Tectonic structural features of the Fauske conglomerates in the Løvgavlen quarry, Nordland, Norwegian Caledonides, and regional implications

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A quarry excavated in a multilayered, carbonate conglomerate formation of apparent Cambrian age in the Fauske Nappe of the Uppermost Allochthon, Nordland, provides evidence for three principal phases of Caledonian deformation. The 60 m-thick Fauske conglomerates are characterised by a rapid, vertical facies change from carbonate debris and carbonate breccia to rhythmite conglomerate-breccia and graded calcareous greywacke. The carbonate clasts were deposited from southeast-directed turbidity currents on the palaeoslope of a basin that deepened to the southeast. Both the basin physiography and the palaeocurrent directions are opposite with respect to features to be expected along the former Baltoscandian margin of Baltica.

The earliest tectonic structures are NW-directed, ramp-and-flat thrust faults and fault-bend folds, that progressed in to a higher-strain regime involving clast flattening and elongation, and the development of an amphibolite-facies schistosity, S1. The early staircase thrusts and folds therefore record a tectonic reversal of the basinal regime, as well as documenting an opposite structural vergence with respect to thrust-sheet assembly during Scandian orogenesis. The early structures are overprinted by SE-verging folds and small-scale thrusts, and a penetrative, NW-dipping, S2 cleavage. Later minor structures are mainly extensional.

The combined palaeodepositional and early structural picture is highly reminiscent of the geological development that has been recorded along the Laurentian margin of the Iapetus Ocean in Cambro-Ordovician time, involving an extensive carbonate shelf and adjacent slope-and-rise. We postulate that the Fauske conglomerates originated along that former passive margin. The staircase thrusting and early folds, and earliest metamorphic fabric, S1, are likely to be Taconian (Mid to Late Ordovician). The Fauske Nappe itself, on the other hand, is a part of the SE-translated Caledonian allochthon, generated during the Scandian orogeny (Late Silurian-Early Devonian) as a result of Baltica-Laurentia continent-continent collision. The second-generation, SE-verging folds and minor thrusts, and associated NW-dipping cleavage (S2), are almost certainly of Scandian age. Later, extensional structures at Fauske are probably a reflection of the WSW-directed, Early to Mid Devonian shear regime recorded widely in this part of the Norwegian Caledonides.

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Introduction

Some of the highest nappe complexes and thrust sheets in the tectonostratigraphy of the Scandinavian Caledonides are extensively exposed in the county of Nordland, in north-central Norway (Nicholson & Rutland 1969, Stephens et al. 1985). Rock types within these nappes are extremely varied but a prominent component, in the Uppermost Allochthon and some of the Køli nappes of the Upper Allochthon, is that of metamorphosed carbonate rocks and polymict to monomict, carbonate-silicate conglomerates. Until recently, little research work had been done on such carbonate formations and their carbonate-clast conglomeratic derivatives. At the Geological Survey of Norway (NGU), an ongoing project is dealing specifically with the detailed mapping, depositional environments, metamorphism and age of selected carbonate formations in Nordland and neighbouring Troms county, aimed at determining the commercial potential of these and other carbonate rocks and carbonate conglomerates in this part of the Caledonide allochthon.

The first unit to be described in some detail, within the NGU project, was the Fauske conglomerate (Melezhik et al. 2000; see also Heldal et al. 1999 for a condensed version, in Norwegian). This is essentially a monomict carbonate conglomerate, where both the clasts and the matrix are composed of carbonate material. The lithology is well known in Norway and abroad as an attractive, colourful, dimension stone, and has been exploited at the Løvgavlen quarry near Fauske (Figure 1) since 1870. Several lithological varieties are present, and quarried, each with its own commercial name. The diverse lithofacies have been described, bed by bed, in Melezhik et al. (2000). That publication dealt specifically with the sedimentology, depositional environment, isotopic geochemistry and age, deriving a depositional model that can be employed in estimation of reserves and as a prospecting philosophy for deposits of similar quality.
In the present contribution we report on the main features of the polyphase, Caledonian, tectonic deformation of the Fauske conglomerate, including some strain data on clasts of differing viscosity, based on its exposure in the Løvgavlen quarry and immediate vicinity. The combined basin depositional scenario and structural history are then discussed in the context of regional geological and inter-plate palaeogeographical development. At the outset, we note that the name Fauske conglomerate (FC) is an informal designation; and its lithofacial, bed-to-bed variation is such that we will, from time to time, use the plural form – Fauske conglomerates (FCs).

Geological setting

In earlier literature dealing with the geology of this district, the principal, thick, carbonate unit was called the Fauske limestone (Vogt 1927, Strand 1972) or the Fauske marbles (Rutland & Nicholson 1965), encompassing both dolomite marble and an overlying calcite marble. Subsequent detailed mapping and map compilation resulted in the two carbonate formations being united under the term Rognan Group (Gustavson 1996). In a more regional context, Nicholson (1974) had earlier introduced the term Fauske Nappe for all the medium-grade, carbonate-rich successions lying structurally above the high-grade Gasak Nappe and below rocks of the Rödingsfjället Nappe Complex (Figure 1). Within the Fauske Nappe, Gustavson (1996) established a lithostratigraphy consisting of 4 separate groups; in ascending order, the Pålsfjell, Rognan, Kjerktind and Øynes Groups. The first three groups each contain marble formations, with the Rognan Group comprising just two unnamed formations – the dolomite marble and calcite marble, mentioned above. The Fauske conglomerate of the present study constitutes a c. 60 m-thick lenticular unit, or member, within the upper, calcite marble formation of the Rognan Group. A feature of this calcite marble is the local presence of a particular, pink to maroon, colour-banded, carbonate lithofacies known as the 'Leivset-type' marble.

To the northwest of the Løvgavlen quarry, the carbonate rocks of the Rognan Group are succeeded by some of the formations of the Kjerktind Group, but to the southwest, and on the Øynes peninsula west of Fauske, the Kjerktind rocks are successively cut out and the polymict conglomerates of the Øynes Group lie unconformably upon the Rognan carbonate lithologies.

In establishing a modern tectonostratigraphy for the Scandinavian Caledonides, Gee et al. (1985), Roberts & Gee (1985) and Gustavson et al. (1987) placed the Fauske Nappe in the Uppermost Allochthon, an interpretation favoured by the present authors. Some map compilers, however, have put the Fauske Nappe in the highest part of the Upper Allochthon (Gjelle 1988, Gustavson 1996), an assignment which is now rejected (S.Gjelle, pers. comm. 2000). Various other lithological correlations have been suggested in the literature (cf. Melezhik et al. 2000, p.149), but these are hampered by the fact that no fossils have been found in the marbles of the Rognan Group. Our only evidence bearing on the age of the Rognan carbonate formations is provided by

Fig. 1. Simplified geological map of the Fauske area, showing the location of the quarry at Løvgavlen (L). FC – Fauske conglomerate; RW – Rishaugfjell Window.
Clast and matrix composition of the Fauske conglomerates

- Pink and white calcite and dolomite marble in quartz-chlorite-calcite matrix
- Predominantly "blue" calcite marble in calcite matrix
- Predominantly white dolomite marble in calcite matrix
- Pink and white dolomite and calcite marble in calcite matrix

Local "basement"
- Dolomite marble
- Strike & dip of bedding
- Thrust faults

Fig. 2. Geological map of the Løvgavlen quarry, showing the traces of the main thrust faults. The four main prospecting channels are indicated (Ch.1-4). This shows the quarry topography as it was in 1999. Contour interval - 1 metre.

here, and in Melezhik et al. (2000), are based on natural outcrops and quarry faces exposed during the years 1997-1999.

Lithologies and lithofacies

In the quarry, only the lower contact of the FC is exposed, against the subjacent dolomite marble. Twenty-five beds with thicknesses of 5 cm to 3 m have been recorded and described in the FC, which is characterised by rapid, vertical and lateral, facies changes (Melezhik et al. 2000). The unit comprises carbonate debris, carbonate breccia, rhythmite breccia and rhythmic, graded, calcareous greywacke. Large blocks, boulders, cobbles, pebbles and smaller clasts are composed mainly of white dolomite marble and colour varieties of calcite marble; white, pink, beige and dark grey ('blue'). A few small clasts of quartzite and vein quartz are present in one particular bed. Clasts derived from a local source (white dolomite and 'blue' calcite marble) are characterised by angular, subangular and platy shapes in cross section, whereas the clasts incorporated from unidentifiable sources (pink, beige and white calcite marbles) are moderately rounded. Platy fragments commonly exhibit a form of 'imbrication', though with the clasts dipping in the opposite sense to that expected from the dominant paleocurrent flow direction; thus suggesting a tectonic rather than sedimentary origin for the apparent imbrication. The matrix to the FCs shows a similar range in lithology, con-

the isotope geochemical study, by Melezhik et al. (2000), of marble clasts and calcite matrix in the intraformational Fauske conglomerate and its immediate dolomite marble substrate. This showed that the least altered ⁸⁷ Sr/⁸⁶ Sr isotopic value plotted on the Sr-isotope, worldwide reference curve is consistent with any one of three groups of apparent depositional ages ranging from 520 to 470 Ma, whereas the least altered ⁸¹³C_carb value intersects only at 520 Ma; i.e., indicating a probable late Early Cambrian (Landing et al. 1998) age of deposition for these carbonates.

The Løvgavlen quarry

General features

In the immediate vicinity of the Løvgavlen quarry, exposure is poor (Gustavson et al. 1995). In the quarry itself, which covers an area of c. 500 m x 200 m, quarrying and production strategy has involved the incision of four, 4-6 m-deep, prospecting channels (Figure 2) with near-vertical, smooth walls, which provide excellent sections through the lithostratigraphy and lithofacies of the conglomerate unit. There are also long, near-vertical, quarry walls cut almost at right-angles to these channels. The descriptions and photographs presented
Fig. 4. The nature of clast stretching, relating to $D_1$ deformation, as seen on a quarry wall between channels 1 and 2, Løvgavlen; looking c. NNW. The surface is within $15^\circ$ of the true clast elongation trend, and is thus close to the XZ plane of the $D_1$ strain ellipsoid. The white clasts are of dolomite marble; the remainder are diverse colour varieties of calcite marble. For scale, the large, grey marble clast, bottom left and centre, is 6-7 cm thick.

sisting of variable amounts of quartz, muscovite, calcite, sericite, fuchsite and chlorite. A normal grading of clasts can be recognised in many beds, and the calcareous greywacke layers show both cross-bedding and channelling indicating a normal way-up and with palaeocurrents directed approximately towards the southeast. The depositional model involves a tectonically unstable, carbonate shelf margin traversed by a submarine channel, with the marine basin deepening to the present-day southeast. Full details of the lithofacies and the depositional model can be found in Melezhik et al. (2000).

Structural geology

General features

In this part of the region, the many formations within the Fauske Nappe generally show intermediate to steep dips to the northwest, by virtue of their location on the western flank of an antiformal tectonic window of basement granitic gneisses; the Rishaugfjell window of Nicholson & Rutland (1969) (Figure 1). Local upright folds with steeply NW-dipping axial surfaces interrupt this pattern, and at Løvgavlen the FCs are situated in the SE-dipping short limb of one such fold. In the area of the quarry, the lower parts of the FC unit close to the subjacent dolomite marble dip at 20-30$^\circ$ to the SSE, whereas dips increase to 35-45$^\circ$, and are directed more to the SE, in the highest exposed beds. While the metamorphic grade of carbonate rocks is notoriously difficult to judge, mica schists in adjacent groups and formations in this same nappe contain garnet and, in places, staurolite, indicating that PT conditions attained those of amphibolite facies.

Structural sequence

Inspection of the artificial channel walls in the quarry, and especially those oriented approximately normal to the general NE-SW strike of bedding, provides a fairly clear indication of the sequence of tectonic events following the deposition of the FCs. In addition, in parts of the quarry there are quartz veins and a few mafic dykes that cut across pre-existing structures but were themselves deformed to a minor degree during later components of movement. A prominent feature is that the conglomerate clasts show evidence of variable reaction to tectonic deformation, dependent on lithological composition. White dolomite marble clasts, in particular, are commonly aligned at a moderate to low angle to bedding, dipping northwest; an alignment which appears to derive from a mechanical rotation of these comparatively rigid clast types in a yielding matrix. Calcite marble clasts, on the other hand, have responded to this same component of externally imposed deformation by small-scale folding, rather than rotation. Although some clasts, particularly those of white dolomite and 'blue' calcite marble, were originally platy, it is apparent that all clasts, whatever their lithology, were strongly deformed and elongated during a tectonic event that predated the rotational and/or small-scale folding event noted above. In addition to this ubiquitous clast deformation, the quarry faces provide text-book examples of ramp-and-flat thrusting with a movement sense which is opposed to that generally found elsewhere in the allochthon of the Scandinavian Caledonides.

Fig. 5. Deformation plot showing finite strains measured from deformed clasts of calcite marble and dolostone, Løvgavlen quarry. The tie lines link measured dolostone (circles) and calcite marble (squares) clasts from two separate localities within the quarry ($n = 20$ for each clast group). The dots represent five dolostone clasts extracted from a quarried block in Channel 1. The cross marks the mean value of these clasts.
Early deformation episode

Structures that can be ascribed to the earliest recognizable tectonic deformation (D1) in these metasedimentary rocks are of two disparate, though not entirely unrelated types: (1) meso-scale, ramp-and-flat type thrusts with associated, thrust-related, fault-bend folds; and (2) strongly deformed (flattened and stretched) calcite and dolomite marble clasts. Taking the clast deformation first, it is evident that the small-scale folding and clast rotation noted above had affected an already fairly highly strained conglomerate. All the clasts, even the originally platy clasts of white dolomite and 'blue' calcite marble, show features of extreme flattening though with partly prolate shapes, ascribed to an early phase of deformation. The pebbles and cobbles are clearly tectonically stretched, and in the quarry this prominent, clast elongation lineation plunges at a few degrees to the southwest (Figures 3 and 4). On quarry walls normal to this lineation, the flattened clasts dip at c. 4° to 10° steeper than bedding, and also to the southeast, which accords with the principal metamorphic, schistose fabric (S1) in the groundmass and in calcarenite and silty greywacke interbeds. This relationship, of S1 steeper than bedding (S0), also accords with the fact that the beds are younging normally.

In an attempt to quantify the approximate finite strain state of the rock, measurements were made of clasts of white dolomite marble and pink to white calcite marble at separate sites in two of the quarried channels (channels 1 and 2). Clasts were measured in the same horizon in two dimensions on two near-vertical, sawn, quarry walls orientated more or less at right angles to each other. These faces are within 15° of the clast-stretching trend, and the normal to that trend, respectively.

In terms of the three principal axes of the deformation ellipsoid, where \( X > Y > Z \), one quarry face is close to the XZ plane while the other approximates to YZ. The data are presented in a logarithmic deformation plot (Figure 5), and show clear differences in the finite strains of the dolomite and calcite marble clasts. Whereas the mean deformation ellipsoids of the dolomite marble clasts in both channels are similar at c. 1.95: 1: 0.30, the ellipsoids for the calcite marble clasts range from 1.65: 1: 0.22 to 2.19: 1: 0.19. The average dimensional shortening across \( S_1 \) (parallel to \( Z \)) ranges from 65 to 75% and stretching in the direction of greatest finite elongation varies from 125% to almost 200%. Extension has also occurred along the intermediate axis, \( Y \), by some 40%, indicating that the overall deformational mode involved a significant component of flattening.

An attempt to extract clasts from blocks, for individual measurement, proved too difficult because of the extent of recrystallisation. However, just five dolomite marble clasts recovered from quarried blocks in channel 1 were measured; and their mean ellipsoid value (3.24: 1: 0.38) is close to that of a plane strain deformation mode (Figure 5). It is important here to note that had the quarry wall been perfectly parallel to the clast elongation trend, then the resulting increased \( X:Z \) ratios would have brought the other mean values closer to the median, plane strain line, in the field of S/L rather than S> L tectonites. Nevertheless, the deformed clasts of calcite marble are clearly far more oblate than those of the dolomite marbles. This is a relationship which conforms with that of reported strain studies, in particular of tie-lines between clasts of different viscosities at one and the same conglomerate locality, and of the predicted displacement vectors (Freeman & Lisle 1987); i.e., for a given strain, the K-value for the clast shape should increase in accor-

Fig. 6. (A) Thrust fault cutting up through the multilayered Fauske conglomerate; Channel 3, Løvgavlen quarry, August 1997, looking in a direction between NE and ENE. The displacement along the thrust surface is 7.6 metres. A fault-bend fold has developed in the hangingwall along the flat, forward of the ramp, the latter cut by a thin mafic dyke. Note that a small normal fault has developed just beneath the toe of the fold. The dark layers within the conglomerates are calcareous greywackes. (B) Small thrust fault (bottom right to top left) showing two separate ramps and one short flat (centre of photo), offsetting along the fault by c. 2.3 m, in multilayered carbonate conglomerate and darker calcareous greywackes; Channel 3, southeasternmost thrust fault (cf. Figure 7), looking ENE. Scale -- the mafic dyke to the left is 8 cm thick.
dance with the viscosity contrast. Here, it should be noted that there are several unknown factors involved in any quantitative appraisal of finite strain in conglomerates, namely, initial clast shape, possible volume change during deformation, viscosity contrast between clast and matrix, clast/matrix volume percentages, and the extent of early compaction. In the case of the FCs, one of the most important and fundamental conditions in assessing the state of strain, namely that there should be no ductility contrast between clasts and matrix, appears to be met, at least for the calcite marble clasts in the calcite marble matrix. Thus, the data presented, although sparse, and the evident differences in strain between clast lithological types, do provide a useful indication of the deformation mode and finite strain state of the FCs.

An important feature, and one most clearly seen along channel 3, is the presence of thrust faults (Figure 6). These take the form of ramp-and-flat fault structures, i.e., faults that climb up through the multilayers from a bedding-parallel ‘flat’ via an inclined ‘ramp’ to a new ‘flat’, and thus define a staircase trajectory. In three cases, prominent anticlinal, fault-bend folds have developed in the hangingwall of such thrust faults (Figure 6a); and in two cases there are transected synclines preserved in the footwalls of ramps. The folds ($F_1$) have c. NE-SW axial trends and face NW, and the fault ramps dip at c. 35-50° towards SE. One of the hangingwall anticlines has developed further into a tight overturned structure where the beds in the inverted limb are strongly attenuated and dragged into the fault surface (Figure 7). In this particular case, it is clear that the clast flattening ($XY$ plane) and matrix schistosity are broadly axial planar to the fold. The overall impression, therefore, is that the deformation mode has evolved gradually, with increasing strain and ductility, from the inaugural thrust detachments along flats and ramps with coeval birth of folds, into a higher grade domain involving initial clast deformation and the generation of a pervasive $S_1$ schistosity.

Because of the limited exposure, the true extent of this staircase thrusting is impossible to judge. Within channel 3 (53 m in length in August 1999), four separate thrust faults were recorded (Figure 8), two of which had thrust displacements toward NW of 4.3 m and 7.6 m. Although an array of stacked thrusts is almost certainly involved, there are no thrust surfaces yet exposed which would qualify as definite floor or roof thrusts – which would otherwise help to define the definite presence of a duplex. At the stage of quarrying in 1999, two of the thrusts at the southeast end of channel 3 merged at the surface, to the ‘east’ of the channel, at a branch point, in the manner of a rejoining splay. Future quarrying activity may help to shed further light on the precise geometry involved in this imbricate thrust system.

Summing up, the early deformation in the FC involved NW-directed, ramp-and-flat thrusting, fault-bend folding, and the progressive flattening and NE-SW stretching of clasts during the generation of the pervasive metamorphic fabric. Although the staircase faulting was evidently the earliest manifestation of the deformation, in response to an imposed, NW-directed compressive stress, this is believed to have given way progressively, with increasing strain, to a more ductile, higher PT regime involving clast flattening and stretching, such that we prefer to view this ‘early’ deformation as one gradually evolving process rather than separate, unrelated events. The increasing strain may largely relate to the stacking, and thus loading and compactional effect, of higher thrust slices during this particular orogenic event.

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**Fig. 7.** Small thrust fault in conglomerate beds and intercalated calcareous greywackes; looking NE. The thrust displacement here is 1.9 m. The prominent alignment of clasts from top right to bottom left corresponds to the $S_2$ fabric.

**Fig. 8.** Sketch of the northeast wall of Channel 3, August 1999, drawn to scale, showing the four principal thrust faults. The fault-bend fold visible at 20-25 metres from the left is that shown in Figure 6a.
Ted into subparallelism with $S_2$, the more ductile calcite marble clasts are commonly buckled, with the axial surfaces of these small folds parallel to $S_2$ (Figure 10). Larger mesoscopic ($F_2$) folds relating to this $S_2$-forming event, and verging SE, are uncommon in the quarry area, but are more prominent elsewhere in the region (Nicholson & Rutland 1969) where they are also seen to deform nappe boundaries. Careful inspection of the actual surfaces of the earlier, NW-facing thrusts reveals local examples of very small-scale folding (Figure 11), with $S_2$ cutting cleanly across both hangingwall and footwall. In other parts of the quarry, two cases of SE-directed reverse-faulting were recorded; one along the short limb of a small $F_2$ fold (Figure 12) and the other parallel to $S_2$.

Recognition of structures postdating $F_2/S_2$ is facilitated by the local presence of useful markers such as mafic dykes and quartz veins. The dykes, up to 15 cm in thickness, intruded after the early phase of thrust-related deformation (Figure 6). They dip to the NW and generally 10-15° steeper than $S_2$, but they also carry the $S_2$ fabric. Since the dykes are aligned close to the XY plane of the theoretical $F_2$ strain ellipsoid, they have deformed largely by shear along $S_2$; accordingly, no folded dykes would be expected in this particular strain regime and none has been recorded. The quartz veins are commonly only a few millimetres thick and they also dip NW, subparallel to $S_2$. In a few cases, dykes are cut by small, bedding-parallel, extensional faults, with offsets of just a few centimetres. Such late extensional structures would have been difficult to detect without the help of the mafic dykes, although there are also a few cases of extensional displacements of conglomerate clasts, again parallel to bedding surfaces. Quartz veins and veinlets are particularly common in the vicinity of channel 3 and in many cases show extensional displacements along the vein-filled fracture, i.e., downstepping by 2-3 cm to the NW. A few veins, however, show reverse (top SE) offsets. By and large, though, these later components of movement are

![Fig. 9. Conglomerobreccia beds with interlayered calcarenite showing the (re-)orientation of white dolostone clasts parallel to and defining the $S_2$ cleavage. Photograph taken of part of the northeast face of Channel 1. Bar scale = 15 cm.](image)

![Fig. 10. Fauske conglomerate in Channel 4, Løvgavlen quarry, showing the small-scale buckle folding of the calcite marble clasts. The whiter and generally smaller, more competent dolostone clasts, on the other hand, tend to have been reorientated within the prominent $S_2$ fabric. (A) Looking NE (B) looking SW.](image)
extensional. Outside of the carbonate formations in this same district, we have recorded late, extensional shear bands in NW-dipping schist units and banked quartzite lithologies, with a general top-WSW sense of shear. Farther south, on the western flanks of the Nasafjallet basement window, late-Scandian, WSW- to NW-directed, extensional structures have been reported (Albrecht 2000, Essex & Gromet 2000, Osmundsen et al. 2000, and in prep.); and >100 km farther northeast, top-W extensional displacements characterise the western margin of the Rombak window (Rykkelid & Andresen 1994).

Discussion

The sequence of structural events recorded in the multilayered FCs commenced with a distinctive early episode of NW-directed, ramp-and-flat thrusting and coeval fault-bend folding that, in its later prograde stages, involved transition into a more ductile, higher strain domain where carbonate clasts were both flattened and elongated. It is essential, at this point, that this deformation cycle be viewed in conjunction with the depositional model for the carbonates of the Rognan Group. As noted, this involved a tectonically unstable carbonate bank or shelf margin, submarine slide deposits and debris flows on the palaeoslope of a basin that deepened to the present-day southeast (Melezhik et al. 2000). This direction is opposite to that expected, and indeed recorded, from basins fringing Baltica. The NW staircase thrusting thus represents a form of tectonic reversal of the basinal regime, and a tectonic scenario that is characteristic of the external zones of passive margins of many orogens, not least the Caledonian-Appalachian belt.

The orogen-scale implications of these depositional and early structural developments in the FCs are thus, in our view, quite significant. We note here, briefly, that the situation described above is most reminiscent of the extensive carbonate bank accumulations in Cambrian to Early Ordovician time along the Laurentian margin of the Iapetus Ocean from the Appalachians to central East Greenland (Rodgers 1968, Swett, 1969, Swett & Smit 1972, Schwab 1974). There, in some areas, bank-edge breccias and proximal basin-slope, carbonate conglomerates have been reported (Rodgers & Neale 1963, James & Stevens 1986, Schwab et al. 1988), and many of them, for example in western Newfoundland, Quebec and New England, are involved in NW- to W-transported thrust sheets (Williams 1975, 1995, Stanley & Ratcliffe 1985) which form an integral part of the Taconian (or Taconic) orogen.

In Scandinavia, the general tectonostratigraphy for the Caledonides (Roberts & Gee 1985) comprises the Lower and Middle Allochthons in the east, which consist of rocks indigenous to the Baltoscandian margin. The Upper Allochthon has, at its base, the palaeo-continent/ocean transition zone (Seve Nappes) and is succeeded by a series of accreted suspect terranes comprising ophiolites and diverse magmatosedimentary associations (Köli Nappes) of varied faunal affiliation (Laurentian or, in places, Baltican) and unknown, intra-Iapetus origins (Roberts 1988, Stephens & Gee 1989). At the top of the SE-transported nappe pile, the Uppermost Allochthon is deservedly the most suspect and exotic of all, and has been interpreted as having probably derived from the Laurentian side of the Iapetus Ocean (Roberts et al. 1985, Stephens & Gee 1985, 1989, Stephens et al. 1985, Andresen & Steltenpohl 1994, Grenne et al. 1999). The depositional model and early structural development for the FCs thus strengthen the notion of a Laurentian affinity for these rocks, and for the Rognan Group as a whole. Since the Fauske Nappe is reported to contain a continuous lithostratigraphy embracing 4 groups of diverse lithologies (Gustavson 1996), then it is reasonable to assume that all these rocks were deposited along either the carbonate-dominated shelf or the adjacent, deeper water, slope-rise environment of the passive Laurentian margin. The highest unit, however, the polymict conglomeratic Øynes Group, marks a changing provenance with a sudden input of igneous material. All these features would also help to support the inference that the rocks now forming the overlying Rödingfjallet Nappe Complex, as well as the Helgeland Nappe Complex farther south (Gustavson 1975, Nordgulen et al. 1993), have also derived from outboard of this same palaeocontinent, though most likely from a palinspastically more distal, magmatic arc-dominated location similar to that described and elegantly illustrated by Stanley & Ratcliffe (1985).

Although the lithological successions and earliest structures in the Fauske Nappe thus appear to be of Laurentian continental-margin origin, the nappe itself is one of several nappes and nappe-complexes that together constitute the SE-transported Caledonian allochthon. Accretion of these nappes, onto the Baltoscandian margin or upon each other, or even, in part, as out-of-

Fig. 11. Small-scale folding of the thrust surface shown in Fig. 7; looking NE. The axial surfaces of these small buckles are parallel to the prominent S2 fabric in the rock (roughly top right to bottom left).
sequence thrust sheets, is generally considered to have occurred during two main orogenic episodes; the Late Cambrian to earliest Ordovician Finmarkian, and the Late Silurian-Early Devonian Scandian, tectonothermal events. In the case of the Fauske Nappe, forming part of the highest allochthon, southeastward translation during just the Scandian event seems reasonable, at a time when Baltica was colliding with, and subducting beneath Laurentia. During this stage of orogenic development, the Laurentia-margin packages, with their early, Laurentian (Taconic) structures, were in some way detached and transferred on to what are now the upper levels of the Scandinavian Caledonide metamorphic allochthon. In some cases, these rocks and structures are surprisingly well preserved, as at Fauske, perhaps in (Scandian) low-strain zones such as one can observe, e.g., in the short limbs of many macroscopic folds, or in other, favourable, strain-shadow situations. In other parts of the Uppermost Allochthon, the Scandian strains are assumed to have been much higher and pervasive enough to have eradicated almost all signs of the Laurentian origins of these rocks. Several workers in the central Nordland region have described polyphase Caledonian deformation involving up to 5-6 fold phases, with ductile recumbent fold structures dominating in the earlier stages (Nicholson & Rutland 1969, Farrow 1974, Cooper 1978, Tragheim 1982). Marbles, in particular, are isoclinaly folded and refolded in some areas of intense deformation. Late-stage fold nappes have also been reported (Nicholson 1973). To our knowledge, the only indication of possible early thrust faults akin to those at the Lovgavlen quarry are the imbricate, pre-F1 slides described by Tragheim (1982) from the Sorfolda area c. 50 km north of Fauske. These may have been generated as early staircase thrust faults, i.e., Taconian, and subsequently been reactivated, ironed out and transformed into ductile slides during the pervasive Scandian orogenesis.

While the true age, or ages, of the structures and metamorphic fabrics in the Rognan Group carbonates and FCs are, as yet, unknown, from the above comparisons we postulate that the early NW-directed, thrust structures and fault-bend folding are most likely to be Taconian (Mid to Late Ordovician), as in the Appalachians of New England, USA, and eastern Canada (Williams & Stevens 1974, St.Julien & Hubert 1975, Stanley & Ratcliffe 1985, Williams 1995, Robinson et al. 1998). In New England, the age of the main Taconian thrusting and metamorphism is Caradoc-Ashgill (Bradley 1989, Hames et al. 1991), in Quebec it is Llanvirn-Caradoc (Whitehead et al. 1996, Prave et al. 2000), whereas in Newfoundland the assembly and transport of the Taconic allochthons began slightly earlier, in Late Arenig-Llanvirn time (Stevens 1970, Williams 1995), though with final emplacements extending into the Late Ordovician. Nearer to Scandinavia, in the Laurentian-margin successions of Scotland and Ireland, the equivalent Grampian orogeny (or Grampian phase of the Caledonian orogeny; McKerrow et al. 2000) is now considered to be of Late Arenig-Llanvirn age (Friedrich et al. 1999, Soper et al. 1999, Oliver et al. 2000).

In the case of the Fauske conglomerates, if, as we have suggested, the initial NW thrusting, clast flattening and elongation, and S1 fabric developed during one protracted 'event', then this, too, would almost certainly relate to the Ordovician, Taconian orogenic phase. An alternative is that the metamorphism peaked separately, in Early Silurian time, as has been suggested in western Newfoundland – corresponding to the Salinian event of Dunning et al. (1990) and Cawood et al. (1994). Farther north in Norway, however, in the Uppermost Allochthon in the county of Troms, there is growing evidence from some of the nappes pointing to a significant tectonothermal event in Mid to Late Ordovician time (Dallmeyer & Andresen 1992, Coker et al. 1995, 2000, Selbekk et al. 2000, FCorfu, pers. comm. 2001), also involving obduction of the Lyngen Ophiolite (Oliver & Krogh 1995). In our opinion, this metamorphism and deformation would equate with the Taconian; and these processes, including obduction of the Lyngen ophiolitic rocks, are inferred to have occurred along the Iapetan margin of Laurentia. Similar geological and isotopic dating constraints favouring an intra-Ordovician orogenic event have been reported from the Helgeland Nappe Complex in central Norway (Nordgulen & Schouenborg 1990, Nordgulen et al. 1993).

The age of the SE-verging F2 folding, associated penetrative S2 fabric, and small-scale SE-directed thrusting is also unknown at the present time, but we suggest that this is likely to relate to, and partly postdate, the Scandian emplacement of the Fauske Nappe onto the developing, subjacent Upper Allochthon, coeval with and immediately following Baltica-Laurentia collision. Later structures in this area, on the other hand, are of extensional character, and are considered to be part of the widespread Devonian, WSW- to W-directed, extensional regime that superceded the main Scandinavian nappe translation phase in this part of the north-central Scandinavian Caledonides (Rykkelid & Andresen 1994, Albrecht 2000, Braathen et al. 2000, Osmundsen et al. 2000, and in prep.).
The mafic dykes that cut across the early, inferred Taconian structures in the Fauske conglomerate are the subject of an ongoing study. They can be considered as feeders to volcanic or subvolcanic units in higher level lithostratigraphical successions, which may not exist now in this particular region. These sequences most likely accumulated in a successor basin, or basins, following the Taconian orogenic phase. A possible analogy farther north is that of the Balsfjord Group in Troms (Bjørlykke & Olaussen 1981, Steltenpohl et al. 1990, Coker et al. 2000), which lies with marked unconformity above the deformed Lyngen Ophiolite (Minsaas & Sturt 1985). This fossil-bearing lithostratigraphic unit, of Late Ordovician-Early Silurian age, contains both metabasalts and carbonate rocks, locally with zinc and lead mineralisations, a combination which is reminiscent of several of the late- to post-Taconic successor basins in the Canadian Appalachians.

Conclusions

Polyphase tectonic structures affecting a multilayered, carbonate conglomerate formation in the Fauske Nappe of the Uppermost Allochthon in Nordland are described, based largely on exposures revealed during quarrying operations at Løvgavlen, near Fauske. Deposition of these Cambrian-age, Fauske conglomerates occurred at the tectonically unstable margin of a carbonate bank and adjacent palaeoslope of an ocean basin deepening to the southeast. The very earliest structures recognised are NW-directed, ramp-and-flat, thrust faults and fault-bend folds. As a result of a progressively more ductile, higher strain regime, these folds became tight and recumbent and the carbonate clasts were both flattened and elongated within the developing, axial-planar schistosity, the pebble stretching lineation parallelling the NE-SW fold axes. The early staircase thrusting and fold development is thus a form of tectonic reversal of the basinal regime. The combined depositional and early structural picture is reminiscent of that widely documented from the Laurentian passive margin of the Iapetus Ocean in Cambrian to Early Ordovician time, for example in the north-eastern US and Canadian Appalachians, northern Scotland and East Greenland. We interpret the described conglomerates, and most of the lithostratigraphy now composing the Fauske Nappe, as having originated on the Laurentian side of Iapetus. Although isotopic dating is lacking, we suggest that the early, NW-directed thrusting and related folding is most likely to be of Taconian (Mid to Late Ordovician) age, and occurred along the Laurentian continental margin as a result of arc-continent collision (cf. Stanley & Ratcliffe 1985). The early S1 schistosity is also likely to be Taconian; but a slightly later Salinian (Early Silurian) age cannot be ruled out.

The Fauske Nappe itself — lying above the Gásak Nappe and below the Rödingsfjallet Nappe Complex — is a part of the SE-translated, Caledonian allochthon, arising in this case from Baltica-Laurentia collision that produced the Scandinavian orogeny, in Late Silurian-Early Devonian time. The SE-verging F3 folds and penetrative, NW-dipping S3 fabric in the FCs are inferred to be of Scandanian age since, within the region, equivalent but larger F3 folds with associated cleavages deform the nappe boundaries and early foliations. The later, extensional structures can be viewed as part of the Early to Mid Devonian, WSW- to W-directed, extensional regime that is now so widely documented in this part of the Norweginan Caledonides. Taken as a whole, the tectonic deformation sequence in the Fauske Nappe is thus both polyphase and polyorogenic.

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