Polyphase deformation in the Hattfjelldal Nappe, internal zone of the Scandinavian Caledonides, North-Central Norway

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This paper presents a structural investigation of the Hattfjelldal Nappe (part of the Storfjället Nappe Complex), Nordland, Norway, leading to a tentative model for the sequence of deformational events within the nappe and its bordering thrust zones. The investigated area belongs to the internal zone of the Caledonian fold-and-thrust belt. The rocks have been subjected to multiple deformational phases. The deformational sequence comprises at least two generations of isoclinal folds, as well as younger transverse and longitudinal folds. The phases can be correlated with movements in the bordering thrust zones. Finally, some aspects of correlation of fold phases in neighbouring nappes are discussed by comparing the Hattfjelldal Nappe with the underlying Jofjället Nappe.

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Published literature concerning the Hattfjelldal Nappe is sparse compared with that elsewhere in the Seve-Köli Nappe Complex in the Scandinavian Caledonides. The first lithological descriptions appeared in the work of Holmsen (1912). Regional mapping of the Hattfjelldal district on the scale 1:250,000 was first presented in 1924, together with a description of the map (Rekstad 1924). More detailed work was started in 1950, in connection with prospecting for sulphide deposits, but was restricted to the area around Mikkeljord (Færden 1953). Until this date, it was known that the upper boundary of the Hattfjelldal rocks was defined by a major thrust zone, which could be followed northward from the Grong district to the Hattfjelldal area (Foslie 1923, 1924). Strand (1953, 1955) published his results of mapping and stratigraphical investigations in the area between Rössvatnet (Fig. 1) and Tunnsjöen (Grong district), and made a first attempt at lithostratigraphical correlation. Furthermore, he recognized the minor thrust zone at the base of the rocks around Hattfjelldal and introduced the term 'Hattfjelldal Nappe'.

The mapping in the Köli Nappes since the 1960's has significantly increased our knowledge of the structure and stratigraphy in this nappe complex. The area north and west of the Börgefjellet Window (Fig. 1), however, was not investigated in detail. In the 1970's, L. A. Barkey compiled a series of lithological maps on the scale 1:50,000, which remained unpublished. Though these maps were still rather general and lacked structural elements, they have provided a valuable base for further investigations. Finally, the initiation of the IGCP Nordland project led by I. B. Ramberg (University of Oslo) has increased our understanding of the regional geological situation (Mörk 1979, Ramberg 1981, Ramberg & Stephens 1981, Stephens et al. 1985, Stölen 1985, Sverdrup 1985). Fig. 1 shows the present knowledge of the tectonostratigraphy in this area.

The aim of this paper is to present a structural analysis of the Hattfjelldal Nappe, which is the uppermost nappe of the Seve-Köli Nappe Complex in the area between Rössvatnet and Börgefjellet. A detailed description of the structural elements is followed by a discussion of the deformational events, which leads to a tentative model for the structural development of the nappe.

Regional context

In the western part of Central Scandinavia, both continental margins of the early Paleozoic Iapetus Ocean (or a segment of it) are thought to be exposed, the eastern margin being the Baltic Shield, the western margin probably being the uppermost thrust nappes (Helgeland and Rödingsfjället Nappe Complexes; Stephens et al. 1985). The whole nappe pile in between reflects different settings of miogeoclinal and eugeoclinal character (Table 1).

Helgeland Nappe Complex			
			Rødingsfjället Nappe Complex
Upper Allochthon (Seve-Köli Nappe Complex)	Köli unit	Upper:	Hattfjelldal and Akfjellet Nappes
			Jofjället Nappe
			Krutfjellet Nappe
		Middle:	Gjersvik Nappe
			Leipikvattnet Nappe
			Gelvenåkko Nappe
			Stikke, Atofjället or Laxfjället Nappe
		Lower:	Björkvattnet Nappe
	Seve unit		
Middle Allochthon			
Lower Allochthon			
autochthonous cover sediments			
Baltic Shield			

Table 1. Tectonostratigraphic table of the Caledonian Nappes in Southern Västerbotten (Swedish side) and Southern Nordland (Norwegian side).

The Baltic Shield is overlain by an autochthonous cover sequence, succeeded by a series of nappes (Lower and Middle Allochthon) derived from areas on or adjacent to the Baltoscandian continent (Gee 1975, Gustavson 1978, Roberts 1978, Ramberg & Stephens 1981, Stephens et al. 1985, Stephens & Gee 1984). Above them occurs the Seve-Köli Nappe Complex (Upper Allochthon) derived from distal continental, oceanic and volcanic arc-related settings (Gee 1975, Stephens & Gee 1985), which is succeeded by nappes thought to be derived from a western continental margin (Uppermost Allochthon).

Based on earlier work, Stephens & Gee (1985) interpret the Upper Köli Nappes as being derived from a fore-arc related setting, and the Middle Köli Nappes from volcanic arc and back-arc related settings. Assuming a time relationship between these complexes, these authors suggest an eastward dipping subduction zone during the early Ordovician. After the collision of the western continental margin with the volcanic arc complex, the sense of vergence was considered to have changed to allow the final thrusting eastward onto the Baltic Shield.

Fig. 1 shows the location and tectonostratigraphic position of the Hattfjelldal Nappe that here forms the highest thrust unit within the Seve-Köli Nappe Complex. Due to this position, it is thought to represent sediments derived from a tectonic setting situated between the volcanic arc (represented in the underlying Middle and Upper Köli Nappes) and the presumed western continental margin (represented in the overlying Helgeland Nappe Complex) – before, during or after the collision of the two units.

This interpretation requires a Lower Paleozoic age of the rocks of the Hattfjelldal Nappe. This is discussed in detail in Dallman (in prep.), where an Ordovician to Silurian age can be envisaged via lithostratigraphical correlation with other Köli Nappes.

The metamorphism in the investigated Köli lithologies is low-grade. The Helgeland Nappe Complex, however, where it overlies the Hattfjelldal Nappe, shows transition from medium- to high-grade metamorphism towards the south.

Concerning the terminology on Table 1 and Fig. 1, one should note that Häggbom (1980) defined the term 'Jofjället Nappe' for all the Köli rocks between the Krutfjellet Nappe and the Rödingsfjället Nappe Complex. This was modified by Ramberg (1981), who had mapped out the 'Akfjellet Nappe' as an isolated unit with the higher metamorphic Brakfjellet Tectonic Lens at its base. As a result of field work in this area (Theisen & Dallmann 1984), I consider it more appropriate to follow the terminology of Ramberg, as a tectonic break of the same order can be observed at the base of both the Akfjellet and Jofjället Nappes. Furthermore, the Akfjellet Nappe has a similar regional importance to that of the Hattfjelldal Nappe. To follow the first published work by Häggbom would mean to increase the complexity of the terminology of the Köli Nappes by finding new terms and building up a more complicated system of overlapping collective names and subunits.

Outline of the stratigraphy

The reconstruction of the lithostratigraphy of the Hattfjelldal Nappe is difficult because of strong deformation and comparatively low degree of exposure in many areas. Obvious primary rock boundaries are restricted to those between rocks that are weakly foliated (some marbles, conglomerates, quartzites). The lithostratigraphic reconstruction is mostly based on frequently observed repetitions or bed sequences in tectonically different positions and way-up indications from conglomerate pebbles.

The establishment of the stratigraphy will be explained in detail in Dallmann (in prep.), and only the main division is introduced here. It consists mainly of two groups (Fig. 2):

1. A lower marble group, mostly consisting of the so-called 'Hattfjelldal limestone' (Strand 1955), which is referred to as the 'Hattfjelldal Group';

2. An upper phyllitic, quartzitic and conglomeratic group showing many similarities with the 'Limingen Group' of the Gjersvik Nappe (Lutro 1979), with which it has been correlated (Dallmann 1984).

General characteristics of deformation

The Hattfjelldal Nappe provides an example of structural development in the internal zone of the Caledonian thrust-and-fold belt. It is characterized by syn-sedimentary tectonics (Dallmann, in prep.) and by later, strongly compressive deformation resulting in polyphase folding combined with thrust and shear movements. The structures of the whole nappe are easterly vergent.

Fig. 3 shows a structural map of the Hattfjelldal Nappe. The main map-scale repetitions of the stratigraphy are interpreted as early isoclines, because alternating upright and inverted stratigraphical sequences can often be observed

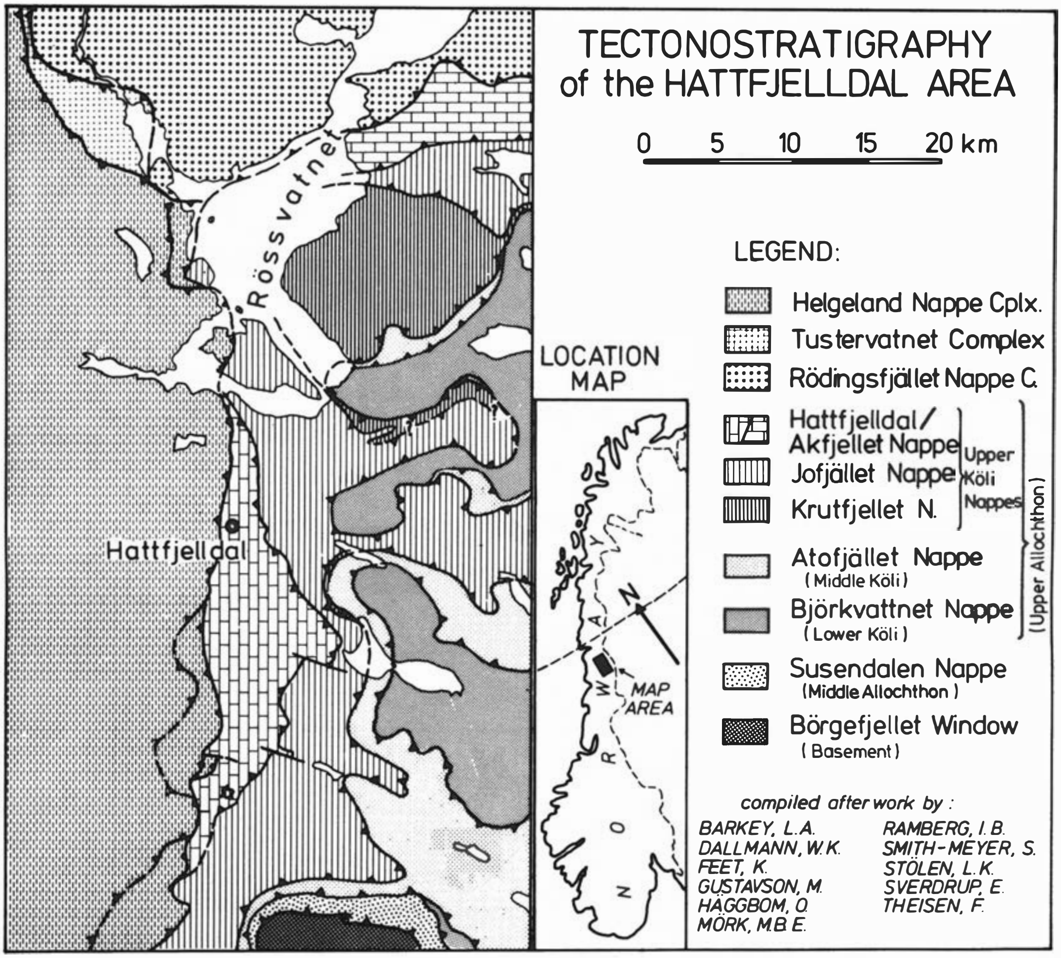


Fig. 1. Tectonostratigraphic map of the Hattfjelldal area. Correlation based on work by: Barkley, L. A., unpubl. maps; Dallmann, this paper; Feet, K., pers. comm. 1985; Gustavson 1981; Häggbom 1980; Mörk 1979; Ramberg 1981, in: Ramberg & Stephens 1981; Smith-Meyer, in prep.; Stölen 1985; Sverdrup 1985; Theisen & Dallmann 1984.

in the presumed limbs (Dallmann, in prep.). Minor shear zones and imbrication related to the early phases of isoclinal folding are abundant, but are mostly not mapped because of poor exposure and because of the lack of macroscopical evidence in many phyllitic rocks. A regional, penetrative foliation is associated with the isoclinal folds. These early features are overprinted by younger folds with both Caledonian and transverse axial trend.

This structural style differs from other Köli

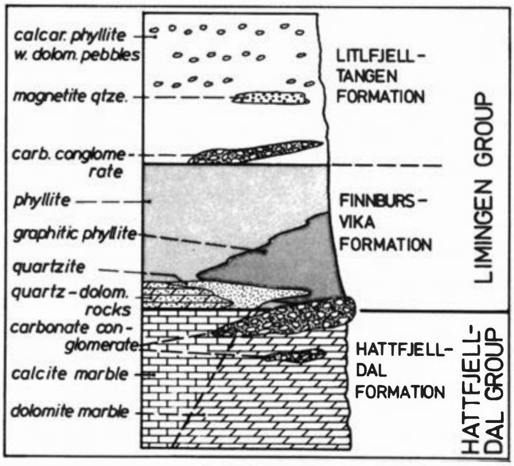


Fig. 2. Generalized lithostratigraphical succession of the Hattfjelldal Nappe. The formation names of the Limigen Group are taken from the Gjersvik Nappe (Lutro 1979).

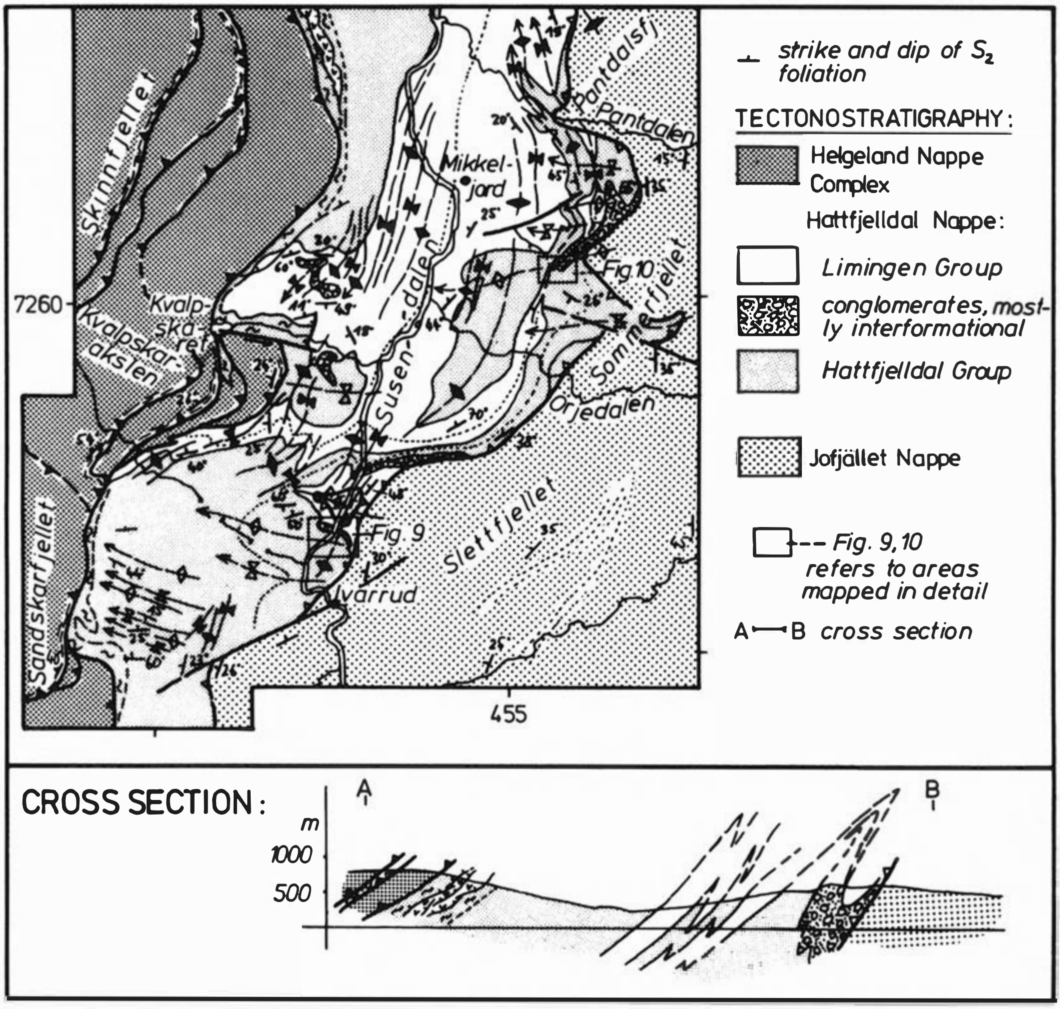
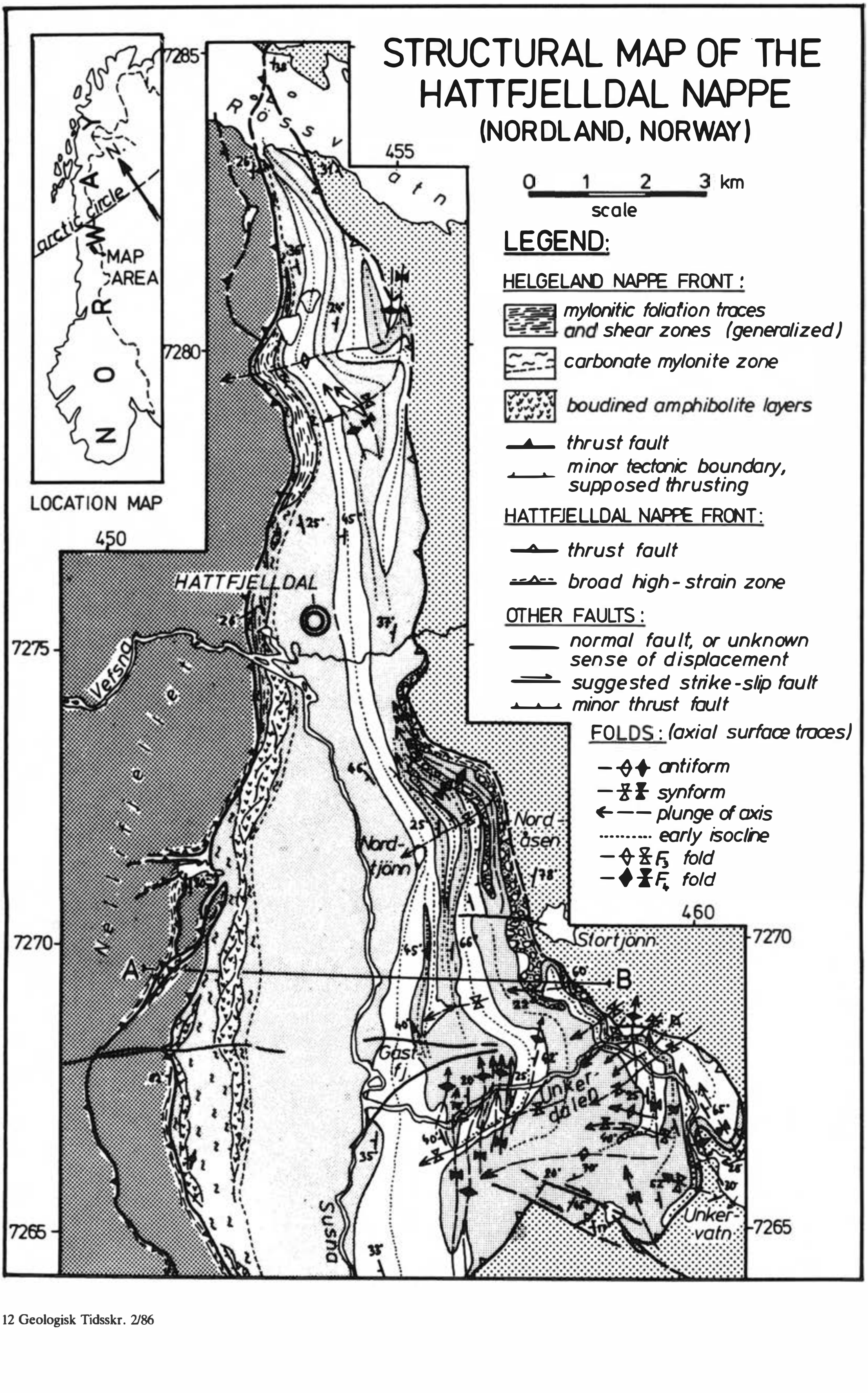


Fig. 3. Structural map of the Hattfjelldal Nappe, showing main stratigraphic groups, thrust zones, trend of main foliation and traces of fold axes correlated with different phases. The cross-section A-B is approximately representative for the middle and northern part of the area, whereas the southern part is represented by small subareas on Fig. 9 and 10 (position indicated on the map).


STRUCTURAL MAP OF THE HATTFJELLDAL NAPPE
(NORDLAND, NORWAY)
0 1 2 3 km
scale
LEGEND:
HELGELAND NAPPE FRONT:
mylonitic foliation traces and shear zones (generalized)
carbonate mylonite zone
boudined amphibolite layers
thrust fault
minor tectonic boundary, supposed thrusting
HATTFJELLDAL NAPPE FRONT:
thrust fault
broad high-strain zone
OTHER FAULTS:
normal fault, or unknown sense of displacement
suggested strike-slip fault
minor thrust fault
FOLDS: (axial surface traces)
antiform
synform
plunge of axis
early isocline
F3 fold
F4 fold
LOCATION MAP
arctic circle
MAP AREA
N
NORWAY
HATTFJELLDAL
Rössvatn
Vefsna
Nellfjellet
Nordtjönn
Nordåsen
Stortjönn
Gåstfj.
Unkerdalen
Unkervatn
Susna
A
B
450
455
460
7285
7280
7275
7270
7265

def. phase	main structural elements	conditions of deformation, suggested generating events
D_5	conjugate fracture sets, reactivation of planar features	remaining stress fields after decreased ductility
		transition from ductile to brittle deformation
D_4	F_4 longitudinal folding with increasing intensity towards the Helgeland Thrust, "flow folding" close to the thrust, kink folding and fracture cleavage at late stages	further thrusting of the HNC, possibly due to gravity collapse stretching, viscous flow in calcite marbles, brittle deformation in siliceous rocks at late stages, transition from transverse to longitudinal folding by changing strain ratios
D_3	F_3 transverse folding with varying intensity and orientation, "flow folding" close to the thrust	
D_2	F_2 isoclinal folding, S_2 regional penetrative foliation, intensity increasing toward the Helgeland Thrust	thrusting of the Helgeland Nappe Complex, totally ductile deformation, subsequent to continent-continent collision
	peak of low-grade metamorphism	
D_1	F_1, S_1, isoclinal folding causing repetition of the stratigraphy, probably more than one deformational event	thrusting of the Hattfjelldal Nappe

Table 2. Deformation sequence of the Hattfjelldal Nappe and its suggested generating events.

Nappes immediately below, which – at map scale – are less intensively folded. The deformation style of the Akfjellet Nappe, however, is comparable with that of the Hattfjelldal Nappe. Both nappes lie in the same tectonic position beneath the Uppermost Allochthon and represent a similar zone of intense polyphase folding and thrusting.

To permit later attempts at correlation, some data from the underlying Jofjället Nappe are taken into account in the following sections.

Analysis of the structural elements

The deformation events are referred to as D_1 (oldest) to D_5 (Youngest), the corresponding folds as F_1 etc., and planar features (foliations, axial planes) as S_1 etc.

Folds and foliations

D_1 structures. – Those structures that are older than and cut by the regional, penetrative foliation S_2 are collectively referred to as D_1 structures. They do not necessarily belong to only one event of deformation. Due to the strongly superposed D_2 structures in most of the area, no age relationship between the individual D_1 structures could be observed.

The most frequent D_1 elements are relic foliation planes (S_1; Fig. 4a, b, c) that are not entirely transposed by S_2. They are normally preserved in quartz-rich phyllites, preferably in the hinge zones of F_2 isoclines.

The S_1 foliation is defined by the orientation of white mica and chlorite. In calcite marbles, some recrystallization results in a distinct banding or lamination. Furthermore, calcite, quartz and mixed calcite-quartz veins occur parallel to the S_1 foliation. The foliation is parallel to the lithologic layering (Fig. 4e). However, small-scale isoclinal folds (F_1), e.g. preserved in the pressure shadow of quartz veins folded by F_2, have been observed at a few localities (Fig. 4d). In addition, it is proposed that even the major map-scale isoclines (compare Fig. 3) are F_1 folds, as the D_1 Hattfjelldal Thrust cuts these folds, and is not repeated by isoclinal folding.

D_2 structures. – The D_2 phase gave rise to the strongest deformation structures that are preserved. It caused intense isoclinal folding (F_2) and a penetrative axial surface cleavage (S_2), which is the dominant foliation throughout the Hattfjelldal Nappe, except for a narrow zone along the Helgeland Thrust, where the younger

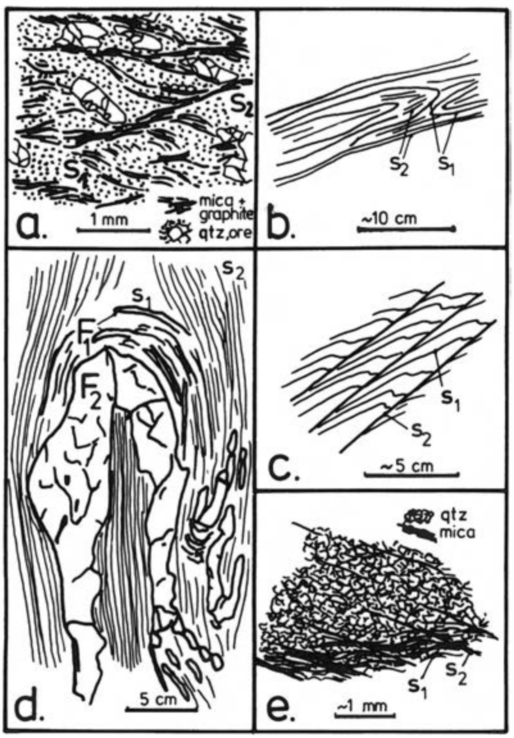


Fig. 4. D_1 structures – a and e thin sections; b, c, and d field sketches (vertical W-E sections, approximately downplunge).
a: Relict S_1 foliation and S_2 crenulation cleavage. Graphitic quartz phyllite, Susendalen.
b: S_1 foliation, folded by F_2 during development of an S_2 axial plane foliation. Quartz phyllite, N of Ivarrud.
c: Penetrative S_1 foliation, cut by S_2 shear foliation. Calcareous quartz phyllite, Pantdalsfjellet, Jofjället Nappe.
d: F_1 isoclinal folds in pressure shadow of quartz vein, refolded by F_2. Calcareous quartz phyllite, Unkerdalen.
e: S_1 foliation parallel to lithologic boundary, obliquely cut by S_2 shear foliation. Quartz phyllite, Susendalen.

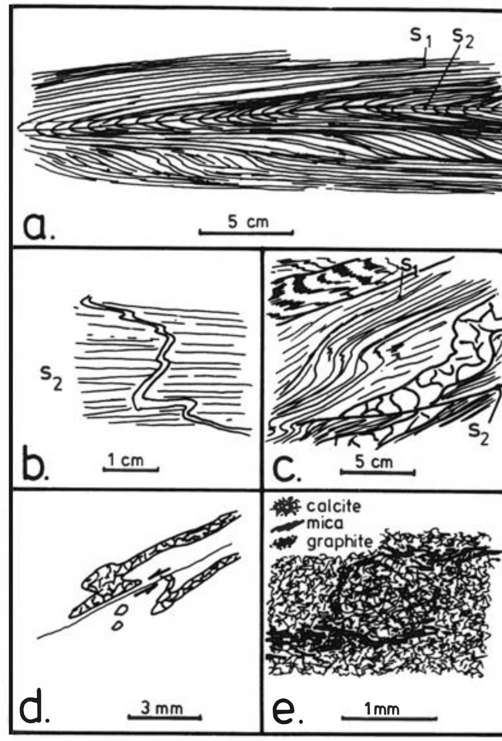


Fig. 5. D_2 structures – a, b, and c field sketches (vertical W-E sections, approximately down-plunge)- d and e thin sections.
a: F_2 isoclinal shear fold. Graphitic phyllite, Sommerfjellet.
b: F_2 shear fold. Quartz vein in a fine-banded greenstone, Sandskarfjellet.
c: D_2 shearing of layers of different competence. Quartz phyllite, Örjedalen, Jofjället Nappe.
d: Micro-scale F_2 shear fold. Dolomite marble, Kvalpskaret.
e: Rotated rock fragment. Calcareous conglomerate, Sandskarfjellet.

S_4 foliation may dominate. It is remarkable that, within the underlying Jofjället Nappe, the intensity of D_2 deformation decreases rapidly toward the east. Finally, it occurs only in local shear zones, which deform a penetrative S_1 schistosity. On the other hand, D_2 structures are increasingly superposed by younger deformation ($D_{3,4}$) towards the Helgeland Thrust.

The S_2 foliation is defined by the parallel orientation of white mica, chlorite and biotite, and sometimes elongate recrystallized grains of carbonates and quartz. There is often a distinct enrichment of graphite and micas along the foliation. Growth of low-grade metamorphic minerals (clinozoisite, biotite, actinolite etc.) occurred pre- to syn-D_2, and never across the S_2 foliation.

Mica-rich rocks show mostly an S_2 transposition foliation, whereas mica-poor rocks (quartzites, some marbles) may still show primary bedding or other sedimentary structures.

F_2 folds are defined by the bending (quartzites, dolomites) or shearing (phyllites etc.) of the S_1 foliation and/or the lithologic layering. They occur mainly as medium- and small-scale structures, but also some of the map-scale isoclines may belong to D_2. Fig. 5 shows F_2 fold shapes and shear structures from different lithologies (see also Fig. 4).

D_3 structures – The folds are defined in that they fold the regional S_2 foliation, and that their axial surfaces are refolded by the only rarely occurring younger folds observed in the field, F_4 (Fig. 6a). Field criteria to recognize F_3 folds are essentially restricted to the style of folding and geometrical parameters described below, which are primarily observed at outcrops showing a clear relationship (Fig. 6).

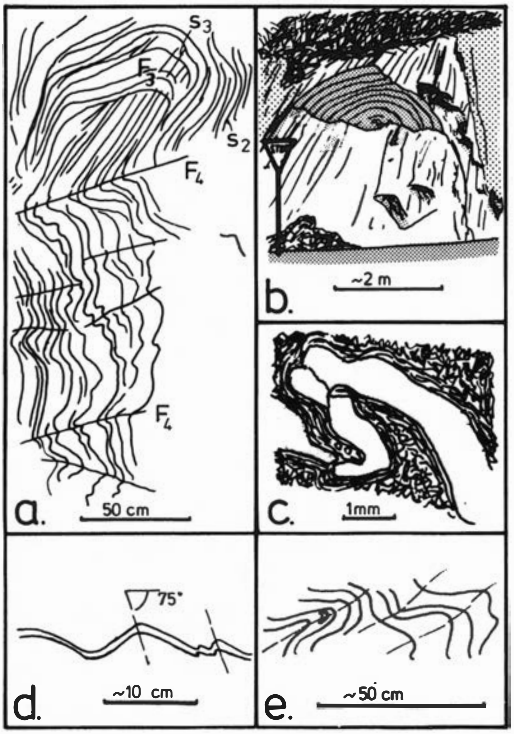


Fig. 6. D_3 structures – a, b, d, and e field sketches; c thin section. Down-plunge, except b.
a: S_2 foliation folded by F_3 (S_3 axeal plane foliation developed!) and refolded by F_4. Down-plunge F_3 axis. Quartz phyllite, N of Ivarrud.
b: Close F_3 fold. Dolomitic marble, road cut in Unkerdalen.
c: Micro-scale F_3 fold. Carbonate band in calcareous phyllite, Unkerdalen.
d: Small-scale open F_3 fold. Calcareous chlorite schist, Sandskarfjellet.
e: Transition to 'flow folding'. Calcite marble, W of Nordtjönna.

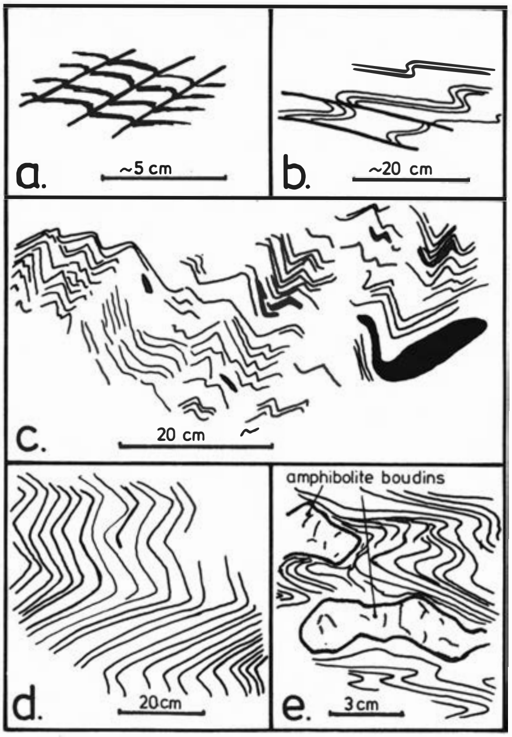


Fig. 7. D_4 structures – field sketches (vertical W-E sections, approximately down-plunge.
a: S_4 fracture cleavage. Banded calcite marble, W of Ivarrud.
b: S_4 fracture cleavage, dissecting earlier folds. Calcite marble, near Gastfjellet.
c: Kink-formed parasitic folds. Calcareous phyllite with dolomite pebbles (black), SE of Hattfjelldal.
d: Kink folds. Banded calcite margle, W of Ivarrud.
e: 'Flow folds' and boudinage of amphibolitic layers. Calcite marble, close to Helgeland Thrust, Skinnfjellet.

The F_3 fold axes and crenulations plunge westward (230–295°) at low angles between 0° and 35°. Axial surfaces are steep (normally > 75°), but there are local exceptions with almost recumbent folds. The inter-limb angle of the folds varies considerably at different localities; the folds may be close to tight, mainly in the Unkerdalen and Kvalpskaret regions (subareas III and V on Fig. 8) or open to gentle elsewhere.

Generally, F_3 and F_4 folds can be distinguished by their characteristic directions of axes, though this distinctive feature vanishes in the calcite marbles in the vicinity of the Helgeland Thrust. There, deformation grades into 'flow folding' and finally into a persistent transpositional banding, disturbed by 'flow' structures around boudins of more competent amphibolite (Fig. 6e, 7e).

(The term 'flow folding' here and in the following sections is used for commonly non-cylindrical folds with curving axes and axial surfaces, as a result of non-affine, probably viscous flow, as described by Carey (1954)).

The S_3 axial surface foliation, if present, is indicated by the recrystallization of white mica. Where phyllitic rocks underlie the Helgeland Thrust, S_2 and S_3 superpose each other at moderate angles, giving rise to a 'pencil' cleavage with rhomboidal cross sections.

D_4 structures – The F_4 folds are defined by folding of the S_2 and the S_3 (if present) axial surface foliations, the S_4 axial surfaces are not refolded. The determination of F_4 folds in the field is restricted to the recognition of the style of folding and the geometrical parameters, which are characterized below (Fig. 7).

The fold axes, measured on S_2 planes, are generally directed subhorizontally N–S, but sometimes plot into two distinctly separated areas on the stereo net, due to rotation by the previous folding of S_2 by F_3 (compare Fig. 8, subareas III and IV).

S_4 axial surfaces of megascopic folds dip 40–50°W on average. Field observations at mesoscopic folds provided dip values between 0 and 75° W. Low dip values appear preferably in the vicinity of the Helgeland Thrust. In several places, S_4 is developed as a fracture cleavage (Fig. 7 a, b) with a weak displacement.

The style of folding changes from gentle flexures in the east to tight shear folds towards the Helgeland Thrust. Marbles are increasingly deformed by 'flow folding' towards the Helgeland Thrust, as described above. Intercalated amphibolitic layers are boudined. At the uppermost levels of the Hattfjelldal Nappe (the uppermost tens of meters), a strong transposition banding is developed, and this zone is designed as the 'carbonate mylonite zone' on Fig. 3. There appears to be a gradual transition from the S_4 axial surfaces at lower levels to the transposition banding, which is subparallel to the thrust plane.

In mica-rich rocks at moderate distances from the thrust, i.e. the central zone of the Hattfjelldal Nappe, F_4 folds are kink-like, occasionally with parasitic folds on the limbs of larger ones (Fig. 7 c, d).

The Hattfjelldal Thrust

The lower boundary of the Hattfjelldal Nappe is often developed as a discrete thrust plane, though it often forms a broad zone of high-strain. As it is difficult to recognize thrusting in phyllitic rocks, there is no continuous evidence for thrusting along this zone. The following observations, however, may confirm the assumption of a thrust:

1. There is a stratigraphic discordance along the supposed thrust zone.
2. The discordance has in many places a tectonic origin, and is marked by the occurrence of strongly deformed marbles with transposition banding and 'flow' structures, zones with strongly elongate pebbles in conglomerates, or thin bands of usually graphitic phyllite between the two supposed nappe units.

F_2 folds and S_2 foliation are well developed in the thrust zone, the latter often as a crenulation cleavage. A thrust that could be dated as D_2 would be supposed to contain zones in which D_1 structures are destroyed and replaced by a strong S_2 shear foliation. In areas where the Hattfjelldal Thrust is well exposed (e.g. top region of Sommerfjellet), such zones could not be found. Both conglomerates and phyllites here preserve the S_1 relic foliation between S_2 foliation planes and similar features have been observed in many other places along the thrust zone.

These observations indicate that thrusting of the Hattfjelldal Nappe was pre-D_2, and the Hattfjelldal Thrust is therefore regarded as a D_1 feature.

The Helgeland Thrust

The upper boundary of the Hattfjelldal Nappe is the basal thrust zone of the Helgeland Nappe Complex (HNC). This complex is built up of more competent lithologies. In the vicinity of the thrust zone, these are essentially quartz dioritic and meta-gabbroic intrusions, mica gneisses, migmatitic or granite-intruded quartzo-feldspathic gneisses and banded gneisses with amphibolitic layers. The lithologic break with the marbles and phyllites of the Hattfjelldal Nappe leads to a clearly visible escarpment along the thrust front.

The thrust planes dip generally at 25–30°W, but exceptionally up to 90° between Nellifjellet and Skinnfjellet (Fig. 3). The thrust plane often

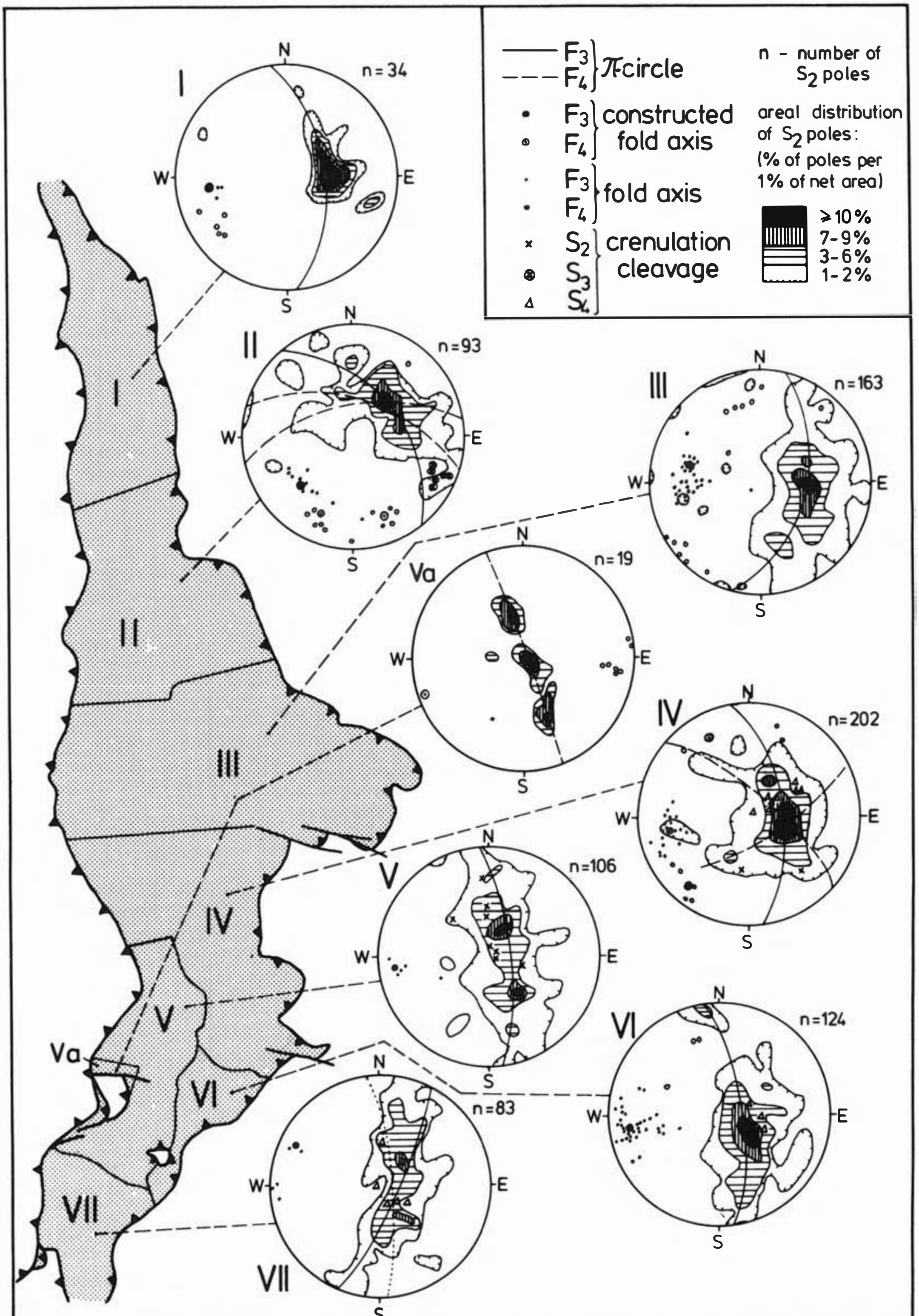


Fig. 8. Stereographic representation of post-D_2 structures for eight subareas within the Hattfjelldal Nappe. Equal-areal projection. Interpretation in the text.

splits up into two or more thrust faults and forms imbricate structures with slices of mylonite-bounded quartz diorite sheared off the HNC.

Rocks of both nappes are affected by mylonitization. Within the Hattfjelldal Nappe, the mylonite zone lies mostly within the calcite marbles of the Hattfjelldal Formation. Most of these carbonate mylonites are totally recrystallized, but show a well-developed thin transposition banding parallel to the thrust planes, which grades downwards into the irregular 'flow folds' described above. The banding and 'flow folding' is supposed to be an interference feature of several deformational events.

A number of tectonically emplaced amphibolitic layers with partly mylonitic boundaries occur exclusively within or close to this zone. They are mostly sheared and boudined, and their origin is unknown. Occasionally, boudins of other material are found in the marbles of the thrust zone, e.g. quartz diorite and siliceous mylonite of the type found at the base of the HNC.

A consideration of the geometry and spatial distribution of the D_2 and D_4 folds in the Hattfjelldal Nappe in addition to the observations at the thrust front provides several arguments for polyphasal thrusting (note that the term 'phase' here is used descriptively and means a period of uniform mode of transport with a uniform style of developing structures; there is no evidence for a cessation of movement between these phases):

1. Rotated fragments of siliceous mylonite in a carbonate matrix indicate one phase of ductile flow in silicates ($\pm$ carbonates), and a second phase of ductile flow only in calcitic carbonates.

2. In parts, the HNC lies without a silicious mylonite zone upon the mylonitic 'Hattfjelldal Limestone'. A continuous siliceous mylonite zone, however, must be considered to have developed initially when the Helgeland Nappe was sheared off underlying rocks. Consequently, these mylonites must have been cut off later in several places. Further nappe transport did not form any siliceous mylonites. As no cataclastic deformation occurred, the movement is considered to have been entirely within the marbles, which reacted by ductile flow.

Thus, there were at least two phases of thrusting: an initial ductile phase, and a later phase, when only calcite marbles were ductilely deformed, and silicate rocks were deformed in a brittle fashion or not at all.

3. Both the D_2 and D_4 folds are orientated with axial surfaces at an acute angle to the thrust, and axial traces subparallel to the thrust front, as the stress distribution during thrusting demands (compare Fig. 11). The inter-limb angle of folds of both phases, and the degree of transposition of older structures increases toward the thrust both during D_2 and D_4.

The sum of these observations suggests that thrusting of the HNC was a continuous event during D_2 and D_4. The initial thrusting, however, may have even been older. The stretching lineations and small scale transverse folds in the mylonites indicate a thrust direction between NNE and ESE.

Faults and fractures

Throughout the Hattfjelldal Nappe, a conjugate fracture pattern is readily mapped on air photos. The fractures cut the D_4 folds. The acute angles are oriented in an E-W direction indicating the unchanged orientation of the axis of highest stress during that late, brittle deformation. Some of the fractures show a minor displacement. In addition, there is evidence for older faults of possibly syn-D_4 origin.

The regional refolding pattern

General structural analysis. – To permit analysis of the regional post-D_2 deformation the Hattfjelldal Nappe was divided into seven subareas. Each subarea represents a region with a fairly uniform style of F_3 and F_4 folding, although transitions between those styles are gradual. S_2 foliation poles (and occasionally S_3 and S_4 foliation poles) and F_3 and F_4 fold axes from each subarea were plotted in equal area Schmidt nets (Fig. 8).

The scattering of the S_2 poles along the F_3 π-circles is due to F_3 folding, whereas scattering away from the circles is generally due to F_4 folding (compare orientation of folds!).

On average, the F_3 fold axes plunge ca. 260/15–30°. In subarea II, they plunge more southerly (230/37°), and in subarea III and VII more northerly (280/35° and 285/15°). Subarea V and VII show distinctly two maxima of S_2 poles belonging to each one limb of the F_3 folds.

The F_4 folds are sometimes defined by two fold axis maxima, which appear to be the result of interference between F_3 and F_4 folds (subarea II, III and IV): For measurements of all fold axes, S_2 had to be used as a reference plane. The two maxima of F_4 fold axes may thus reflect measurements on the two limbs of F_3 folds, because the probability of measuring on an F_3 limb is much higher than in the hinge zone.

The F_3 axes do not show this phenomenon in the same way, because the F_4 fold limbs dip less regularly. They become more regular in smaller subareas (Fig. 9 d, 10 d). Consequently, F_3 may also show two maxima.

Another possible explanation of this phenomenon is the presence of conjugate folds. These were observed at only one place in the Jofjället Nappe near subarea II. In this subarea, the two maxima of F_4 fold axes plot on the same side of the field of F_3 axes. Consequently, the explanation by conjugate folds may be applicable in this case.

The S_4 axial surfaces dip 20–30° in subarea VI, 10–25° in subarea VII, and 5–45° in subarea IV. The general strike direction is N – S, and the axes are, on average, subhorizontal.

The subareas II, III, IV and VI, where most of the S_2 values were taken in the eastern (lithologically more heterogeneous) parts, show the highest deviation of S_2 poles from the F_3 π-circles. This is due to the more open shape of F_4 folds with increasing distance from the Helgeland Thrust. Near the thrust, the F_4 folds are close to tight, and the S_2 poles on the limbs plot closer to each other.

Subarea Va was regarded separately because of its close relationship to a slice of rocks of the HNC emplaced along a fault at Kvalpskaret. The F_4 axis is rotated into ENE direction (ca. 250/0°), and can be explained as a local effect caused by the emplacement of the slice within the marbles of the Hattfjelldal Nappe.

To illustrate the relation between these stereographic considerations and the real situation in the field, two small areas with a different tectonic style were mapped in detail (1:5.000). They were chosen, because they are relatively well exposed, provide a variety of structural elements on a small area, and exhibit heterogeneous and easily distinguishable lithologies. The area 'Nyhaugen-Trangbergan' (Fig. 9) shows predominantly the late F_3 and F_4 folds, whereas the area 'Tjönnlaenget' (Fig. 10) shows mainly early isoclinal folds.

The 'Nyhaugen-Trangbergan' area, Ivarrud, Susendalen (Fig. 9). – This area is situated adjacent to the Hattfjelldal Thrust. The structure is dominated by interfering F_3 and F_4 folds. Evidence for major F_1 and F_2 isoclinal folds is absent. Note that the minor deviations from the expected axial surface trace directions in Fig. 9 b are due to the rough topography, especially along the river banks, which could not be indicated on the map for technical reasons.

In the stereogram (Fig. 9 d), the rotation of S_2 poles by F_3 is of higher degree than the rotation by F_4. The reason can be seen in the cross sections through the area (Fig. 9 c): F_4 folds are close to tight and overturned, and the difference between the dip values of the two respective limbs is therefore less than that of most of the more open F_3 folds. The equivalent importance of both fold sets, however, is indicated by dome structures generated by the interference of F_3 and F_4 folds. Dome structures (partly overturned) are shown both by the meta-gabbroic sill (middle of map, Fig. 9 a, b), and by the thrust plane (top of map, Fig. 9 a, b,; compare Fig. 3). Two maxima of F_3 fold axes, each related to one possible position of the F_3 π-circle, are indicated in the stereogram (Fig. 9 d). Fig 9 e shows the reconstructed lithostratigraphy to facilitate the understanding of deformation in Fig. 9 a, b, c.

The 'Tjönnlaenget' area, Sommerfjellet, Susendalen (Fig. 10). – Here, the map-scale structure is dominated by F_1 or F_2 isoclinal folds, on which F_3 and F_4 are superposed to a minor extent. The isoclinal fold axes are indicated by dotted lines on Fig. 10 b. F_3 folds form a main open antiform with smaller, hardly reconstructable folds on the limbs. F_4 fold axes have distinctly different directions on both limbs of the antiform (Fig. 10 b),

Fig. 9. Structural analysis of the Nyhaugen-Trangbergan area, N of Ivarrud, Susendalen. Position of area indicated on Fig. 3. Interpretation in the text.

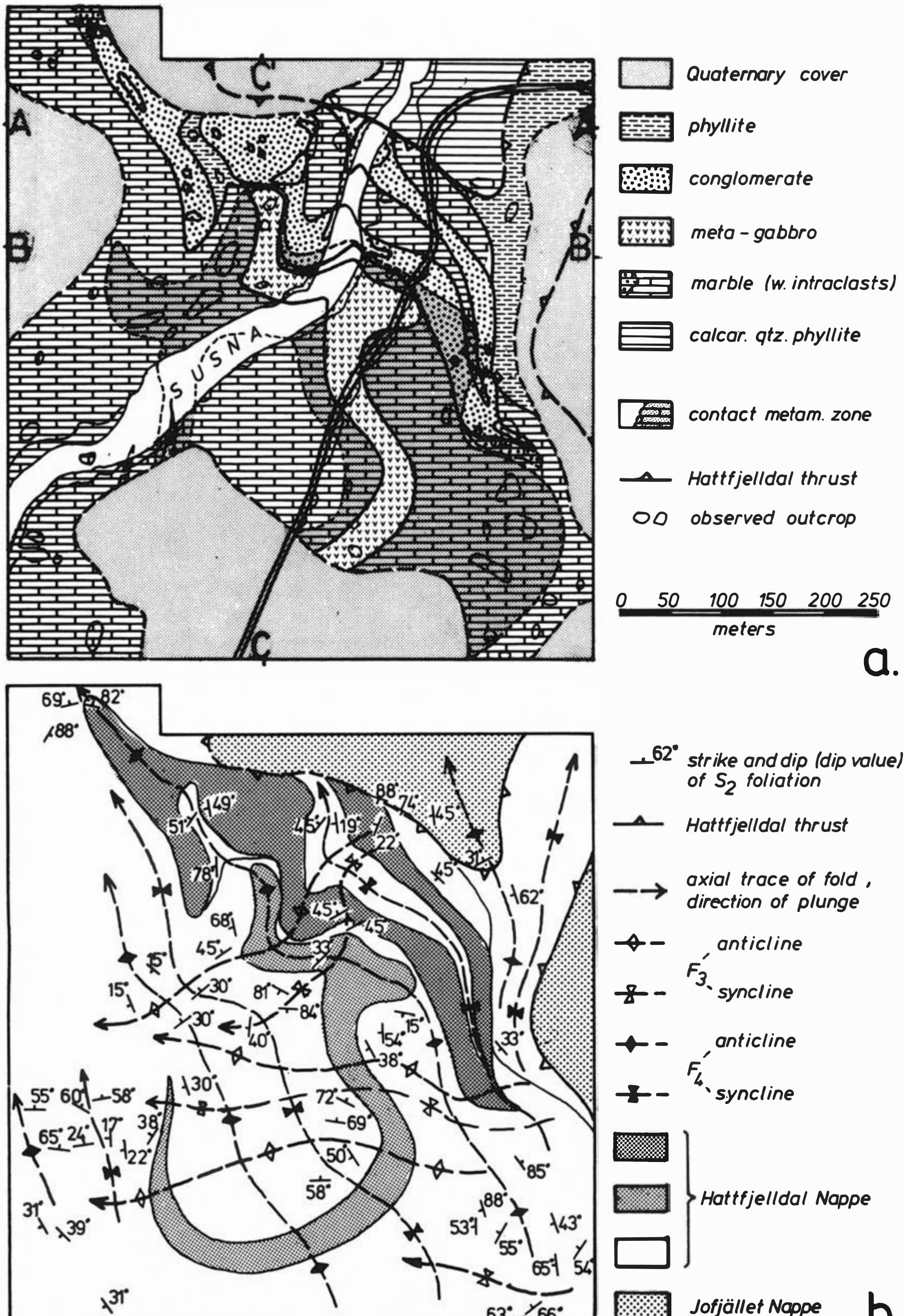
a: Geological map. Lithologic boundaries are based on topography in addition to the observed outcrops.

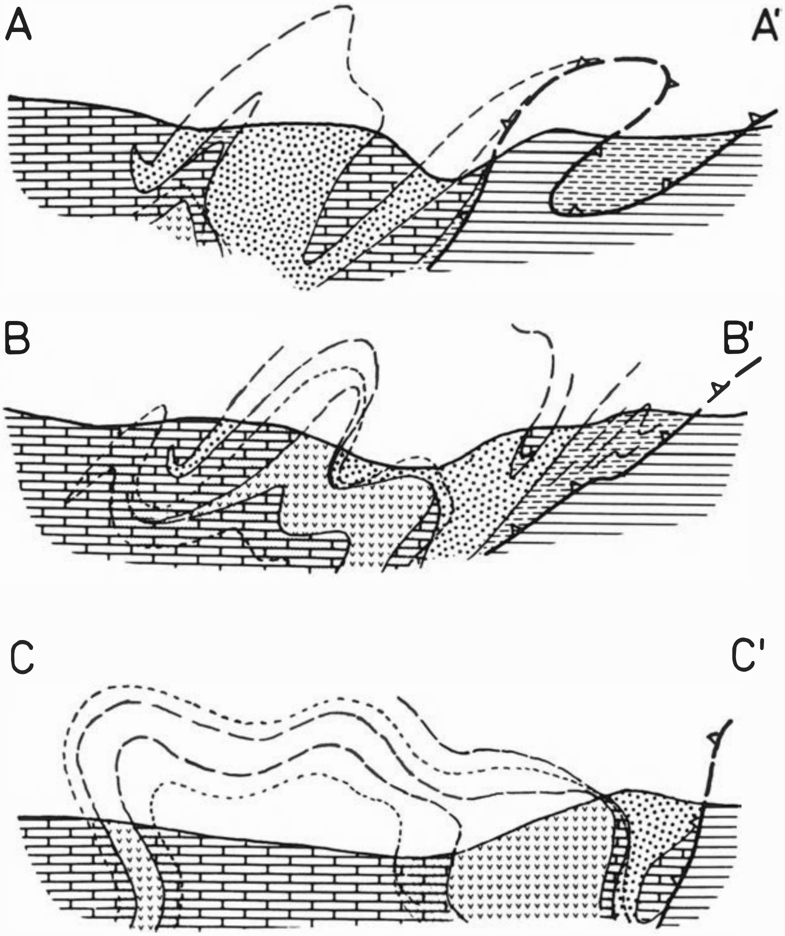
b: Structural interpretation map. Some lithologic layers are shaded to indicate fold traces. Lithologic boundaries are parallel to S_2 foliation.

c: Cross-sections: A-A′ amd B-B′ show mainly F_4 folds, C-C′ mainly F_3 folds.

d: Equal-area stereogram representing post-D_2 structures.

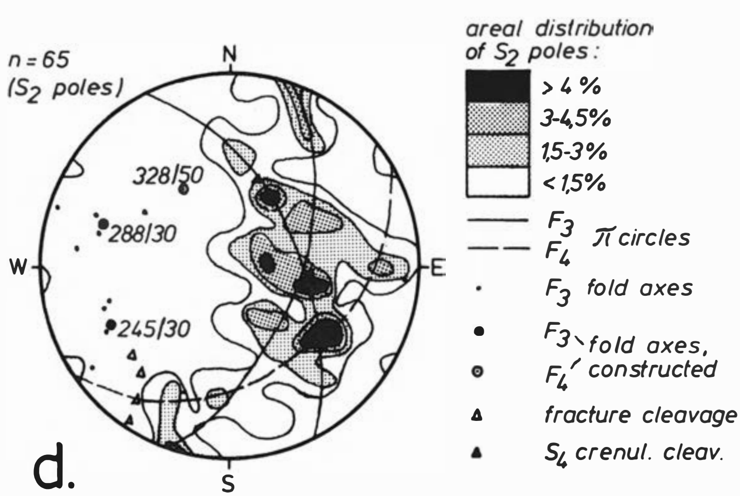
e: Reconstructed lithology with collective information from the entire map area. Position of the Jofjället Nappe's calcareous quartz phyllite on top of the sequence is taken from Dallmann (in prep.).


Quaternary cover
phyllite
conglomerate
meta - gabbro
marble (w. intraclasts)
calcar. qtz. phyllite
contact metam. zone
Hattfjelldal thrust
observed outcrop
0 50 100 150 200 250
meters
SUSNA
a.
strike and dip (dip value) of S_2 foliation
Hattfjelldal thrust
axial trace of fold, direction of plunge
anticline
F_3
syncline
anticline
F_4
syncline
Hattfjelldal Nappe
Jofjället Nappe
b.

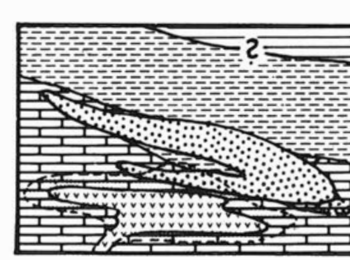


c.

legend and scale see Fig. a.



d.



no scale

same legend as Fig. a.

e.

which points at an F_4 axial surface with low westward dip. The rotation of both F_3 axes by F_4, and F_4 axes by F_3 is indicated by the stereogram (Fig. 10 d). Although there are very few fold axis observations, the necessary information is obtained by tracing of the fold axes on the map (Fig. 10 b).

Fig. 10 e shows the generalized, reconstructed lithostratigraphy of the area to facilitate the understanding of the deformation pattern on Fig. 10 a, b, c. The cross sections (Fig. 10 c) were chosen to demonstrate F_4 folds on the northern limb of the main antiform (A-A′), F_4 folds on the southern limb of the main antiform (B-B′), and the twice refolding of the early isoclinal folds by both F_3 and F_4 (C-C′).

Discussion

The deformation sequence

Early isoclinal folds. – It has been suggested that the large-scale isoclinal folds are mainly D_1 features, which had been superposed and transposed by the D_2 phase to a great extent, so that it is no longer possible to reconstruct orientation, trends of increase of intensity, etc. of these folds. Furthermore, the features related to D_1 deformation may belong to several phases of deformation, which cannot be discriminated. However, it has been stated above that thrusting of the Hattfjelldal Nappe over the underlying Jofjället Nappe occurred and ceased during the D_1 deformation. The thrust was not reactivated during the later D_2–D_4 thrusting of the HNC. This suggests that the Hattfjelldal Thrust was already fixed at an early time in the deformational history of the Köli rocks.

The D_2 phase gave rise to the most penetrative deformational structures in a wide zone underlying the basal thrust of the HNC. The intensity of D_2 deformation increases toward the thrust and is considered as relating to it. Furthermore, the fold geometries suggest an upwards increasing portion of simple shear directed from the west to the east (Fig. 11 a). The illustration is idealized, i.e. it does not take into account the influence of different lithologies, which makes the fold pattern more irregular in nature.

Although it cannot be excluded that at least some of the D_1 structures are the result of early HNC thrusting, the D_2 phase is considered to have been one particular event of thrusting of the HNC onto the Köli nappe pile.

Later events. – D_3 is a phase of transverse folding, i.e. the fold axes are orientated W – E, i.e. subparallel to the direction of nappe transport.

The development of transverse folds in thrust regimes has been discussed since Balk (1936). He stated that transverse folds may be generated under thrusting due to inhomogeneities in both the underlying and the thrusting substratum. In the Scandinavian Caledonides, transverse folds are common. They may refold an earlier set of longitudinal folds (Foslie 1941, Kulling 1950), or both sets may develop contemporaneously (Kautsky & Tenengren 1952, Kautsky 1953, Ramberg 1967). In recent times, the significance of rotation of fold axes into the X-direction of the strain ellipsoid due to stretching within the axial plane of the folds has been emphasized (Sanderson 1973, Escher & Watterson 1974, Rhodes & Gayer 1977). Such fold axis rotation is thought to be due to strongly increased X/Y strain ratio under strong shear stress.

In the Hattfjelldal Nappe, F_3 and F_4 folds were not totally simultaneous, as the F_3 axial planes may be refolded by F_4 (Fig. 6a), though such refolded structures are infrequent. Areas with tight and many transverse folds lack intensive longitudinal folding (F_4). 'Flow folding' and transposition in the thrust zone of the HNC grade into both F_3 and F_4 folds at lower levels. A certain dependence of both fold sets upon each other may thus be suggested. They are supposed to be generally contemporaneous events, due to different strain orientations in different areas. Changing strain ratio in a certain area could give rise to refolding of the transverse by longitudinal folds, whereas transverse folding may have continued elsewhere. Inhomogeneities of regional or local nature may have been responsible for the concentration of transverse folds in certain areas. Those of regional nature may be basement culminations like the Börgefjellet Window (Fig. 1) or minor culminations eventually underlying the Köli rocks. Pinch-and-swell structures like those of the Krutfjellet Nappe (Häggbom 1980, Ramberg 1981) also come into question. Local inhomogeneities are present within the strata of the Hattfjelldal Nappe, e.g. quartzite bodies, which form embayments into neighbouring phyllites or calcite marbles. Those were less competent and consequently easily compressed. A previously mentioned example for fold axis rotation into the supposed direction of nappe transport due to local inhomogeneities is the subarea Va (Fig. 8),

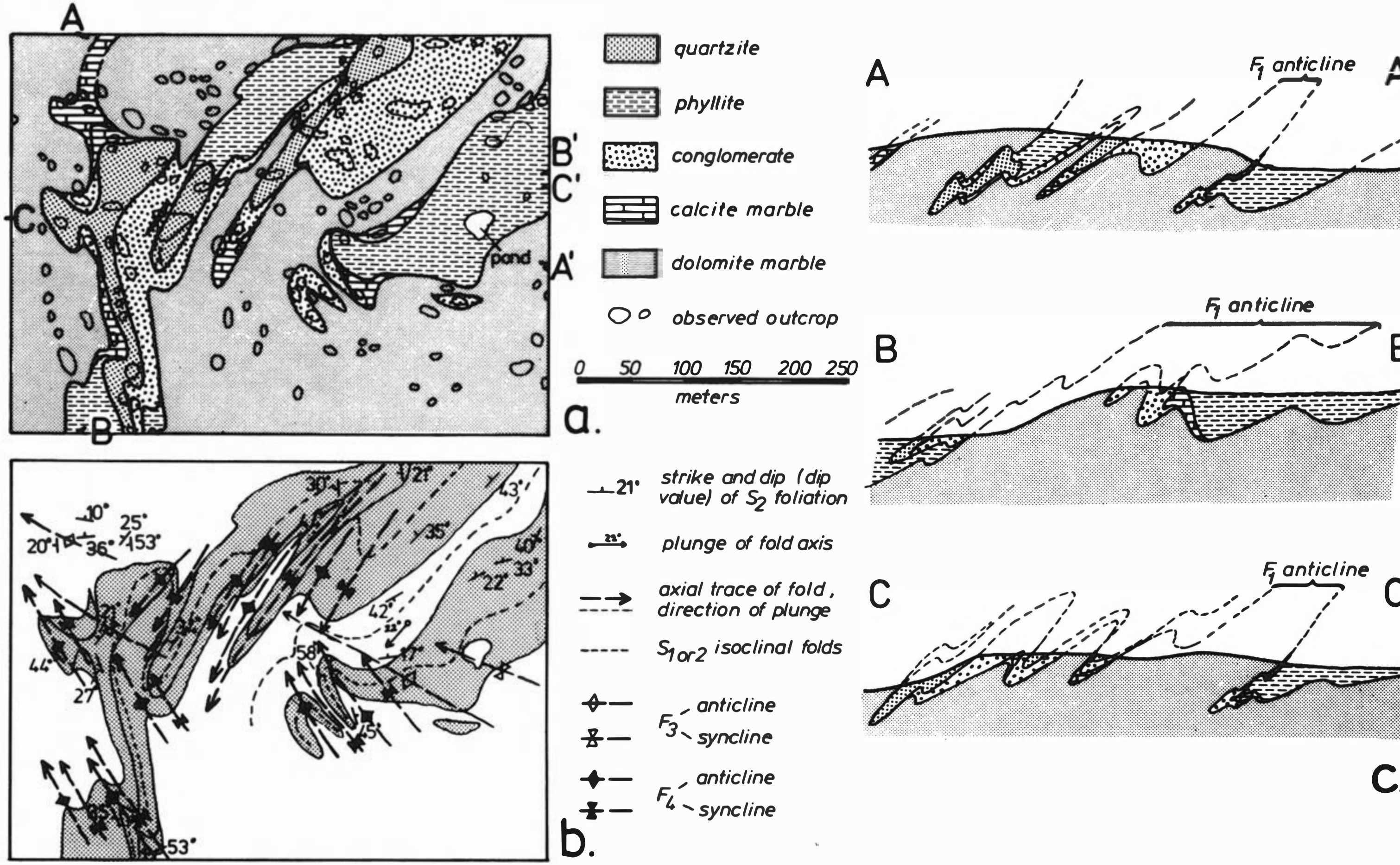
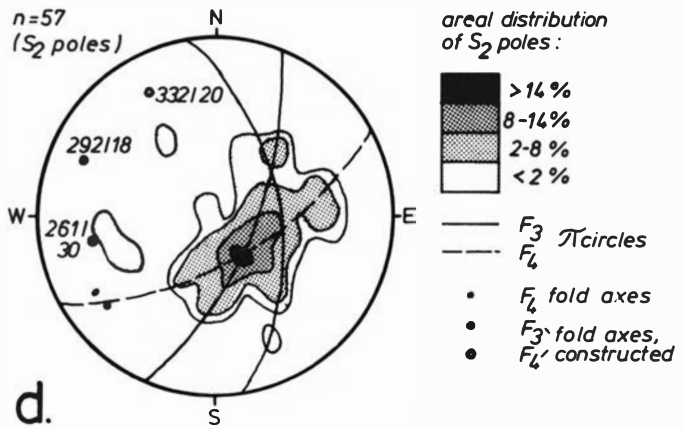
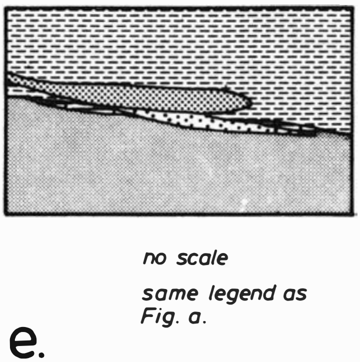


Fig. 10. Structural analysis of the Tjönnlaenget area, Sommerfjellet, Susendalen. Position indicated on Fig. 3. Interpretation in the text.

a: Geological map. Lithologic boundaries are based on vegetation on topography in addition to the observed outcrops.
b: Structural interpretation map. The Limingen Group's lithologies are shaded to indicate fold traces.
c: Cross-sections, showing early isoclinal folds refolded by F_4 (A-A' and B-B') and by both F_3 and F_4 (C-C').
d: Equal-area stereogram representing post-D_2 structures.
e: Reconstructed lithology with collective information from the entire map area.





where a slice of quartz diorite has been emplaced within the marbles of the Hattfjelldal Nappe.

Minor transverse folds in thrust or shear zones – as well as some observed westward plunging stretching lineations – are thought to be due to strongly increased shear movement in the sense of Sanderson (1973), without the necessity of an inhomogeneous substratum.

Longitudinal folding (F_4) follows transverse folding (F_3) in those areas, where refolding has been observed. Also kinking and fracture cleavage are related to F_4, but not F_3 folds, which supports the supposition that the F_4 folds include the latest folds observed in the field. Fig. 11 b shows the changing style of D_4 deformation dependant on the upward increasing portion of simple shear deformation in an idealized manner. In nature, this pattern is complicated by the influence of different lithologies and by the superposition of deformation phases.

Aspects of correlation with the underlying Jofjället Nappe

The only previous publication giving a detailed structural analysis of the Jofjället Nappe is that of Sandwall (1981) from the Swedish Jofjället area ('low-grade part of the Storfjället Nappe'). This area is situated between 20 and 45 km east of Rössvatnet, outside of the map (Fig. 1). There, the Jofjället Nappe underlies a thin wedge of the Akfjället Nappe (a tectonostratigraphic equivalent of the Hattfjelldal Nappe). The Uppermost Allochthon in this area is represented by the Rödingsfjället Nappe Complex (RNC).

Repetitions of the stratigraphy within the Jofjället Nappe are interpreted as resulting from imbrication (Sandwall 1981) In the Hattfjelldal Nappe, however, stratigraphic repetitions usually show symmetric successions (A-B-C-B-A) and are therefore regarded as being caused by isoclinal folding. Nevertheless, D_2 thrust zones of minor importance occur.

Sandwall correlates the thrusting of the Jofjället Nappe and the underlying nappes with his D_2 phase because of the increasing transposition of D_1 by D_2 structures toward the thrusts, resulting in the mylonitic foliations of the thrust zones. He assumes that the nappe emplacement was contemporaneous for all nappes and correlates the D_2 phase of each nappe on the basis of this assumption, involving the possibility of a small diachroneity (p. 89).

The non-contemporaneous emplacement of the Hattfjelldal and Helgeland Nappes onto the respective underlying units, and the downward decreasing intensity of thrust-related deformation (Fig. 11, Sandwall p. 67) put this assumption to question. The mylonitic foliation of a thrust zone may correspond to S_1 in the overlying, but to S_2 in the underlying nappe. Discrimination may be difficult, as both foliations tend to turn parallel to the thrust plane, transposing all earlier structures to such an extent that age relationships can no longer be recognized. Indeed, both Sandwall and I consider the D_1 phase as a composite one, which may hide the record of the respective earlier episodes because of the strong superposition of D_2 structures (Fig. 12).

Sandwall's D_3 phase can most likely be correlated with the D_{3+4} phase in the Hattfjelldal

Nappe, and his D_4 phase with the late kink folds, which I was unable to discriminate from my D_4 phase. Sandwall explains these folds with gravity-controlled disturbance after thrusting. The Hattfjelldal Nappe, however, reveals evidence for continuous thrust movement of the HNC during these phases (Fig. 11 b). A synthesis of both explanations can be made by adopting the model of Gee (1978), where the Caledonian Nappes are considered to have suffered a gravity-controlled collapse after emplacement. This generates stretching tectonics causing further eastward displacement. The presence of a similar interfering system of transverse and longitudinal folds in the HNC (Johnsen 1979) and RNC (Ramberg 1967) fits well with this hypothesis. The Köli Nappes might have suffered this process earlier (e.g. pinch-and-swell structures of the Krutfjellet Nappe; Häggbom 1980, Ramberg 1981).

Conclusions

The established sequence of deformation of the Hattfjelldal Nappe and the suggested generating events are summarized in Table 2. The following conclusions of more general character can be drawn:

The thrusting of the Hattfjelldal Nappe over the Jofjället Nappe ceased considerably earlier (D_1) than the thrusting of the Helgeland Nappe Complex over the Hattfjelldal Nappe ($D_{2\text{-}4}$). The D_2 to D_4 phases of folding are related to thrusting of the Helgeland Nappe Complex under changing strain and ductility conditions (Fig. 11).

The D_1 and D_2 phases are dominated by isoclinal folding of the strata. Nappe imbrication, e.g. observed by Sandwall (1981) in the Jofjället Nappe (Jofjället area), is of minor importance here. That the early phases of isoclinal folding in neighbouring nappes can be correlated with each other is uncertain, because of the possible step-

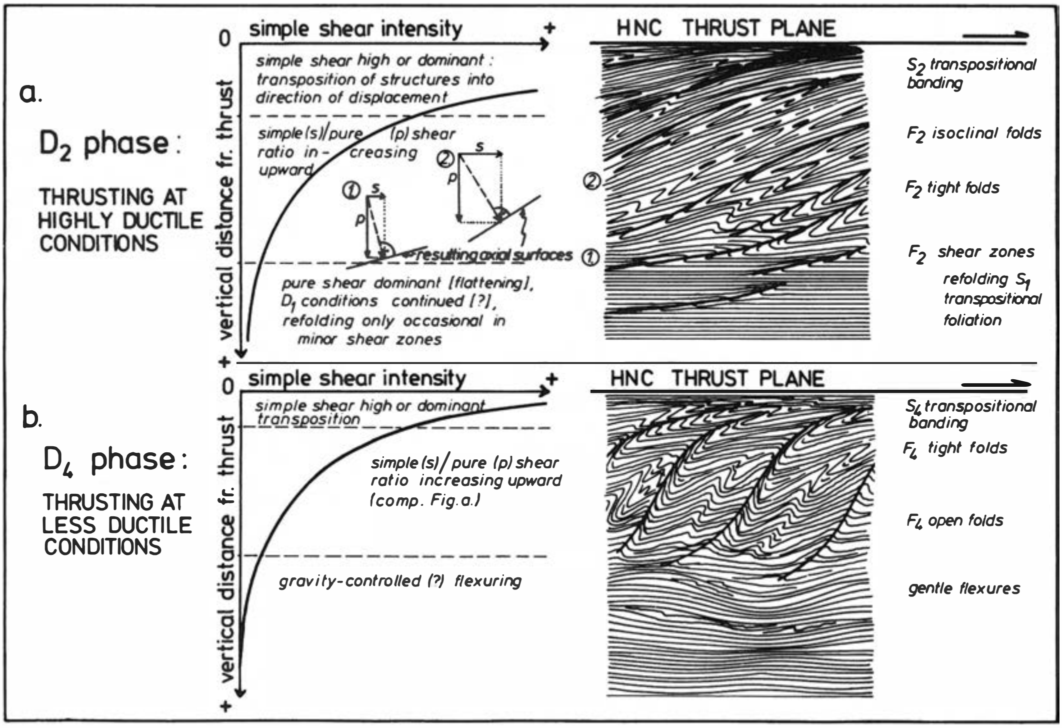


Fig. 11. Diagram to show the style of deformation of the Hattfjelldal and upper part of Jofjället Nappe during the D_2 and D_4 phases, dependant on the distance from the Helgeland Thrust. The diagram is idealized, i.e. it does not take into account the influence of different lithologies, nor minor thrust zones within the Hattfjelldal Nappe.

The lower curves of the S-shaped axial surfaces are the result of increasing simple shear portion, the upper curves are due to strongly increasing transposition in the vicinity of the Helgeland Thrust.

Note that comparable structures in both sections set in at a *higher* level during D_4, because the medium reacts less ductilely.

wise translation of the deformation phases from one nappe to the next (Fig. 12).

The D_3 transverse and D_4 longitudinal folds seem to have developed more or less simultaneously, with a tendency toward the longitudinal trend. Transverse folding is mostly considered to relate to lithologic inhomogeneities of the substratum.

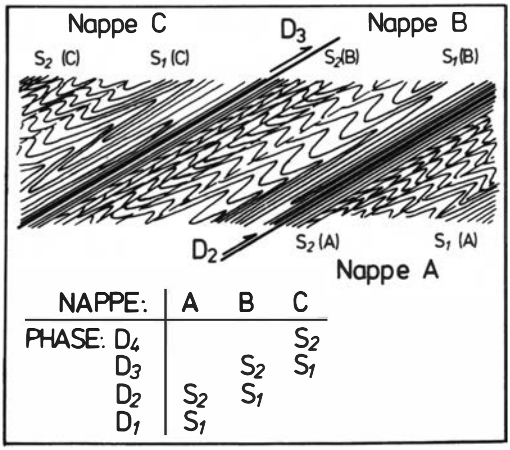


Fig. 12. Idealized sketch to demonstrate the resulting foliations by a stepwise emplacement of nappes. Explanation in the text.

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References

Balk, R. 1936: Geological studies of sedimentary rocks. *Geol. Soc. Am. Bull. 47,* No. 5, 685–774.

Dallmann, W. K. 1984: Stratigrafi og tektonostratigrafi i Kölidekkene, Helgeland, som indikasjoner på en ordovicisk kontinent-öybue kollisjon. Abstr. NGF IX Landsmöte, Tromsö Jan. 1985. *Geolognytt 20,* p. 21.

Carey, S. L. 1954: The rheid concept in geotectonics. *Geol. Soc. Australia Jour. 1,* 67–117.

Escher, A. & Watterson, J. 1974: Stretching fabrics, folds and crustal shortening. *Tectonophysics 22,* No. 3–4, 223–231.

Foslie, S. 1923: Grongdistriktet. *Nor. Geol. Unders. 98,* 27–42.

Foslie, S. 1924: Grongdistriktet. *Nor. Geol. Unders. 122,* 59–70.

Foslie, S. 1941: Tysfjords geologi. *Nor. Geol. Unders. 149,* 298 p.

Færden, J. 1953: Sink-bly forekomstene ved Mikkeljord, Hattfjelldal i Nordland. *Nor. Geol. Unders. 184,* 145–153.

Gee, D. G. 1975: A tectonic model for the central part of the Scandinavian Caledonides. *A. J. Sci. 275 A,* 468–515.

Gee, D. G. 1978: Nappe displacement in the Scandinavian Caledonides. *Tectonophysics 47,* 393–419.

Gustavson, M. 1978: Caledonides of North-Central Norway. IGCP project 27, Norw. contrib. No. 5 c, *Geol. Surv. Canada, paper 78–13,* 25–30.

Häggbom, O. 1980: Polyphase deformation in a discontinuous nappe in the Central Scandinavian Caledonides. *Geol. Fören. Stockh. Förh. 100,* 349–354.

Holmsen, G. 1912: Oversigt over Hatfjelddalens geologi. *Nor. Geol. Unders. 61,* 34 p.

Johnsen, S. 1979: *Petrografisk, petrologisk og strukturgeologisk undersökelse i Elsfjord/Korgen området, Nordland.* Unpubl. cand. real. thesis, Univ. of Oslo, 347 p.

Kautsky, F. & Tenengren, F. G. 1952: Die Geologi der Umgebung des Tuoddarjaure. *Geol. Fören. Stockh. Förh. 74,* 455–473.

Kautsky, G. 1953: Der geologische Bau des Sulitjelma-Salajaure Gebietes. *Sver. Geol. Unders. C 528, årbok 46, No. 4,* 228 p.

Kulling, O. 1950: Berggrunnen södcr om Torneträsk. *Geol. Fören. Stockh. Förh. 72,* 454–471.

Lutro, O. 1979: The geology of the Gjersvik area, Nord-Trön-delag. *Nor. Geol. Unders. 354,* 53–100.

Mörk, M. B. E. 1979: *Metamorf utvikling og gabbro-intrusjon på Krutfjell, Nordland.* Unpubl. cand. real. thesis, Univ. of Oslo, 307 p.

Ramberg, I. B. 1967: Kongsfjell-områdets geologi, en petrografisk og strukturell undersökelse i Helgeland, Nord-Norge. *Nor. Geol. Unders. 240,* 152 p.

Ramberg, I. B. 1981: The Brakfjellet Tectonic Lens: Evidence of pinch-and-swell in the Caledonides of Nordland, North-Central Norway. *Nor. Geol. Tidsskr. 61,* 87–91.

Ramberg, I. B. & Stephens, M. B. 1981: *The Central Scandinavian Caledonides – Storuman to Mo i Rana* (excursion guide). Uppsala Caledonide Symposium 1981, excursion N. A 3.

Rekstad, J. 1924: Hattfjelldalen. Beskrivelse til det geologiske generalkart. *Nor. Geol. Unders. 124,* 35 p.

Rhodes, S. & Gayer, R. A. 1977: Non-cylindrical folds, linear structures in X-direction and mylonite development during translation of the Caledonian Kalak Complex of Finmark. *Geol. Mag. 114, No. 5,* 329–408.

Roberts, D. 1978: Caledonides of South-Central Norway. IGCP project 27, Norw. contrib. No. 5 d, *Geol. Surv. Canada, paper 78–13,* 31–37.

Sanderson, D. J. 1973: The development of fold axes oblique to the regional trend. *Tectonophysics 16,* 55–70.

Sandwall, J. 1981: Caledonian Geology of the Jofjället area, Västerbotten County, Sweden. *Sver. Geol. Unders. C 778, årbok 74, No. 6,* 105 p.

Stephens, M. B. & Gee, D. G. 1985: The tectonic evolution of the Caledonides in Central Scandinavia. *In* Gee, D. G. & Sturt, B. A. (eds.), *The Caledonian orogen – Scandinavia and related areas.* John Wiley & Sons, New York.

Stephens, M. B., Gustavson, M., Ramberg, I. B., Zachrisson, E. 1984: The Caledonides of Central-North Scandinavia – a tectonostratigraphic overview. *In* Gee, D. G. and Sturt, B. A. (eds.), *The Caledonian orogen – Scandinavia and related areas.*

Strand, T. 1953: Geologiske undersökelser i den söröstlige del av Helgeland. *Nor. Geol. Unders. 184,* 124–141.

Strand, T. 1955: Sydöstlige Helgelands geologi. *Nor. Geol. Unders. 191,* 56–70.

Stölen, L. K. 1985: *En geologisk studie av solitære ultramafiske bergarter og omkringliggende metavulkanitter/metasedimenter i Krutådalsområdet, Hattfjelldal, Nordland.* Unpubl. cand. scient. thesis, Univ. of Oslo.

Sverdrup, E. 1985: *Et strukturgeologisk studium av Helgelandsdekkets skyvefront, der den ligger over Seve-Köli dekkekompleks i sydlige deler av de sentrale, nordskandinaviske Kaledonider.* Unpubl. cand scient. thesis, Univ. of Oslo.

Theisen, R. & Dallmann, W. K. 1984: *Kartlegging i Favnvatnområdet, Hattfjelldal, Nordland.* Internal report, Prospektering A/S, Stabekk, Norway.