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The tectonic implications of Solundian (Upper Devonian) magnetization of the Devonian rocks of Kvamshesten, western Norway

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The allochthonous Old Red Sandstone of Kvamshesten, western Norway, records polyphase orogenic deformation, and palaeomagnetic results from both the Devonian sediments and mylonites associated with the basal thrust define a syn- (to post-) tectonic magnetization with $D = 218^\circ$, $I = +3^\circ$ and $\alpha_{95} = 9.7^\circ$. The corresponding pole position (lat 21°S , long 324°E) suggests a Late Devonian/Early Carboniferous magnetization age (Solundian), and probably dates the time of thrust movements.

1. Introduction

Palaeomagnetism and magnetic fabric studies may identify, date and evaluate the nature of tectono-morphic events, and combined with structural geological studies, the Norwegian Old Red Sandstone (ORS) deposits form the subject of a major investigation into the nature and timing of post-depositional deformation.

In western Norway (Vestlandet), Lower to Middle Devonian Old Red Sandstone deposits are located in four large massifs (Fig. 1; Solund, Kvamshesten, Håsteinen and Hornelen). The present account concentrates on palaeomagnetic and magnetic fabric data from the Kvamshesten ORS, while structural geological aspects will be detailed in Sturt et al. (in preparation). The age of the Kvamshesten ORS has been ascribed to the Middle Devonian [1], and some of the sedimentary facies patterns are held to reflect syn-depositional tectonism [2]. The Norwegian ORS deposits are known to have suffered "Late Caledonian" deformation [3,4], notably E-W or NE-SW folding. The Kvamshesten ORS has been deformed by north-south compression, and apart from the western margin of the basin, where the Devonian rests unconformably on mangerite-syenite basement rocks, the lower contact of the Devonian sedi-

ments is a thrust plane [5]. This contact is strongly mylonitized, and the Devonian sediments and mylonitic layering display east-west folding, but the bedding in the Devonian is more steeply inclined than the thrust contact.

For palaeomagnetic purposes a total of 80 hand-samples were collected from 16 sites (Fig. 2; N.B. site numbers are not listed sequentially). The Kvamshesten ORS has been divided into three formations: the Markavatn, Heilefjell and Litjehesten Formations [6]. The basal Markavatn Formation is dominated by coarse breccias and con-

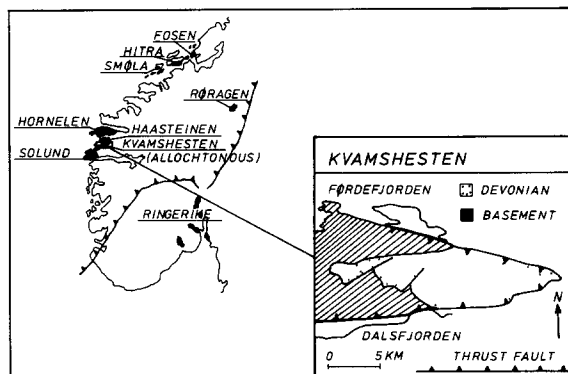


Fig. 1 Distribution of Old Red Sandstone sequences in southern Norway [4], and sketch map of the Kvamshesten area (simplified from Skjerve [6])

glomerates, grading upwards into the Heilefjell Formation, predominantly red and grey-green sandstone and siltstone (/mudstone). The Heilefjell Formation (sites 47–53 and 65–67) forms the basis for the present study, but in addition samples were collected along the mylonitic contact (Fig. 2; Table 1) in an attempt to apply the findings of palaeomagnetism to dating thrust movements. The studied assemblage include Devonian mylonites and deformed sediments (sites 38–40), pseudotachylites and intruded contact sediments (site 64) and mylonitized Precambrian mangerite-syenite (sites 41, 42).

2. The magnetic fabric

The anisotropy of magnetic susceptibility (AMS) was measured on a low-field (1 Oe) susceptibility bridge (KLY-1). The orientation and

shape of the magnetic susceptibility ellipsoids are given by the principal axes $K_{\max} \geq K_{\text{int}} \geq K_{\min}$, and the axial ratios $P1 = K_{\max}/K_{\text{int}}$ (lineation) and $P3 = K_{\text{int}}/K_{\min}$ (foliation). $P2 = K_{\max}/K_{\min}$ (anisotropy) is expressed in the form of degree of anisotropy $\%An = (P2 - 1) \times 100$.

Sites 47–53 embrace an east-west fold with the dip of the strata being near vertical at sites 47 and 48 (Fig. 2). Steeply inclined cleavage with east-west trend was occasionally observed in siltstones. Magnetic foliation planes (K_{\max}/K_{int}) are substantially bedding-parallel, apart from site 49 (Fig. 2) where the magnetic foliation diverges to some extent from both bedding (S_0) and cleavage (S_1). K_{\max} , however, closely reflects the intersection of S_0 and S_1 . K_{\min} and poles to bedding are distributed in a north-south girdle (Fig. 3A), indicating folding on an east-west axis, with an easterly plunge of ca 25°. Lineations have a near easterly

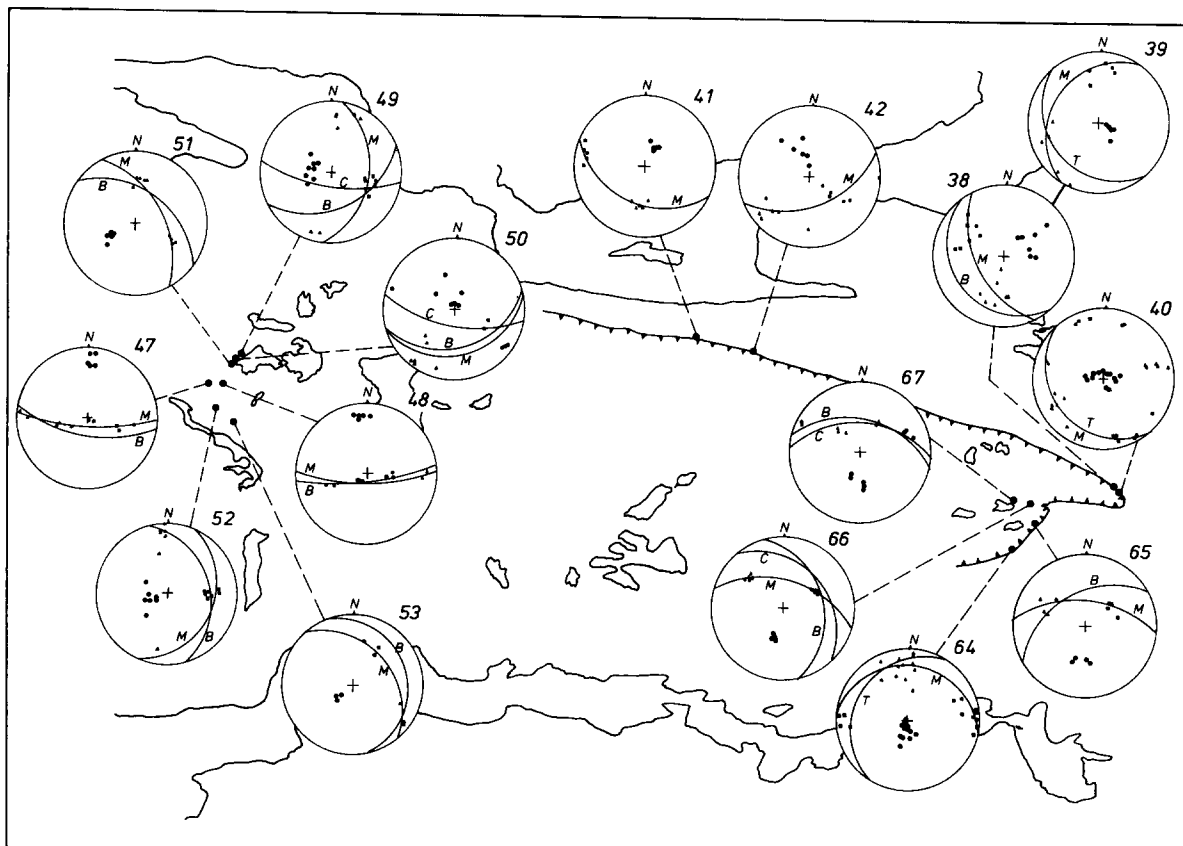


Fig. 2 Sampling sites (numbered) along with petrofabric and structural data. Orientation and downward dip of magnetic foliation, cleavage and bedding are marked with *M*, *C* and *B* respectively. In stereoplots K_{\max} , K_{int} and K_{\min} (downward dip) are shown by closed squares, triangles and circles, respectively. The Dalsfjord Fault is only drawn along the sampling sites.

TABLE 1

In situ site mean statistics

Site	Rock type	D ($^{\circ}$)	I ($^{\circ}$)	α_{95} ($^{\circ}$)	Polarity, N		
					normal	reverse	*
38	Deformed sandstone	217	-8	10	2	9	(140/19)
39	Devonian mylonites	(NRM below instrumental noise level)					
40	Deformed sandstone/mylonites	210	23	14	7	7	(140/19)
41	Mangerite mylonite	220	-6	13	-	3	(114/25)
42	Deformed sandstone/mylonite	(NRM below instrumental noise level)					
47	Grey sandstone	(no successfully tested samples)					
48	Red sandstone	231	16	15	-	10	(090/75)
49	Red-grey sandstone	217	19	12	-	9	(065/35)
50	Red sandstone	228	10	17	-	8	(072/32)
51	Red sandstone/siltstone	221	-5	6	-	6	(305/40)
52	Grey sandstone	191	14	14	-	5	(020/23)
53	Grey sandstone	212	-20	6	-	3	(340/15)
64	Pseudotachylite	231	15	10	-	3	(209/25)
65	Red sandstone/siltstone	217	-5	16	-	7	(240/40)
66	Red silt/mudstone	252	9	18	-	4	(345/30)
67	Red silt/mudstone	189	-20	8	-	10	(283/40)

 D = declination, I = inclination, α_{95} = 95% confidence circle [29], N = number of samples

* Strike and dip used for structural corrections

plunge at the majority of tested sites, in both the Devonian sediments and mylonites (Fig. 3B). Where cleavage can be observed (sites 49 and 50) there is a close correspondence between K_{\max} and the intersection of S_0 and S_1 . The degree of anisotropy from sites 47–53 is relatively low, i.e. 3–7%, and the shape of the magnetic ellipsoids is chiefly oblate. The prolate form in some sites may reflect the superposition of S_1 on the regional

bedding. The fabric parameters exhibit small, but systematic variation between the gently inclined limbs and the tightly folded hinge-zone. Sites 48 and 49 demonstrate a stronger foliation (P_3) and degree of anisotropy, the former being reflected by an apparent increase in oblateness of the magnetic ellipsoids (cf. Flinn diagram in Fig. 3A). This observation, together with the easterly plunging lineations which bear no consistent relation to

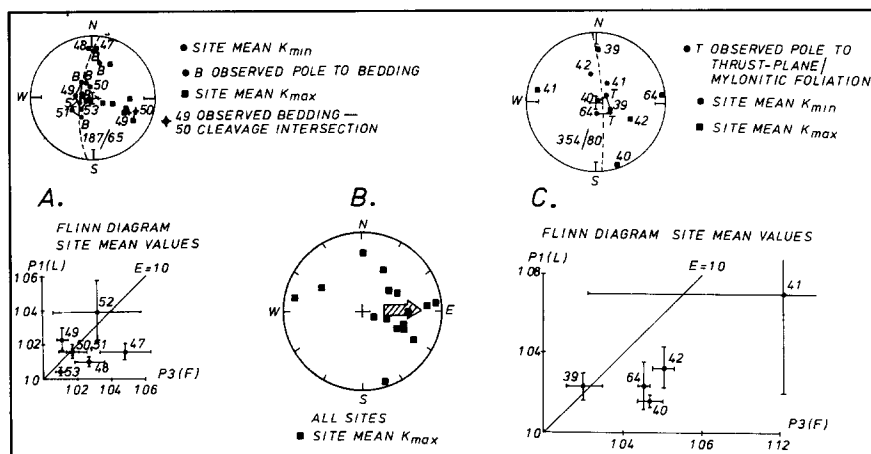


Fig. 3 Comparison of poles to bedding, cleavage and K_{\min} , mean sites values for K_{\max} (lineation) and Flinn diagram for sites 47–53 (A) and mylonitic/contact sites (C). Site mean values of K_{\max} for all investigated sites, having a predominantly easterly plunge are shown in (B).

primary sedimentary textures, suggests a weak, but secondary style fabric, which almost transposes the bedding plane.

The eastern part of the massif (sites 65–67) displays a more pronounced secondary style of fabric, in which the magnetic foliation is controlled by cleavage, in particular sites 65 and 66 (Fig. 2). These sites, however, are close to the mylonitic contact, and gross similarities occur between the magnetic foliations and those of the pseudotachylites (site 64). The magnetic ellipsoids were all oblate, with anisotropies around 3–5%

In the basal mylonites, the magnetic foliation is in reasonable agreement with the mylonitic foliation and thrust-plane orientation (Fig. 3). Poles to mylonitic foliation (K_{\min}) indicate a gently plunging fold (Fig. 3C), compatible with the orientation of the more strongly folded sediments, but with a westerly plunge of ca. 10° . Two discrete stages in the growth of the fold are suggested from the structural fabrics: e.g. folding of Devonian sediments, *thrusting* and folding of the mylonitic layering with continued folding of the sediments. Apart from site 39, mylonites and pseudotachylites display oblate magnetic ellipsoids. Within-site variation of the fabric parameters is considerable, and the degree of anisotropy varies from 2% to 15%. Vertical profiles through the Devonian sediments and the mylonites generally show an increase in strain intensity, i.e. oblateness or total degree of anisotropy (cf. Figs. 5 and 6D) towards mylonites. However, “strain” calibration is not justified due to magneto-mineralogical changes when approaching the mylonites (see next section). Lineations plunge chiefly towards the east, parallel to the fold axis. This suggests that the lineation is either an axis of principal extension, or more likely the axis of shearing within the foliation plane.

3. Palaeomagnetic and rock-magnetic experiments

The direction and intensity of natural remanent magnetization (NRM) was measured on a Mol-spin magnetometer. The stability of NRM for a total of 130 samples was tested by means of stepwise thermal demagnetization, using a Schonstedt (SD-1) furnace. Characteristic remanence directions were obtained by line fitting in vector diagrams. The natural remanent magnetization

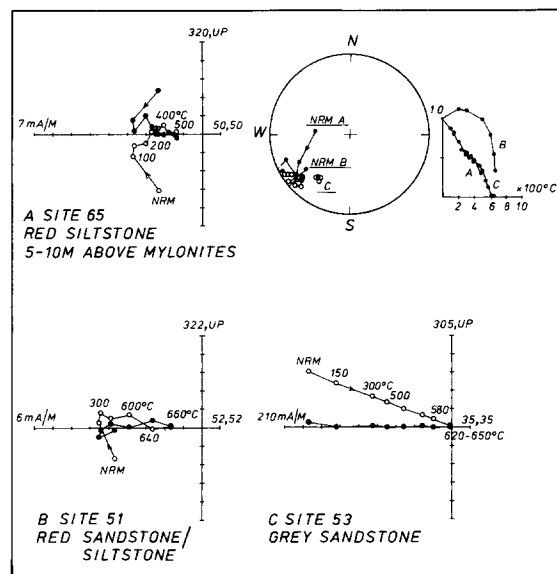


Fig. 4 Examples of thermal demagnetization of Devonian sediments. In vector-diagrams, open (closed) symbols represent points in the vertical (horizontal) plane. In stereoplots, open (closed) symbols represent upward (downward) dipping magnetizations. Note that vector-diagrams are optimally projected closely reflecting the authors choice of declination of characteristic remanence components. All demagnetization examples are shown in in-situ co-ordinates.

(NRM) of Devonian samples can be accounted by almost univectorial, southwest shallow dipping magnetizations (Fig. 4C), or a two-component structure (Fig. 4A, B) in which a poorly defined, steeply downward dipping component (probably of Recent/Tertiary origin), is randomized in the early stages of demagnetization (< 200 – 300°C). The high-temperature components are predominantly characterized by distributed unblocking, a major part of the NRM being unblocked below 600°C , but remanence stability was mostly achieved up to temperatures around 650 – 660°C . Only occasionally, did discrete unblocking take place above 600°C (Fig. 4B).

Isothermal remanent magnetization (IRM) curves and thermomagnetic analysis of the Devonian sediments show overall differences between red and green/grey coloured sandstones and siltstones. The red beds are dominated by haematite, while the grey-green beds reveal the presence of both haematite and magnetite, being potential carriers for both remanence and anisotropy. Vertical profiles, through deformed contact sediments, mylonites and pseudotachylites, may differ with

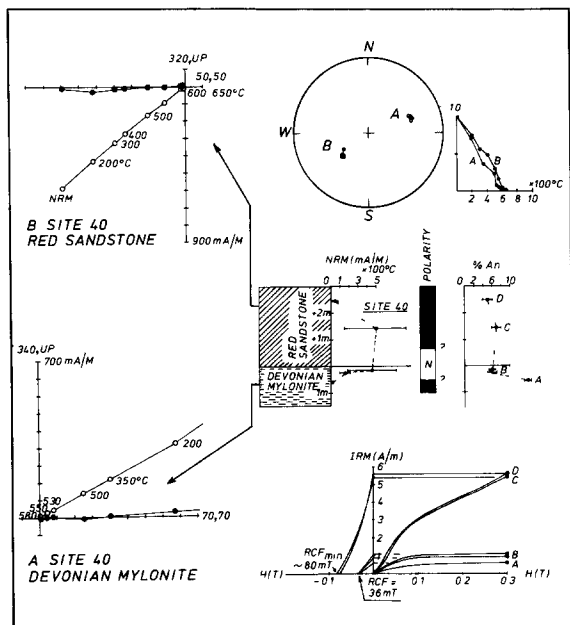


Fig. 5 Further examples of thermal treatment (site 40), along with vertical profiles of NRM, polarity, degree of anisotropy (%An) and examples of IRM curves from both Devonian mylonites (level A, B) and contact sediments (level C, D)

respect to magneto-mineralogy, NRM intensity and magnetic fabric parameters. Fig. 5 applies to the northeastern margin of the Kvamshesten Massif, and includes Devonian mylonites and contact sediments (deformed red sandstone). From typical NRM intensities in the 5–20 mA/m range for Devonian sediments, transition-zone samples gave NRM intensities as high as 1000 mA/m. This feature was only observed in this profile. Distinct magneto-mineralogical differences can be observed between the mylonites and the contact red beds; the latter are strongly influenced by non-saturated phases in maximum available fields of 0.3 T, having minimum remanence coercive forces (RCF) of 70–80 mT. Curie temperatures around 580 and 680°C, along with remanence analysis, indicate both magnetite and haematite remanence carriers. Secondary magnetite was readily produced in the laboratory during heating above 600°C. In contrast, Devonian mylonites show saturation in fields of less than 0.1 T, and single Curie temperatures around 580°C (magnetite).

In general, the remanence of contact sediments resides in both magnetite and haematite, whilst the mylonites and pseudotachylites have exclu-

sively a magnetite carrier. The latter rocks have RCF values above 35 mT, and are characterized by distributed unblocking, suggesting fine-grained magnetite, presumably in a single-domain state. This is sustained from petrographic studies, in which extremely fine-grained, almost unaltered and perfectly cubic magnetites have been observed. These magnetites are inferred to be recrystallized. From Fig. 5, it is noted that there is a polarity transition along the mylonitic contact, the basal part of the mylonites gave reverse field-directions, but mylonitic rocks close to the contact show almost univectorial normal polarity field directions, being confined to blocking temperatures below 580°C (Fig. 5A). On the other hand, the overlying contact sediments show remanence stability up to 650°C (Fig. 5B), with reverse polarity field directions. The majority of tested samples, including all “basinal” sediments, show a uniform reverse polarity magnetization, and normal polarity data are confined to sites 40 (Fig. 5; see above) and 38, i.e. close to the mylonitic transition zone. From the latter site, example of almost antiparallel field directions is shown in Fig. 6A and B. Reverse field direction is isolated in the 500–630°C range (1.5 m above the mylonite zone), while the low-temperature blocking component of normal polarity is recognized ca. 2 m above the mylonitic rocks.

Magnetite-syenite mylonites (Fig. 6C) and successfully tested pseudotachylites (Fig. 6D), with NRM intensity mostly below the instrumental noise level, revealed characteristic remanence components closely similar to those of the sediments and the Devonian mylonites.

4. Remanence analysis and fold test

The majority of tested samples gave reverse field components with shallow to moderate south-westerly inclinations (Fig. 7A). Remanence components obtained in contact deformed sediments, mylonites and basinal sediments are fairly similar, thus almost independent of the structural fabrics. Apart from some poorly defined, steeply dipping magnetization, eliminated in the early stages of demagnetization, the NRM can be accounted for single-component magnetizations. The distribution of individual sample directions (Fig. 7A), however, is rather scattered, but within-site scat-

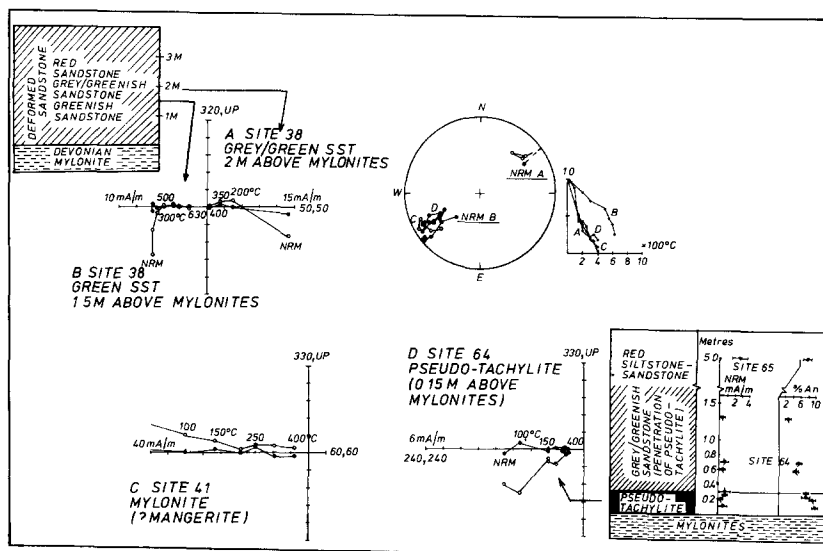


Fig 6 Examples of thermal treatment of mylonitic samples, pseudotachylites and contact-deformed sediments. Inset vertical profiles of sites 38 and 64, the latter including NRM intensity and %An

ter may also be considerable (cf. Fig. 7B and E; Table 1).

Fold tests are of vital importance in establishing the origin of magnetization, and curve *A* in Fig. 8 applies to the western part of the Kvamshesten Massif (sites 48–53). The beds were stepwise unfolded and it is noted that the confidence circle, α_{95} , shows a local minimum at ca. 30% of unfolding, suggesting a syn-fold origin of magnetization. Due to the relatively good correspondence between poles to bedding and K_{min} from these sites, a similar test was performed by

using the orientation of the magnetic foliation planes. As noted by curve *A_m* in Fig. 8 an even more pronounced, and statistically significant syn-

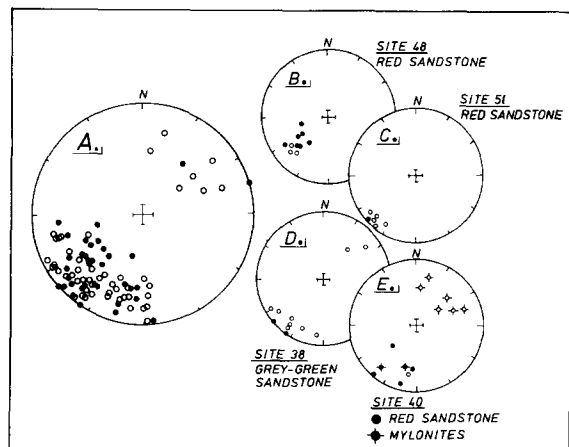


Fig 7 Distribution of characteristic remanence components (in situ) on sample level (A) and examples of within site scatter (B–E, cf. Tables 1 and 2)

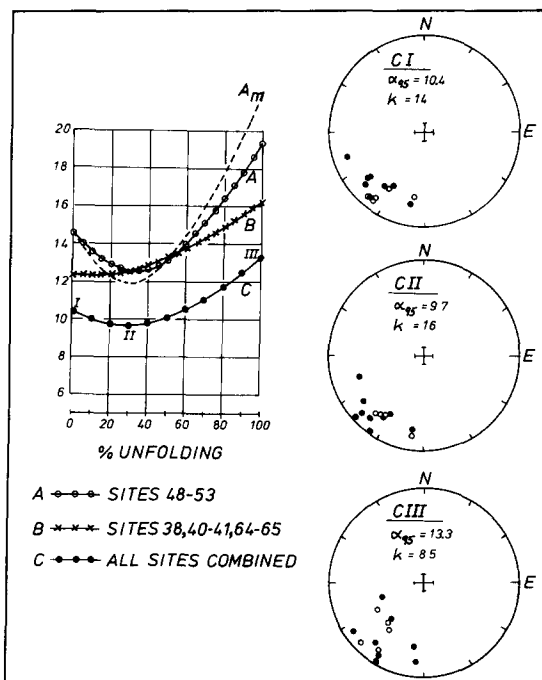


Fig 8 Progressive fold tests, showing variation of α_{95} (vertical axis) as a function of unfolding (cf. text). Stereoplots refers to all sites combined (C), showing distribution of site means of in situ directions (CI), 30% unfolding (CII), and finally 100% unfolding (CIII)

TABLE 2

Overall palaeomagnetic results from the Kvamshesten area

	D (°)	I (°)	N	α_{95} (°)	k
0% unfolding	218	3	13	10.4	14.0
30% unfolding	218	3	13	9.7	16.0
100% unfolding	218	2	13	13.3	8.5

VGP (30%) 21°S, 324°E ($dp = 5^\circ$, $dm = 10^\circ$)

(Mean sampling co-ordinates 61.4°N, 5.5°E)

 N = number of sites, k = precision parameter (see Table 1)

fold origin is indicated, suggesting that the magnetic foliation is more accurate than field measurements of bedding.

Application of this test to all the investigated sites indicates a similar picture, though not so pronounced (Fig. 8, *CI-III*). This may reflect the combination of areas with different tectonomagnetic history (syn- and post-tectonic origin) and/or age diachronism. An essentially syn-tectonic origin of magnetization is favoured, but the less pronounced local minima for all sites combined, is due to the fact that "contact magnetizations" essentially define a post- or late syn-tectonic origin (Fig. 8, *B*). The significance of this latter test, however, is uncertain, since a rotation of the thrust plane fully back to the horizontal plane, is an unlikely position of nappe translation. The conventional statistical significance and interpretation of these tests are arguable, and without detailing the possible choices, we suggest that the obtained remanence components may date the thrusting and basal-mylonite formation and the early folding of the sediments, i.e. remanence blocking associated with a partial unfolding of Devonian sediments, leaving the thrust plane unfolded, but with an westerly dip of 10–15°. This model almost matches the distribution of site mean directions at a 30% unfolding level (all sites: *CII* in Fig. 8), which is adopted in the final analysis (Table 2). Unless, the remanence components have a post-tectonic origin, the within-site scatter may have originated from strain. However, due to the lack of recognition of a quantitative relationship between the direction and intensity of strain and remanence (-scatter), this remains to be established.

Remagnetization processes affecting the Kvamshesten area may have occurred at different times, but without any significant apparent polar

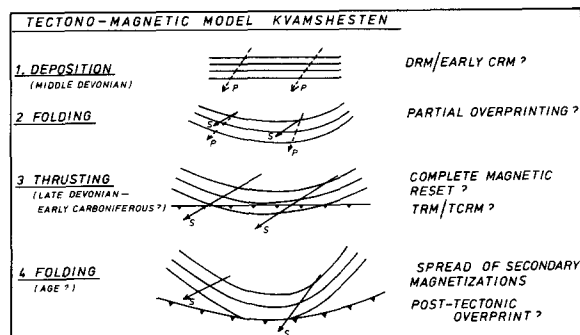


Fig. 9 A generalized tectono-magnetic model for the Kvamshesten Massif (cf. text)

wander (APW). The observation of some normal polarity data in the mylonitic zone, most likely postdates the main deformation/remagnetization (reverse polarity), either by secondary retrograde alteration provided by fluid circulation in the "fracture" zone, or local secondary mylonitization.

5. Generalized tectono-magnetic model

The Kvamshesten ORS was probably deposited during the Lower/Middle Devonian (Fig. 9; stage 1), and on account of the geometry and occurrence of some marginal deposits, Bryhni and Skjerlie [2] have argued for syn-depositional tectonism. The Devonian sequence subsequently suffered east-west folding, and an axial plane cleavage was developed locally in the fine-grained lithologies. During this stage (2), partial overprinting of any primary NRM, detrital or chemical (CRM), and the development of secondary style magnetic fabrics (weak) may have occurred. Skjerlie [6] contends that the sediments may have been folded before final consolidation, and that diagenesis may have been contemporaneous with folding. The present work, however, indicates that low greenschist-facies temperatures pertained during folding. Petrological studies on the Devonian sediments, present no strong evidence for primary detrital grains; haematite, which is the main constituent of red beds and a partial carrier of the remanence in grey-green beds, almost occurs as coating along grain boundaries or as pseudomorphs of iron-bearing silicates.

The next stage (3) in the history of this sequence most likely involved easterly translation on a thrust plane, accompanied by the development

of a conspicuous zone of mylonite which excised already folded sediments. Pseudotachylites formed along the eastern contact which locally may intrude the adjacent sediments. Some authors (e.g. [7,30]) consider that the Dalsfjord Fault (Fig. 1) is a listric normal detachment (see also Steel et al. [8]), appealing to syn-depositional tectonism in explaining the structural features of the Kvamshesten ORS. As the formation of the fault appears to be part of a progressive sequence of folding during crustal shortening the authors prefer the term thrust.

Characteristic remanence components are essentially syn-tectonic, and remanence blocking through uplift and decrease in regional thermal gradient must have taken place prior to a second stage of folding. This affected the nappe boundaries as well as intensifying the already folded Devonian sediments (stage 4): this stage of deformation probably occurred shortly after or during regional uplift and consequent decrease in the geothermal gradient (transition to brittle deformation), leaving the thrust overprint fairly unbiased. Late faulting has also occurred, cutting the Devonian folds and thrust plane. Well-defined magnetic lineations, with a near east-west trend and parallel to the fold-axes, probably reflect intersection lineations (S_0/S_1) and possible also stretching lineations.

The precise nature of the complete magnetic resetting of the Kvamshesten area is uncertain, but was probably achieved through a combination of viscous-thermal (VTRM) and thermo-chemical (TCRM) processes, although diagenesis and final syn-fold consolidation may have been an important element in the sediments [6]. Taking account of the fact that mylonite formation occurs at considerable depths, in the order of 10–15 km [9], then burial effects and subsequent viscous-thermal unblocking probably took place at temperatures in excess of 300°C in all of sites investigated (the depths are probably less than 2 km above the mylonite). Along the mylonitic zone, frictional heating, e.g. formation of pseudotachylites, must have upset the regional geothermal gradient, and thermal effects alone (TRM) were high enough for a complete magnetic resetting. However, thermochemical alterations and recrystallisation were probably of major importance in the mylonitic zone. It is also suggested that late,

but localized, retrograde processes took place along the mylonitic contact (TCRM).

The tectonization of the Kvamshesten area is corroborated by the anchimetamorphism indicated by preliminary illite 'crystallinity' results by one of us (H.J.K.) on five siltstone and mudstone samples from the ORS—corresponding to sites 47, 49, and 52 in the western area, and 66 and 67 in the eastern area. The experimental conditions were essentially those of Kisch [31], except that cation saturation was with Ca^{2+} rather with K^+ and Mg^{2+} , and that re-calibration of the X-ray diffractometer showed that the low- and high-grade limits of anchimetamorphic zone (0.42 and $0.25^\circ \Delta 2\theta$ of Kubler) correspond to 0.36 and $0.19^\circ \Delta 2\theta$ under the instrumental settings used.

The $-2 \mu\text{m}$ fractions of the five samples gave very uniform 10 \AA half-height peak width of $0.22\text{--}0.25^\circ \Delta 2\theta$, indicating an advanced grade of anchimetamorphism. The $2\text{--}6 \mu\text{m}$ fractions of the samples give narrower 10 \AA peaks of $0.16\text{--}0.21^\circ \Delta 2\theta$, due to presence of less altered clastic mica in the coarser fractions. However, the broader 10 \AA peaks in this fraction, around $0.20^\circ \Delta 2\theta$, were found in siltstones from localities with a distinct cleavage, corresponding to sites 49 and 67, suggesting that in these cleaved siltstones the recrystallization during the anchimetamorphism has also affected the coarser mica fractions.

6. Age and geodynamic perspectives

Apart from a previous palaeomagnetic result from the Kvamshesten ORS [10], palaeomagnetic data are available from only two Norwegian ORS developments, Røragen and Ringerike [11,12]. Pole positions from these ORS formations are shown in relation to a suggested British apparent polar wander (APW) path in the Lower Devonian (Late Silurian)/Permian range (Fig. 10A; [13]). Independent of the age constraints and the reliability of the British APW path used in the present account, it has been argued by various authors that Devonian poles from Norway fall outside the British polar swath. This palaeomagnetic discordance may in principle be explained by regional tectonics [14–16] or magnetic age differences [17]. The mean pole position of the present study, however, is ca. 20° more westerly than the previous estimate of the Norwegian "Devonian" pole

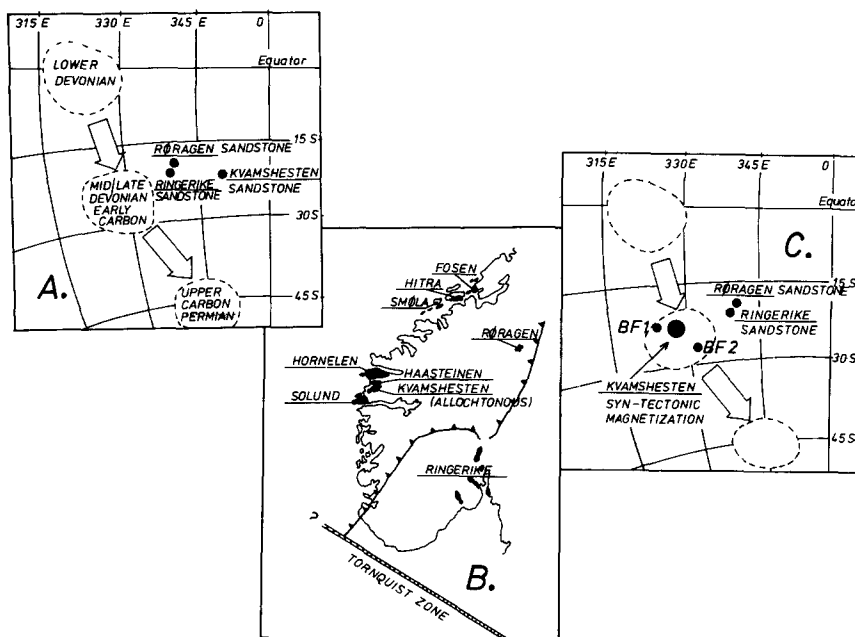


Fig. 10 British APW path in the Lower Devonian to Permian range [13], compared with available Norwegian Devonian poles (A) [10–12] and the present results from the Kvamshesten Massif along with two recent results from Spitsbergen (C). The Spitsbergen data are as follows: *BF1* = Mimer Valley Formation (postulated Svalbardian, Late Devonian remagnetization [13]) and *BF2* = Lower Carboniferous Billefjorden Sandstone [18] (B) shows distribution of Old Red Sandstone sequences in southern Norway [4]

position. The revised pole-position (Fig. 10C, Table 2), in fact, *conforms closely to British mid-late Devonian poles*, and Lower Carboniferous/?Late Devonian results from Spitsbergen [13,18]. This means that the “established” discrepancy between British and Norwegian Devonian data is questionable. The palaeomagnetic data from the Kvamshesten area presented by Lie et al. [10], as indicating a primary Devonian magnetization must be considered as incorrect, and the magnetization is evidently secondary (syn- to post-tectonic). Forthcoming palaeomagnetic results from the autochthonous Håsteinen ORS (see Fig. 10B) are in fair correspondence with the overall palaeomagnetic results in the present study [33]. Thus, local rotation of the Kvamshesten area is unlikely to explain some discrepancies (?significant) with the Røragen and Oslo (Ringerike Sandstone) areas. The Ringerike Sandstone is most likely of Upper Silurian/Lower Devonian age, and in a recent abstract, Douglass and Kent [32] present evidence for a pre-fold magnetization very similar to the direction of Storetvedt et al. [12]. If this magnetization is primary or secondary acquired during the Late Silurian/Early Devonian, Scandian orogenic

phase, which probably affected the complete Lower Palaeozoic succession up to Downtonian in the Oslo area [8], any palaeomagnetic discrepancies between western Norway and the Ringerike Sandstone can be related to age differences.

From the overall within-site scatter obtained from the Kvamshesten Massif, with directions SW, up and SW, down, may suggest the possibility of Permian(?) contamination (SW, up), rather than strain effects (if syn-fold origin). Such speculations are not justified from demagnetization behaviour of individual specimens. It is of interest, however, that Permian reactivation along the western part of the Dalsfjord Fault (Atløy) has been palaeomagnetically detected in extensional fault breccias [34].

7. Conclusion

Deformation of the Norwegian ORS and substrata has generally been ascribed to a late Caledonian tectonothermal event, the Svalbardian Orogeny [4,6,19], which also affected the ORS sequences of Spitsbergen and Bear Island. From these areas, stratigraphic and faunal relationships

demonstrate that tectonism terminated during the lowermost Upper Devonian and Middle Devonian respectively. Deformation of the Norwegian ORS is less precisely controlled, but some of the evidence available indicate a Late Devonian age [4]. In western Norway, the local name Solundian (Orogeny) has been applied to this event [20].

Palaeomagnetic data from the polyphasally deformed Kvamshesten ORS and the basal mylonites have been shown to be syn- to post-tectonic, with secondary style magnetic fabrics exhibiting a pronounced easterly plunging lineation. The relative pole-position is considered to fit Mid-Late Devonian to Lower Carboniferous poles from the British Isles and Spitsbergen [13,18]. Provided that the magnetic age of "reference" poles is correct, it is concluded that deformation of the Kvamshesten area occurred during the latest Devonian (Solundian/Svalbardian). In a recent paper [21], a $^{40}\text{Ar}/^{39}\text{Ar}$ stable plateau biotite age of 375 ± 3 Ma from Stadlandet, western Norway, is presented. This may well correspond with the age of folding and basal mylonite formation obtained palaeomagnetically, and represents an uplift age through a blocking temperature of approximately 300°C .

A major palaeomagnetic discordance between Norwegian and British Devonian data is not supported by the present study. Unfortunately, the state of Devonian Palaeomagnetism and its tectonic implications abounds in inconsistencies complicated by the possibility of magnetic overprinting. With our present knowledge, however, the proposed sinistral megashear in the North Atlantic [22–24], by some thought to facilitate the production of a transtensional tectonic regime in southern Norway [4] is most unlikely [13,25–28]. On the other hand, re-examination of the Røragen ORS, augmented by new studies of other rock-formations in Scandinavia, are urgently required before attempting a detailed reconstruction of the late Caledonian assemblage of northwestern Europe.

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