatible with previous palaeomagnetic findings in this region. After structural correction the dominant remanence component has $D = 205°$, $I = +3°$, $\alpha_{95} = 6.4°$ ($N = 27$). The existence of this shallow inclined magnetization in the Middle Devonian strata of Caithness invalidates the model, proposed by Van der Voo and Scotese (1981), involving a ca. 2000 km sinistral offset along the Great Glen Fault in the Carboniferous. However, the available data are in favour of a few hundred kilometres sinistral movement along this fracture zone. However, the possibility of there having been a much larger transcurrent shift between Europe and North America in late/post-Devonian times, accumulated along various fracture zones within the Caledonian fold belt, is discussed. On the basis of an inferred overprinted magnetization, it is tentatively concluded that the tectonic deformation of the Old Red Sandstone of Caithness has a mid-Jurassic or younger age.

INTRODUCTION

In view of the current interest in the aspects and implications of possible transcurrent movements along the Great Glen Fault (GGF) in Scotland (for example, Kennedy, 1946; Winchester, 1973; Storetvedt, 1974, 1975; Mykura, 1975; Van der Voo and Scotese, 1981) the authors are presently engaged in a systematic palaeomagnetic study of rock formations adjacent to the Fault. This survey involves both re-examination of earlier work as well as studies of new rocks. Storetvedt (1974) has suggested the existence of a ca. 15° discordance in Devonian palaeomagnetic declination across the GGF which can be accounted for by a 200–500 km sinistral displacement along this fracture zone in late/post-Devonian time (Storetvedt, 1974, 1975). However, this relatively modest palaeomagnetic difference, frequently coupled with complex magnetization build-ups (see for example Storetvedt et al., 1978; Storetvedt and Carmichael, 1979), makes it important to reconsider earlier results that were based on less sophisticated experimental and

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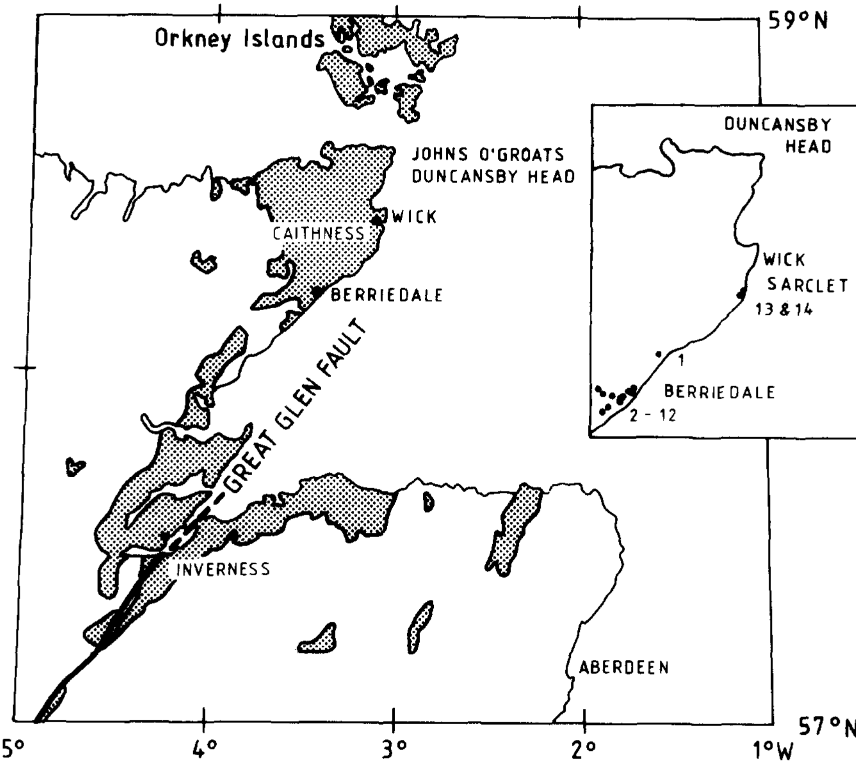

Fig. 1. Distribution of the Old Red Sandstone of northeast Scotland (Orcadian Basin) including the palaeomagnetic sampling sites of the present study.

analytical procedures than are generally used today. In this context we have taken a new look at the lower strata of the Caithness Old Red Sandstone (ORS). These rocks, which form part of the Orcadian Basin (cf. Fig. 1), were deposited essentially in mid-Devonian times though the basal strata may well have formed in the uppermost Lower Devonian (Crampton and Carruthers, 1914; Bennison and Wright, 1969). The earlier study of these beds (Waage and Storetvedt, 1973) encountered severe experimental problems in determining high temperature single-component magnetizations, and palaeomagnetic field directions were successfully unravelled from only very few specimens. Some of the sites, however, showed promising potential for further analysis, providing a strong impetus for the present study.

The rock material for the extended demagnetization work reported here comes from the same oriented block samples that formed the basis for the previous investigation. Due to lack of storage capacity the hand samples collected were discarded at an early stage, after a total of 111 $\frac{3}{4}''$ cylindrical specimens had been cut from them. 70 of these specimens were studied in the original investigation and the remaining 41 are included in the present analysis. The earlier demagnetization data have been subjected to re-examination with particular emphasis on remanence components other than the high temperature ones. For sampling and other field details the reader is referred to Waage and Storetvedt (1973).

EXPERIMENTAL RESULTS

While the remanence measurements of the previous study were carried out using a sensitive astatic magnetometer, the new measurements have been made using a Digico Spinner Magnetometer. Field cancellation in the present thermal demagnetization studies has generally been down to the level of 5–10γ (shielding provided by mu-metal layers) while the field strength in the previously used demagnetizer (surrounded by Helmholtz coils) was difficult to control to better than 10–20γ. In general, only the higher numbered sites (nos. 7–14) are sufficiently strongly magnetic to provide meaningful demagnetization results. Many specimens of this study

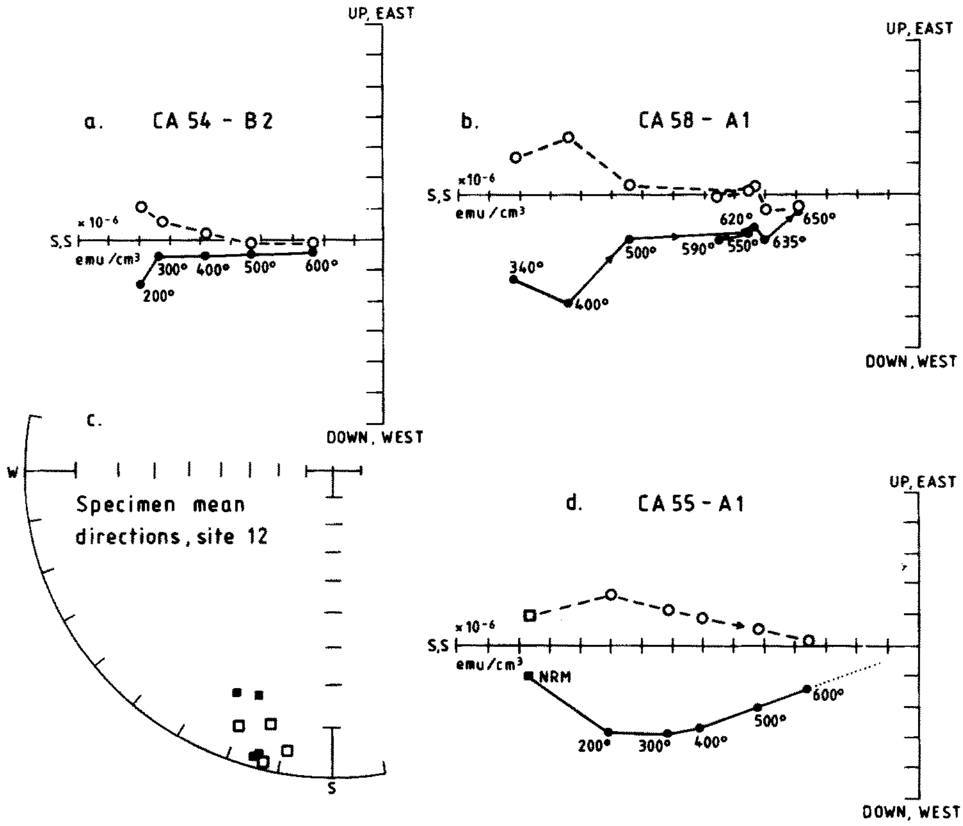

Fig. 2. Orthogonal projections of thermal demagnetization behaviour of specimens from site 12. Open symbols represent points in the vertical plane and solid symbols are points in the horizontal plane. Note that the horizontal plane is inverted. The directions of Fig. 2c (square symbols) correspond to the fairly stable bulk magnetization; as suggested from the vector diagrams these are not necessarily identical with the high temperature magnetization but the difference is probably quite small. The unit in the vector plots is $1 \cdot 10^{-6}$ emu/cm^3.

acquire viscous magnetization on thermal treatment, but rarely below 600°C. Apart from this stage, which has been ignored in the data analysis (incl. diagrams) the experimental error in direction is probably only a few degrees (based on repeated measurements and by comparing results from the two independent laboratory studies).

The most important axis of magnetization, and the only one that can be numerically estimated, is of shallow inclination with N–NE and S–SW declinations. In other palaeomagnetic studies of ORS rocks from Caithness (Storetvedt et al., 1978; Storetvedt and Carmichael, 1979) this field axis has been named the *B*-axis. The reversed *B* component of the present study has been more frequently determined than its normal counterpart, and many specimens remain in the reverse *B* position over the major range of demagnetization (some discordant high temperature/low intensity data ignored). Site 12 (at Berriedale Bridge) is an unusual site in that it only displays minimal directional changes (on progressive demagnetization) compared to the other sites of the collection (Fig. 2). The bulk magnetization of the eight specimens measured define a fairly clustered group of directions in the reverse *B*-axis position (Fig. 2c).

Site 13 (Sarclet Harbour) has a more complex magnetization than site 12 but it is still relatively simple since only the two antiparallel B components tend to be present (Fig. 3). For specimen CA59-B1 the vectorial change above 600°C justifies the estimation of a high temperature direction (stable end point defined by the 625° and 650°C demagnetization steps) that is slightly more westerly than that of the bulk remanence (at $T \leq 600°C$) which we do not regard as a single component magnetization. For specimen CA63-B1 the direction of both polarity components can be established through stable end-point determination (N) and vector subtraction (R), respectively. Normally, however, the different component spectra overlap to such an extent that, at best, only a certain "great circle" path is traced out on demagnetization: stable end points are not attained and vector plots have no straight line segments. Specimens CA59-A2, CA60-B2 and CA64-A2 seem to define "great circle" segments that intersect in the normal *B*-axis position, but in general (apart from sites 12 and 13) the directional trends of this study are quite irregular due to the co-existence of a second axis of magnetization (see below) and a suggested complex interplay of the various components. CA62-B is one of the magnetically stable specimens from site 13, and the palaeomagnetic direction has been based on results at $T \geq 400°C$ (Fig. 3c).

The stereoplots of Fig. 4 give further directional information from other sampling locations. In addition to giving more *B*-axis results (Fig. 4b, c and f) there is another group of data that suggests the presence of a second axis of magnetization. Thus, specimens CA40-A2 and B2 (Fig. 4a) have stable endpoint magnetization with northerly declination and intermediately steep downward inclination. Vector subtracted directions (not shown in the diagram), estimated between successive points along the directional paths from 200°C to 500°C, are poorly grouped but they tentatively indicate that the less stable remanence vector of these specimens are directed roughly antiparallel to their high temperature direction. Other evidence in

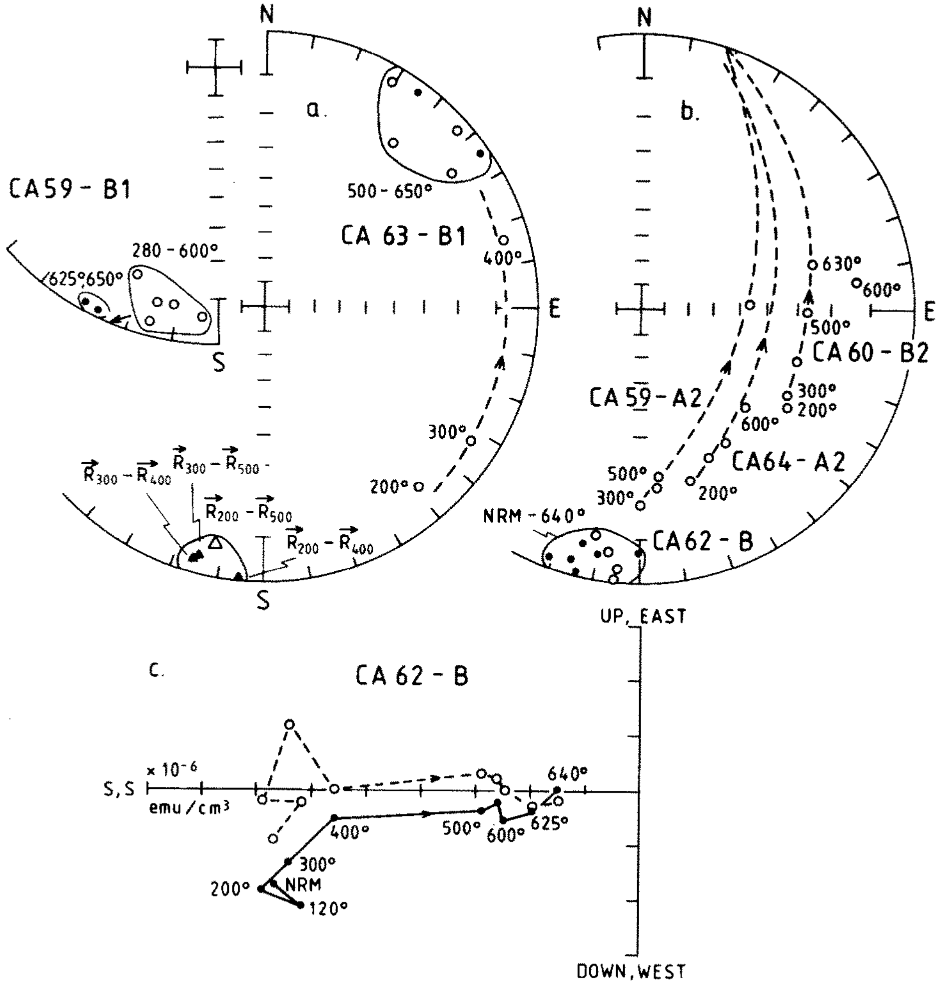

Fig. 3. Stereoplots and orthogonal vector projections for demagnetization data of site 13. In the stereograms open symbols represent upper hemisphere results. The triangles of Fig. 3a are vector subtracted directions for specimen CA63-B1, obtained between various demagnetization steps along the great circle path from 200°C to 500°C. The unit in diagram C is $1 \cdot 10^{-6}$ emu/cm^3.

favour of this second magnetization axis may be given by the results of Fig. 4d and e. This latter remanence component would correspond to the so-called *A*-axis that has been very well defined in some other palaeomagnetic studies of Caithness rocks (Storetvedt et al., 1978; Storetvedt and Carmichael, 1979). In the present rock sample collection there is a certain preference for the specimens to display reversed *A*-axis directions at the initial stages of thermal treatment, but as a general rule the directional changes are away from this position (even for very limited reduction of the remanence intensity) attaining mostly the *B*-axis directions when stable end-point results are achieved. Based on all available evidence it seems, however, that the

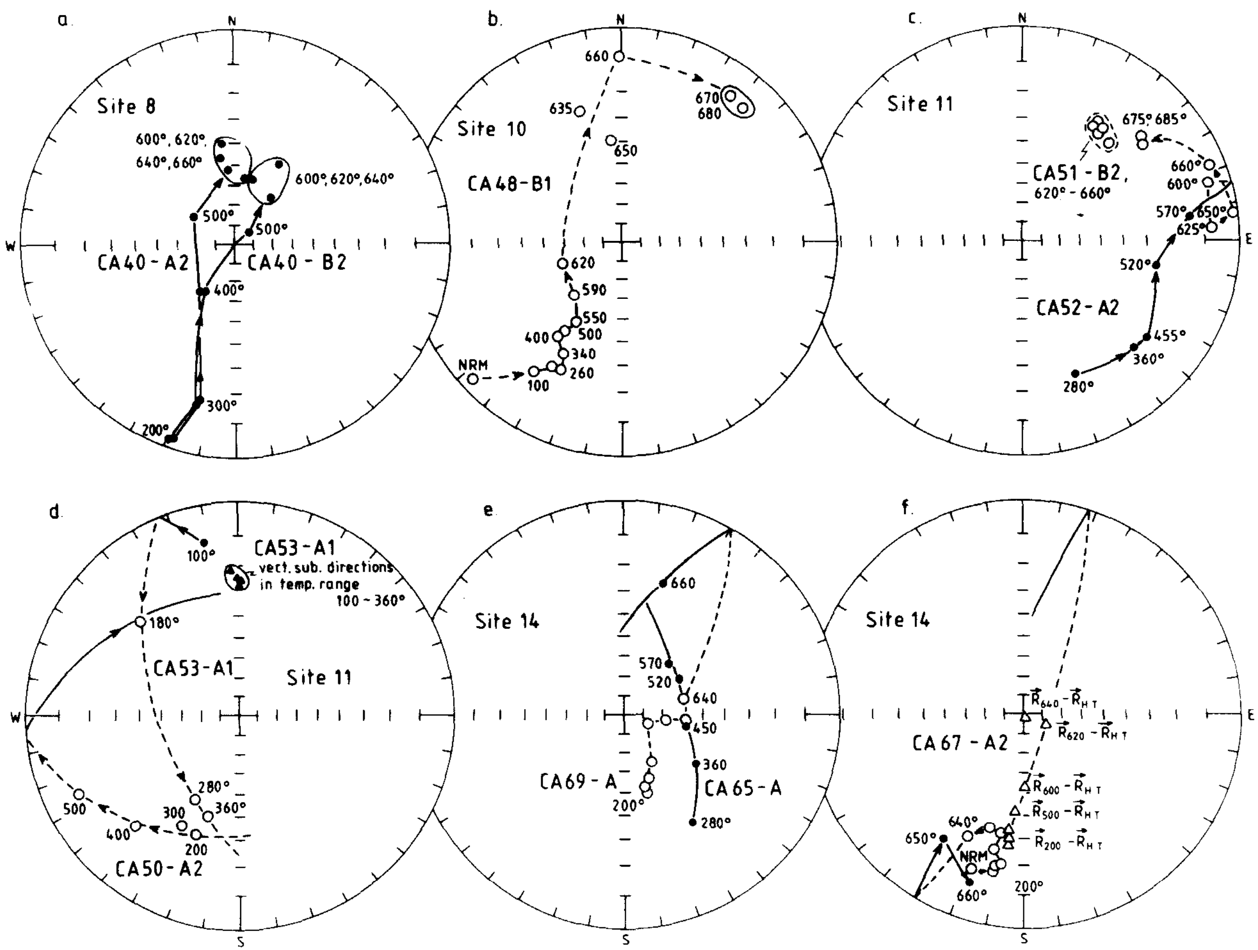

Fig. 4. Stereographic projections of specimens from various locations illustrating the remanence complexity. Note the evidence for "great circle" intersection in the *A*-axis positions (Fig. 4d, e) which is further demonstrated by specimens of site 8 (Fig. 4a) and the vector subtracted direction of CA53-A1 (Fig. 4d).

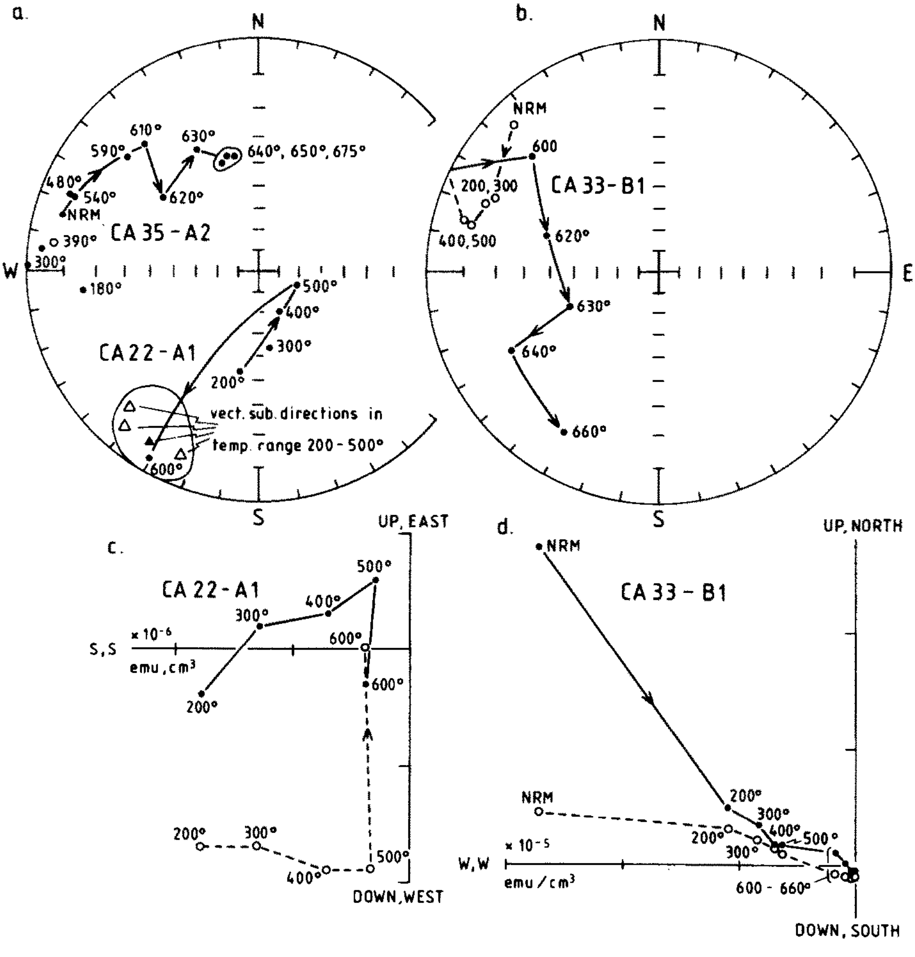

Fig. 5. Further thermal demagnetization results: site 5 (CA22) and site 7 (CA33 and 35). Diagram conventions as for Figs. 2 and 3, but the unit in diagram 5c is $2 \cdot 10^{-6}$ emu/cm^3.

contribution of A-magnetization is more important here than what might be the impression after the quite modest results of all the analytical efforts to define this magnetization more precisely.

In vector plots (Zijderveld, 1967) of many palaeomagnetic papers it is frequently seen that the line through the vector end-points by-pass the origin. This feature is commonly not commented upon or explanations are simply in terms of unspecified experimental problems. This attitude may easily result in critical information not being recovered, and the estimated "characteristic" remanence may even be palaeomagnetically irrelevant. Typical examples of this category are found in site 7 (Fig. 5). These specimens frequently display discordant westerly bulk magnetizations representing more than 90% of the total remanence intensity. Only at high temperature and at relatively low magnetic moments do the remanence vectors move into directions that are characteristic for the formation. The available data suggest that the fairly stable bulk magnetization is the vector resulting from the *A* and *B* components. The details of this directional behaviour could easily be overlooked if only the standard version of vector plots are used (cf. Fig. 5b, d). In cases like this it is imperative to present the directional variation in a more explicit way, either by blow-ups of the central portion of the vector diagrams or by supplementary stereonets.

PALAEOMAGNETIC INTERPRETATION

The 111 investigated specimens from the lower Caithness ORS beds (Waage and Storetvedt, 1973; present study) may be subdivided into the following categories:

(I) 40 specimens have remanence properties that allow estimation of either (1) stable end point magnetization or (2) the remanence direction for components of lower magnetic stability (by vector subtraction/vector diagrams). Nearly all of these results come from higher numbered sites (Nos. 7–14).

(II) 13 specimens trace out "great circle" segments on demagnetization but without reaching terminal directions before their intensity falls below the level of reliable measurement (see for instance Fig. 3b, specimen CA50-A2 of Fig. 4d, and specimen CA65-A of Fig. 4e). Attempts at vector subtraction for this group of samples did not prove successful, which suggests that their magnetizations have too much stability spectra overlap. The relatively few examples in this category, and the fact that it was frequently difficult to decide which magnetization axis (*A* or *B*) they were heading toward, have prevented a realistic application of the remagnetization circle technique (Halls, 1976).

(III) The remaining 58 specimens were either too weak for laboratory analysis, or they gave too complex vectorial patterns on demagnetization to enable extraction of individual remanence components. The latter problem is thought to arise from the interplay of a maximum of four palaeomagnetic vectors, aligned along two axes of magnetization (*A* and *B*).

From the 40 category I specimens 41 remanence directions have been established (specimen CA63-B1, Fig. 3a, has given two "antiparallel" components). These results, which form the basis for the present palaeomagnetic consideration, are listed in Table I. The majority of the data, 27 directions, are clustered around a nearly flatlying axis that strikes NNE–SSW. This is the so-called *B*-magnetization as defined in the Duncansby volcanic neck and in the John O'Groats Sandstone (Storetvedt et al., 1978; Storetvedt and Carmichael, 1979) which is assumed to represent the original direction of magnetization in these Devonian rocks (see below). It is worth noting, however, that in the present case the *B*-magnetization is much more predominant than in earlier studies of the Caithness ORS rocks. The present data come from eight locations, the distribution between sites varying according to magnetization complexity from eight specimen directions for site 12 to only one specimen direction for sites 4 and 5. However, the ample evidence for long-time palaeomagnetic records in single specimens/hand samples (cf. the two

TABLE I

Palaeomagnetic results from individual specimens of the Caithness Old Red Sandstone. Each direction, specified by declination and inclination, represents either the overall mean direction over given stability interval, or the average vector subtracted direction (v.s.) for given range of demagnetization. Both directional groups, *A* or *B*, are after structural correction (cf. text).

Site	Specimen	*D* (°)	*I* (°)	Group	Range (°)
2	CA6-D	038	+53	*A*	600–650
	8-B	207	−5	*B*	NRM–400
3	13-A1	221	−4	*B*	200–500
	14-B2	223	+8	*B*	500–600
4	17-A2	089	+64	*A*	500–650
5	22-A1	212	−9	*B*	v.s. 200–500
7	31-A1	310	−17	*A*	NRM–500
	35-B1	045	−16	*B*	630, 640, 650
	35-A2	345	+38	*A*	640, 650, 675
8	36-A2	214	−15	*B*	200–660
	40-A2	359	+46	*A*	600–660
	40-B2	026	+52	*A*	600, 620, 640
9	44-B1	187	−17	*B*	600–670
	45-A1	140	+29	*A*	590–680
10	46-A1	050	51	*A*	620, 630, 640
	47-B1	039	−27	*B*	400–650
	47-B2	218	−7	*B*	v.s. 200–400
	48-B1	030	−10	*B*	670, 680
	48-A1	162	+32	*A*	v.s. 200–600
11	51-B2	032	−22	*B*	620, 630, 640, 660
	52-A2	051	−18	*B*	675, 685
	52-B1	187	−13	*B*	v.s. 300–600
	53-A1	358	+24	*A*	v.s. 100–360
12	54-B	189	−4	*B*	200–620
	55-A1	200	−6	*B*	200–600
	56-A1	195	+3	*B*	200–600
	57-A	197	+15	*B*	600–685
	57-B	204	+14	*B*	520–680
	57-D1	193	−9	*B*	NRM–600
	58-B2	195	+2	*B*	200–500
	58-A1	204	+14	*B*	520–680
13	59-B1	207	+4	*B*	625, 650
	62-B	190	+2	*B*	NRM–640
	63-B1	187	−5	*B*	v.s. 200–500
	63-B1	044	−5	*B*	500–650
14	67-A	204	+17	*B*	650, 660
	67-B1	133	−30	*A*	340–650
	68-A1	186	+12	*B*	v.s. 500–625
	68-B2	081	−24	*A*	300–640
	69-B1	198	+39	*A*	400–660

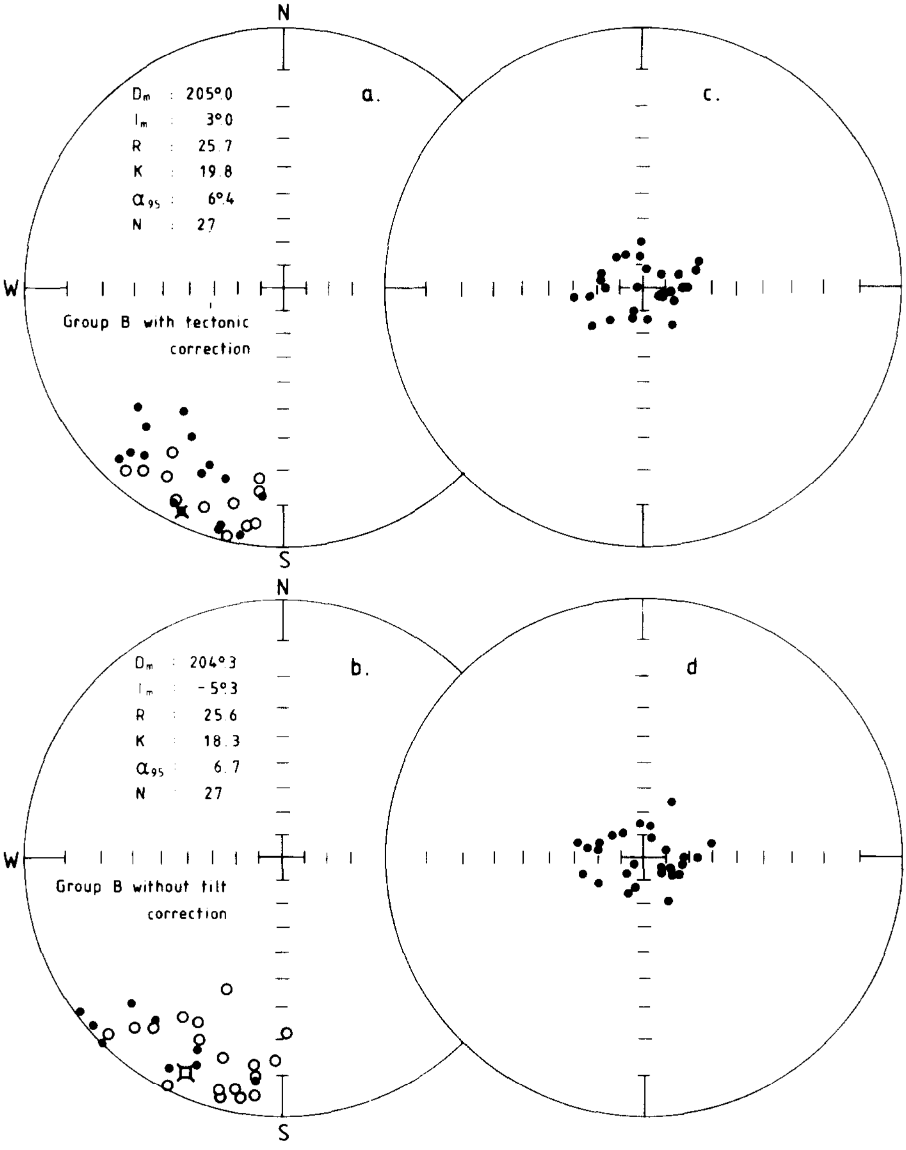

Fig. 6. The *B* component (the suggested original magnetization after (a) and before (b) structural correction). Specimen directions in stereographic plots. Diagrams c and d show the corresponding distributions centered on the relevant mean directions of magnetization. The "N–S" plane in the centered plots corresponds to the plane through the origin and the respective mean magnetization direction (diagrams a and b).

polarity structure) suggests that, in the calculation of overall palaeomagnetic parameters, it would be appropriate to give unit weight to specimens rather than to sites. The 27 B-specimens are plotted in Fig. 6 in which plot (a) is after and plot (b) before structural correction (simple rotation of bedding about present strike direction). The

TABLE II

Palaeomagnetic data for Caithness Old Red Sandstone rocks *

Formation	Group	D_m (°)	I_m (°)	K	α_{95}	Pole (°)	Reference
John O'Groats Sandstone	A	188.3	−41.1	32	3.9	163.6E, 54.2N	Storetvedt and Carmichael (1979)
	B	209.2	+5.7	18	10.4	144.5E, 24.1N	Storetvedt and Carmichael (1979)
Duncansby Neck	A	207.9	−54.6	155	2.3	126.5E, 60.3N	Storetvedt et al. (1978)
	B	205.3	+8.0	28	6.3	149.1E, 24.3N	Storetvedt et al. (1978)
Lower Caithness beds I	B	208	+14	26	13.5	147E, 20.5N	Waage and Storetvedt (1973)
II	B	205	+3.1	20	6.4	148.5E, 27N	Present study

* D_m = mean declination, I_m = mean inclination, K = precision parameter, α_{95} = radius in the 95% circle of confidence.

magnetization directions are plotted as though they all had reverse polarity. Plots 6c and d show the corresponding magnetization distributions with respect to group means (transferred to the centre of the projections). The palaeomagnetic groups are fairly well-defined but a slight elongation in the horizontal plane is noticed. There is very little difference between tectonically corrected and uncorrected data but there are reasons to believe (see below) that the former alternative represents the average Middle Devonian geomagnetic field direction relative to Caithness. The palaeomagnetic field direction concerned is $D = 205°$, $I = +3°$, $\alpha_{95} = 6.4°$ and this is not significantly different from the earlier palaeomagnetic estimate for this formation (Waage and Storetvedt, 1973) of $D = 208$, $I = +14°$, $\alpha_{95} = 13.5°$, which, however, was based on very few results (see also Table II).

The remaining category I results are plotted in Fig. 7. These directions (which all represent stable end-point results) are very scattered compared to the B-axis data and do not allow a reasonable estimate of a palaeomagnetic component. Upon tilt correction, however, eleven of the fourteen specimen directions are distributed along a "great circle" that passes through the well-defined A-axis directions as determined in earlier studies, explained in terms of a Mesozoic overprint coupled to burial and subsequent crustal uplift (Storetvedt et al., 1978; Storetvedt and Carmichael, 1979). It is suggested, therefore, that the fairly scattered distribution of this group of results is basically the consequence of unresolved normal and reverse A-axis magnetizations. Without structural correction (Fig. 7b) the same data set lies in a practically vertical plane which would be much more difficult to explain in terms of component interaction between known Phanerozoic fields. This suggests that the data of Fig. 7, which are thought to reflect an overprinted magnetization of assumed Mesozoic age, should be subjected to structural unfolding. This supports an earlier conclusion (based on a positive fold test on the A-magnetization of the John O'Groats

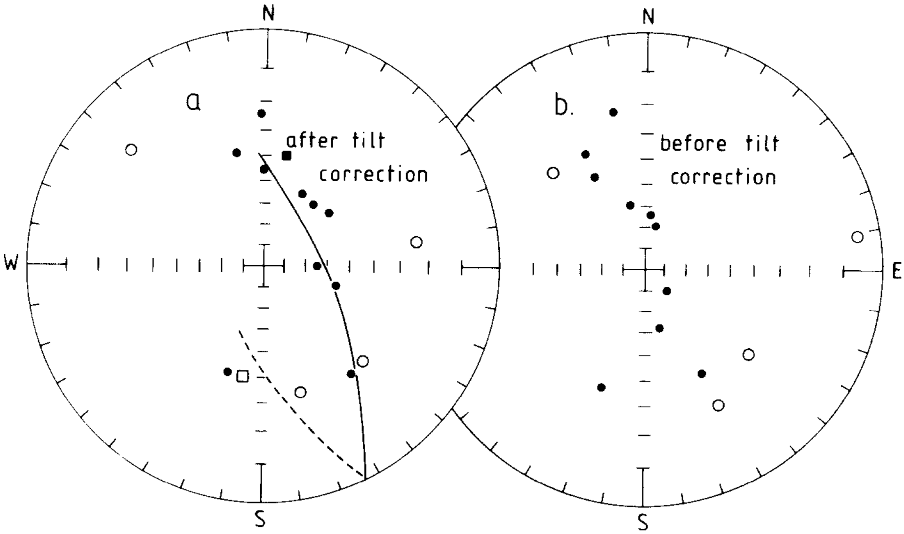

Fig. 7. Distribution of remanence directions that are regarded as representing the *A* "component," an assumed overprinted magnetization of Mesozoic age. The square symbols define the *A*-axis as determined from the John O'Groats Sandstone of north Caithness (Storetvedt and Carmichael, 1979). All directions represent stable end point results. See text for further discussion.

Sandstone) that the age of the tectonic deformation of the Caithness ORS sequence is Mesozoic or younger (Storetvedt and Carmichael, 1979) and not of late Caledonian age as previously assumed.

It is very unfortunate that the majority of estimated *B*-component directions come from sites that are either flatlying or moderately tilted so that a proper fold test cannot be carried out. Furthermore, there is no general difference in blocking temperatures between the two components of magnetization (*A* and *B*), an observation that is fully compatible with corresponding data from the John O'Groats Sandstone. In the Caithness ORS rocks the physical distinction between the *A* and *B* components is exclusively by direction but this difference is statistically very clear (the *A*-component referred to here is that determined in the John O'Groats Sandstone and Duncansby Neck as this magnetization is not satisfactorily defined in the present study). The rather strong occurrence of the *B*-axis magnetization in the rock strata investigated here is in contrast to the results for ORS rocks further north in Caithness that have given predominance to the more steeply inclined *A*-magnetization (Storetvedt et al., 1978; Turner et al., 1978; Storetvedt and Carmichael, 1979). This "regional" variation in the remanence build-up is interpreted as being due to a more severe burial (associated with remagnetization impressing the *A*-component) in the north than in the south.

However, we cannot definitely conclude that our *B*-component was acquired at around the Middle Devonian, but this remanence has indeed a direction that corresponds very closely to the predominant magnetization of Middle Palaeozoic rocks in western Europe.

CONCLUSION AND DISCUSSION

The present study has essentially confirmed the palaeomagnetic results obtained some ten years ago on the same rock samples collection. The principal palaeomagnetic component in the investigated Old Red Sandstone strata is nearly horizontal and strikes NNE–SSW. The inferred palaeomagnetic pole position of 148.6°E, 26.9°N is not significantly different from other Middle Devonian poles from west of the Great Glen Fault (cf. Table II). These poles fall to the west of the polar path for stable continental Europe, ca. 12°–15° of longitude. Thus the results reported here support the earlier proposition of there being a certain palaeomagnetic discordance across the Great Glen Fault, accounted for by a few hundred kilometres sinistral transcurrence along this dislocation in late/post Devonian time (Storetvedt, 1974, 1975).

In a recent paper Van der Voo and Scotese (1981) have considered the *A*-magnetization as representing the true Devonian palaeomagnetic field direction with respect to northwest Scotland, while our *B*-remanence has been ascribed to experimental artifacts. On these assumptions they have argued for a ca. 2000 km sinistral offset along the GGF during Carboniferous time. However, the clear evidence presented above for a flatlying magnetization in the Lower–Middle Devonian strata of Caithness discounts the model of Van der Voo and Scotese and supports the remagnetization alternative (for the *A*-remanence). These conclusions are further substantiated by the palaeomagnetic results from the Helmsdale granite of Upper Silurian–Lower Devonian age (Torsvik et al., 1983, this volume).

Though the idea of a 2000 km displacement along the GGF is not supported by palaeomagnetic evidence, it is quite possible that a transcurrent movement of this magnitude may have occurred between Europe and North America in Upper Devonian–Carboniferous times. Recent deep seismic reflection profiling off the north coast of Scotland (the MOIST profile) has given strong evidence for the presence of previously unsuspected crustal dislocations (Smythe et al., 1982). These major fractures, which in part may be low-angle thrusts, crop out at a considerable distance to the west of the Isle of Lewis (Outer Hebrides); i.e. the inferred Caledonian Front of northwest Scotland may be an insignificant geological feature with regard to the aspects of evolution and palaeogeography of the Caledonian orogenic belt. It appears reasonable to conclude that the Caledonian zone of Scotland extends much further to the west than previously assumed, and that this wider orogenic belt is subdivided by numerous "N–S" fractures. The compressional movements that were involved in the crustal deformation processes are unlikely to be directed perpendicular to the fracture zones: as a general rule one must anticipate strike-slip components. It is therefore not unreasonable to suppose that the individual fracture zones absorbed variable amounts of an extensive transcurrent displacement between Europe and North America in late Caledonian time. It is possible that the GGF took up a few hundred kilometres of this translation (Storetvedt, 1974,

1975) but the palaeomagnetic basis for this displacement figure, though strengthened by the present results, clearly needs further consideration before the issue can be reasonably settled.

It is important to realize that the magnetization of both the John O'Groats Sandstone and the Lower ORS beds of Caithness indicate that the tectonic deformation of the strata post-dates the overprinted remanence component (assumed to be of Jurassic age). This conclusion is probably a surprise to the geologists who have generally preferred a late Caledonian age for this structural deformation despite the lack of adequate field evidence.

ACKNOWLEDGEMENT

T.H.T. acknowledges the Norwegian Research Council for Science and the Humanities for financial support.

REFERENCES

Bennison, G.M. and Wright, A.E., 1969. The Geological History of the British Isles. Arnold, London, 406 pp.

Crampton, C.B. and Carruthers, R.G., 1914. The geology of Caithness. Mem. Geol. Surv., U.K.

Halls, H.C., 1976. A least-squares method to find a remanence direction from converging remagnetization circles. Geophys. J.R. Astron. Soc., 45: 297–304.

Kennedy, W.Q., 1946. The Great Glen Fault. J. Geol. Soc. London, 102: 41–76.

Mykura, W., 1975. Possible large-scale sinistral displacement along the Great Glen Fault in Scotland—Discussion. Geol. Mag., 112: 91–93.

Smythe, D.K., Dobinson, A., McQuillin, R., Brewer, J.A., Matthews, D.H., Blundell, D.J. and Kelk, B., 1982. Deep structure of the Scottish Caledonides revealed by the MOIST reflection profile. Nature, 299: 338–340.

Storetvedt, K.M., 1974. A possible large-scale sinistral displacement along the Great Glen Fault in Scotland. Geol. Mag., 111: 23–30.

Storetvedt, K.M., 1975. Possible large-scale sinistral displacement along the Great Glen Fault in Scotland (reply to W. Mykura). Geol. Mag., 112: 91–94.

Storetvedt, K.M. and Carmichael, C.M., 1979. Resolution of superimposed magnetizations in the Devonian John O'Groats Sandstone, N. Scotland. Geophys. J.R. Astron. Soc., 58: 769–784.

Storetvedt, K.M., Carmichael, C.M. Hayatsu, A. and Palmer, H.C., 1978. Paleomagnetism and K/Ar results from the Duncansby volcanic neck, northeastern Scotland: superimposed magnetizations, age of igneous activity and tectonic implications. Phys. Earth Planet. Inter., 16: 379–392.

Torsvik, T.H., Løvlie, R. and Storetvedt, K.M., 1983. Multicomponent magnetization in the Helmsdale granite, N. Scotland; geotectonic implication. In: E. McClelland Brown and J. VandenBerg (Editors), Palaeomagnetism of Orogenic Belts. Tectonophysics, 98: 111–129.

Turner, P., Vaughan, D.J. and Tarling, D.H., 1978. Palaeomagnetic and mineralogical studies of Devonian lacustrine sediments from Caithness, Scotland. Phys. Earth Planet. Inter., 16: 73–83.

Van der Voo, R. and Scotese, C., 1981. Palaeomagnetic evidence for a large (~ 2000 km) sinistral offset along the Great Glen fault during Carboniferous time. Geology, 9: 583–589.

Waage, H.L. and Storetvedt, K.M., 1973. The Devonian geomagnetic axis relative to the Orcadian basin, N. Scotland. Z. Geophys., 39: 937–951.

Winchester, J.A., 1973. Pattern of regional metamorphism suggests a sinistral displacement of 160 km along the Great Glen Fault. Nature Phys. Sci., 246: 81–84.

Zijderveld, J.D.A., 1967. AC demagnetization of rocks: analysis of results. In: D.W. Collinson, K.M. Creer and S.K. Runcorn (Editors), Methods in Palaeomagnetism. Elsevier, Amsterdam, pp. 254–286.