A discussion: Basement-cover relationships on northern Vanna, Troms, Norway

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The island of Vanna, Troms, has been divided into two parts, the Skipsfjord Nappe and a footwall unit which forms part of the Lofoten 'block'. The former unit was correlated with the Middle Allochthon and the latter with the Autochthon at the Caledonian front. However, palaeogeographic models, based on branch-line maps for the Lower Allochthon in Finnmark, indicate that the Middle Allochthon and autochthon are separated by ca. 300 km in this region. In view of the very strong lithological similarities between the Skipsfjord Nappe and its footwall, these correlations are rejected and it is suggested that both units form the westernmost part of the Lower Allochthon. This has considerable implications for the restoration of the whole Lofoten–Tysford basement block.

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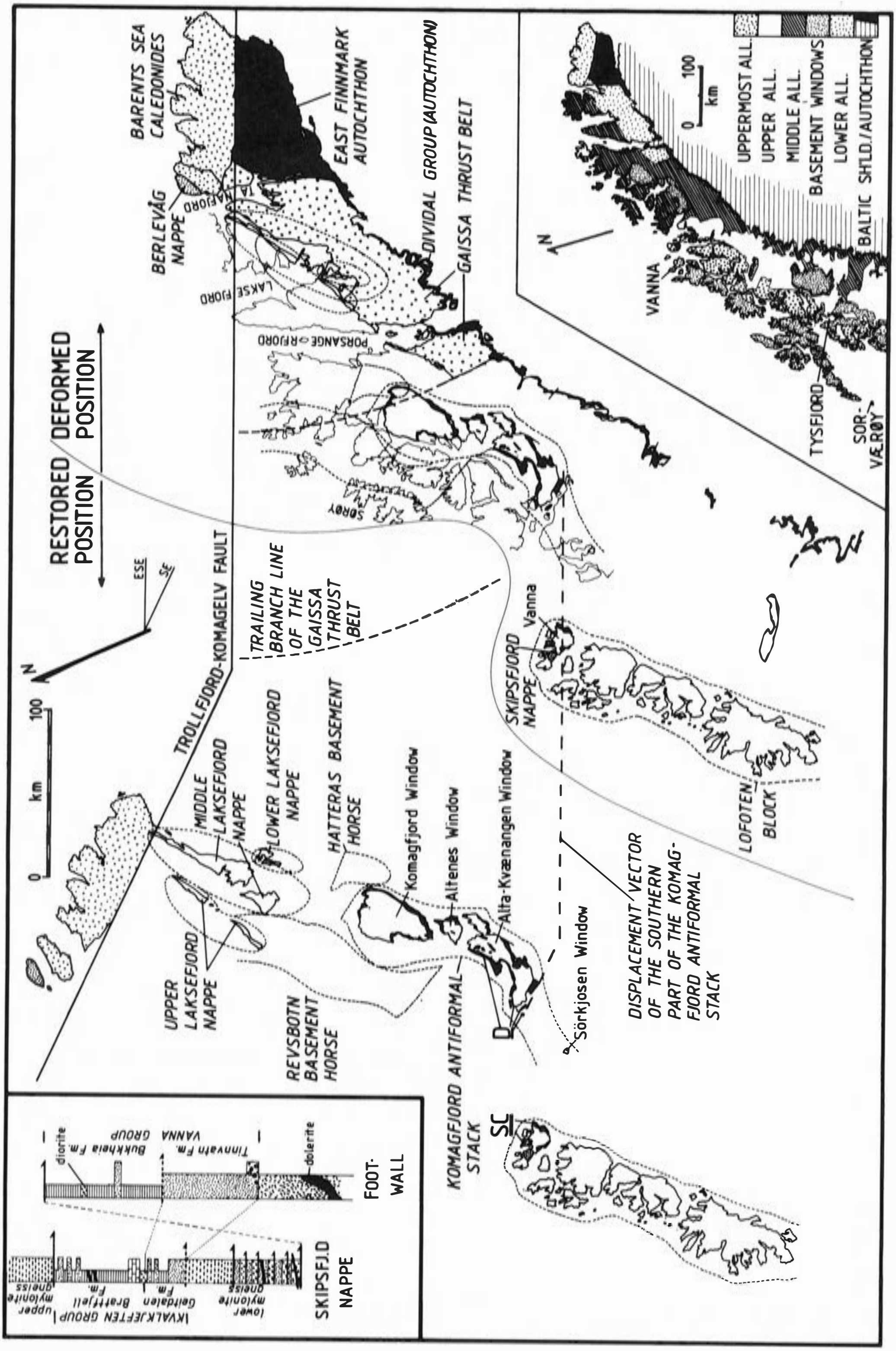
The Skipsfjord Nappe (Opheim & Andresen 1989), which lies in the central part of the island of Vanna, North Troms, consists of two tonalitic mylonite gneiss imbricates, the lower one divisible into a lower part of protomylonite–mylonite, including thin quartzitic metasedimentary bands, and an upper part of homogeneous mylonite gneiss. This is overlain by a thin, highly strained, cover sequence, the Kvalkjeften Group. Although no unconformity has been found, the contact at the base of the Kvalkjeften Group has been tentatively interpreted as a deformed unconformity. The Kvalkjeften Group (up to 100 m) was described in the text as having two formations. The Geitdalen Formation is comprised of a lower quartzofeldspathic unit, passing up to metasiltstones and mica-rich layers, typically with two medium-grained meta-arkoses in the uppermost part. The overlying Brattfjell Formation is described as having carbonate rocks at the base, passing up to metasiltstones with thin pelites, with occasional psammites in the upper part. (This description does not accord with the stratigraphic log illustrated (Fig. 6 of Opheim & Andresen 1989), in which the boundary between the two formations lies *above* ornamentation indicative of carbonate rocks, or with the description in the abstract.) Metabasic sheets, 0.5–5 mm (sic) thick, have been found in the lower basement unit; thicker sheets are present higher in the nappe. Metadiorites are present in the Kvalkjeften Group.

To the north these pervasively deformed rocks have been downthrown along a steep fault against relatively undeformed tonalites, locally containing abundant shear zones. These tonalites, which are the same as those in the footwall to the Skipsfjord Nappe, have been described as being autochthonous. Binns et al. (1981) described a thin stratigraphic sequence, the Vanna Group, unconformably overlying the southern exposures of the 'autochthonous' tonalites. The Vanna Group (up to 180 m thick) contains two formations, a lower Tinnvatn Formation (?deltaic/fluvial) comprising a thin and only locally developed basal conglomerate overlain by arkosic sandstones, and an upper Bukkheia Formation (?shallow marine) consisting of calcareous siltstones and sandstones passing up to somewhat finer grained siliciclastic lithologies. The basement rocks have been cut by basic dykes up to 10 m thick, whilst the Vanna Group is intruded by a gabbro-diorite complex lying subparallel to the bedding.

The metamorphic grade of the Skipsfjord Nappe appears to be upper greenschist/lower


RESTORED POSITION
DEFORMED POSITION
BARENTS SEA CALEDONIDES
BERLEVÅG NAPPE
EAST FINNMARK AUTOCHTHON
DIVIDAL GROUP (AUTOCHTHON)
GAISSA THRUST BELT
LAKSE FJORD
PORSANGE FJORD
SØRØY
TROLLFJORD-KOMAGELV FAULT
TRAILING BRANCH LINE OF THE GAISSA THRUST BELT
MIDDLE LAKSEFJORD NAPPE
LOWER LAKSEFJORD NAPPE
UPPER LAKSEFJORD NAPPE
HATTERAS BASEMENT HORSE
REVSBOTN BASEMENT HORSE
Komagfjord Window
Altenes Window
Alta-Kvænangen Window
Sörkjosen Window
KOMAGFJORD ANTIFORMAL STACK
SKIPSFJORD NAPPE
Vanna
LOFOTEN BLOCK
DISPLACEMENT VECTOR OF THE SOUTHERN PART OF THE KOMAGFJORD ANTIFORMAL STACK
SC
N
ESE
SE
0 km 100
VANNA
TYSFJORD
SØR-VÆRØY
UPPERMOST ALL.
UPPER ALL.
MIDDLE ALL.
BASEMENT WINDOWS
LOWER ALL.
BALTIC SH'LD./AUTOCHTHON
SKIPSFJ.D NAPPE
FOOT-WALL
KVALKJEFTEN GROUP
upper mylonite gneiss
Brattfjell Fm.
Geitdalen Fm.
lower mylonite gneiss
VANNA GROUP
Bukkheia Fm.
Tinnvatn Fm.
diorite
dolerite

amphibolite facies, with biotite porphyroblasts in the Kvalkjeften Group overgrowing the mylonitic foliation and garnets in metabasites similarly overgrowing the main fabric. In the Vanna Group a low to middle greenschist facies metamorphism developed, with green biotites forming a schistosity (Binns et al. 1981).

Comparison of the lithologies, including the basement rocks, the cover sequence and the intrusive rocks, clearly suggests that the rocks of the Skipsfjord Nappe and its footwall are very similar (Fig. 1, inset). There is a slight difference in metamorphic grade, with middle greenschist facies developed in the Vanna Group and upper greenschist to lower amphibolite facies in the Kvalkjeften Group. However, it should be remembered that metamorphic processes are closely linked to fluid composition and mobility, and the latter is much greater in high strain zones. In particular, garnet growth frequently occurs preferentially in high strain zones at the margins of sheared basic sheets (Rice 1986). Thus the lower grade observed in the Vanna Group *may* be more a reflection of a lower finite strain than of a significant variation in P–T conditions: other models incorporating a real increase in metamorphic grade are also possible and could involve an inverted metamorphic gradient developed as a result of the emplacement of an overlying hot slab. As implied, the major difference between the two sequences is in the deformation history, with high penetrative strains in the Skipsfjord Nappe and low strains in its footwall, although evidence of overthrusting towards the southwest has been found in both units.

Vanna forms the northernmost part of a large massif of basement lithologies stretching some 400 km southwards, to Sørværøy and the Tysfjord Culmination (Fig. 1). This is but one of a large number of areas of basement rocks exposed in tectonic windows within the Scandinavian Caledonides. These basement rocks have several features in common. First, they are frequently unconformably overlain by a thin cover sequence, the age of which is generally younger than the Varangian (early Vendian) glaciation, since tillites have been found at the base of some of the cover successions (Gee 1980; Siedlecka & Ilebekk 1982; Lindqvist 1983; Føyn 1985; Pharaoh 1985; Anderson 1989; Gayer & Greiling 1989). Interestingly, however, dolomitic rocks form part of the cover sequence to the basement rocks in the western part of the Alta–Kvaenangen Window (Fig. 1; Miles & Ritchie 1962; Gautier et al. 1987), approximately 80 km to the east of Vanna; these are probably of Sturtian age (cf. Gayer & Rice 1989). Second, the cover sequences on the basement rocks have been correlated with the sequences found in the autochthon and Lower Allochthon, rather than the Middle Allochthon (Gee 1980; Krill 1980; Thelander et al. 1980; Føyn 1985; Pharaoh 1985). Third, many of the basement rocks in the tectonic windows show evidence of considerable Caledonian tectonic deformation (Fareth 1979; Bowden 1981; Greiling 1982; Björklund 1987; Milnes et al. 1988; Sjöström & Talbot 1988; Vollmer 1988) and in many cases two distinct major basement units can be distinguished, with similar cover stratigraphies (Gee 1980; Krill 1980; Thelander et al. 1980). In many cases the basement rocks have an upper zone reworked in the Caledonian orogeny, underlain by structurally unreworked basement. Fourth, the metamorphic grade of the cover sediments overlying the basement rocks in these windows gradually increases to the west and is higher than that observed in the adjacent Lower Allochthon (Griffin et al. 1985; Lindqvist 1987; Anderson 1989; Rice et al. 1989a, b).

In these respects the basement/cover rocks on Vanna are no different to those described from elsewhere in the Scandinavian Caledonides; indeed, they are precisely what one might have predicted. Attempts to correlate the Skipsfjord Nappe with the rocks of the Kalak Nappe Complex (Middle Allochthon) to the northeast seem highly speculative, especially since it is known that the high metamorphic grade early deformation (D1–D2) in the Kalak Nappe Complex was a pre-Caledonian event (Daly et al. 1987, 1990). Further, the stratigraphy of the Kvalkjeften Group is not at all similar to that of the Kalak Nappe Complex (Ramsey 1971). A more reasonable and consistent pattern emerges if the stra-

Fig. 1. Palinspastic restoration of the Lower Allochthon (Barents Sea Caledonides, Komagfjord Antiformal Stack, Laksefjord Nappe Complex and Gaissa Thrust Belt) in the Finnmark Caledonides (from Gayer et al. 1987; Gayer & Rice 1989; Rice et al. 1989b). Superimposed is the suggested restoration of the rocks of Vanna and the Lofoten region. 'D' indicates dolomite and 'SC' indicates calcareous schists in the unconformable cover successions.

tigraphy is correlated with that in the autochthon at the Caledonian front and Lower Allochthon, although in this instance this does not seem to be particularly easy. (This is also a problem for the Lomvatn Formation in the northwest part of the Komagfjord Tectonic Window.) The higher strain in the Skipsfjord Nappe can be attributed to its greater proximity to the sole thrust of whichever major allochthon overlay this region; this argument could be extended to invoke an inverted metamorphic gradient in the rocks. In any event, the great similarity of the Skipsfjord Nappe and its footwall (inset Fig. 1) demand that they be considered part of essentially the same unit and restored to adjacent positions.

The tectonic status of the basement rocks exposed within the major tectonic windows has been a matter of discussion for some time; Gee et al. (1985) show the central parts of the 'composite' basement rocks within the tectonic windows to be autochthonous/parautochthonous and the upper imbricate part to be a component of the Lower Allochthon (as in the Nasafjell, Grong–Olden and Tömmerås Windows). In restored cross sections these units have tended to be restored to positions either underlying the Lower Allochthon or to the east of the Lower Allochthon, forming part of the thinned continental shelf sequence (cf. Fig. 4 of Dyrelius et al. 1980).

However, it has been known for some time that the basement rocks (Raipas Supergroup) in the Komagfjord, Altenes and Alta–Kvaenangen Windows in Finnmark (and perhaps also those in the Sørkjosen Window; Zwaan 1988), which together form the Komagfjord Antiformal Stack (Gayer et al. 1987) are fully allochthonous and form the westernmost part of the Lower Allochthon: the evidence for this model is based on structural, stratigraphic and metamorphic criteria (Chapman et al. 1981, 1985: Townsend et al. 1986; Gayer et al. 1987; Rice et al. 1989a). Restoration of the Komagfjord Antiformal Stack results in the most southerly parts of basement rocks in the Alta–Kvaenangen Window passing over the basement rocks in the Vanna region (Fig. 1).

In the model proposed here all the rocks of Vanna are regarded as being allochthonous and thus, by implication, so are all the basement rocks of the Lofoten–Tysfjord 'block'. This is supported by several observations. First, SE directed thrusting orientations are typical of the internal part of the Lower Allochthon in Finnmark, and ESE-directed directions of the later or more external deformation (Townsend 1987); thus the SE-directed deformation in the Skipsfjord Nappe would appear to be an early event. Second, ductile deformation is, in general, a feature of the internal parts of orogenic belts and brittle deformation a feature of the external parts. Deformation in the Komagfjord Antiformal Stack is on the border between ductile and brittle deformation, possibly with slightly more ductile deformation in the west (Bowden 1981). Thus the intense ductile strain in the Skipsfjord Nappe implies a more internal source than that for the eastern part of the Komagfjord Antiformal Stack. The lower strains in the Vanna Group and its basement substrate can be accounted for by arguing that they lay at a greater depth below the sole thrust of the over-riding slab. Third, in a single orogenic event, the metamorphic grade is higher in rocks which come from closer to the hinterland. The metamorphic grade of the cover sediments unconformably overlying the basement rocks in the eastern part of the Komagfjord Antiformal Stack varies between uppermost anchizone and epizone (Rice et al. 1989a), considerably lower than the middle greenschist to lower amphibolite facies recorded on Vanna. Finally, by placing the Vanna and Kvalkjeften Groups to the west of the Komagfjord Antiformal Stack a palaeogeography can be envisioned in which the calcareous/carbonate sediments in the two units on Vanna might represent detritus derived in part from the erosion of the Sturtian dolomites in the Burford area of the Komagfjord Antiformal Stack (Fig. 1).

In conclusion, therefore, comparison of the geology of the Skipsfjord Nappe and its footwall clearly suggests that they are two parts of the same, variably strained, basement-cover unit. Further, it seems more consistent with the regional geology, both in the deformed state and in palinspastic reconstructions, to consider both the Skipsfjord Nappe and its footwall on Vanna as part of the western margin of the Lower Allochthon rather than as part of either the Middle Allochthon or the autochthon.

Finally, the restoration in Fig. 1 clearly illustrates a large gap in the restored section in the Finnmark–Troms border area, between the autochthon and the basement rocks of the Lofoten–Tysfjord block, probably resulting from the erosion of the Lower Allochthon. This demonstrates the enormously greater value of branch-line restorations over single cross-section line restorations.

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