Palaeomagnetism of the Middle–Upper Devonian Esha Ness ignimbrite, W. Shetland

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Storetvedt, K.M. and Torsvik, T.H., 1985. Palaeomagnetism of the Middle–Upper Devonian Esha Ness ignimbrite, W. Shetland. Phys. Earth Planet. Inter., 37: 169–173.

The ignimbrite division of the Esha Ness volcanics of W. Shetland has been studied palaeomagnetically. The major blocking temperature spectrum ranges between 650 and 680°C, implying that haematite is the principal remanence carrier. The magnetization build-up is simple: a minor low stability magnetization aligned along the direction of the present Earth's field is superimposed on a well-defined and highly stable palaeomagnetic component with Dec. = 220 and Inc. = +3. The Esha Ness volcanic sequence is folded into a gentle syncline trending NNE. The rock collection concerned covers 8 sites: 7 from the western flank and 1 from the eastern flank of the syncline. The 7 sites on the west flank are consistently reversely magnetized while the site on the east flank has a normally directed magnetization. After structural unfolding the normal and reverse directions are almost perfectly antiparallel, i.e., the stable magnetization most likely predates the tilting which is probably of Devonian age. Esha Ness is located some 12 km to the west of the Walls Boundary Fault (WBF) which is considered as the northward continuation of the Great Glen Fault (GGF). The shallow palaeomagnetic inclination found in Old Red Sandstone rocks to the west of GGF/WBF corresponds to that encountered in most other European Old Red formations, discounting therefore megascale (> 1000 km) late-post Devonian movements along this dislocation.

The geological structure of Shetland is influenced strongly by 3 major northward trending faults: the Nesting, Walls Boundary and Melby Faults (Fig. 1). The Walls Boundary Fault (WBF) is by far the most prominent of these, being associated with a deformation zone of the order of at least 1 km with highly cataclastic and shattered rocks (Flinn, 1977). The WBF divides Shetland into the 2 geologically disparate regions of West and East Shetland. In the eastern area the geology is basically made up of metamorphic and plutonic rocks while in West Shetland igneous and sedimentary rocks of Middle–Upper Devonian age predominate.

While the Shetland Fault zones (notably the WBF) are recognized generally as transcurrent faults there is so far no collective opinion on the sense and magnitude of relative displacements.

Mykura (1975) and Flinn (1977) argued for dextral movements of the order of tens of kilometres while Storetvedt (1974, 1975) linking the WBF with the Great Glen Fault (as suggested by Flinn, 1961, 1969) and using palaeomagnetic data arrived at a sinistral nature for this major dislocation, the displacement figure ranging upwards to c. 500 km. More recently, Van der Voo and Scotese (1981) proposed an offset of the order of 2000 km along the Great Glen Fault (GGF) in Late Devonian–Early Carboniferous time, but the palaeomagnetic basis for this proposition has subsequently been discounted (Storetvedt and Torsvik, 1984; Torsvik et al., 1983).

Palaeomagnetic results of the Devonian of Shetland may have great potential for clarifying the nature of the major shear zones of the region. The present note provides a small contribution in this
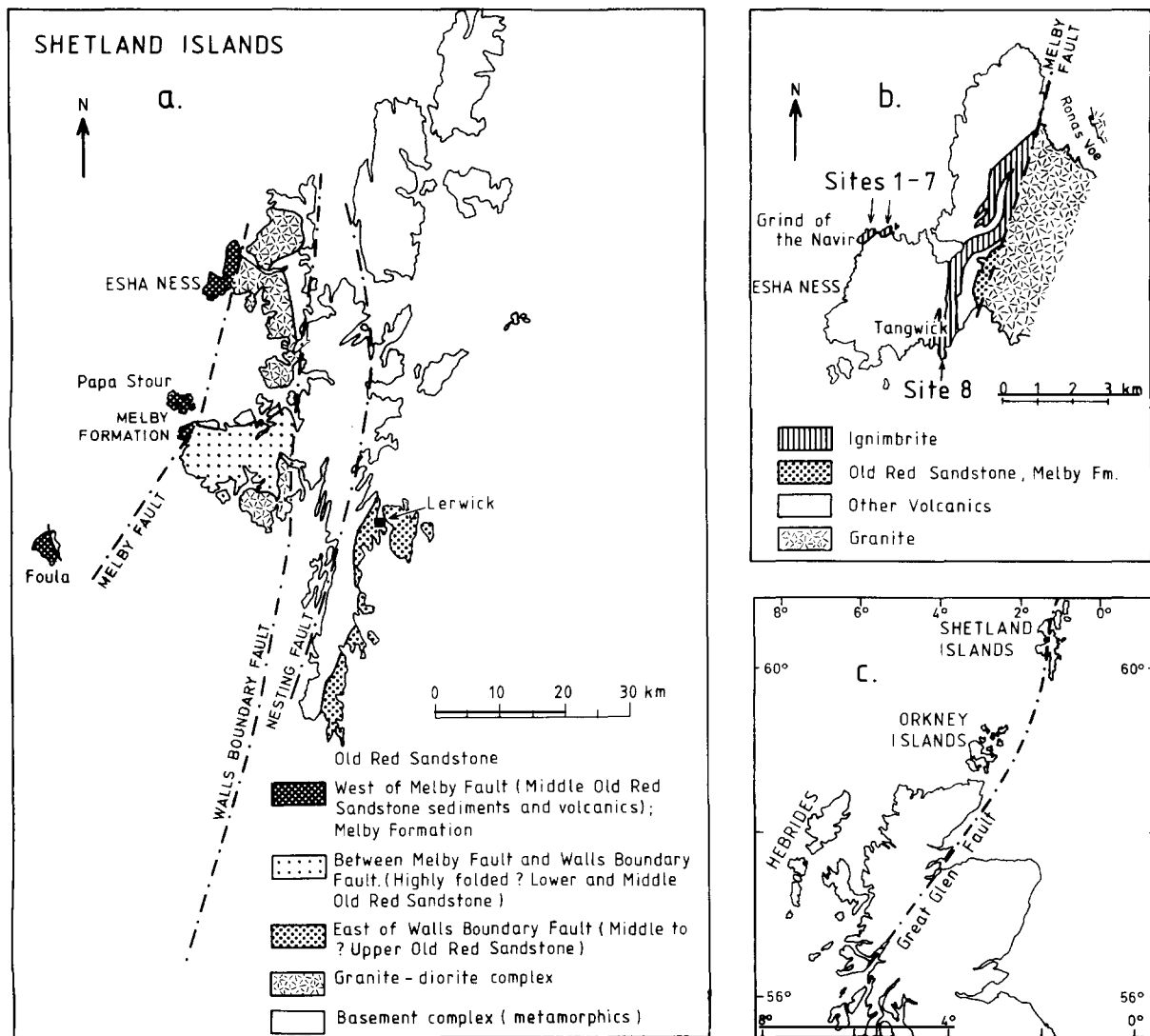
170

Fig. 1. Geographical (c) and geological setting of Shetland (a) and the Esha Ness Peninsula (b). The geological sketch maps are simplified after Mykura (1976).

respect, reporting on data from an ignimbrite horizon in the Esha Ness peninsula, W. Shetland. The area concerned is located more than 10 km west of the WBF but only 1–4 km west of the Melby Fault (Fig. 1). The rocks of Esha Ness constitute a sequence of lavas, tuffs, agglomerate and ignimbrite overlying Old Red Sandstone strata of Middle Devonian age (the Melby Formation). Also the volcanics are regarded as Middle–Upper Devonian in age (Wilson et al., 1935; Mykura,

1976) being most likely equivalent to one of the Devonian volcanic horizons of the Orkneys. The Esha Ness sequence is folded into a shallow NNE-trending syncline having a southward plunge in the study area.

The investigated ignimbrite horizon forms the second lowest division of the Esha Ness volcanics. At Grind of the Navir (Fig. 1) the rock is well exposed and easily recognized by flattened and welded plumice clasts. Locally the rock is ex-
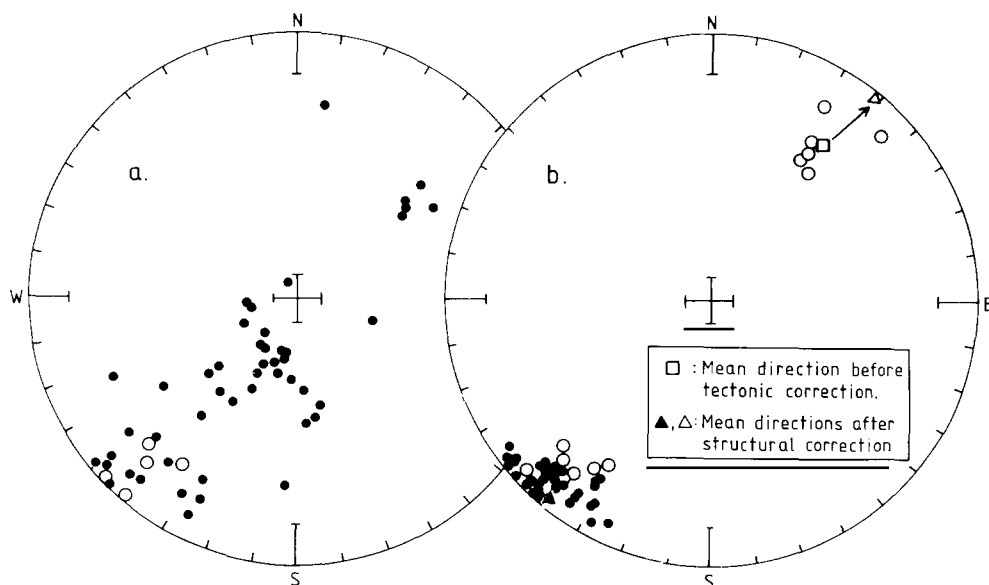
Fig. 2. Distributions of the directions of natural remanent magnetization (a) and of the high temperature magnetization (b). Open (closed) symbols are upward (downward) pointing magnetizations. All specimen directions (circular symbols) are without tilt correction. Tectonic correction has only a negligible influence on the reversed group (Grind of the Navir), but note how the normal group (Tangwick) becomes perfectly antiparallel to the former group upon structural correction.
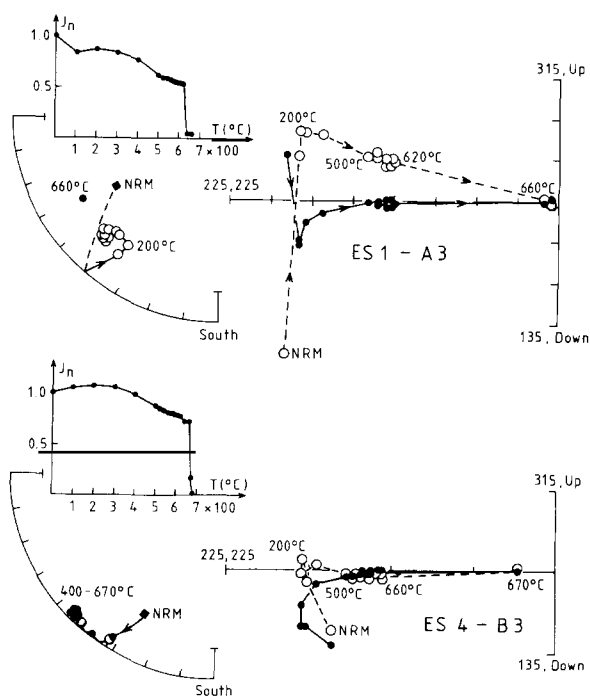

Fig. 3. Representative examples of the remanence vector behaviour upon thermal demagnetization. Stereoplot conventions as for Fig. 2. In the orthogonal vector plots (note the planes of projection) open (closed) symbols represent points in the vertical (horizontal) plane. In the vector diagrams the unit for ES1-A3 is $1 \cdot 10^{-2}$ Am^{-1} and for ES4-B3 it is $4 \cdot 10^{-2}$ Am^{-1}.
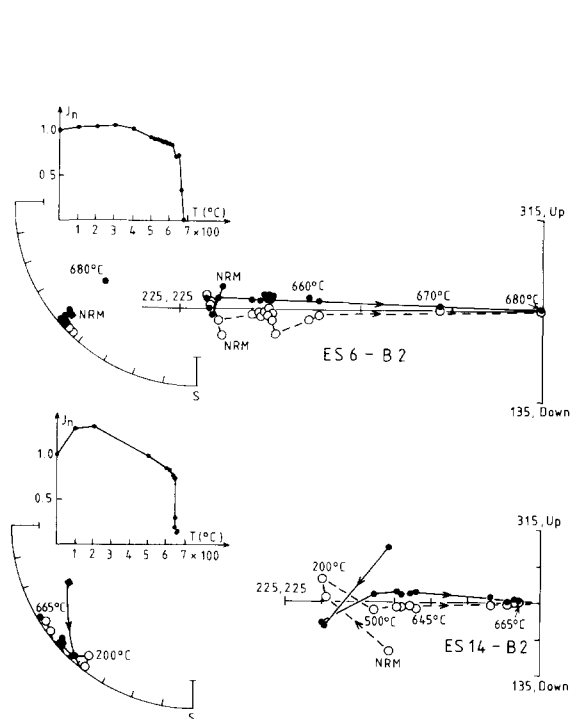
Fig. 4. Further thermal demagnetization results. Diagram conventions as for Fig. 3. In the vector plots the unit for ES6-B2 is $5 \cdot 10^{-3}$ Am^{-1} and for ES14-B2 it is $2 \cdot 10^{-2}$ Am^{-1}.

tremely hard and sampling by field drill was difficult. From this northwest limb of the syncline a total of 7 sites, spread over the entire outcrop, were collected. On the other hand, the rocks on the southeast limb of the syncline are generally more fractured and decomposed, probably due to the closer proximity to the Melby Fault, and it was difficult to find potentially suitable material for the palaeomagnetic analysis. Only one site, at the shore of Tangwick, was sampled from this part of the syncline.

From the 8 sites collected altogether 55 specimens were subjected to progressive thermal demagnetization. Apart from a minor low stability component, aligned along the direction of the present geomagnetic field, the underlying fossil magnetization is well defined with D ~ 220 and I ~ 3 (cf. Fig. 2b). The thermal demagnetization results (see Figs. 3 and 4 for characteristic examples) show that the dominating remanence carrier is haematite, the most important blocking temperature range being c. 650–680°C. For the overwhelming majority of analysed specimens the high temperature direction is well defined. All Grind of the Navir sites are reversely magnetized while the stable remanence of the Tangwick site is normally directed and antiparallel to the former group.

The suggested mode of formation of ignimbrites should imply that a fair amount of haematite formed by oxidation before the hot "pyroclastic" flow came to rest. However, the Esha Ness section shows a 2-polarity palaeomagnetic structure, implying that the total magnetization process spans at least the time scale of geomagnetic polarity changes. This evidence along with the nearly perfect antiparallelism between normal and reverse
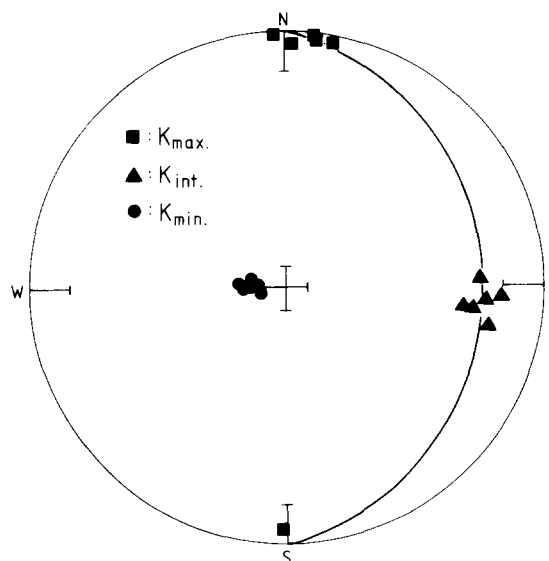

Fig. 5. Measurements of anisotropy of magnetic susceptibility (AMS) for site 4 defining a magnetic foliation plane dipping c. 15° due east.

directions, particularly after tectonic correction (cf. Fig. 2b), suggests that the resultant magnetization axis is likely to include an averaging out of the geomagnetic secular variation.

The tectonic tilting at Grind of the Navir is modest, the dip not exceeding c. 15° (in easterly directions). As an independent tectonic test measurements of anisotropy of magnetic susceptibility (AMS) were carried out. AMS gives an average anisotropy of 4.5% and well defined oblate ellipsoids. Assuming the Kmin axis to be vertical and the Kmax and Kint axes oriented in the horizontal plane at the time the ignimbrites were laid down (i.e., reflecting the original horizontal

TABLE I

Palaeomagnetic data for the Esha Ness ignimbrite

Group	N	D_m	I_m	K	α_{95}	Pole	
I: no structural correction	55	220°.5	+4°.0	52.6	2°.6	134.8E,	20.1N
II: with tectonic correction	55	220°.4	+3°.1	47.6	2°.7	134.7,	20.6 N
III: with tectonic correction using magnetic fabric data	55	220°.6	+2.2	57.5	2°.5	134.3,	20.9 N

N = number of specimens; K and α_{95} are statistical parameters according to Fisher (1953); D_m = mean declination; I_m = mean inclination.

plane), the present orientation of the magnetic foliation plane should determine subsequent structural tilting. Except for site 2 which has scattered results the magnetic fabric is well defined (see for example Fig. 5), corresponding closely to the direct field observations of stratal orientation. At the Tangwick site the rocks are fractured and there were problems in establishing the tectonic setting. However, the magnetic fabric has a c. 30° dip in a westerly direction which is in excellent agreement with the local dip given on the geological map of W. Shetland (Ordnance Survey, 1968).

Table I gives the overall palaeomagnetic results along with statistical parameters and pole positions. The overall difference between tectonically corrected and uncorrected data is statistically insignificant, but the tightest grouping occurs after structural unfolding using magnetic fabric results.

The characteristic magnetization of the Esha Ness ignimbrite is unusually clearcut and gives strong evidence in support of the corresponding (but generally weaker) flatlying magnetizations found in other Mid–Palaeozoic rocks to the west of GGF (Storetvedt et al., 1978; Storetvedt and Carmichael, 1979; Storetvedt and Torsvik, 1983; Meland, 1983; Torsvik et al., 1983). When comparing these data with the majority of other N. European ORS results the only palaeomagnetic difference across the GGF/WBF tends to be a slight change in declination (c. 15°). This implies that there is no palaeomagnetic basis for invoking a large "N–S" translation (i.e., ∼ 15–20° of latitude) along the Great Glen/Walls Boundary Fault in Late Devonian–Early Carboniferous (Van der Voo and Scotese, 1981), but a left-lateral displacement of the order of a few hundred kilometres (Storetvedt, 1974), causing a certain relative change in declination, is still a viable proposition.

Acknowledgements

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