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Palaeomagnetism of the ophiolite complexes of Meldal, Sør-Trøndelag

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REPORT

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Title: Palaeomagnetism of the ophiolite complexes of Meldal, Sør-Trøndelag

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Summary:
A palaeomagnetic investigation of the Early-Ordovician (middle to late Arenig) sheeted dyke complexes of Meldal has revealed a complex multicomponent magnetization history. Three components of remanent magnetization were identified based on their differing stabilities; 'L' (low stability), 'I' (intermediate) and 'H' (high stability). The 'L' component is considered to be a recent overprint. The 'I' component corresponds to an *in-situ* palaeomagnetic pole at 91.9°E, 58.6°N, $D_{\psi}=12.1$, $D_{\chi}=14.3$. By comparison with a reference apparent polar wander (APW) path for Baltica, 'I' is considered to be an overprint of Jurassic age. The 'H' component (with the highest magnetic stability) was identified in two block samples from Resfjell. In *in-situ* form it corresponds to a palaeo-pole at 99°E, 16.4°N and in tilt-corrected form (palaeo-horizontal simply rotated into present horizontal) to a palaeo-pole at 281°E, 13.4°N. Both the *in-situ* and tilt-corrected versions of the data fall far away from reference APW paths for Baltica and Laurentia. We suggest that a series of (Silurian) tectonic rotations, more complicated than the rotation accounted for in our simple tilt-correction procedure, are responsible for this deviation. If the remanence component does indeed pre-date complicated Silurian tectonic rotations, as its deviation from the APW paths suggests, one must consider the possibility of the remanence dating-back to when the dykes were still part of the Iapetus Ocean floor. The palaeolatitude for the dykes implied by the remanence is 12.6°S (tilt-corrected) assuming that 'H' is of *reversed* polarity. This choice of polarity minimises the net vertical-axis rotation (in this case anticlockwise through 100 degrees or so) necessary to restore the pole to reference data sets. The palaeolatitude 12.6°S would place them near the Laurentian margin of the Iapetus Ocean (if the remanence is presumed to be the same age as the dykes themselves: middle to late Arenig). If this scenario is correct, which we hasten to add is not yet conclusively proven, certain allochthonous terranes in the Scandinavian Caledonides –such as the Meldal Ophiolites– may have early tectonic histories independent of the palaeo-continent 'Baltica'.

Keywords:	Palaeomagnetism	
Geophysics		Technical report

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FIGURES

1. INTRODUCTION

The Støren-Horg-Hølonda area has served as a key area for the stratigraphy of the central Norwegian Caledonides (Vogt, 1945, Walsh, 1986) and forms part of the Trondheim Nappe which dominates the geology of the central Trondheim region (Fig. 1). The stratigraphy of the Trondheim Nappe complex comprises five separate units (Wolff & Roberts 1980);

UNIT	**AGE**
Horg Group	? Lower Silurian
Upper Hovin Group	Upper Ordovician (? to Lower Silurian)
Lower Hovin Group	middle Arenig to lower Upper Ordovician
Støren Group	uncertain; ? Cambrian to ? lower Arenig
Gula Group	uncertain; ? late Precambrian-Cambrian

The original setting of the Trondheim nappe sequence has proved to be enigmatic, particularly with regard to the Lower Hovin group. At present there are two conflicting interpretations of the early Ordovician palaeogeography of the Lower Hovin group (Fig. 2). One interpretation, based on sedimentological and geochemical evidence, holds that the original setting of this unit was as a marginal basin on the Baltic foreland (Roberts *et al.* 1984, Grenne 1989). The second interpretation, based on the provinciality of the fauna contained within one of the formations at the base of the Upper Hovin Group; the Kalstad Limestone, is that the sequence originated on the Laurentian margin and was subsequently emplaced on the Baltic margin during Caledonian orogenesis (Bruton & Bockelie 1980). Given that the Baltic and Laurentian margins were separated by the 3000-4000 km wide Iapetus Ocean at the time, the two interpretations are mutually incompatible.

It is quite possible that the Iapetus margin of Baltica faced the palaeo-continent Siberia in early Ordovician times, and not Laurentia (Torsvik et al. 1995). This uncertainty, however, does not affect the purpose of the present investigation greatly. We know that the Iapetus margin of Baltica faced Laurentia at the time of final closure of the ocean, at which time the ophiolites were either (1) already accreted to the margin of Baltica, or (2) were introduced from an already accreted position on the Laurentian continent.

In certain favourable circumstances the palaeomagnetic method can be used to resolve such discrepancies, even when other approaches have proved unsuccessful. Favourable situations are those where terranes move with significant palaeo-latitudinal change and where suitable lithologies carrying stable ancient remanent magnetisations can be found. The major advantages of the technique are that, where a magnetisation can be shown to be primary, quantitative measurements of latitudinal separation can be obtained and palaeomagnetic analysis is not restricted to any one rock type.

We therefore carried out a palaeomagnetic investigation of some of the sheeted dykes in the ophiolite sequences of the Lower Hovin Group at Resfjell and Grestadfjell, central Norway, to try to obtain an original palaeolatitude from them. As the Iapetus ocean had significant palaeo-latitudinal width at the time of dyke intrusion we hoped that an original palaeolatitude for the host terrain would enable us establish whether the rocks originated (1) marginal to Baltica as Roberts *et al.* (1984) and Grenne (1989) would have it or (2) marginal to Laurentia as proposed by Bruton & Bockelie (1980).

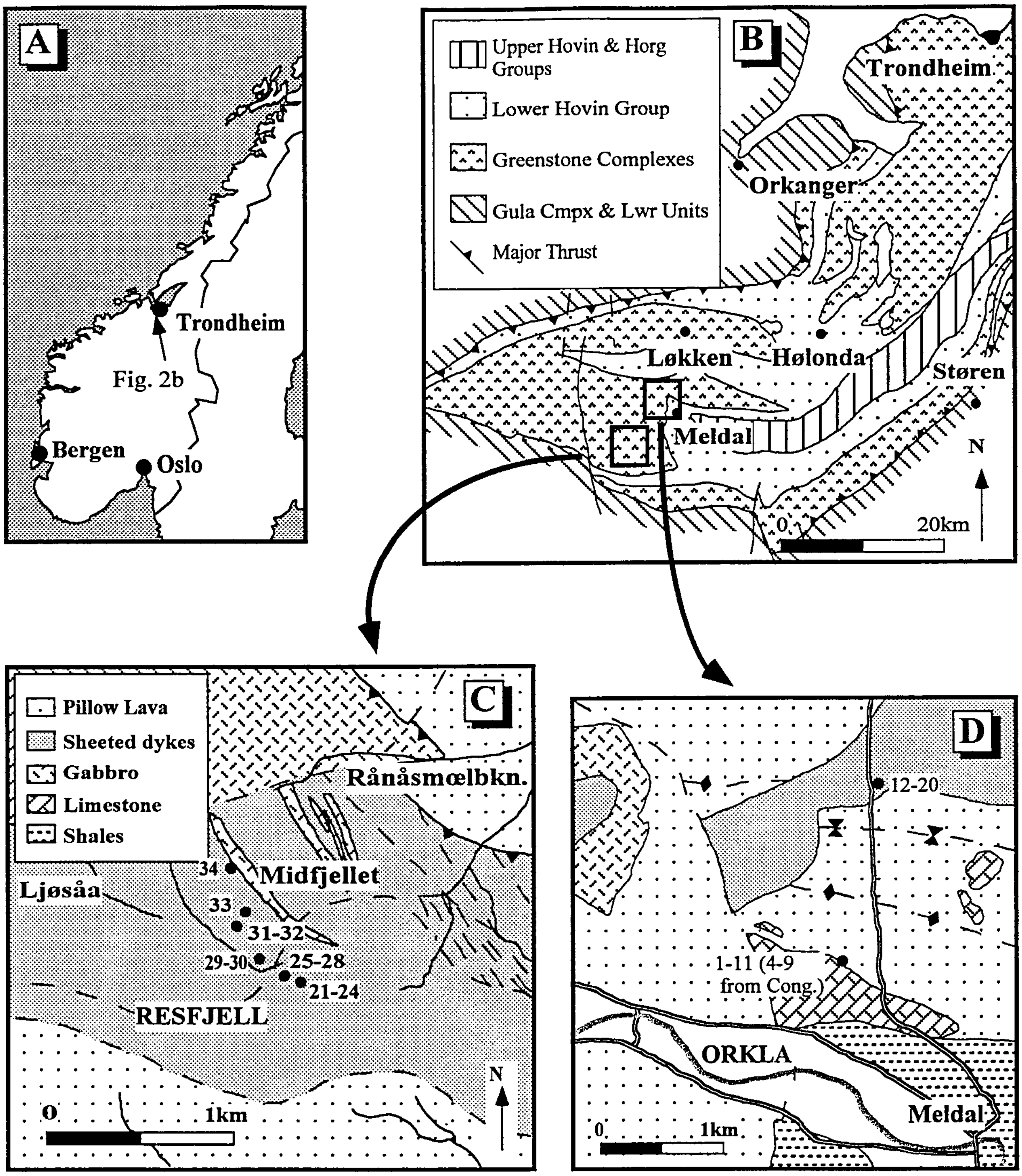


Figure 1. Location of the study area (A) with the regional geology of the Trondheim district (B; modified after Heim et al. 1987). Sampling sites are shown from Resfjell (C; with local geology from Heim et al. 1987) and Grestadfjell (D; with geology after Ryan et al. 1980 and unpublished field maps).

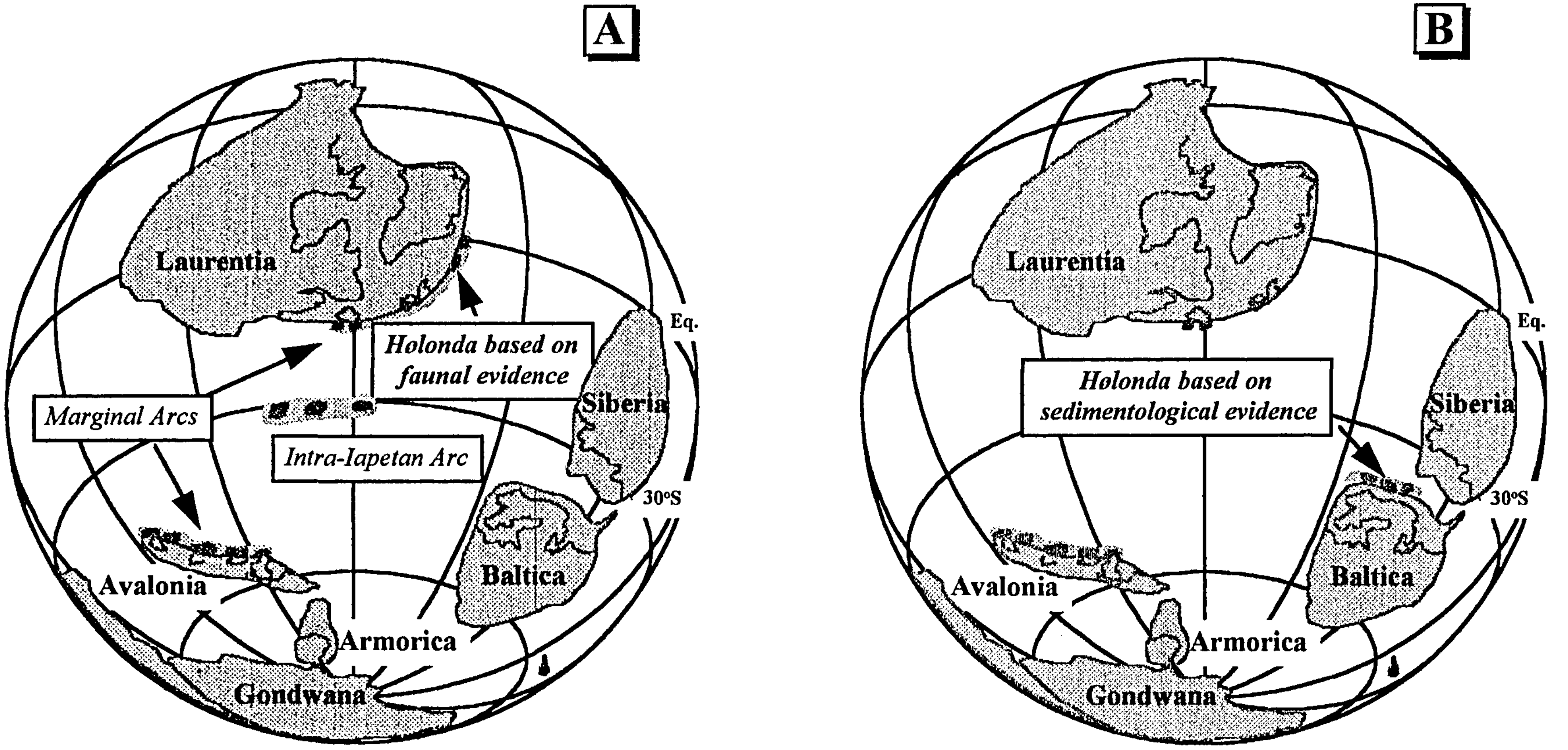


Fig. *2* Two contrasting models for the early-Ordovician Palaeogeography of the ophiolite sequences at Meldal. Model A, based on palaeontological evidence, places the ophiolites in an arc marginal to Laurentia. Model B, based on sedimentological evidence places the ophiolite sequence in an arc on the Baltic margin. Given that Laurentia and Baltica are separated by a 3-4000km wide ocean the two models appear to be irreconcilable.

2. REGIONAL GEOLOGY

Strata belonging to the Lower and Upper Hovin and Horg Groups have been recognised in the Meldal region (Ryan *et al.* 1980).

2.1 The Lower Hovin Group

The oldest rocks recorded within the Lower Hovin Group comprise black shales, micritic limestones, siliceous shales and siltstones which have been termed the Lo Formation (Ryan *et al.* 1980). Graptolites from the Formation yield an age of mid-late Arenig. Deposition of this unit was most likely coeval with, or followed by, emplacement of the Grestadfjell ophiolite complex which has intercalated (mid-late Arenig) graptolitic shales at the top of the lava pile (Ryan & Williams 1985).

The overlying Bogo and Nyplassen Formations comprise black shales, limestone and andesite breccias, green shales, conglomerates (with a wide variety of clast types) and quartzose wackes (Ryan & Williams 1985). Graptolites recovered from the Nyplassen Formation are early-mid Llanvirn in age.

2.2 The Upper Hovin Group

The lower-most unit of the Upper Hovin Group is the Kalstad Limestone (Caradoc) which is only occasionally present (Ryan *et al.* 1980). At Meldal it is in unconformable contact on the Grestadfjell ophiolite complex and the Nyplassen Formation. It comprises calcarenites at the base, overlain by shales which then pass upward into massive micritic limestones with a silicic volcanic horizon near the top of the Formation. The Kalstad Limestone is overlain by the Ryanda Formation which comprises black shales and thin sandstones. Soft sediment folds are present on all scales within the Ryanda Formation as well as sedimentary breccias.

2.3 The Ophiolite Complexes

Ophiolite fragments occur in the area around Meldal and Løkken at Resfjell, Grestadfjell, Løkken and Vasfjell (Grenne 1989). At Resfjell an almost complete cross-section of the uppermost part of the ophiolite is exposed (Heim *et al.* 1987). The lowermost rocks comprise metagabbro and microgabbro which are followed by a sheeted dyke complex, a transition zone composed of haloclastites, pillow-lavas and dykes. Geochemical analyses from this and other ophiolite fragments within the region (Heim *et al.* 1987, Grenne 1989) reveal an evolutionary trend from mid-ocean ridge basalt (MORB) type volcanism in the lower parts to transitional MORB / intermediate to acid type volcanism in the upper part of the sequence.

2.4 **Palaeogeography**

In the Meldal region there is a marked facies change in the Lower Hovin Group from deep-water sediments (turbidites) predominating in the west to limestones and shallow water sediments in the east. Ryan *et al.* (1980) found that in the Meldal area Lower Hovin type sediments interdigitate with the uppermost part of the Grestadfjell ophiolite. It seems most likely, therefore, that the Lower Hovin Group sediments and the ophiolite complexes were closely linked temporally and spatially. For this reason Ryan *et al.* (1980) chose to include the ophiolite as part of the Lower Hovin Group.

Channel morphology and sedimentary structures in the Nyplassen Formation (uppermost Lower Hovin group) indicate that the sediment was derived from the north-east or east (Ryan *et al.* 1980), with the high quartz content of the sediments indicating the presence of a nearby continental source.

Geochemical analyses from the Resfjell and other ophiolite sequences within the region, reveal an evolutionary trend from mid-ocean ridge type volcanism in the lowermost parts of the ophiolite to intermediate to acid volcanism towards the top of the ophiolite sequence (Heim *et al.* 1987, Grenne 1989). Taken together the geological and geochemical data imply that the Lower Hovin Group was deposited in a marginal basin whose fill was derived from a continental source to the east or north-east, with the ophiolites forming a floor to the basin, consistent with a setting on the Baltic Foreland (Roberts *et al.* 1984, Grenne 1989). In conflict with this model trilobite, brachipod and conodont fauna recovered from the limestones of the Kalstad Formation compare closely with those found in rocks of the Laurentian margin (Bruton & Bockelie 1980 and references therein). Moreover, recent statistical analyses of faunal distributions within the early Ordovician Iapetus Ocean have reaffirmed the north American affinity of these fauna (Harper 1992, Williams *et al.* 1995).

3 PALAEOMAGNETIC SAMPLING AND LABORATORY METHODS

To test the suitability of the rocks around Meldal for palaeomagnetic analysis a total of 34 large block samples were collected from sheeted dykes within the ophiolite complexes at Resfjell and Grestadfjell.

Five of the aforementioned blocks (1,2,3,10 and 11) were from sheeted (dolerite) dykes immediately below the unconformity with the Kalstad limestone (Caradoc) 2 km northwest of Meldal (Fig. 1d). At the same locality six blocks were taken from clasts of dolerite in the conglomerate immediately above the unconformity, thereby permitting the application of a conglomerate test of palaeomagnetic stability (to establish whether the remanence in the dolerite pre- or post-dates deposition of the conglomerate). Nine blocks were collected in a small roadside quarry 2 km north of Meldal. Fourteen blocks were collected in a traverse through the sheeted dykes on Resfjell.

Of the total collection, six blocks proved to be too small, friable or weathered for the extraction of palaeomagnetic specimens (25 mm diameter cylinders). From the remaining 28 blocks a total of 90 spcimens were obtained, which were subjected to progressive thermal or alternating field (AF) demagnetization to separate components of natural remanent magnetization (NRM) with contrasting magnetic stabilities. The NRM of specimens was measured at the palaeomagnetic laboratory of the Geological Survey of Norway using a JR5A spinner magnetometer, capable of making reproducible measurements down to approximately 0.02mA/m. A large proportion of the collected material proved to have NRM intensities approaching the practical measuring limit of this instrument and therefore a number of specimens were analyzed in the palaeomagnetic laboratory at Oxford University where a CCL cryogenic magnetometer was available, capable of repeated measurements down to 0.005mA/m.

Curie Balance experiments were carried out at the Institute for Solid Earth Physics at the University of Bergen. Curie points were determined from the decay of induced magnetization with increasing temperature. The applied field used was 0.7 Tesla. Rock samples were prepared in the form of rock chips, these being found to be less prone to mineralogical alteration during heating than powders.

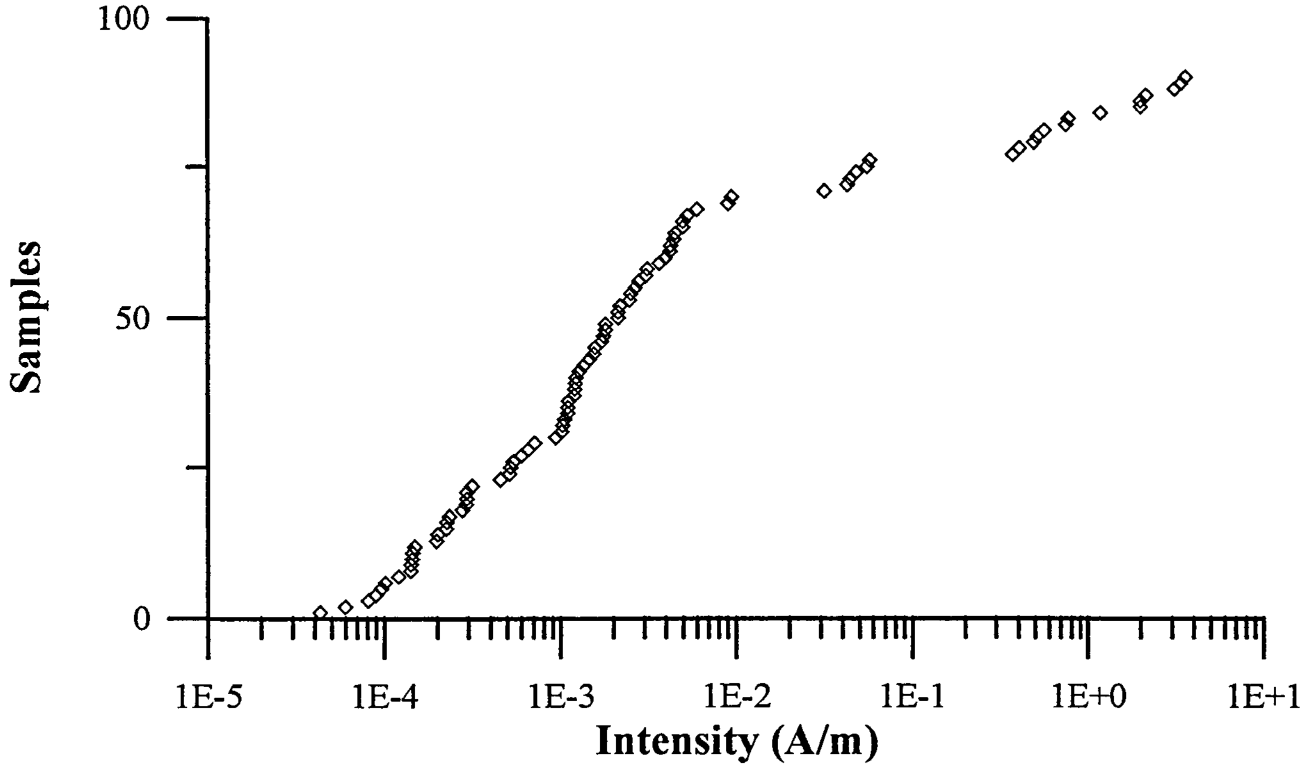
4 DEMAGNETIZATION EXPERIMENTS

NRM intensities were in the range $5x10^{-5}$ to 5 A/m, with approximately 70% of the collection having an NRM intensity below 0.01 A/m (Fig. 3a). The initial susceptibility of the specimens lay in the range $5x10^{-4}$ to $5x10^{-3}$ SI units (Fig. 3b). The NRM directions are shown in Figure 4. Whilst some degree of scatter is evident, a large proportion of the NRM directions are directed steeply down to the north-east. Upon demagnetization (thermal and AF) approximately 60% of the specimens proved to be magnetically unstable and yielded little useful information on any ancient palaeofield. The remaining 40% of specimens had remanence characteristics which could readily be divided into three categories:

Category one: a steep downward and north directed remanence component with 'L'ow stability (unblocking temperatures, T_b, generally < 350°C, unblocking alternating fields < 15mT). This remanence component is hereafter referred to as the 'L' component (Fig. 5a-c; Table 1). Magnetic instability prevailed above 350°C with the exception of a number of specimens from site 2 which remained stable up to treatments of 520°C.

Category two: coexisting low and intermediate stability remanence components. This behaviour was restricted to specimens from the quarry at Osplihaugen (Fig. 1d). The low stability viscous component was removed by thermal and AF treatments up to 100°C and 5mT respectively (Fig. 6a&b). The remaining 'I'ntermediate stability component, hereafter referred to as the `I' component, was generally directed steeply down to the northeast (Table 1). The `I' component had a rather wide unblocking temperature range, usually between 100 and 560°C. Similarly, under AF demagnetization the component had a wide coercivity range and generally unblocked in fields of 5 to 40mT. A number of the weaker specimens in this category showed a demagnetization trajectory that missed the origin (Fig. 6c). Great-circle analysis was attempted on these specimens (Fig. 6d), but no clear planar elements to the demagnetisation trajectories could be identified. Therefore the magnetization component was presumed to be random noise.

Category three: coexisting low and high stability remanence components. This behaviour was restricted to specimens from Resfjell. Although the general quality of data was poor, two remanence components were identified; a low unblocking temperature component (T_b<400°C, coercivity < 25mT) similar to that observed in the first category of samples and a 'H'igher stability component (T_b 400-580°C, coercivity 30-90mT) directed with shallow upward dip to the west, hereafter termed the `H' component (Fig. 7a&b; Table 1). Based on the lower stability of the first of the two components, and it's directional similarity with the `L' component observed in the first category of samples, we group it with the `L' component in our analysis.



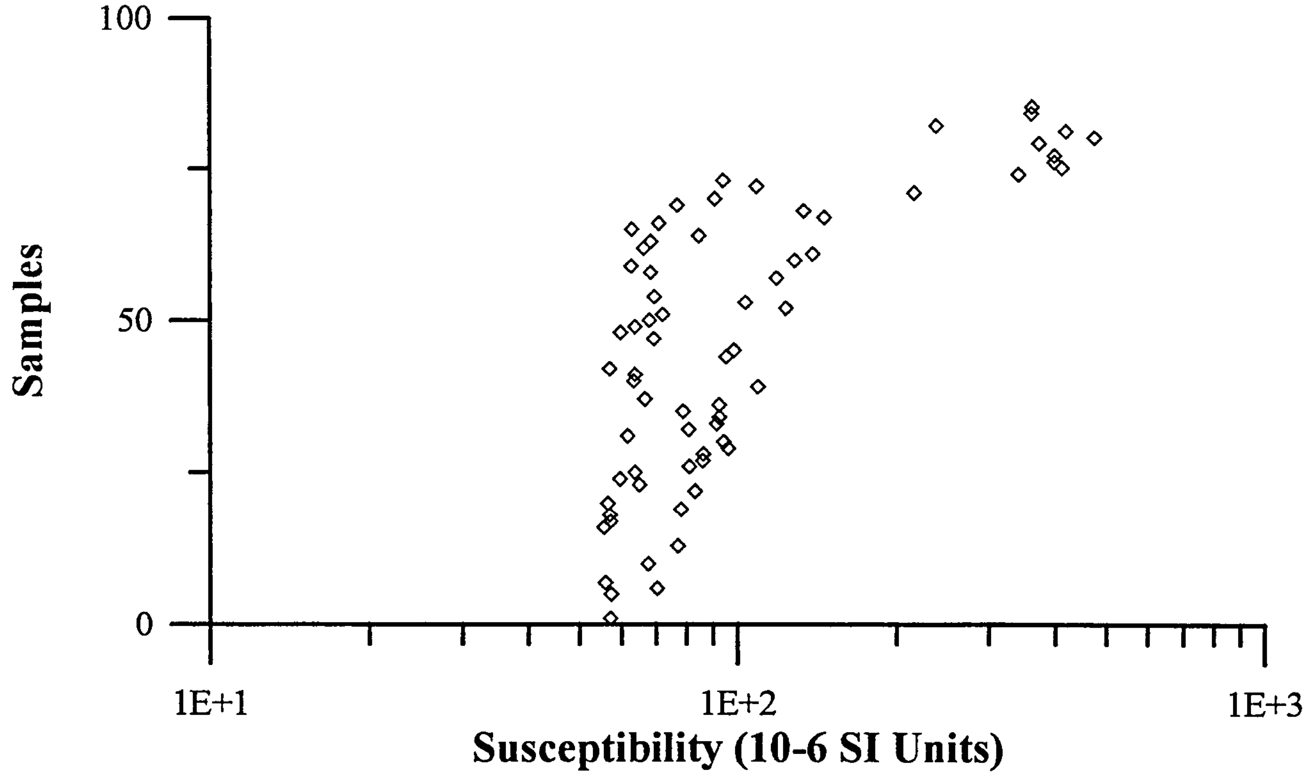


Figure 3. Initial Intensity and Susceptibility measurements of the sheeted dykes at Resfjell and Grestadfjell

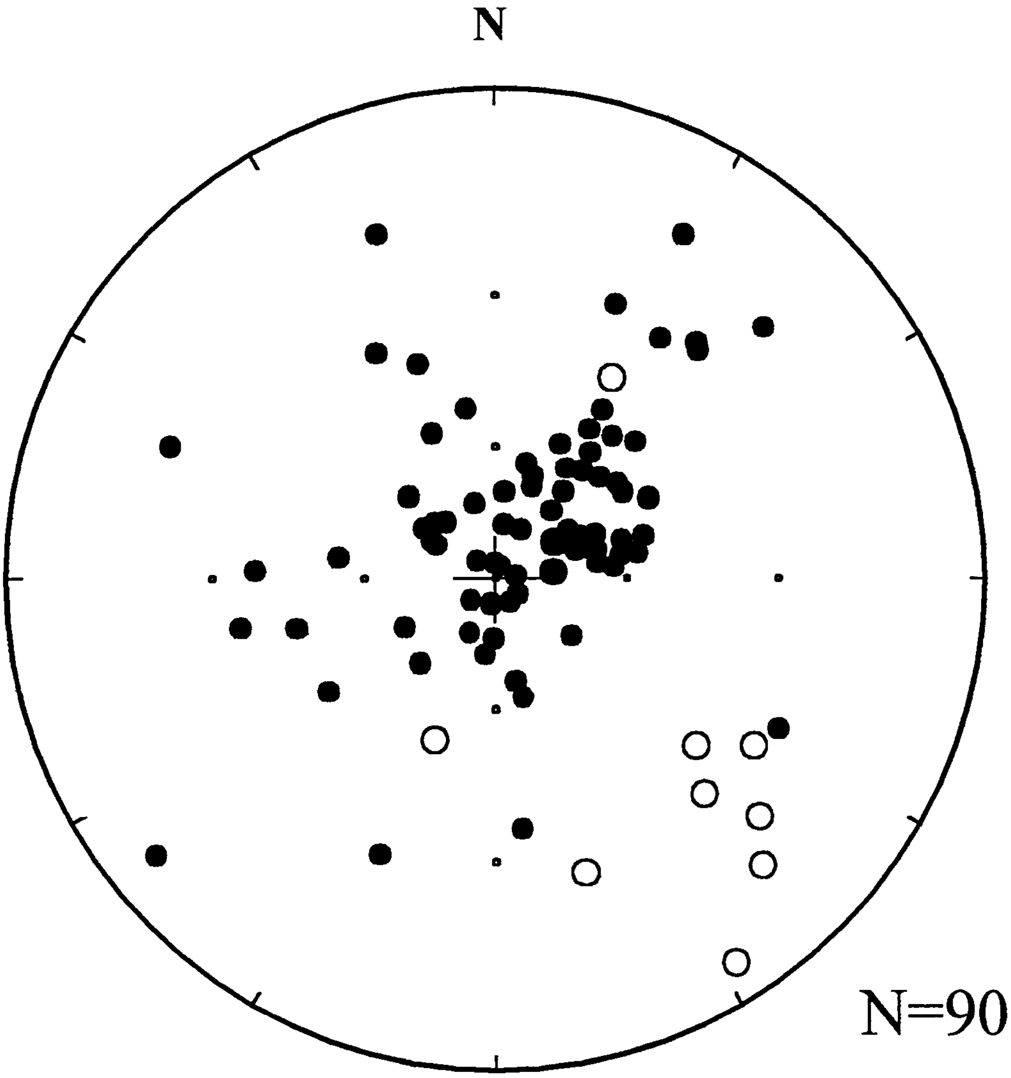


Figure 4. NRM directions from the sheeted dykes at Resfjell and Grestadfjell

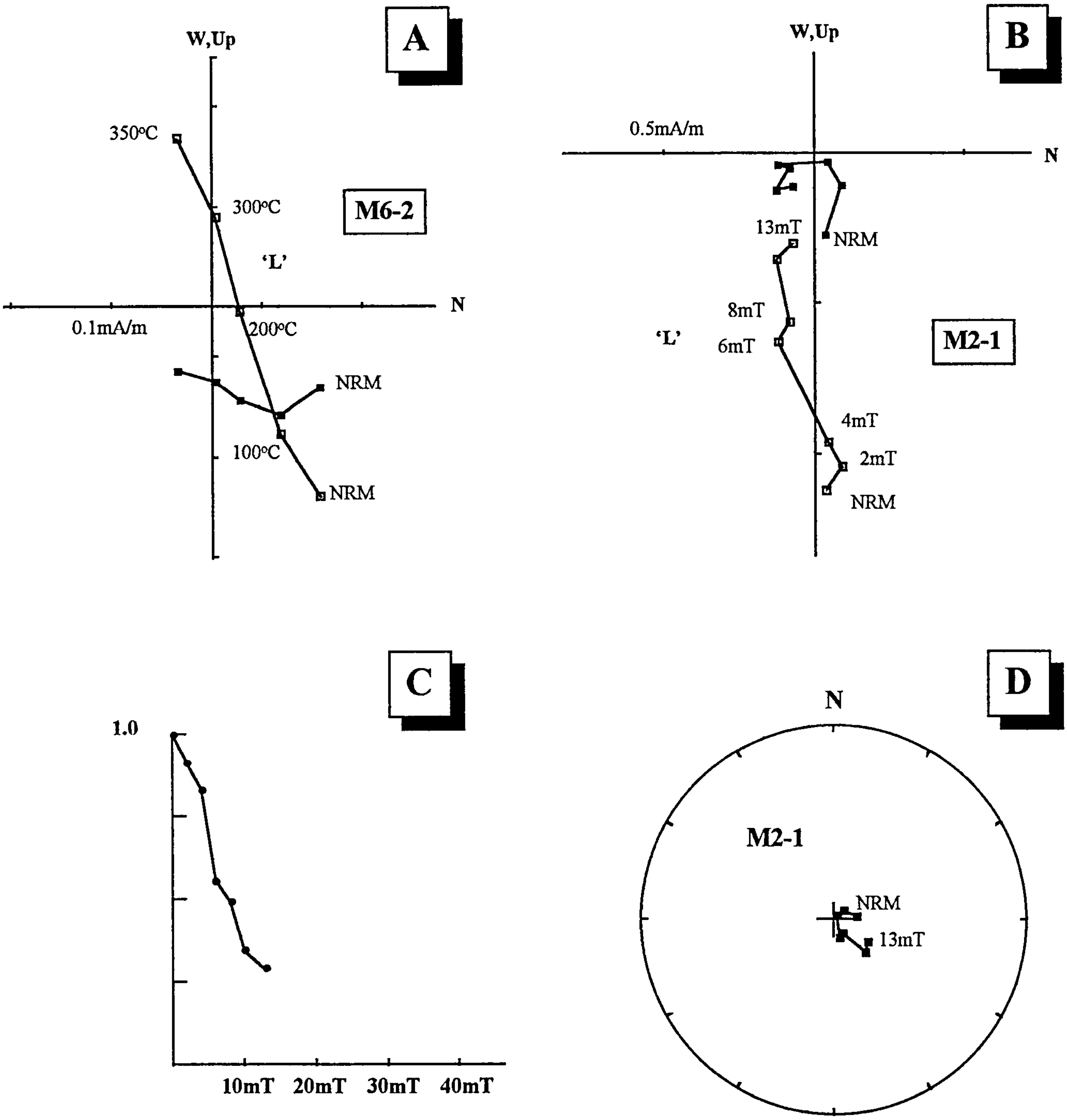


Figure 5. Example orthogonal plots of progressive demagnetization data for specimens containing the 'L'-component (A & B). In the case of the specimen in A erratic demagnetization behaviour was observed above 350° C. In B the intensity of the sample was approaching the limit of sensitivity of the magnetometer. Figure 5C illustrates the decay in intensity of the sample in Figure 5B with Figure 5D illustrating it's directional behaviour in a stereographic projection. Orthogonal projections: full (open) squares indicate data projected into the horizontal (vertical) plane; numbers beside data points represent laboratory treatment temperatures / alternating fields. The intensity-plot (C) shows the decay of the intensity normalised to the NRM versus the applied field.

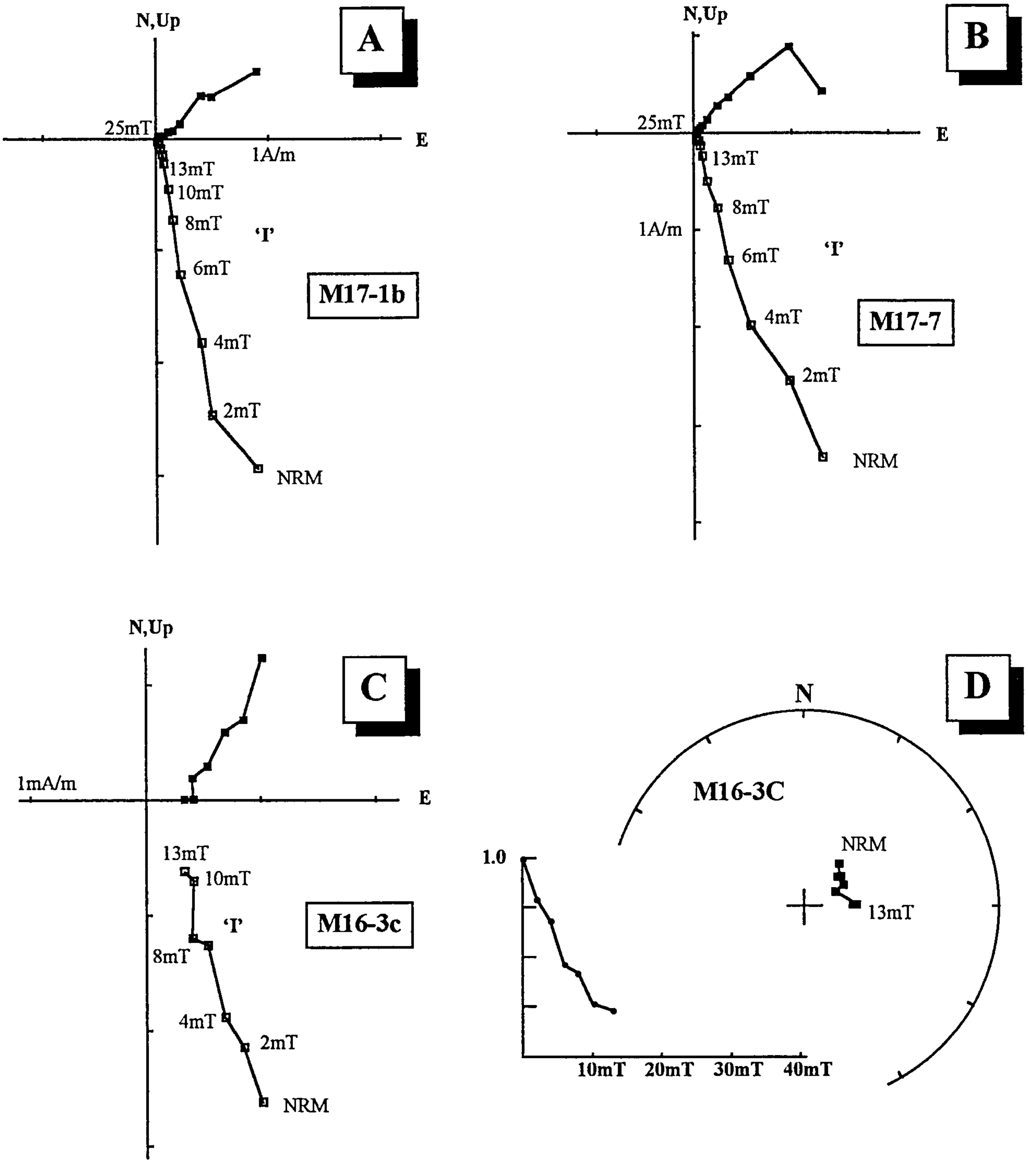


Figure 6. Representative orthogonal and stereographic projections of stepwise demagnetization data for specimens containing the 'I' component. The specimens in A & B are representative of samples with a high NRM intensity whereas the specimen in C & D is representative of specimens with a low NRM intensity. The demagnetization trajectory of the specimen in C appears to miss the origin, but examination of the trajectory in the stereographic projection (D) fails to reveal a great-circle trend. (Conventions and symbols are as for Fig. 5.)

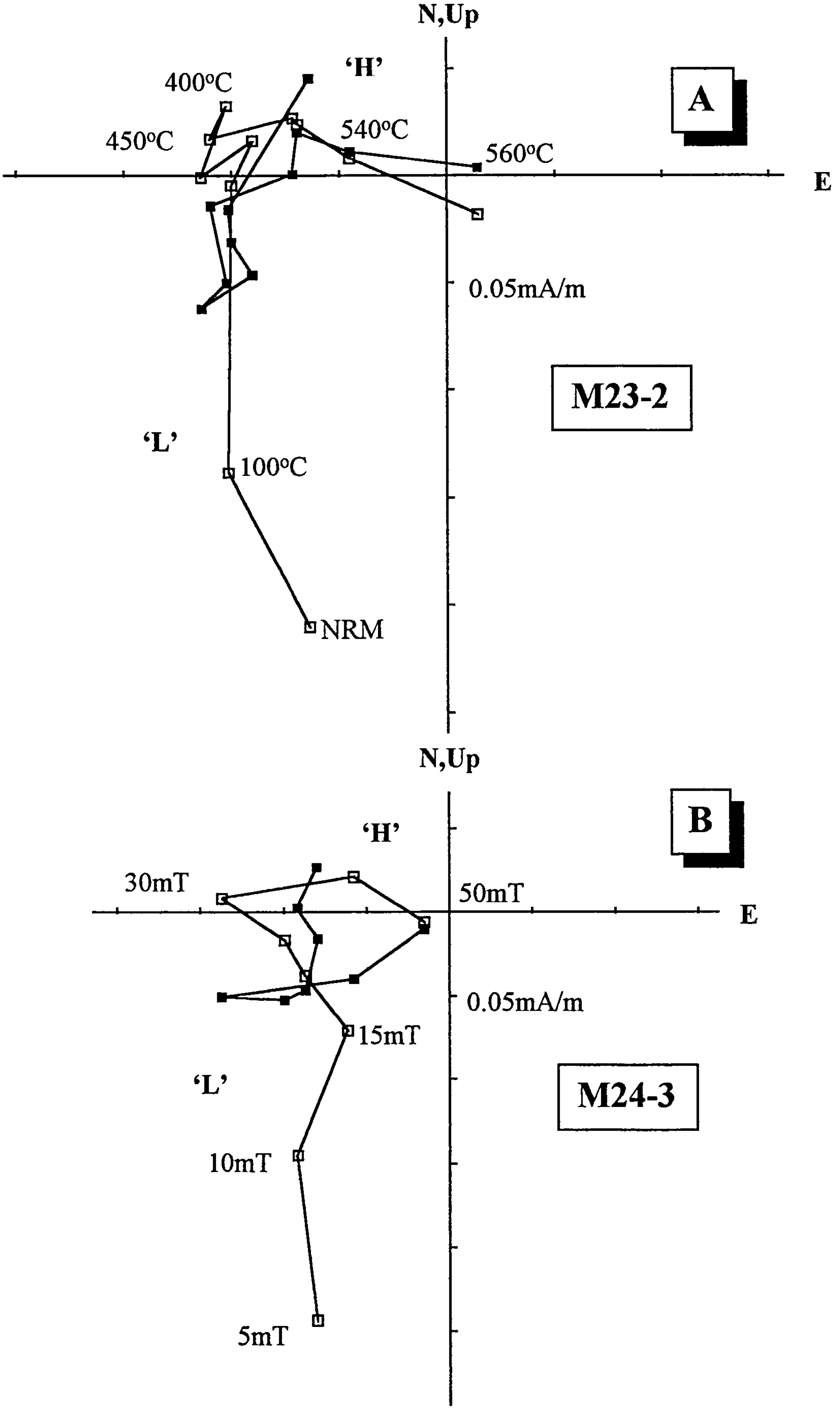


Figure 7. Representative orthogonal plots of progressive demagnetization data for specimens containing the 'H' component. These specimens, both from resfjell, also carry the lower stability 'L' component. (Conventions and symbols are as in Fig. 5)

'L' Component

		In-Situ					*Tilt-Corrected*		
Site No.	n/n_0	*Dec*	*Inc*	*k*	$\alpha95$		*Dec*		*Inc*
M2	3/4	354.5	75.2	26.3	24.5		27.1		28.9
M5	1/3	16.6	77.4	-	-		33.6		28.2
M6	2/3	17.5	69.7	-	-		31.2		20.0
M23	3/3	334.3	76.5	107.6	11.9		175.0		-41.9
M24	3/4	17.0	74.7	124.2	22.6		160.9		-40.9
Mean	*N*	*Dec*	*Inc*	*k*	$\alpha95$	*Pole Lat*	*Pole Long*	D_ψ	D_χ
In-situ	5	5.0	75.0	199.5	5.4	87.4	126.6	9.0	9.9
Tilt-corrected	-	-	-	-	-	-	-	-	-

'I' Component

		In-Situ					*Tilt-Corrected*		
Block No.	n/n_0	*Dec*	*Inc*	*k*	$\alpha95$		*Dec*		*Inc*
M14*	5/5	027.5	33.7	30.8	14.0		29.1		-15.5
M15	5/5	071.0	76.3	16.8	19.2		47.2		28.1
M16	3/4	048.0	63.9	74.9	14.3		43.1		14.1
M17	4/4	055.2	71.7	56.6	12.3		44.4		22.3
M18	3/4	064.3	62.7	21.8	18.2		50.7		14.7
Mean	*N*	*Dec*	*Inc*	*k*	$\alpha95$	*Pole Lat*	*Pole Long*	D_ψ	D_χ
In-situ	4	58.0	69.0	120.6	8.4	58.6	091.9	12.1	14.3
Tilt-corrected	4	46.0	20.0	120.6	8.4	28.0	136.5	4.6	8.8

'H' Component

		In-Situ					*Tilt-Corrected*		
Block No.	n/n_0	*Dec*	*Inc*	*k*	$\alpha95$		*Dec*		*Inc*
M23	3/3	274.8	-37.5	28.2	23.5		274.0		37.5
M24	3/4	253.3	-17.0	31.8	22.2		275.5		9.9
Mean	*N*	*Dec*	*Inc*	*k*	$\alpha95$	*Pole Lat*	*Pole Long*	D_ψ	D_χ
In-situ	2	263	-28	-	-	16.4	099.0	-	-
Tilt-corrected	2	275	24	-	-	13.4	281	-	-

Table 1. Summary of sample and site mean palaeomagnetic directions; n=number of specimen directions used in the analysis, n_0=number of specimens demagnetized, N= number of sites, Dec=declination, Inc=inclination, k=Fisher's (1953) precision parameter, α95=Half-angle of the cone of 95% confidence and D_ψ and D_χ are the semi-axes of 95% confidence about the pole. The 'I' component direction from block M14(*) is an outlier and was not used in the calculation of the overall mean for 'I' (we suspect an error in the field orientation of that block sample).

5 MAGNETIC MINERALOGY

Thermomagnetic analysis uncovered two different types of behaviour (Fig. 8a & b):

- Specimens with a high NRM intensity generally yielded a single Curie point in the range 560-580°C. On cooling, a 10-20% decrease in the saturation magnetization was observed with a lowering of the Curie point by 20-50°C. This type of behaviour indicates the presence of almost pure magnetite or titanium poor titanomagnetite.

- Specimens with a low NRM intensity produced very poor J_i-T curves. Onle one specimen yielded an interpretable Curie point, in the region 560°-600°C; presumed to indicate the presence of magnetite. The cooling curve rose markedly as the specimen cooled through 500°C indicating the production of a new magnetic mineral phase during laboratory heating.

Both types of thermomagnetic curve indicate that magnetite is the major magnetic mineral phase present in the samples which yielded stable remanence components. We presume, therefore, that the remanence components are carried be magnetite.

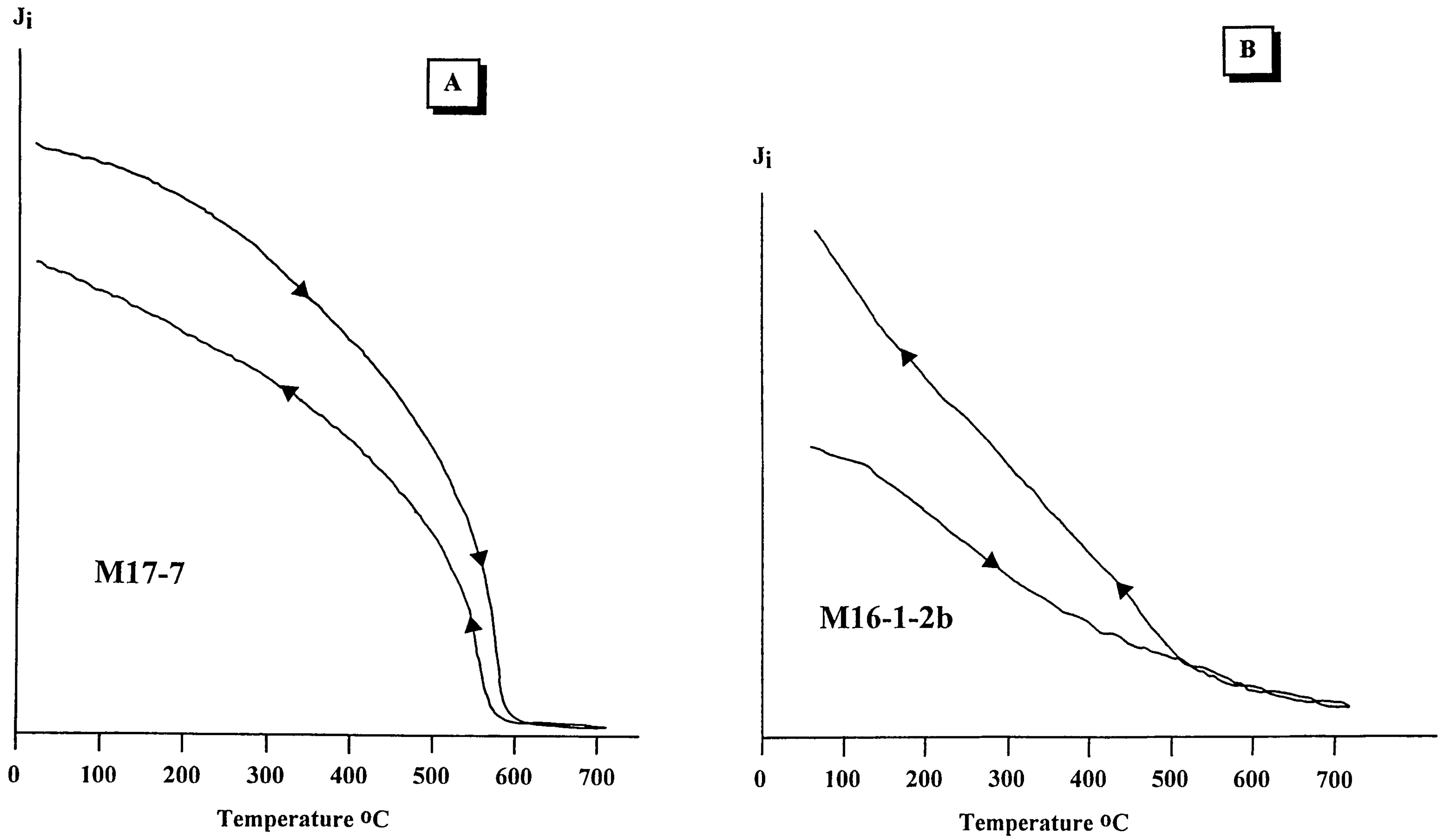


Figure 8. Example thermomagnetic analyses for samples with a high (A) and a low (B) NRM intensity. Samples with a high NRM intensity (A) generally yielded a single Curie temperature at 560-580ºC. Samples with a low NRM intensity (B) generally yielded poor Curie point determinations and a marked increase in the induced magnetization upon cooling, indicating the production of a new magnetic mineral phase.

6 INTERPRETATION AND DISCUSSION

6.1 The 'L' Component

This component was observed in five samples; three from Grestadfjell and two from Resfjell (Table 1) and, in it's *in-situ* form, is directed steeply down to the north, similar to the present earth's field. Upon 'un-folding' about local structural trends there is a clear divergence between the sample-mean directions (Fig. 9a&b), thereby indicating that the component post-dates folding. Given it's directional similarity with the present earth's field direction in central Norway and it's low stability the 'L' component is interpreted to be a recent magnetic overprint.

6.2 The 'I' Component

This component was observed in five samples, all from the quarry at Osplihaugen near Grestadfjell. Unfortunately this prevented the application of a palaeomagnetic fold test and therefore tilt-correction does not provide any constraints on the age of this component (Fig. 9c&d). A comparison with a reference Apparent Polar Wander (APW) path for Baltica (Fig. 10) shows that in it's *in-situ* form the 'I' component falls on the early Jurassic segment of the path and in it's 'un-folded' form falls near the late Devonian/early Carboniferous segment of the path. Given that the age of folding in the region is Scandian (i.e. pre-Devonian) the resemblance of the tilt-corrected pole to the early-Devonian/early-Carboniferous segment of the path must be coincidental. A post-tectonic (early Jurassic) origin for 'I' is therefore favoured.

6.3 The 'H'Component

The 'H' component was found in only two blocks, both from Resfjell. Therefore 'un-folding' does not provide any constraints on the age of the component (Fig. 9e&f.). When compared with the reference APW path for Baltica (Fig. 10) neither the *in-situ* or the tilt-corrected direction corresponds with any segment of the path. From this we deduce that some as yet unconstrained tectonic rotation affected the orientation of the remanence. Given that the age of deformation (and rotation) of the region is Scandian and older, the rotated remanence component must be Silurian or older. We propose two possible senarios for the origin of the remanence component: (1) it is an overprint related to Silurian uplift and deformation in the region or (2) it is an early magnetization dating from the time of (or shortly after) sheeted dyke emplacement (Arenig-Llanvirn?).

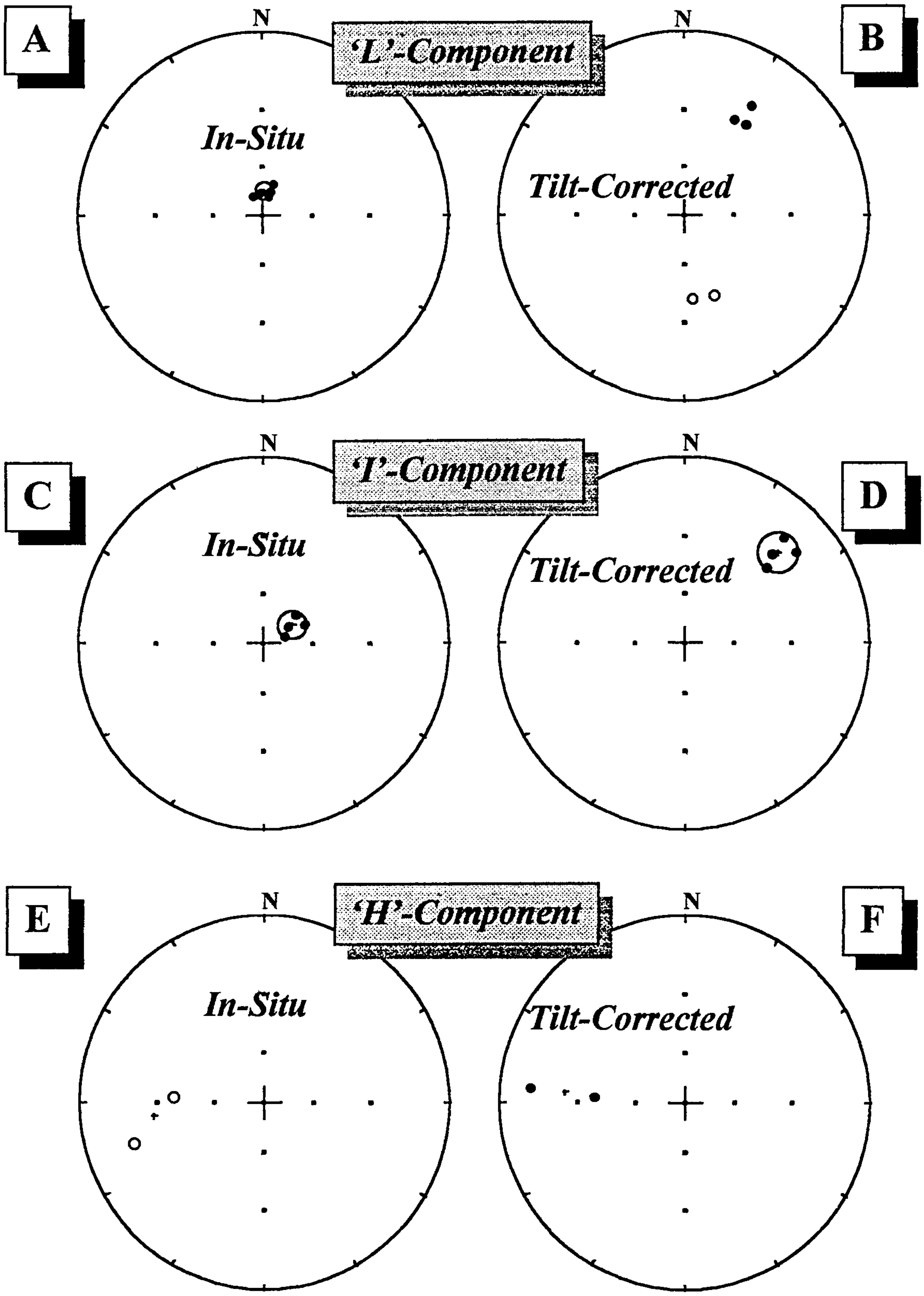


Figure 9. Stereographic projections of the 'L', 'I' and 'H' components, before and after tectonic correction. The 'L' component yields a negative fold test, wheras correction of the 'I' and 'H' components is inconclusive. See text for details.

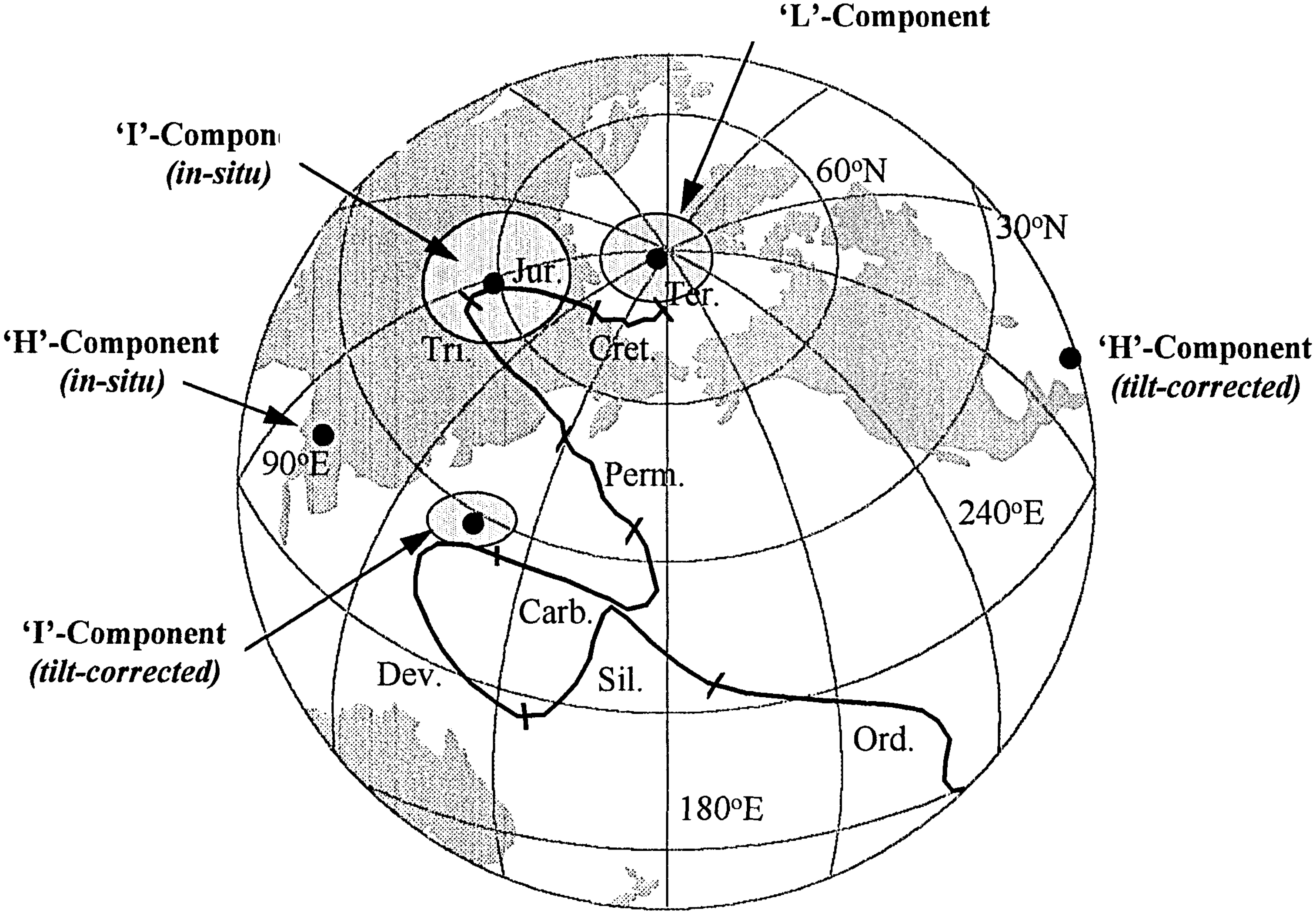


Figure 10. Comparison of the poles associated with the 'L', 'I' and 'H' components identified in this study with a reference Apparent Polar Wander (APW) path for Baltica. The path consists of Vendian to Permian poles, listed in Torsvik *et al.* (1992) with Triassic and younger poles taken from Van der Voo (1990). The 'L' and 'I' components are interpreted to be of recent and early-Jurassic ages, respectively. The 'H' component does not resemble any younger poles in either *in-situ* or tilt-corrected co-ordinates and may represent a primary magnetization.

To test senario (1) we compared the palaeolatitudes implied by both the *in-situ* and 'un-folded' versions of the 'H' component with the expected palaeolatitude for the region (Baltica) *in Silurian time*. To test senario (2) we compared the palaeolatitude corresponding to the 'un-folded' 'H' component with the expected palaeolatitudes for the appropriate margins of Baltica and Laurentia for the time of formation of the dykes in the *early-Ordovician*.

Regarding the test of senario (1), the palaeolatitudes corresponding to the *in-situ* and 'unfolded' 'H' component directions are 14.9° and 12.6° respectively (Table 1). Both of these are similar in magnitude to the expected palaeolatitude for the appropriate margin of Baltica in the Silurian (*ca.* 10 °S). 'H' in form would have to be of *normal* polarity and have been rotated more than 100 degrees anticlockwise about a vertical axis (after folding) to be a record of the Silurian palaeofield for Baltica. 'H' in 'unfolded' form would have to be of *reversed* polarity and have been rotated more than 100 degrees clockwise about a vertical axis before, during or after folding to be a record of the Silurian palaeofield for Baltica.

It seems unlikely that Meldal region would have undergone a vertical-axis rotation of more than 100 degrees *after* mid-Palaeozoic folding was complete. We therefore reject the hypothesis that 'H' is post-folding (Silurian) and of *normal* polarity. It is much easier to view large rotations about vertical axes as taking place *during* the emplacement and deformation of nappes rather than afterwards. This favours the hypothesis that 'H' is of *reversed* polarity, pre-folding, and underwent a large component of vertical-axis (clockwise) rotation during deformation of the Trondheim nappe. The main problem with this scenario is that a significant part of the deformation (folding) in the Meldal region is likely to be *older* than Silurian. This means that it is inappropriate to compare the palaeolatitude for the 'unfolded' 'H' component direction with Silurian palaeolatitudes for Baltica. Either (1) if 'H' is Silurian a revised 'unfolding' adjustment is required (which cannot at its stage be established) or (2) if 'H' is older than Silurian the 'unfolded' palaeolatitude should be compared with some other part of the Baltica path.

Regarding the test of senario (2), if we then take the palaeolatitude for the 'un-folded' result (12.6°) as being representative for the time of (or shortly after) sheeted dyke emplacement (early Ordovician) we can compare it with the palaeolatitudes expected for the margins of both Baltica and Laurentia at that time. The palaeolatitude for the dykes (12.6°) fits with a position marginal to Laurentia rather than Baltica in the early Ordovician, suggesting that the remanence might indeed pre-date emplacement of the ophiolite and record an early position for the terrane on the Laurentian side of Iapetus (Fig. 2a).

Our consideration of senarios (1) and (2) does not allow us to reject either one of them. We are, however, able to say that is is most likely that 'H' pre-dates much of the folding of the

Meldal region and has undergone a large rotation, of the order of 100 degrees or more. If the remanence is near primary (early Ordovician), it implies a position for the ophiolite near the Laurentian margin of the Iapetus Ocean (and therefore the presence of terranes in the Scandinavian Caledonides which have early tectonic histories quite unrelated to Baltica). If the remanence is an overprint associated with emplacement of the ophiolite onto the Baltica continent in Silurian time or just before, it tells us little of the original position of the ophiolite in the Iapetus Ocean.

7 CONCLUSIONS

A palaeomagnetic investigation of the Early-Ordovician (middle to late Arenig) sheeted dyke complexes at Meldal has revealed a complex multicomponent magnetization history. Three components of magnetization were identified based on their relative stabilities; 'L', 'I' and 'H'. The 'L' and 'I' components are considered to be magnetic overprints, of recent and Jurassic age respectively.

From the present sparse palaeomagnetic data it seems likely that ‘H’ pre-dates much of the folding in evidence in the Meldal region. We also deduce that the rotation of ‘H’ during deformation had a large vertical-axis component, perhaps exceeding 100 degrees of arc. We recognise two possible models for the origin of ‘H’. One is that ‘H’ is near primary (early Ordovician). This would imply an original position for the ophiolite near the Laurentian margin of the Iapetus Ocean (and therefore the presence of terranes in the Scandinavian Caledonides which have early tectonic histories quite unrelated to Baltica). The second model is that the remanence is a Silurian (or slightly older) overprint associated with emplacement of the ophiolite onto the Baltica continent. If this is the case the palaeomagnetic record offers no constraints on the original position of the ophiolite in the Iapetus Ocean.

It is possible that more extensive sampling and laboratory analysis of the other lithologies, including the pillow-lavas overlying the sheeted dykes and the underlying gabbros may yield further and definitive constraints on the age of the 'H' component.

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