Palaeocurrent data from the Kalak Nappe Complex, northern Norway: a key element in models of terrane affiliation

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Palaeocurrent data recorded from a 2,000 km^2 area of fluvial, cross-bedded metasandstones in the lower thrust sheets of the Kalak Nappe Complex on the Sværholt and Nordkinn peninsulas, Finnmark, show unimodal patterns with low directional variance. Sediment dispersal was directed towards NW to NNE, and sourced in a highland region of crystalline basement (the 'Finnmark Ridge') situated to the S-SE. Sedimentary facies changes from south to north reflect a gradual transition from fluvial apron conditions into a marine basin with mudstone and greywacke deposition. This pattern of NW/NNE-directed palaeocurrent flow and facies changes is repeated in the underlying Laksefjord Nappe Complex. Fluvial to shallow-marine, lithostratigraphic successions in the subjacent Gaissa Nappe Complex, parautochthon and autochthon also show a predominant northward dispersal of sediment from the Fennoscandian Shield, but there is a current reversal in the highest exposed formations of the Gaissa with material shedding E-SE off the above-mentioned basement ridge which formed an important palaeodrainage divide. Taken as a whole, the successions constituting the tectonostratigraphy up to and including the lowest 5-6 thrust sheets of the Kalak Nappe Complex on Sværholt and Nordkinn are considered to derive from basement terranes of the Fennoscandian Shield. Recent models requiring that the Kalak Nappe Complex, and indeed the entire sandstone-dominated, Kalak-Seve-Särv allochthons (continental rise prism) of the Scandinavian Caledonides are exotic and derive from either the Laurentian or the Amazonian palaeoplate need to be carefully reconsidered. This is not to deny that some of the higher-lying thrust sheets of the Kalak Nappe Complex may be semi-exotic, with a mixed Timanian-Baltoscandian provenance. The vast area of Fennoscandian crystalline basement concealed beneath the nappes of NW Finnmark and a 200-250 km-wide segment of the continental shelf clearly holds important information that may be revealed only by major drilling programmes.

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Introduction

The metamorphic allochthon in the Caledonides of Finnmark, northern Norway, has long been known to be composed of a series of comparatively thin-skinned nappes or thrust sheets, emplaced roughly southeastwards, and sequentially, onto the crystalline Precambrian basement of the Fennoscandian Shield in Early Palaeozoic time (Sturt et al. 1975; Williams et al. 1976; Zwaan & Roberts 1978; Chapman et al. 1985; Ramsay et al. 1985; Gayer et al. 1985, 1987). Although interpretations and discussion had earlier entertained the possibility of a regional, latest Cambrian to Early Ordovician, metamorphism and deformation – the *Finnmarkian* phase of the Caledonian orogeny (Sturt et al. 1978; Dallmeyer 1988) – most workers now believe that almost all of the Caledonian folding and thrusting occurred in Silurian time during the Siluro-Devonian *Scandian* orogeny (Krill & Zwaan 1987, Binns 1989, Dallmeyer et al. 1989; Kirkland et al. 2005; Slagstad et al. 2006).

Early subdivision of the metamorphic allochthon into 3 or 4 main nappes proved to be a simplification; detailed mapping showed, in fact, that each original main nappe consisted of several thrust sheets and they were accordingly renamed as nappe complexes. With the advent of an orogen-wide tectonostratigraphy for the Caledonides, ranging from the Parautochthon through Lower, Middle, Upper and Uppermost Allochthons (Roberts & Gee 1985), the nappe complexes of Finnmark were assigned to one or other of these major subdivisions (Fig. 1). In the simplest of terms, the lithostratigraphical successions of the Parautochthon and Lower Allochthon have been considered to represent fluvial to shelfal, pericratonic deposition on the shallow platform of Baltica (Banks et al. 1971; Siedlecka & Siedlecki 1971; Siedlecka et al. 1995), whereas the 'sandstone nappes' of the Middle and lower part of the Upper Allochthon (the Laksefjord and Kalak nappe complexes) were regarded as parts of the continental rise prism, or miogeocline, again closely linked to the northern Baltoscandian margin of Baltica (Laird 1972; Roberts 1988; Siedlecka et al. 2004). These sandstone nappes can, in turn, be traced southwestwards into Troms county (Zwaan & Roberts 1978; Zwaan 1988) and thence into the classic Seve and Särv nappes of north-central Sweden and Norway (Zachrisson 1986; Stølen 1994); Andréasson et al. 1998).

This somewhat traditional view of the age or ages of thrusting, and the derivation and affinity of the diverse

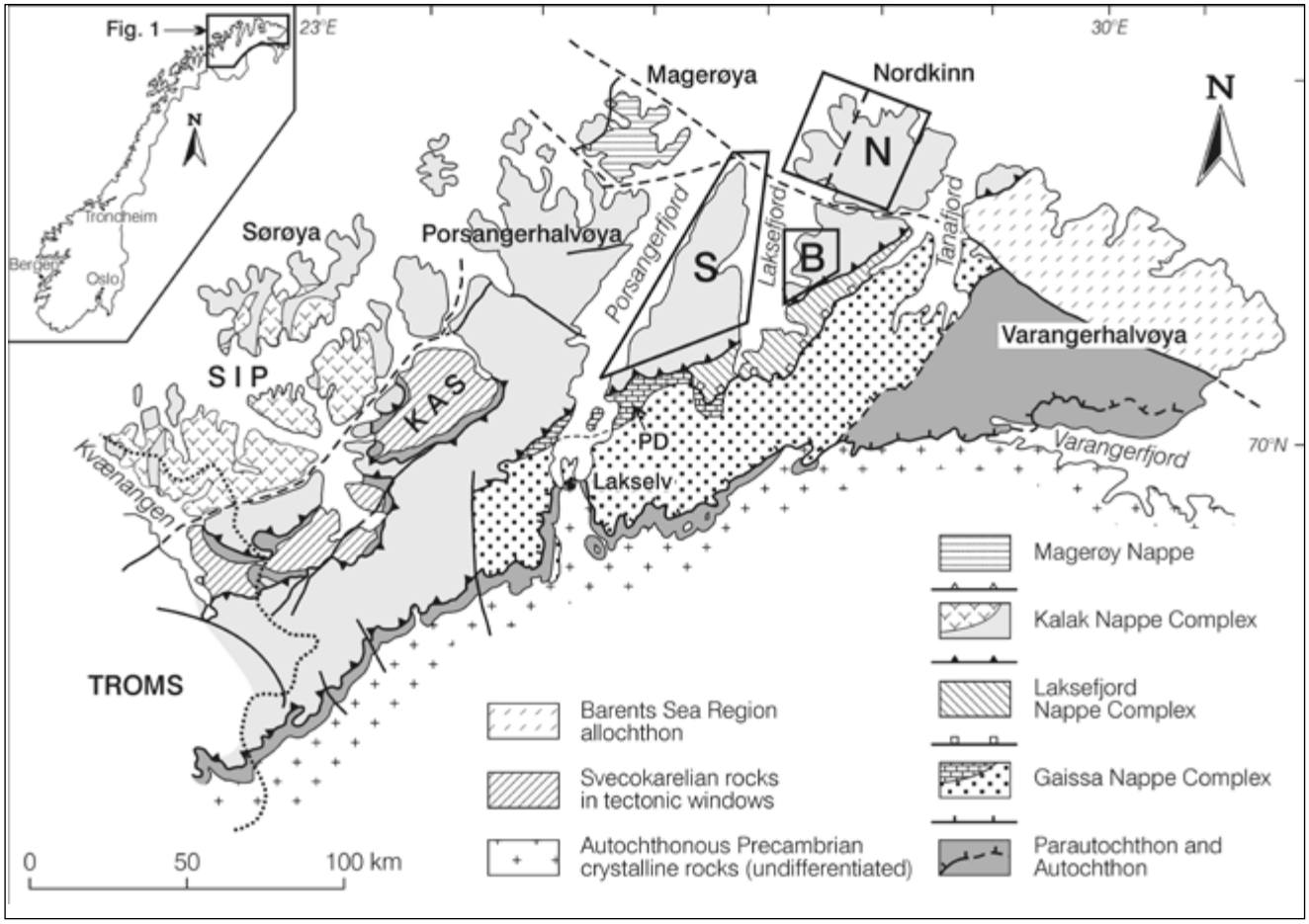

Fig.1. Simplified tectonostratigraphy of the Caledonides in Finnmark, showing the extent of the Sværholthalvøya (S) and Nordkinnhalvøya (N) areas considered in this paper. The dashed line on Nordkinnhalvøya marks the division between western and central subareas (see text and Fig. 4). The boxed area B is the area discussed by Williams (1974). KAS – Komagfjord Antiformal Stack. SIP – Seiland Igneous Province. PD – Porsanger Dolomite.

sedimentary successions in the nappe complexes, has been shaken in recent years with the publication of a series of U-Pb zircon dates on adamellitic S-type granites, orthogneisses and migmatite leucosomes either entrained in thrust slivers or emplaced in formations in different parts of the Kalak Nappe Complex in Finnmark and Troms (Daly et al. 1991; Kirkland et al. 2005, 2006; Corfu et al. in press). Since some of these older granite ages (ranging from c. 980 to c. 602 Ma) have not hitherto been reported from the exposed autochthonous crystalline basement in Finnmark or Troms, and as some folding and thrusting as old as Sveconorwegian appears to have been involved in the Kalak Nappe Complex, it has been suggested that the entire Kalak magmatosedimentary package may have a Laurentian or even Amazonian ancestry and represent an exotic mobile belt sutured to Baltica(Kirkland & Daly 2004; Corfu et al. 2005, in press; Kirkland et al. 2006, 2007).

The purpose of this short contribution is to present palaeocurrent data collected over a number of years from metasandstones in different parts of less strongly deformed units in the Kalak Nappe Complex, on the peninsulas Sværholthalvøya and Nordkinnhalvøya (Fig. 1), covering an area of more than 2,000 km^2. Such palaeocurrent data have had a tendency to be regarded as of lesser significance during field examination of the metamorphic allochthon – or not even recorded at all by many geologists – although there are important exceptions (Williams 1974; Chapman 1980; Føyn et al. 1983). The new data, however, and their interpretation, clearly have a bearing on the recent models discussed in the papers cited above.

Geological setting

Details of the regional geology of the Finnmark Caledonides are given in several of the aforementioned papers; consequently, only the briefest of summaries is presented here, with emphasis of some of the features that are relevant to the topic of this contribution. In this regard, the 1:500,000 bedrock map of Finnmark county provides a useful overview of the regional geological picture (Siedlecka & Roberts 1996).

In northeastern Finnmark, autochthonous and parautochthonous sedimentary successions resting unconformably on Archaean crystalline complexes are present in the Varanger region (Vadsø and Tanafjorden groups)

and farther to the southwest along the Caledonian front (Dividal Group) (Banks et al. 1971; Føyn 1985; Siedlecka et al. 1995). These are succeeded by anchizone-grade, Upper Riphean to Lower Ordovician (Tremadoc) sedimentary rocks of the Gaissa Nappe Complex. Both the Parautochthon and the Gaissa Nappe Complex include two stages of Vendian, *Varangerian* tillite deposition (Reading & Walker 1966; Føyn et al. 1983; Edwards 1984), which have recently been suggested to correlate with the worldwide Marinoan and Gaskiers glaciations (Halverson et al. 2005). To the west and northwest, above the Gaissa allochthon, is the Laksefjord Nappe Complex (Fig. 1), consisting mostly of alluvial fan and fluvial to shallow-marine, greenschist-facies sedimentary rocks of inferred Neoproterozoic age in a middle and an upper nappe (Føyn et al. 1983). A lower nappe, named the Kunes Nappe (Rice 2001), comprises a basement complex of diverse gneissic adamellite, alkali granite, diorite, gabbro, greenstone and quartzite of unknown but inferred Svecokarelian age; although it is not inconceivable that the adamellites may be Neoproterozoic. The basement rocks are overlain by a thin unit of very low-grade dolostone, limestone and siltstone (Chapman 1980; Føyn et al. 1983; Rice 2001), with a basal unconformity recorded in one area.

The Kalak Nappe Complex overlies the Laksefjord Nappe Complex along a major thrust and covers large areas of northern and western Finnmark (Fig. 1). It has been subdivided into 13-14 thrust sheets, or nappes (Gayer et al. 1985, 1987; Ramsay et al. 1985), the highest of which (Sørøy-Seiland Nappe) includes the voluminous rift-related, Seiland Igneous Province (Robins 1996). There are no rocks along the mylonitic base of the Kalak which could possibly indicate that it may represent a major suture zone. Metamorphic grade varies from upper amphibolite facies in western areas (with kyanite and sillimanite common in schists) to upper greenschist facies, locally biotite grade, in the extreme northeast of Nordkinnhalvøya (Rice & Roberts 1988). In western areas, a dominant stratigraphy known informally as the 'Sørøy succession' (Ramsay 1971) was originally considered to be unbroken, but has recently been reinterpreted as consisting of at least three, disparate, successions or tectonic units (Kirkland et al. 2005, 2006; Slagstad et al. 2006). Only the basal lithostratigraphic formation of the lowest tectonic unit, comprising the thick, psammitic Klubben Formation, really concerns us here. In at least three areas, the psammites are documented to lie unconformably upon diverse Archaean to Mesoproterozoic gneissic rocks (e.g., Ramsay & Sturt 1977; Ramsay et al. 1979; Sturt & Austrheim 1985).

The Klubben Formation on Sørøya, where the rocks were first described (Roberts 1968), is dominated by feldspathic to quartzitic psammites with intervening semipelitic members. In SW Sørøya, pelitic migmatites form the lowest parts of the succession (Rice 1990). In central parts of Sørøya, cross-bedding (including much herring-bone type), channelling and ripple-marked bedding surfaces have been reported in the c. 2.3 km-thick, high-grade metasandstones (Roberts 1968), and such primary features can be seen in the same formation on the mainland to the east, on Porsangerhalvøya (Gayer 1971; Williams et al. 1976). To the east of Porsangerfjord, however, direct correlation of successions with those in western Finnmark is not possible; hence, the diverse lithostratigraphic units on Sværholthalvøya and Nordkinnhalvøya were purposely not correlated with the Klubben and overlying formations in formal map compilations or descriptions (e.g., Roberts & Andersen 1985; Roberts 1998). Even so, thick, metasandstone successions do occur on Sværholthalvøya in 6-7 thrust imbricates (Noake 1974; Roberts 1998), and can be traced northeastwards across Laksefjorden into the Bekkarfjorden area (Williams 1974) and Nordkinnhalvøya (Roberts & Andersen 1985; Siedlecka & Roberts 1996). The sedimentary structures reported are generally indicative of a fluvial flood plain milieu with rare transitions into shallow-marine, partly tidal-influenced environments.

The age of the Klubben Formation on Sørøya was thought to lie within the range 1.2 to 0.98 Ga (Aitcheson 1990; Daly et al. 1991; Kirkland et al. 2006), but has recently been narrowed down to the period 910 to c. 840 Ma based on detrital zircon U-Pb dating (Kirkland et al. 2007). On Sværholthalvøya, on the other hand, the metasandstones are considered to have been deposited in a separate basin between c. 1030 and 980 Ma (Kirkland et al. 2007) and are consequently unrelated to the Klubben Formation, thus supporting the notion of non-correlation of these two successions (Roberts 1998).

The metasandstones of Sværholt- and Nordkinnhalvøya

Bulk strains in the rocks of the Sværholt and Nordkinn peninsulas are generally lower than in equivalent units in western Finnmark, except near the basal thrust of the Kalak Nappe Complex. As a consequence, the pale-grey to beige metasandstone beds, generally from 20 cm to 1.5 m in thickness, carry abundant sedimentary structures, dominantly cross-bedding (Fig. 2), but also with some erosional channels (e.g., Roberts & Andersen 1985, fig. 7b). Basal parts of some beds may be gritty or gravelly, and small-pebble conglomerates (clasts up to 1.5 cm) have been recorded locally. A feature of a large number of beds, mostly on Nordkinnhalvøya but also recorded on Sværholt, is the enrichment of laminae and foreset strata in a variety of heavy minerals, including Ti-magnetite, titanite, rutile and zircon (Roberts & Andersen 1985, fig.11) (Fig. 3), producing a distinctive, black-and-white striping in the rock. Many tabular to weakly trough cross-bedded units also show penecontemporaneous deformation of the foresets (Fig. 2b, c), akin to that described by Williams (1974) from the Bekkarfjorden area. Such primary fold structures, which are uncommon

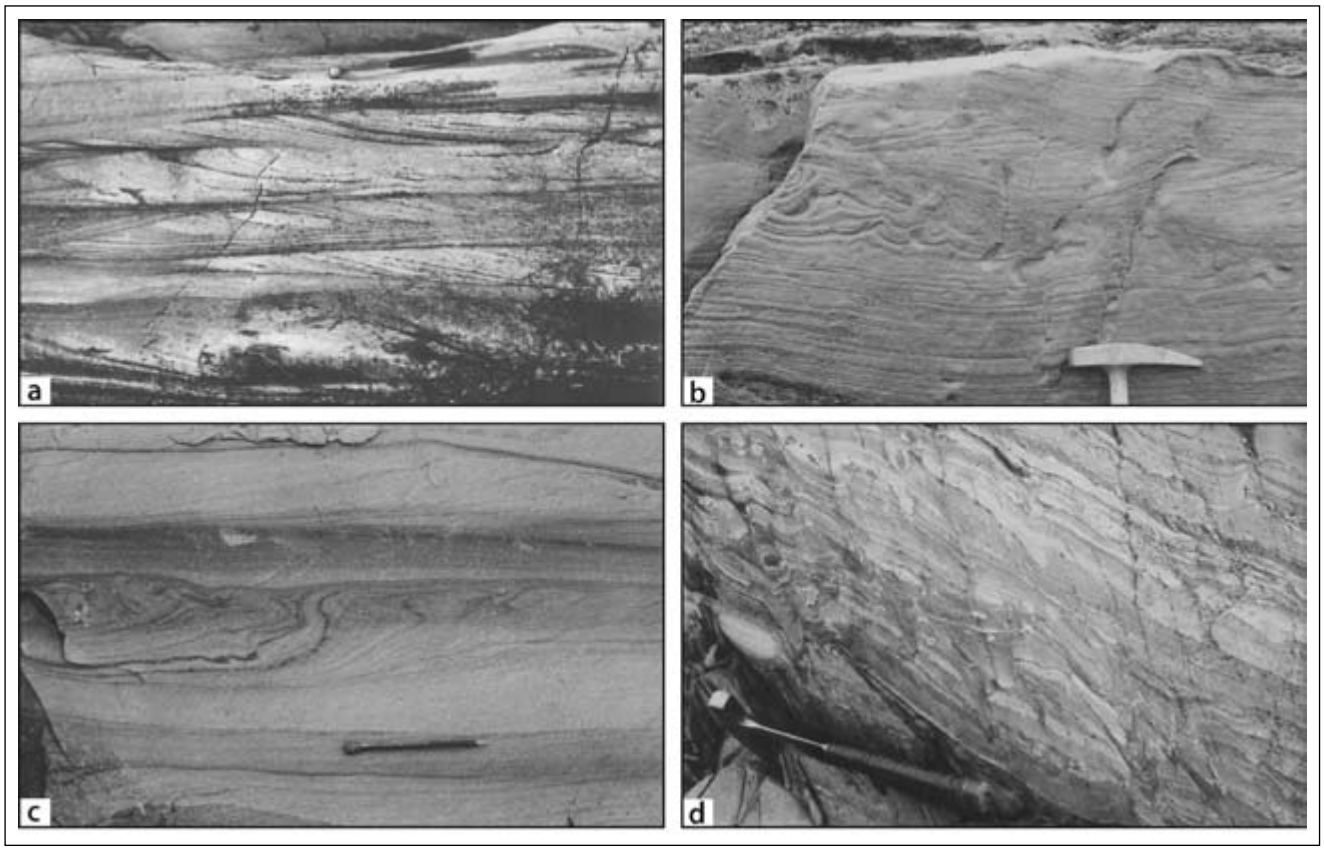

Fig. 2. Field photos of sedimentary structures. (a) Tabular cross-bedding in metasandstones, southeastern Sværholthalvøya, c. 2 km north of Masterneset; looking west-southwest. (b) Cross-bedded metasandstone showing penecontemporaneous deformation of the upper parts of foreset strata. Foresets in the overlying bed show no such deformation. North coast of Nordkinnhalvøya; looking c. east-northeast. (c) Cross-bedded metasandstone with penecontemporaneously deformed foresets truncated by the succeeding sandstone bed. North side of inner Kjøllefjorden, Nordkinnhalvøya; looking c. northeast. (d) Alternating metagreywacke, metasiltstone and phyllite showing diverse bottom structures, small-scale clastic dykelets, graded bedding, and synsedimentary disruption of a package of strata in the lower part of the photo. A steeply dipping crenulation cleavage with associated small folds also affects the multilayered lithology. Near Gamvik, north-central Nordkinnhalvøya; looking approximately north.

in the Klubben Formation of western Finnmark, are generally ascribed to tectonic activity, involving earthquakes, in the fault-prone source areas during sedimentation.

The other stratigraphic units in these two areas, i.e. Sværholt- and Nordkinnhalvøya, are: (1) alternating metasandstones and schists or (in the northeast) phyllites; (2) pelite-dominated members. On Sværholthalvøya, the pelitic units comprise mostly fine-grained schists, whereas phyllites are encountered in the lower-grade rocks on Nordkinnhalvøya where the general lithology is reminiscent of turbidites (Fig. 2d) with good examples of graded bedding, load casts, ball-and-pillow structures and chaotic slump units (Roberts & Andersen 1985, figs. 13, 14). In the western part of Nordkinnhalvøya, the lower to middle greenschist-facies succession includes

Fig. 3. Hand specimen of a metasandstone from c. 2 km east of Mehamn, Nordkinnhalvøya, showing dark grey to black foreset strata rich in titanomagnetite and other heavy minerals. Bar scale = 1 cm. Such heavy-mineral enrichment and prominent black-and-white striping is common in the sandstones of Nordkinnhalvøya and parts of Sværholthalvøya but has not been reported from the Klubben Formation on Sørøya.

two white quartzite units, each exceeding 150 m in thickness, and some of the pelitic members are developed as slates.

Palaeocurrent observations

As noted earlier, the palaeocurrent data were collected quite randomly during the course of regional geological mapping. Measurements were taken mostly where a reliable three-dimensional appreciation of the attitude of foresets could be gained, e.g., from two or more joint planes, or ideally where the foreset strata intersected bedding surfaces. Parting lineations on bedding surfaces, indicative of the trend of current flow, are also quite common. Although similar to mineral lineations, and can be misrepresented as such, their subtle changes of trend from bed to bed attest to a primary origin and river current sinuosity. The field measurements were later corrected for the dip of the bedding and for fold plunge on a stereographic net, before being plotted on rose diagrams. All directional data, given below, refer to present-day coordinates.

The palaeocurrent data are shown in Fig. 4 as three subsets. Based on the general geology and structure, Sværholthalvøya appeared to represent a coherent unit, or subarea (Fig. 4a). Nordkinnhalvøya, on the other hand, could readily be divided into a central subarea (Fig. 4c), where tiny garnets are common in pelites, and a fault-delimited western subarea (Fig. 3b) where metamorphic grade is slightly lower and the succession contains the two aforementioned, prominent quartzite members.

The data show interesting changes in moving from (north)east to (south)west. The central Nordkinn subarea shows a prominent palaeocurrent flow direction towards NW to NNW (320-340°) with just a minor vector directed NNE. In western Nordkinn, a more bimodal flow is apparent; the NNW direction (now 330-350°) dominates, but the NNE (010-020°) flow is slightly more accentuated as compared with the central subarea. In moving across to Sværholthalvøya (Fig. 4a), the predominant, recorded palaeocurrent flow has swung even more clockwise into a clear N-NNE (000-020°) direction, but the NNW azimuth can still be recognised albeit as a minor mode. All in all, the flow distributions in each of the subareas show a dominant mode and the directional variance is notably low, even across the package of thrust imbricates. The change in flow azimuth noted between Nordkinnhalvøya and Sværholthalvøya may relate partly to the fact that the dominant structural trend on Nordkinn is NNE-SSW; and on Sværholt it is NE-SW.

Discussion

From studies of cross-bedded sandstones worldwide it is well known that palaeocurrent flow patterns which are basically unimodal and at the same time generally show relatively low directional variance are characteristic of fluvial or deltaic depositional regimes (e.g., Selley 1976, Miall 1984). Furthermore, braided low-sinuosity streams commonly show lower directional variance than high-sinuosity and meandering streams (e.g., Miall 1996). In the present case, the pale-grey metasandstones of the lower thrust sheets of the Kalak Nappe Complex, with their gritty or granule-conglomeratic layers, are characteristic of a facies association that almost certainly originated in a fluvial regime with the rivers entering a coastal flood plain from an upland region in the south to southeast. In this context, it is interesting that the flow pattern, and by inference the palaeoslope, remains reasonably consistent, between NW and N-NNE, over such a wide geographic area and some 130 km of strike, in what are now tectonically telescoped thrust sheets where the pervasive stretching lineation is aligned approximately WNW-ESE (Townsend 1987; Rice 1998; Roberts 1998). Moreover, observations of herring-bone cross-bedding and ripple marks – which are generally indicative of a tidal marine influence with regular current reversals – in these particular metasandstones are comparatively few.

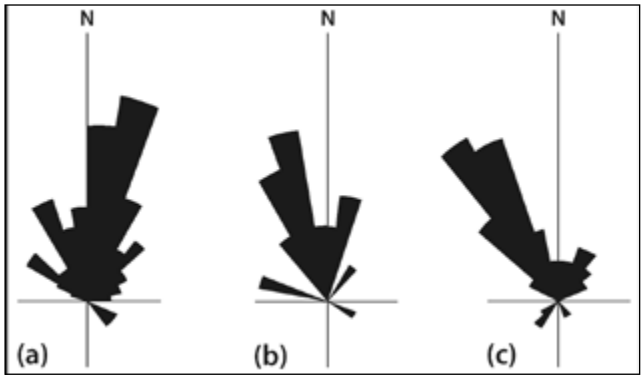

Fig. 4. Rose diagrams of palaeocurrents based on foreset azimuths in cross-bedded metasandstones. (a) Sværholthalvøya. n = 30. (b) Western Nordkinnhalvøya. n = 22. (c) Central Nordkinnhalvøya. n = 52.

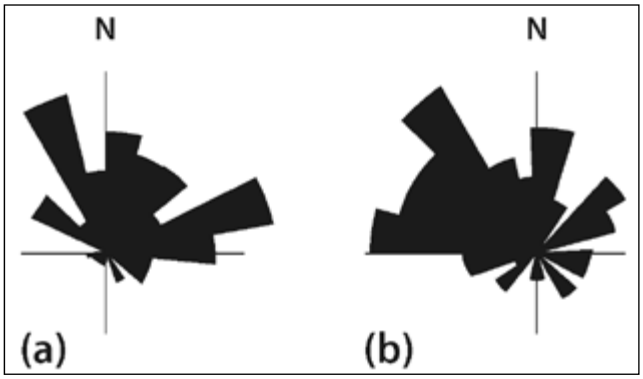

Fig. 5. Rose diagrams of palaeocurrents based on foreset azimuths in cross-bedded sandstones from: (a) The Bekkarfjord area of the Kalak Nappe Complex – B in Fig. 1. n = 60; from Williams (1974). (b) The Landersfjord Formation of the Laksefjord Nappe Complex. n = 69; from Chapman (1980).

The implications, therefore, are that the source of the sandy and, in part, gritty sediments in this lower part of the Kalak Nappe Complex lay in a rapidly degrading, highland region situated to the S-SE. This conclusion is in broad agreement with the study by Williams (1974) in the lower thrust sheets of the Kalak Nappe Complex farther to the northeast, to the east of Laksefjorden (Fig. 1), who reported palaeocurrent flows between NNW and NE (Fig. 5a).

The alternating metasandstone and pelite members, and the more pelitic units with darker grey, turbiditic sandstones – the latter notably in the northern parts of central Nordkinnhalvøya – also show broadly the same palaeocurrent flow as the thick-bedded feldspathic sandstones, even though they are of marine origin. On Nordkinnhalvøya, one can detect a very gradual thinning of the cross-bedded sandstones in the widespread, alternating sandstone-pelite unit from south to north until, ultimately, the unit is replaced by the facies association consisting of cleaved mudstones, shales and thin turbiditic greywackes. Palaeocurrent flow varies between NW and NNE even in the marine turbidite/pelite member; thus, both the outcrop-scale situation and the regional sedimentary facies changes on Nordkinnhalvøya are pointing to a palaeobasin deepening roughly towards the NW to NE quadrant.

In the middle and upper nappes of the subjacent Laksefjord Nappe Complex there is an 8 km-thick succession (Laksefjord Group), the lower two-thirds of which is composed of low-grade alluvial-fan to fluvial conglomerates and sandstones (Chapman 1980; Føyn et al. 1983), the latter (Landersfjord Formation; c. 2.6 km in thickness) reminiscent of the metasandstones on Sværholthalvøya. Palaeocurrent data from these Landersfjord Formation metasandstones (Fig. 5b) show similar directional modes to those reported here from the Kalak Nappe Complex, and have also been interpreted to indicate the former presence of a rapidly eroding highland area to the southeast with streams and rivers flowing to the northwest (Laird 1972; Chapman 1980; Føyn et al. 1983). Clasts in the conglomerates can be matched with many of the crystalline rock types in the basement complex of the Kunes Nappe, and pebbles of dolomite have also been reported. The highest parts of the lithostratigraphic succession of the Laksefjord Nappe Complex are shallow-marine siliciclastics with distal shelf pelites at the top. This facies development may be partly coeval with some of the continental sandstone deposition (Chapman 1980), which is again a similar situation to that seen in the Kalak Nappe Complex on Nordkinnhalvøya.

Although sediment dispersal patterns in the siliciclastic rocks of the Gaissa Nappe Complex, Parautochthon and autochthon are not directly relevant to this contribution, it would complete the general provenance picture to mention that sediment source areas lay predominantly in the SW-to-SE quadrant, within the crystalline rock complexes of the Fennoscandian Shield (Føyn 1937; Banks et al. 1971, 1974; Siedlecka & Siedlecki 1971; Gayer & Roberts 1973; Hobday 1974; Siedlecka et al. 1995a; Siedlecka & Lyubtsov 1997). The age of the oldest, fluvial and deltaic, autochthonous sedimentary rocks (the Vadsø Group: Banks et al. 1974) is poorly constrained, but within the earliest part of the Late Riphean; detrital illite ages of c. 930 Ma (Gorokhov et al. 2001) are inferred to provide a maximum age of sedimentation. Overlying shallow-marine successions of the Gaissa Nappe Complex are believed to have accumulated in a shallow basin (the 'Gaissa Basin' of Gayer & Rice 1989) that was bordered to the northwest by a prominent mountainous ridge of basement rocks exceeding 100 km in width (the 'Finnmark Ridge' of Gayer & Roberts 1973; now represented, in part, by the allochthonous Palaeoproterozoic basement of the Komagfjorden Antiformal Stack (Gayer et al. 1987; Townsend 1987). The youngest exposed formations of the Gaissa Nappe Complex, in the north and northwest, have provided evidence of low-energy currents flowing mainly towards E and SE (White 1969, Tucker, 1976, 1977, Williams 1976), i.e., away from this uplifted basement terrane and into the Gaissa Basin. Interestingly, the wide basement ridge bordering the Gaissa Basin would also have been the highland region that sourced the detritus of the Laksefjord Group on its steeper northwestern side.

In summary, the palaeocurrent data recorded from the fluvial metasandstones and shallow-marine deposits of the lower thrust sheets of the Kalak Nappe Complex across the wide area from eastern Porsangerfjorden (Sværholthalvøya) to Tanafjorden denote that the source region for the sediments lay to the S-SE in a highland tract of what has been assumed to have been the Fennoscandian Shield. This pattern is repeated in the subjacent Laksefjord Nappe Complex. A detritus source mainly to the 'south' is also registered in the Gaissa Nappe Complex and the autochthonous Vadsø Group that unconformably overlies the Archaean to Palaeoproterozoic crystalline basement, the only exception being in formations closest to the Finnmark Ridge. Given this common pattern of sediment dispersal, it would thus seem highly improbable that the several lower thrust sheets of the Kalak Nappe Complex could have had a Laurentian or Amazonian ancestry, with proposed correlations for example to the Moine Supergroup of the Scottish Highlands, as has been suggested in several of the earlier cited, recent papers and abstracts. Even so, while laying doubt on a Baltoscandian margin origin, Kirkland et al. (2006, p. 46) were shrewd enough to hedge their views by noting that this still "remains a possibility".

Palinspastic restoration of balanced cross-sections across the Caledonian nappes of Finnmark have demonstrated that the very highest thrust sheets of the Kalak Nappe Complex, and the Seiland Igneous Province, lay 300-400 kilometres to the (west)northwest of where they reside today (Gayer et al. 1987, Rice 1998). The age of the struc-

tures, Neoproterozoic or Palaeozoic, or both, is of lesser importance here. The restored original widths of the sedimentary apron of the combined Kalak and Laksefjord nappe complexes exceeded 420 km. Although fragments and slices of the basement to this extensive clastic wedge are contained in some of the thrust sheets, with ages ranging from Archaean to Mesoproterozoic, a vast area of crystalline basement of unknown character and age remains concealed beneath NW Finnmark and the continental shelf. However, based on integrated geophysical data analysis, the Fennoscandian Shield extends for a further 200 km to the northwest of Magerøya (Ritzmann & Faleide, in press) eventually passing, across a complex collisional suture zone, into basement of Laurentian affinity. Whether or not granites of the type and ages reported by Daly et al. (1991), Kirkland et al. (2006) and Corfu et al. (in press) are represented in this concealed Baltican basement remains to be seen, but most are S-type and were produced by anatectic melting within the sedimentary column. Only major deep-drilling operations can provide a reliable answer. Until recently, we were lacking detrital zircon data which may ultimately help to provide some clues. Judging from what we know of the Precambrian terranes now exposed in inner Finnmark southeast of the Caledonian front, and their NW to NNW extension beneath the thin-skinned nappes, detected by geophysical methods (e.g. Olesen et al. 1990), and incorporation of Svecokarelian, metabasaltic greenstone-dolomite complexes in several thrust sheets, we can expect to see a major detrital input from Palaeoproterozoic (Svecofennian, c. 1.8-1.7 Ga) to latest Mesoproterozoic/earliest Neoproterozoic sources. This now appears to be borne out by the work of Kirkland et al. (2007) who report three peaks for detrital zircons within the time-span c. 1680 to 1150 Ma for the metasandstones from Sværholthalvøya. These authors are also suggesting, as noted earlier, that the Klubben Formation metasandstones of the upper nappes and thrust sheets of the Kalak Nappe Complex developed in a separate basin to that of the Sværholthalvøya succession, a proposal which, if confirmed, would lend support to our reluctance to correlate lithologies in the lower (eastern) and upper (western) parts of this multi-imbricate nappe complex (Roberts & Andersen 1985; Roberts 1998).

The palaeocurrent data presented here clearly favour a likely Fennoscandian/Baltican source for sedimentary successions extending from the Vadsø Group autochthon up to at least the lowest 6-7 thrust sheets of the Kalak Nappe Complex in the succession on Sværholthalvøya. This, in no way, repudiates the possibility that higher thrust sheets in the Kalak Nappe Complex may be semi-exotic. It is conceivable, for example, that the thrust sheet and Klubben sandstones hosting the Seiland Igneous Province may have derived from a microcontinental block (cf. Gayer et al. 1987) in the environs of the Balto-Timanian triple junction (Siedlecka et al. 2004), where the Baltoscandian and Timanian margins of Baltica are inferred to have once met, thus allowing for a mixed, semi-exotic provenance. Moreover, the facies changes recorded in the Laksefjord Nappe Complex and lower tectonostratigraphic levels of the Kalak Nappe Complex denote the presence of a marine basinal regime located to the north, which is a situation reminiscent of the north-eastern (Timanian) passive margin of Baltica during latest Mesoproterozoic to Neoproterozoic time (Olovyanishnikov et al. 2000; Roberts & Siedlecka 1999, 2002; Siedlecka et al. 1995b, 2004).

Irrespective of the widely diverse interpretations of terrane affiliation reached by different geochronologists based on their own isotopic data, the palaeocurrent evidence needs to be considered and, ideally, in conjunction with other, ongoing and future, detrital zircon studies and more geochronology. The recent reinterpretations of Finnmark Caledonide geology have relied, in part, on negative evidence – in other words, what these authors (i.e., Kirkland & Daly 2004; Corfu et al. 2005, in press; Kirkland et al. 2006, 2007) have now discovered (new Neoproterozoic ages for anatectic granites and migmatites, etc., ranging from 980 to 602 Ma) is not what we see today in the *exposed* Fennoscandian basement. Consequently, in their view, Fennoscandia/Baltica therefore has to terminate abruptly somewhere here, and preferentially along an inferred suture zone at the base of the Kalak Nappe Complex. Such assumptions are indeed unwise, as shown by the geophysical evidence (Olesen et al. 1990; Ritzmann & Faleide in press). Taking the case of the nearby Timanides, for example, little of the true geological evolution of this orogenic belt would be known today had it not been for the wealth of geophysical data and especially the several dozen deep drillholes (c. 4.5 km maximum depth) that penetrated into the *concealed* parts of the orogen and its basement (Belyakova & Stepanenko 1991; Kostyuchenko 1994; Pease et al. 2004). Samples from drillcores and, in part, from coastal exposures have revealed U-Pb isotopic ages of granite, syenite and gabbro magmatism in the range 617-540 Ma (Gee et al. 2000; Larionov et al. 2004; Andreichev & Larionov 2007). Moreover, variable amounts of inherited zircon in some of the Timan granites are indicative of the presence of Meso- to Neoproterozoic source rocks in the northern part of the Fennoscandian Shield (Andreichev & Larionov 2007).

Taking into account the overall geological and geophysical features from this extensive onshore and offshore region, it is thus difficult to accept the interpretations of Kirkland et al. (2006, 2007) and Corfu et al. (in press) that the Kalak Nappe Complex and, in their view, also the entire Middle and lowermost Upper Allochthons (Kalak-Seve-Särv nappes) of the Scandinavian Caledonides (c. 1700 km in strike length) are likely to represent an exotic mobile belt or series of exotic terranes originating from a Laurentian or Amazonian source and welded onto the platformal Lower Allochthon of Baltica. This would imply that the original, sandstone-dominated, continental-rise prism and rift basins of the former Baltoscandian

passive margin of Baltica, outboard of the platform, have been removed in their entirety, presumably by a vast, strike-slip displacement, and coincidentally replaced by deposits from a foreign continental rise. The tracing of Palaeoproterozoic-Mesoproterozoic rock complexes and Late Mesoproterozoic dyke swarms from the Fennoscandian autochthon into the Middle Allochthon and Seve part of the Upper Allochthon has provided secure evidence of geological continuity as far as the outermost part of the Baltoscandian margin (Gee 1975, Gorbatschev et al. 1987, Andréasson et al. 1998; Greiling et al. 2007). Beyond that, we are dealing with the truly suspect terranes of the Iapetus Ocean realm (Köli Nappes of the Upper Allochthon) which, on faunal-provincial evidence, are largely Laurentian in origin with only some of the lowermost thrust sheets showing indications of linkages with Baltica (Stephens & Gee 1989).

Conclusions

Palaeocurrent data recorded from a >2000 km^2 area and 130 km strike-length of dominantly fluvial, cross-bedded metasandstones in the lower thrust sheets of the Kalak Nappe Complex on Sværholthalvøya and Nordkinnhalvøya, Finnmark, show essentially unimodal patterns with low directional variance. Current flow was directed fairly consistently towards the NW to NNE quadrant, indicating that a rapidly degrading highland region (Finnmark Ridge) lay to the S-SE. On Nordkinnhalvøya, facies changes can be detected along strike from south to north, with an association of marine turbiditic pelites and thin greywackes taking over in the far north. This pattern of N-NW palaeocurrent flow, with facies changes, is repeated in the underlying Laksefjord Nappe Complex.

In common with sediment dispersal patterns in the subjacent, fluvial to tidal shallow-marine Gaissa Nappe Complex, the parautochthon and autochthonous succession on Varangerhalvøya, the sediments of the Laksefjord Nappe Complex and lowest 6-7 thrust sheets of the Kalak Nappe Complex in the Sværholthalvøya and Nordkinnhalvøya region, are considered to be derived from crystalline basement terranes of the Fennoscandian Shield. Recent models requiring that the entire sandstone successions of the Kalak Nappe Complex, and indeed the entire Kalak/Seve/Särv allochthon of the Scandinavian Caledonides, were once completely exotic and originated on either the Laurentian or the Amazonian palaeoplate and have since been sutured onto Baltica need to be carefully reconsidered. This is not to deny that some of the high-lying thrust sheets of the KNC may be semi-exotic with, for example, a mixed Timanian-Baltoscandian provenance. The vast area of concealed basement beneath the nappes of NW Finnmark and the adjacent continental shelf clearly holds many important clues that, unfortunately, can be solved only by expensive deep-drilling programmes.

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