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EXCURSION GUIDE: The otta nappe and its integration into the Trondheim Nappe in the South-Central Scandinavian Caledonides.

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Summary:
This is an excursion guide for the Gudbrandsdalen - Nord-Østerdalen Region. It emphasises change in the stratigraphy/tectonostratigraphy from previous models. The excursion demonstrates the presence of major unconformities in the sequence and a major synclinal recumbent fold (Jonndalen Syncline).

Keywords: Excursion	Stratigraphy	
Otta Nappe	Tectonostratigraphy	
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EXCURSION GUIDE

The Otta Nappe and its integration into the Trondheim Nappe in the South-Central Scandinavian Caledonides.

By

Donald M.Ramsay and Brian A.Sturt

INTRODUCTION

Recurring changes in the pattern of lithospheric process along the Caledonide margin of Baltica, throughout the Lower Palaeozoic, are suggested by the evidence of rifting, island arc and back-arc basin formation, collision, subduction and obduction. These resulted in a polyorogenic historical record with major events in late Cambrian - early Ordovician, mid - late Ordovician, mid - late Silurian and late Devonian times. The first two orogenies resulted from arc - continent collisions, whilst the Silurian climax resulted from continent - continent collision.

Modern opinion on the evolution of the Caledonian orogenic belt, in Scandinavia, is divided between two schools of thought :

(1) The train of events leading to the formation of the belt occurred along the margin or peripheral to Baltica.

(2) The succession of orogenic events was concentreated initially in a peri-Laurentian setting, the allochthonous and exotic elements of the Scandianavian nappe pile only being acquired during the climactic collision of Baltica and Laurentia.

The evidential data-pool for the first line of argument is large and varied and derived from a range of geological disciplines, i.e. sedimentology and lithostratigraphy, structural geology, palaeomagnetism, Pb-isotopes and geochemistry. Argument in support of the second viewpoint leans heavily on interpretation of the palaeontological record, in particular in regard to faunal provincialism.

The polyorogenic, as distinct from polyphasal, history of the belt has been overlooked by many earlier workers leading to unified model interpretations rather than the build-up of a composite orogenic montage.

Orogenesis is manifest in thrust nappes, polyphasal folding and plurifacial metamorphism. Physiographically this has been associated with island arcs, orogenic welts, inter-orogenic quiesence with denudation, regression-transgressional basinal turbidite sedimentary associations, in a recurring sequence.

1.2 Geology of the Trondheim Nappe Complex.

The Trondheim region between the Grong-Olden and Otta-Vågåmo areas is dominated by a major slab of the Upper Allochthon. Conventionally this is differentiated into a number of nappes in the so-called Trondheim Nappe Complex (TNC), disposed in a broad basinal structure (Fig. 1). The nappe sequence of the Trondheim region has played a dominant role in thinking on the evolution of the Scandian Caledonide Belt.

In the TNC the status of the Gula Gp. and its axial position, separating two belts of Ordovician-Silurian rocks, has been a source of debate for more than a century

(Fig. 3). These Ordovician-Silurian sequences have been correlated with the Køli sequences further East and North, in Sweden, while the Gula and its equivalents have been likened to the Seve in the same regions.

Conventionally each of these belts has been interpreted as a separate nappe (Table A, Fig.2). The Støren and Meråker Nappes (Ordovician-Silurian) were originally equated, but more recent investigations (Grenne and Lagerblad 1985) have highlighted significant geochemical differences between the prominent volcanic members in each i.e. the Støren and Fundsjø (= Hersjø = Folldal) Volcanic Fms. These differences suggest non-contiguous provenances for the volcano-sedimentary sequences, even if they are time equivalents. Grenne and Lagerblad (1985), suggested that a thrust must separate the two belts, located at the western margin of the Gula Gp., with the low grade Tronget unit beneath the Støren Volcanic Gp. Guezou (1978) carried this proposed thrust southwards to intersect the basal thrust of the TNC south-west of Dombås. At Dombås the present authors, on the other hand, traced the Gula Gp. round the termination of the Støren Belt onto the western side of the Dombås (= Støren) Belt, i.e. the Drivdalen Belt; thereby casting doubt on the existence of this thrust and its tectonostratigraphic consequences (Map 1).

The lack of connection between the Støren and Meråker Belts and the status of the enigmatic Gula Gp. has coloured interpretations of the Trondheim region. It is perhaps suprising that the relationship of the Gula Belt to the Seve-type psammite-schist sequences flanking the Støren and Meråker Belts, on the western and eastern margins respectively of the TNC, has received comparatively little attention. Rather, these marginal belts have been assigned to small nappes beneath the main TNC, i.e. Skjøtingen and Essandsjø Nappes (Fig. 2). At the northern end of the TNC, where study has been most intensive, evidence of a connection between these belts has not been forthcoming. In the Otta - Vågåmo area of the South, however, the Heidal Group can be traced continuously into the main Gula Belt and round the terminations of the Støren and Meråker Belts into the afore-mentioned psammitic sequences, along either margin of the TNC (Maps 1 and 2). It is obvious, therefore, that both belts of Ordovician - Silurian rocks have an envelope and substrate of Heidal Gp. (= Gula) equivalents, giving a greater continuity to the large-scale structure.

Insufficient data on stratigraphic polarity within the Ordovician - Silurian Belts, together with uncertainty concerning the nature of key lithostratigraphic contacts has made the internal structure of the belts uncertain and their origins speculative. As thrust-nappe tectonics has dominated modern thinking and most structural analyses, the number of thrusts has increased with the passage of time, thereby diminishing concerns over stratigraphy. In consequence very different interpretations have emerged, typified by the Røros area and the eastern part of the TNC (Fig. 2).

In the Røros region Rui (1972) mapped a stratigraphy free of the major stratigraphic breaks suggested by other workers (Nilssen 1978, Nilssen and Wolff 1989, Gee et al. 1985, Roberts and Wolff 1981) and confirmed the major stratigraphical inversion of the sequence suggested by earlier authors (Bugge 1954, Wolff 1967), see also Table B and Fig. 3. This inversion he envisaged as persisting eastwards across Østerdalen as far as the first major thrust separating the sequence from the sparagmites of the underlying Middle Allochthon, making the structure a major recumbent fold (Fig. 3). Suprisingly, he paid little attention to the structurally lowest member namely, the augen gneisses of Rapakivi-type, especially with regard to their stratigraphic significance. On his map these are merely referred to as Caledonian augen gneisses. However, this unit can be traced westwards and into Gubrandsdalen where a U-Pb zircon age of 1189 +/- 1.0 Ma. (Table B) has been obtained (Sturt et al. 1998).In contrast to Rui's suggestion of a continuous sequence with non-tectonic contacts, several other authors have proposed a more complex interpretation involving a number of smaller nappes beneath the TNC (Table C).

The eastern margin of the TNC (Nilssen and Wolff 1989) is sited between the phyllite sequence east of the Setershø Conglomerate and the greywacke-sandstone-phyllite assemblage of the Røros Gp. (Rui and Bakke 1975). This latter group is referred to as the Øyfjell Nappe (Fig. 1). The psammite-quartzite dominated Hummelfjell Gp. of Seve-style rocks (Table B) was assigned to the Essandsjø Nappe and the augen gneisses at the margin of the TNC to the Remsklepp Nappe (Fig. 1). In the 1:250,000 map Røros & Sveg, Nilsson and Wolff (1989) put forward a somewhat different pattern. They identified the Ordovician-Silurian sequence East of the Meråker Nappe, i.e. the afore-mentioned Røros Gp. and the thin southward extension along Østerdalen as the Øyfjell-Essandsjø Nappe Complex. The Hummelfjell Gp. And augen gneiss were regarded as members of the Remsklepp Nappe (Fig. 2). Both models, however, assign the Øyfjell, Essandsjø and Remsklepp Nappes to a sub-TNC assemblage of Seve-Køli type rocks.

Stephens and Gee (1985) proposed, in addition, another thin nappe situated between the Øyfjell and Essandsjø Nappes in the ground between Feragen and Alvdal, in Østerdalen, to accomodate the belt of ultramafic bodies. This was correlated with the lowermost nappe of the Tännfors Nappe Complex in Sweden. Rui (1972), on the other hand, emphasized an older view on the stratabound character of the string of serpentinite bodies sited on a single stratigraphic horizon close to or at the western margin of the Hummelfjell Gp. This can be traced from Feragen to Tolga, Alvdal, Folldal to Gudrandsdalen and Otta-Vågåmo. He also observed that the close association of serpentine or talc conglomerate with the ultramafites precluded an intrusive origin in the sense of Wolff (1967). The present synthesis returns to a revised version of Rui's views namely, that formational boundaries are largely non-tectonic. The sequences of each of the postulated nappes can be integrated into a single coherent and rational pattern, constrained by evidence of stratigraphic polarity (Map 5) and continuous lateral connection to the Otta-Vågåmo area (Sturt et al. 1991), where stratigraphic relationships are clear and unambiguous (Fig.2 and Table C).

The distinctive sequences of the separate nappes outlined above reflect different parts of the tectonostratigraphic model established in the Otta Nappe. Thus, the augen gneiss (= Hovringen Gneiss Gp.) together with the psammite dominated Essandsjø sequence correlate with the miogeoclinal *Seve-style* assemblage, i.e. the Hovringen Gneiss and Heidal Gps. The thin nappe characterised by ultramafic/mafic rocks is equivalent to the Vågåmo Ophiolite (VO) (Table C), while the *Køli-type* sequences of the Øyfjell Nappe equate with those of the Meråker Belt but demonstrating normal polarity (Map 5). All of these constitute the lower limb of the major recumbent Jonndalen Syncline (see section 2.3.3. and Table B).

Non-recognition of major unconformities has resulted in the whole Seve-Køli sequence being treated as a stratigraphic entity with a common tectonothermal history. The present authors have shown the existence of a major tectonothermal hiatus (Sturt et al 1998) with the high grade (Amphibolite Facies) assemblage of the Heidal Gp. pre-dating the unconformity at the base of the Ordovician Sel Group (Greenschist Facies).

The perception of the Ordovician - Silurian belts occuring in the cores of recumbent or tight synclines, with Heidal Gp. envelopes, strongly favours a return to a fold dominated pattern for the internal structure of the Trondheim Nappe. This proposes an axial mushroom-like anticline flanked by opposite-facing recumbent synclines (Fig. 3) and an overall Orthorhombic Symmetry (Roberts et al. 1970). Fabric analysis, by the authors, dates this structure as D2 in the regional tectonochronology.

1.3: Stratabound sulfide mineralizations in the Eastern part of the Trondheim Nappe Complex.

The Eastern part of the Trondheim Nappe Complex was a major producer of copper and pyrite for more than 350 years and was in this century also an important producer of zinc. The last mine in the region (Killingdal) was closed down in 1987, and after that, only very limited prospecting has been carried out to try to find new ore deposits.

Stratabound sulfide deposits are found in different settings in the region and deposits which may be classified as both Cyprus, Besshi and possibly also Kuroko-type deposits occur.

Deposits in the sedimentary Hummelfjell Group are mainly associated associated with metasediments and no apparent relationship to volcanic rocks, of which the Baugsberget and Tron deposits in Alvdal are the most important (Nilsen 1988). The deposits are pyrrhotitic and cupriferous ores, with low contents of zinc and lead.

Deposits associated with the Vågåmo ophiolite are mainly situated within the sequences of pillow lavas and sheeted dikes and are pyritic, low-grade deposits with a relative enrichment of copper. One example is the Åsoren deposit in Otta which contains reserves of 730000 t with 1.4 % Cu (Rosenquist 1976).

The Røros deposits occur in diverse sedimentary sequences (phyllite, greywacke, sandstone and tuffite) known as the Aursund Group. The deposits are typically situated very close to gabbroic bodies (probably sill-like intrusions), but the deposits are without any obvious relationship to those. The deposits have to a large degree been regarded as being dominated by copper, but actually most deposits in this district are dominated by zinc and also have relatively high contents of lead, silver and in some cases gold. A total of about 6 mill. t ore and about 160000 t Cu-metal was produced from mainly 8 different mines in the area (Bøckman 1942).

Interpretations of geochemistry show that the volcanic units in the Sel Group, i.e. the Hersjø/Fundsjø formations, are of island-arc/back-arc affinity (Grenne 1988, Bjerkgård & Bjørlykke 1994). Deposits in these units vary considerable in compositions, which appear to be mainly controlled by the host rocks of the deposits (Bjørlykke et al. 1993, Bjerkgård & Bjørlykke 1996). Deposits associated with metabasalts have typically a much higher Cu/Zn-ratio and have very low contents of Pb and most trace metals compared to deposits associated with felsic volcanic rocks and especially deposits associated with volcaniclastic rocks (Bjerkgård & Bjørlykke 1994, 1996). Important deposits in this volcanic environment are the Folldal deposits (total of 4.5 mill.t. ore produced from 4 mines), and the Sivilvangen (reserves of 0.7 mill. t.), Vingelen, Hersjø (reserves of 6 mill. t) and Killingdal (3 mill.t produced) deposits.

Deposits in the sedimentary Gula Group are mainly pyrrhotitic and cupriferous ores associated with amphibolites, whereas contents of zinc and lead are very low. Examples includes the Kvikne, Børsjøhø and Røstvangen deposits (Nilsen 1978, 1988). Deposits associated with metasediments and no apparent relationship to volcanic rocks also occur, such as the Fløttum deposit. The sediment-hosted Gula deposits are rich in zinc, lead, arsenic, gold and silver, as opposed to the deposits associated with the amphibolites.

The new models for tectonostratigraphy in the Eastern Trondheim Region, means that the structural and palaeotectonic setting of many sulfide deposits must be revised. Accordingly new lessons will be learned which will be very important for, and should lead to, prospecting after new deposits in the region.

2 The Otta Nappe

2.1. TECTONOSTRATIGRAPHY

The tectonostratigraphy of the Otta Nappe (ON)(Table C) comprises four major rock groups (Fig. 5) derived from two very different provenances. The Heidal Gp. sedimentary sequence and its substrate of cratonic gneisses represents the distal miogeoclinal sequence of Baltica. The exotic VO is a fragmented relict of ophiolite derived from the oceanic (Iapetus) sector and thrust over the Hovringen Gneiss - Heidal Gp assemblage during a Late Cambrian - Early Ordovician Orogeny(Sturt et al.1991, Bøe et al. 1993).The Sel Gp is a predominantly basinal turbidite - shale sequence with extensive developments of conglomerates, deposited over the drowned, deeply dissected roots of the early orogen, sited along the western edge of Baltica. This Sel Gp sequence contains major developments of volcanic rocks.

The whole assemblage consitutes a *nappe within a nappe* i.e. a Finnmarkian (Late Cambrian - Early Ordovician) Nappe within a larger Scandian nappe (ON), emplaced during the main Scandian Orogeny. The ON is a sensibly flat-lying, saucer-shaped slab delineated by the outcrop of the basal plinth of Høvringen Gneiss (Maps 1 & 2). This can be traced northwards from the Otta-Vågåmo area to beyond Feragen in the northeast and Vågåvatn to Dombås and Oppdal along its western margin. The relatively simple form of the ON is in marked contrast to the structural complexity of the cover sequences.

2.2. LITHOSTRATIGRAPHY

The typical lithostratigraphies of the different groups of the ON are given in Section 2.2.1. (Table C). The nature of the contacts between the major groups is summarized in Table C.The major groups of the ON display no conformable 'in sequence' stratigraphic contacts. The Otta Thrust at the base of the nappe (Fig. 5) is associated with a zone of blastomylonites of variable thickness in which there is a progressive reduction of the rapakivi-type granite protolith to augen gneiss, gneiss mylonite and finely banded blastomylonite.

The Heidal Gp.rests unconformably on the Proterozoic gneiss with a basal facies that is generally psammite and only locally conglomerate. There is no tectonic break at this level as postulated in some syntheses (Gee and Roberts 1985).

The base of the VO is a thrust plane attended by a zone of mylonitisation. This is older than the other major thrusts of the nappe sequence which are Scandian in age. This thrust provides a strong clue to the nature of the pre-Arenig (Finnmarkian) Orogeny, i.e. structure characterised by thrust nappes.

The unconformity at the base of the Ordovician Sel Gp. is markedly transgressive, in.places overstepping the VO and several members of the Heidal Gp. (Fig. 4 and Fig.5), and locally coming close to the subjacent gneisses. The basal facies of the Sel Gp. varies considerably along the belt, but in the Otta - Vågå tract is generally of phyllite and sandstones with locally extensive developments of conglomerate (Bøe et al 1993). Some of the latter are well-bedded though others have the characteristics of mass-flow deposits. The Sel Gp with its fossil time markers (Tremadoc, Arenig and Llanvirn) puts constraints on both the docking age of the contrasting terranes and the location of Early Ordovician depocenters.

LITHOLOGIES

2.2.1.Høvringen Gneiss Group.

The most distinctive member of this group is an acid augen gneiss of rapakivi-type derived from a coarse megacrystic protolith with K-feldspars up to 20cm. across. The rapakivi granite is intrusive into an older complex of tonalites, anorthositic gabbro and paragneisses. In the Caledonian reworking these gneisses become variably schistose, climaxing in gneiss mylonites and banded blastomylonites in the vicinity of larger thrusts.

2.2.2 HEIDAL GROUP

A broad three-fold sub-division of this group is possible (Table C) although the passage from one to the other is transitional.
The Lower Heidal Group : This is a pale-grey psammite and quartzite-dominated group with minor developments of quartz- and mica-schist and local sometimes thick developments of polymict conglomerate. The conglomerate is clast-supported, massive to well-bedded with pebbles of different types of gneiss, quartzite, psammite and vein quartz. This facies is locally basal, but more commonly somewhat up-sequence. The maximum development of conglomerate is in the Lågen gorge - Rusten area, North of Sel village.

The psammites and quartzites are typically strongly banded in thick and thin banks. Cross-bedding is found in many localities, but the more common aspect is parallel banding reflecting variable bulk strains. On Hummelfjell and neighbouring areas, considerable quantities of intrusive diabase dykes occur, which are considered to be the equivalents of the Ottfjället (Iapetus opening) dykes.

The Middle Heidal Group : The characteristic of this division is an increase in the lime content manifested in the widespread growth of a calcic hornblende. Typical assemblages are garnetiferous garbenschiefer and garbenfels (+/- diopside, scapolite), amphibole-mica schists, thin psammites, garnet-mica schist (+/- kyanite, staurolite, sillimanite), dolomite and limestone.

The Upper Heidal Group : The characterisitic aspect of this division is the appearance of grey-black graphitic mica schist interbanded with white quartzite and passing up into a sequence dominated by black schist.

2.2.3. THE VÅGÅMO OPHIOLITE (VO).

A complete though disrupted ophiolite pseudostratigraphy is preserved in the VO of the Otta-Vågå tract with upper mantle hartzburgites and dunites, cumulate and varitextured gabbros, sheeted diabase dykes, trondhjemitic dykes, pillow lavas with occasional inter-pillow chert. In the eastern and northeastern parts of the ON the VO is mainly preserved as serpentinized hartzburgites and dunites, in which primary chromite banding and disseminated mineralisation is often well preserved, with less common wehrlites and cumulate gabbros with diabase dykes (Nilsson et al. 1998).

2.2.4. THE SEL GROUP.

In the Otta -Vågå area the Sel Gp. is a phyllite-dominated sequence with local developments of conglomerate, turbidite and sandstones (often current bedded). Volcanism in this area is restricted to thin acid and basic tuff horizons and sporadic levels of impersistent greenstones. In the Dovre area, at the northern end of the Otta-Vågå tract,greenstones (frequently pillowed) and tuff bands are more prominent up-sequence. This passes laterally eastwards into a mappable volcanic member prominently developed at Folldal, i.e. the Folldal (= Hersjø and Fundsjø) Volcanic Fm..Typical Sel lithologies in the Otta-Vågå tract are black slate-phyllite, grey-bronze phyllite with random amphibolite (tremolite-actinolite), hard quartz-mica garbenschiefer, grey thick-bedded sandstone, and a variety of conglomerates.

Three facies of conglomerate are developed in the Lower Sel, most typically in the Otta-Vågå tract (Fig. 4). The Otta Conglomerate is a near monomict rock comprising cobbles and pebbles of serpentinite, variably altered to talc, set in a talcose matrix (+/- magnesite). This serpentine conglomerate may be clast- or matrix-supported. The To Conglomerate, named after To farm near Otta, is a polymict conglomerate with cobbles of gabbro, greenstone, trondhjemite, psammite, quartzite, granite, garbenschiefer, ultramafite, gneiss, vein quartz etc. In some localities it is a matrix supported mass flow deposit, while in others it may be well-bedded, clast-supported or graded. The Skardshoi Conglomerate characterises the northern part of the Otta-Vågå area, particularly where the ophiolite is missing. This is a more oligomict conglomerate with pebbles of quartzite, vein quartz and sporadic greenstone, set in a matrix of quartz sandstone or schist and locally carbonate.

Conglomerate may occur at the base of the Sel sequence but more commonly it occurs up sequence (Fig. 13). One or more facies may occur in any one development. A detailed account of the conglomerates and their sedimentology is to be found in Bøe et al. (1993).

In Østerdalen, N. Of Vangrøftdalen, the Lower Sel passes laterally into a sandstone-turbidite sequence. On the western side of the Meråker Belt this facies is predominantly quartz sandstone - greywacke, interbedded with black phyllite. North of Øyungen this facies reverts to a phyllite dominated one (+/- minor conglomerate and limestone). In places, such as the Ålen area, basic volcanics dominate the lower part of the Sel. On the eastern side of the belt the Lower Sel Gp.is represented by a dominantly greywacke, variably calcareous, i.e. grey sandstone, amphibole sandstone, garbenschiefer, quartz garbenschiefer, black and silver phyllite and sporadic developments of conglomerate (Røros Gp.).

The Folldal (= Hersjø, Fundsjø) Volcanic Fm. suceeds the above-mentioned Lower Sel Gp. on the western side of the Meråker Belt (Table B). This is a sequence of basic (dominant) and acid volcanic flows and tuffs, together with green and grey phyllites.

Above the Folldal Volcanics the Sulåmo Fm. is a black phyllite - grey sandstone sequence culminating in the polymict Setershoi Conglomerate. This polymict conglomerate contains pebbles of gneiss, granite, amphibolite, psammite, trondhjemite and greenstone set in a quartz sand matrix. Mud-flakes are not uncommon in the conglomerate.

2.3. STRUCTURE

The *nappe within nappe* form of the ON, together with the terrane-linking basal Sel unconformity highlights role of the latter in partitioning tectonothermal events into two discrete orogenies, during Caledonian development, separated by a period of denudation and deposition. As a result the bulk assemblage has a complex tectonothermal history, including in part Proterozoic events, rather than a single integrated Caledonian pattern.

2.3.1. Pre-Scandian (Finnmarkian) Deformation

The mylonitic fabrics associated with the Ottdalen Thrust and the local inversion of the ophiolite itself, provide positive evidence of pre-unconformity (basal Sel) orogenesis. Further confirmation is provided by the Sel overstep across the VO (onto the Heidal Gp. substrate) and the complex D2 (Scandian) folding of the Ottdalen Thrust, in contrast to the simple outcrop pattern and disposition of the Otta and Jotun Thrusts..

The pervasive effects of polyphasal Scandian deformation frequently obliterate or mask small-scale details of the Finnmarkian tectonism. In this case it often the internal fabrics of conglomerate clasts which confirm the story. They preserve pre-sedimentation tectonic fabrics, randomly disposed with respect to clast shape and the post-sedimentation deformation fabric in the matrix.

Another compelling line of evidence is provided by the metamorphic hiatus across the basal Sel unconformity. The Heidal Gp. preserves widespread evidence of Amphibolite Facies grade, variably retrograded to Greenschist facies, in marked contrast to the prograde middle-upper Greenschist Facies metamorphism and low crystallinity in the overlying Sel Gp.

Scandian Deformation

2.3.2. *D1 Deformation*

Unambiguous evidence of post-unconformity deformation in provided from the Sel Gp. The earliest deformation (D1) recognised through the dominant D2 fabric is tight, small-scale folding of bedding and axial plane cleavage in pelites and tuffs. The slaty cleavage is widespread, explaining why in some bands of the Otta Slate Belt the dominant s-plane is really a crenulation cleavage related to D2 folds. No large-scale folds have been attributed to the D1 phase.

2.3.3 *D2 Deformation*

This is the main Scandian deformation in the region, responsible for thrusting, large-scale recumbent folding and the dominant regional foliation.

The major Jonndalen Syncline is the largest of these folds, trending ENE-WSW and traceable from its closure near Vågåvatn to Østerdalen and Røros, i.e. at least 160 km. (Sturt and Ramsay, 1998). The inversion of the upper limb of this structure is at least 8 km. in Jonndalen (Map 1).

On the ground north of the Otta River, between Lalm and Otta, another large recumbent and south-facing coupled fold is subsidiary to the Jonndalen Syncline. The synclinal member of this structure, with its core of Sel Gp. widens eastwards towards Otta where it deflects south across Ottdalen, to terminate in a prominent hook structure on Veggumskampen (Map 1).

Minor coupled folds of this phase have flattened 1c profiles with noncylindrical and incongruous axes on all scales. This can be observed in individual outcrops and in synoptic plots from larger sub-areas.

2.3.4. *D 3 Deformation*

The third deformation phase (D3) marked a change in the tectonic regime from one of strong translational character, combining thrusting and recumbent folding, to one of irrotational strain and upright or conjugate folding. Axes in the main trend sub-parallel to the main orogenic grain. Minor folds are more localised and axial plane crenulation cleavage is sporadic in development.

2.3.5. *D4 Deformation*

The final significant fold phase (D4) created a system of large wave-length folds which have a marked effect on major Caledonide trends e.g. on the 1:1,000,000 map (Ramsay and Sturt 1998). They are responsible for the major embayment in the Upper Allochthon between Grimsdal and Gubrandsdalen (the Gubrandsdalen Antiform) and the large re-entrant of the Jotun Massif to the south. Further north it causes a marked deflection of strike at Alvdal, Røros and Feragen. These folds have a general E-W trend i.e. transverse to the main structural grain (Map 2).

2.3.6. *The Dombås Belt*

A belt of Ordovician - Silurian rocks extending from Dombås to Støren and beyond is structurally analogous to the Jonndalen Syncline on the north-western side of the ON (Map 2). This comprises a basal black phyllite - sandstone facies with local developments of volcanic breccia suceeded by a thick sequence of volcanics and volcanoclastic sediments (= Støren Volcanics). Succeeding this is a development of grey-black phyllite and sandstone with a prominent band of quartz conglomerate. The lithologies and lithostratigraphy of this belt are similar to the sequences of the Meråker Belt in Østerdalen.

This belt is flanked on the east by the axial Gula Gp. and on the west by a similar psammite-schist sequence, the Drivdalen Belt, comparable with the Heidal Gp. in the Hummelfjell Belt, in the lower limb of the Jonndalen Syncline. The Drivdalen Belt of psammite-schist unconformably overlies augen gneiss which can be traced southwards to Vågåvatn i.e. the Hovringen Gneiss Gp.

The Gula Gp (= Heidal Gp.) can be traced round the termination of the Dombås Belt into the Drivdalen Belt. Thus both of the Ordovician - Silurian belts have an envelope of the Heidal Gp. or equivalents.

Although strongly affected by upright D3 folds this belt is a major D2 synclinal core gaping westwards, which can be traced continuously northwards into the Støren - Trondheim region.

2.4. REGIONAL CORRELATION

A major outcome of the present revisions in the Otta-Vågå area is the connection established between the ON and the TNC to the north., together with the subjacent group of smaller nappes of similar composition, i.e. the ON is really the southern end of the major complex.

The characteristic tripartite division of the TNC into an axial Gula Nappe flanked by nappes of Ordovician -Silurian rocks, i.e. the Støren and Meråker Nappes persists southwards into the ON, where mutual relations are unambiguous. The indisputably unconformable Sel-Heidal Gp. contact contrasts with the conventional one proposed in the TNC. The Heidal Gp. can be traced round the termination of the Meråker Gp. into the Gula Gp. in the West and Hummelfjell Gp. in the East. From the evidence of younging (Map 5) the Meråker Belt with its envelope of Heidal Gp. and equivalents is a major recumbent syncline. Previous studies differentiated the Høvringen Gneiss, Heidal, and Sel Gps. of the lower eastern limb, of normal polarity, into separate nappes, i.e. Remsklepp, Essandsjø and Øyfjell Nappes (Gee et al. 1985, Nilssen and Wolff 1989)(compare Fig. 2 and Map 2). The Meråker Belt forms the western limb of the Jonndalen Syncline, which is markedly inverted in the ground between Vågåmo and Gauldalen.

Similarly the Heidal and Høvringen Gneiss Gps. Occur along the western margin of the Dombås (= Støren) Belt. These were also previously differentiated into the Blåho and Risberget Nappes.

The present revision integrates the cover sequences of the ON (= Trondheim Nappe) into a pattern of opposite-facing recumbent folds with Orthorhombic Symmetry rather than a complex of nappes. Accordingly the authors propose revival of the concept of a major Trondheim Nappe.

The tectonic hiatus recorded by the basal Sel unconformity argues against the involvement of the Gula sequence in the development of the Gjersvik Terrane, i.e. as a fore-arc assemblage coeval with the Meråker magmatic arc in Tremadocian times (Stephens and Gee 1985).

The demonstrable correlation of the Fundsjø (= Folldal or Hersjø) volcanic sequence with the volcanics of the Sel Gp. at Dovre and the status of the latter group as an unconformable sequence drowning an ophiolite nappe, which is in turn juxtaposed with an underlying high grade metamorphic sequence partitions tectonothermal and magmatic events into a more complex polyorogenic sequence.

3 AIMS AND OBJECTIVES

3.1. *Aims*

An examination of the tectonostratigraphy and structure of the Otta-Vågåmo tract with the aims of testing whether it provides the basis for a model for reassessing the form and history of the whole Trondheim Nappe Complex (TNC).

3.2. *Objectives*

A series of traverses or specific outcrop studies over 5 field days will highlight :
(i) The significant lithological elements of the tectono-stratigraphy
(ii) Key structural and stratigraphic relationships
(iii) Tectonothermal characteristics
These will provide a framework for the form and development of the Otta Nappe.

The Ordovician - Silurian Meråker belts of the TNC will be reinterpreted, and this in turn applied to a critical reappraisal of current views on the multi-nappe nature of the TNC.

Towards the end of the excursion we should be in a position to discuss the merits of opposing views on the evolution of the belt during Early Ordovician and Silurian orogenies.

4. ITINERARY

Day 1.- The Otta Area

4.1. *Introduction*

This area is located at the eastern margin of the Otta Nappe and the complete tectonostratigraphy is represented (Table C, Fig. 5, and Map 1). The complex outcrop pattern is the result of polyphase, large-scale Scandian folding (D2 - D4). The oval outcrop of the Sel Gp. with its envelope of VO and Heidal Gp. is a remnant of a southward-facing recumbent syncline (D2). The hooked pattern, in detail, is the result of D3 folding, modified by D4. From its closure in the vicinity of Lalm the D2 hinge plunges gently eastwards. Two kilometres north of Otta it bends south to cross the Otta River to Tokampen and Veggumskampen, where it curves round the hinge of the large Otta Synform (D3) and ends in a westerly-closing hinge with steep North-North-Easterly plunge (Map 1).

The Ordovician core widens markedly on the slopes to the north of Otta, due to the formation of subsidiary anticlinal and synclinal folds in the hinge of the main core. This larger fold is noncylindrical, with parasite folds even more so and markedly incongruous with respect to the host structure.

The development of the VO on the western side of the Otta core, between Veggumskampen and Åsåren, is the largest in the whole area. This preserves the most complete record of the original ophiolite slab. The width of the band is a reflection of original D2 tectonics (i.e. mega-boudin) and open D4 folding with wave-lengths of up to 3 km. This part of the ophiolite is inverted as the reult of pre-unconformity (basal

Sel) folding. At the Åsåren Quarry and westwards the ultramafic member (now soapstone/serpentinite) is structurally the highest and the one cut by the pre-Sel unconformity. This bulk polarity is confirmed at Dalen (Map 3, loc. 1.6c) where pillow lavas young away from the unconformity surface. The pre-unconformity thrust at the base of the VO cannot be appreciated in this area save at the Brekken Quarry locality (loc. 1.10), where the competent members of the Heidal Gp. beneath the VO exhibit a protomylonitic to mylonitic fabric.

The overall flat-lying nature of the Otta Nappe can be appreciated from the observable attitude of the Høvringen gneiss unit and the basal Otta Thrust along the eastern margin, the occurence of the large Ranglerkampen inlier, and the reappearance of the gneiss unit along the western margin from Vågåvatn northwards (Map 2). The nappe was translated in an East-South-Easterly direction, as indicated by the regional attitude of mylonitic and stretching lineations and minor fold axes in the marginal zones exhibiting high strain.

An impressive topographical expression of the nappe base can be appreciated where the Otta Thrust crosses Heidalsgråhøg on the south side of Sjoadalen.

The form of the large D3 Otta Synform is clearly delineated by the arcuate distribution of former and active slate quarries aligned parallel to the D2 cleavage on the Pillarguri massif. The effects of D4 are not penetrative and the most obvious structural attitudes are related to the large wave-length Gubrandsdalen Antiform, one of the largest folds in Norway (Maps 1 and 6).

4.2. Localities - Otta District (Map 3)

*Loc. 1.1. Bredi Farm.*Map sheet 1718 III. Skåbu. Grid Ref. 2870 4600.
Base of the Heidal Group and reworked gneiss. In a long road-cut quartz-micaschist of the Lower Heidal Gp. is in contact with diaphthoretic mylonitic Høvringen Gneiss.

Loc. 1.2. Sjoa Bridge (Kolo). Map sheet 1718 III. Skåbu. Grid Ref. 2845 3910.
Sub-Otta Nappe complex. Sequence of banded quartzite - quartz-mica schist. Abundant sedimentary structures with normal polarity.

Loc. 1.3. Faukstad - Sjoa Valley. Map sheet 1718 III. Grid Ref. 2560 3950.
Lower part of the Otta Nappe.

a) Impressive view of the base of the Otta Nappe forming prominent escarpment on the mountain Heidalgråhøg, south of Sjoadalen.
b) (Grid Ref. 2115 4280) A long road-cut through the lower part of the Heidal Gp.This shows repetitions of banded psammite, calc schist, garbenfels, mica schist and limestone.
c) In the hamlet of Faukstad (Grid Ref. 2220 4265) there are some small roadside outcrops of coarse-grained intermediate and acid gneiss of the Høvringen Gneiss Gp. Strong Caledonian reworking to banded mylonite, with boudins of little altered protolith.

Loc 1.4. Otta South. Map sheet 1718 IV Otta. Grid Ref. 2760 4850.

Minor road to shooting range. Small roadside outcrop with instructive occurrences of main phase folding and schistosity (D2). Sel phyllite - quartz phyllite with bands of acid tuff. A pre-fold schistosity (D1), paralleled by quartz veins, is slightly oblique to the bedding. Near isoclinal folds (D2) develop the regional crenulation cleavage, particularly in the inner cores of folds.

Loc. 1.5 -1.9 Vågåmo Ophiolite . typical lithologies. Map sheet 1718 IV Otta.

Loc. 1.5. Rusti Mine (derelict). Grid Ref. 2975 4925.
Unconformity with micro-relief between rusty, grey-black phyllite of the Lower Sel and a gabbroic member of the ophiolite. The small outcrops are close to a small stream , east of the tips and southeast of the mine entrance.

Loc. 1.6. Dalen (suburb west of Otta)

a) Quarry road (Grid Ref. 2545 4995). Large bluff on north side of tight bend (ask permission at house). Layered gabbro, cut by dykes, note more pegmatitic facies. There are few signs of tectonic disturbance.
b) Side street (Grid Ref. 2565 4980). Continuous outcrop on the north side of the street of pillow lavas with westerly polarity, note dykes.
c) Gauklihaugen (Grid Ref. 2585 5065). Forestry track 240m. above the main mountain road.Sel turbidites - fine conglomerate to sand. Well preserved grading in some horizons is disrupted by blocks of granite and granite gneiss up to 0.6m. across. This is the protolith to the more commonly schistose To Conglomerate.

Loc. 1.7. Åsåren Bridge. Grid Ref. 2350 5140.
100m. west of the northern abutment on Route 15. Volcanic member of the VO with well preserved pillow lavas. Sporadic mafic dykes.

Loc. 1.8. Baksidevei. Grid Ref. 2300 5130.
500m. west of southern abutment of the Åsåren Bridge. Road-cut of the sheeted dyke member of the VO.

Loc. 1.9. Åsåren Quarry. Grid Ref. 2290 5370.
Working soapstone quarry. The quality of this outcrop will depend on the state of the workings. Unconformity between the Otta Conglomerate (monomict serpentine conglomerate), together with its cover of garbenschiefer (Lower Sel), on the ultramafic (soapstone) member of the VO. This outcrop highlights the pre-unconformity inversion of the VO in this district.

Loc. 1.10. Brekka Quarry (disused), adjacent to Rustdalen Road. Grid Ref. 1230 5865.
Evidence of the Ottdalen Thrust zone on quartzite and garbenschiefer. A mylonitic fabric is developed in the competent members of the Heidal Gp., reflecting high strain beneath the Ottadalen Thrust. This modified the Heidal rocks to a *skifer* fabric of commercial grade.

4.3. Day 2 Vågåmo Area.
Introduction

The Vågåmo area is situated on the western side of the Otta Nappe and while the full tectonostratigraphy is present the nappe thickness is greatly reduced as a result of excision and flattening associated with the overlying major Jotun Nappe complex (Map 1). South of Vågåmo an essentially flat-lying sequence is folded by open to moderately tight upright folds, most clearly expressed in the large oval shaped Flatningen Synclinorium (D3). This sequence passes beneath the Jotun Nappe Complex west and southwest of Tesse. Small klippe of the lower members of this complex occur on Trollhoi between Tesse and Lemonsjø.

On Tristeinen the Ottdalen Thrust is evidenced by the contrast in strain facies between the Otta Conglomerate and quartzite in the immediately subjacent Upper Heidal Gp.. In this particular location the VO is missing, as a result of Sel overstep. The conglomerate displays little-deformed pebbles set in a matrix with weak to moderate spaced cleavage. This low strain contrasts with the mylonitic fabric in the subjacent quartzites within the quartzite-black schist assemblage of the Upper Heidal Gp., on the southern side of a gully 130m. south of the summit (Map 3, loc.2.2.).

North of Vågåvatn on the Skaihoi - Ruphoi massif the broad belt of Ordovician sediments and volcanics terminates in a major synclinal closure. To the northeast of the Finna River the recumbent nature of this syncline is well constrained by stratigraphic polarity indicators on both limbs. On Skardshoi (0490 7105) this major south-facing Jonndalen Syncline (JS) has an upper limb preserving evidence of at least 8 km. of inversion. The long lower limb of the fold is preserved in the Flatningen Synclinorium south of Vågåvatn.

On the hillside north of eastern Vågåvatn this core, called the Meråker Belt further north, bends into a NW-SE trend over the crest of the large D4 Vågåmo Antiform. This causes the hooked pattern in the southern end of the belt.

In the belt of the Heidal Gp. Between the Sel of the Jonndalen core and the basal gneiss at the nappe margin to the west, large tight D3 folds are strongly developed. These exhibit a changing trend round the Vågåmo (D4) fold, from NW-SE near Vågåvatn , to N-S on either side of the Finna River and finally ENE-WSW to the north of Svarthovda.

Intermediate-scale D4 folds are responsible for large slab-like tongues of conglomerate projecting south from the northern margin of the belt, on Fjelltithø, Skardshø and Nonshoi.

The base of the Otta Nappe (western margin) is delineated by a thin band of orthogneiss, traceable northwards from Vågåvatn to beyond Oppdal (Map 2).

4.4. Localities Day 2 Vågåmo district (Map 3). Map sheet 1618 I Vågå

Loc. 2.1. Synstlii, 500m. east of Route 51,.Grid Ref.9870 5515.

On the wooded hillside numerous very large blocks of ultramafics litter the landscape.
Where the power-lines crosses a small escarpment layered dunite-hartzburgite with streaky chromite banding of the ultramafic member of the VO outcrops.

Loc. 2.2. Tristeinen. Grid Ref. 9800 5535
A steep-sided ridge 1 km. East of the northern end of Tesse. This ridge is composed of weakly-bedded, clast-supported Otta Conglomerate. Pebbles exhibit low strain and a weak spaced cleavage is confined to the matrix. On the south side of a small gully, 130 m. to the south of the summit, outcrops of thinly laminated ('skifer') quartzite with a mylonitic fabric occurs. The contrast in strain facies between the competent members of the Heidal Gp. and the incompetent Otta Conglomerate reflects the non-synchroneity of fabric development. The high strain in the Heidal rocks is the result of the pre-Sel Ottdalen Thrust. At this locality the VO is absent due to overstep by sediments of the Sel Gp.
Looking westwards from the summit of Tristeinen affords a fine view and impression of the great mass of the Jotun Nappe Complex.

Loc. 2.3. Seter road on west side of the Skjerva River. Grid Ref. 9925 6945.
In several outcrops along this road two facies of the Skardshoi Conglomerate are developed :

a) Pebbles of quartzite, psammite and vein quartz, in a quartz-schist matrix, some clasts preserve a pre-clast Si fabric.
b) Pebbles of actinolitic hornblende-bearing schist in calc schist matrix.

Loc. 2.4. Hillside west of football pitch. Grid Ref. 990 705
Inverted sequence of the calcareous member of the Skardshoi Conglomerate. Looking east to the slab-like hill Fjelltithoi on the eastern side of the Skjerva River brings out the layering of the inverted limb (Heidal Gp. rocks overlie Sel Gp.) of the major Jonndalen Syncline (D2)

Loc. 2.5. Gjerdingåa stream. Grid Ref. 9440 6755.
Upstream from the bridge on the Finna road the base of the Otta Nappe occurs. Mylonitic Høvringen Gneiss Gp. overlies sub-nappe quartz mylonite.

Loc 2.6. Eastern flank of Bukkehaugen. Grid Ref. 000 616.
Take the prominent track from the disused quarry in Sel Skifer (010 613) for 1.4 km. A sequence of well-bedded sand-silt and conglomerate overlies a thin development of garbenschiefer, which in turn rests unconformably (not exposed) on VO (gabbro with dykes) of the main ridge. A single brachiopod has been recovered from one of the sandy horizons. The VO is in the core of a subsiduary anticline to the Jonndalen Syncline, and the sepentine sediments are repeated on the western limb.

4.5. Day 3 Dombås -Hjerkinn - Folldal area. (map 3).

Introduction

The western margin of the Otta Nappe, defined by the basal plinth of Høvringen Gneiss Gp. can be traced northwards from Vågåvatn to Andbergshoi in the Dombås area where it bends North-East into the regional orogenic trend. In the northwestern part of the nappe, between Dovre and Dombås another major band of low-grade (Greenschist Facies) Ordovician - Silurian sediments and volcanics i.e. the Dombås Belt, has a setting analogous to the Meråker Belt. Like the Meråker Belt (= Jonndalen core) the Dombås Belt is flanked on both sides by rocks of the Heidal Gp. and on the structurally lower side, by Høvringen Gneiss. This belt terminates on the hills west of the Lågen Valley, in the vicinity of Høgseter. Although the belt is basically a major D2 synclinal core similar to the Jonndalen Syncline, the detail of the outcrop reflects upright D3 fold modification.

In the closure zone of the belt in the Hardegg area (i.e. D3 synform) a thin development of probable ophiolite occupies a structural position analogous to the VO. Lithologies in this development include gabbro, sheeted dyke dolerites and pillow lavas. This group overlies garnetiferous black schist of the Upper Heidal Gp.

Along the northwestern side of this belt the Sel Gp. equivalent overlies typical Lower Heidal Gp. rocks, and these in turn rest on typical Høvringen Gneiss. The typical sedimentary lithologies of the Ordovician belt are grey phyllite-sandstone with sporadic tuffs. From Grisunghi (1173 9445) a thick belt of greenstone and acid volcanics, tuffs and sediments separate the dominantly pelitic Sel-type sequences into 3 divisions. The volcanic group develops economic sulphide deposits, previously mined for copper at Hjerkinn. These volcanics are generally equated with the Folldal Volcanics of the Meråker Belt.

North of Hjerkinn the base of the volcanics is marked by thick volcanic conglomerate with angular to rounded clasts of porphyritic to non-porphyritic metabasite and trondhjemites, and agglomerate. Bedding varies from weak to strong. These rest unconformably on amphibole-rich schists and quartzite with interlayered garnetiferous greenstones of the Heidal Gp.

The volcanic group is succeeded by typical Sel dark phyllite-sandstone and this in turn by an extensive Skardshoi-type conglomerate. This occupies a lithostratigraphic position analagous to the Setershø Conglomerate of the Meråker Belt (Table B).

Traced north from Dombås the steep dips produced by upright D3 folding gives way, in the Hjerkinn area, to gentler easterly dips and it can be appreciated that the Dombås Belt rocks dip beneath the Gula (= Heidal) Gp. rocks of the axial belt of the TNC. This indicates that the Dombås core is an overturned syncline facing westwards. The two major belts of Ordovician - Silurian rocks are thus recumbent synclines, facing in opposite directions, indicating an Orthorhombic Symmetry for the major D2 folding.

The axial Heidal Gp. rocks between Hjerkinn and Folldal are essentially high grade paragneisses in mid-upper Amphibolite Facies, developing sporadic migmatites. The contact with the Meråker Belt is well seen at Bakkesætrin (4900 9160) west of Folldal. At the zig-zag bends 400m. southeast of the seter the garnet-kyanite-staurolite bearing semi psammite/gneiss is suceeded, across a few metres of unexposed ground, by dark-grey sandstone and phyllite of lower grade (upper Greenschist Facies) and low crystallinity.

4.6. Localities Day 3 Dombås-Hjerkinn-Folldal area (Map 3).

Loc. 3.1. Sel village. Map sheet 1718 IV Otta. Grid Ref. 2140 5730.
Enter the small forestry-track from the Rustdalen road at the west end of the village (signposted Medical Senter). Lower Heidal psammites with abundant cross-bedding structures and normal polarity.

Loc. 3.2. Lågen Gorge. Map sheet 1718 IV Otta. Grid Ref. 2200 6090.
In high road-cuts on the E6 the lithology is a coarse polymict conglomerate (Lower Heidal Gp.). Boulders are predominately basement gneiss, granite and quartzite.

Loc. 3.4. Dombås. Map sheet 1419 II Dombås.
Continuous high road-cuts on the E6 at the south end of the village. Banded meta-sandstone and phyllite (Lower Sel Gp.), in Greenschist Facies metamorphism. These are the first outcrops of the western major Ordovician - Silurian belt i.e. Støren Belt near Trondheim, but informally called the Dombås Belt in the south.

Loc. 3.5. Hogsætri. Map sheet 1419 II Dombås.
Where the seter road bridges a small stream there is a good exposure of greenstone with some relict pillow structures cut by mafic and acid dykes (? Vågåmo Ophiolite).
Ca. 1 km upstream mylonitic greenstone/gabbro rests on black schist of the Upper Heidal Gp.. On the roadside to and at the seter there are many outcrops of fine-grained grey meta-sandstone and phyllite of Sel type.

Loc. 3.6. Hjerkinn Station. Map sheet 1593 III Hjerkinn. Grid Ref. 2840 9900.
Sequence of conglomerate, grit, pale quartzite and black phyllite.The pebbles of the conglomerate are chiefly quartzite and vein quartz in a matrix of grey sandstone.Although it lithologically resembles the Skardshoi Conglomerate its stratigraphic position suggests a correlation with the Setershoi Conglomerate of the Meråker Belt.

Loc. 3.7. E6 at Grønnbakken. Map sheet 1519 IV Snøhetta. Grid Ref. 3100 0545. Park in car park.
The contact between the Sel and Heidal Gps. Runs across the E6 at the large bend. To the north of the bend are long roadside outcrops of greenstone with shadowy relicts of pillows (?), greenschist, garbenschiefer and garbenfels, streaks of dolomite, calc psammite and dark grey psammite. Amphibole is a conspicuous constituent varying from 'wheat-sheaf' to linear (Heidal Gp.).
To the south of the bend semi-continuous roadside cuts of a volcanic conglomerate/breccia with clasts of porphyritic and non-pophyritic metabasite set in a matrix of biotite-chlorite-calc schist. Occasional blocks of agglomerate may be observed. Clasts range from angular to strongly elongated. This lithology

persists for more than 1.5 km. Before giving way to greenstone. This greenstone has been correlated with the Folldal Volcanics of the Meråker Belt.

Loc.3.8. Folldal District-Bakkesetrin. Map sheet 1519 II. Grid Ref. 4910 9190.
Numerous outcrops behind the seter of coarse-grained garnetiferous quartzo-feldspathic gneisses (in thin-section these contain relict staurolite and kyanite) of the Gula (= Heidal) Gp., with bands of coarse amphibolite (with green-brown hornblende). One of these amphibolites preserves pillow-like structures. The metamorphic grade is Amphibolite Facies.

Loc. 3.9. Ornhovda. Grid Ref. 4935 9130.
Although unexposed the contact between Sel and higher grade Gula (= Heidal) Gp. can be located to within a few metres. At the sharp bend in the road occur dark grey amphibole-bearing (tremolite-actinolite) sandstones and phyllites of low crystallinity. (Åsli Formation = Lower Sel Gp.).

4.7. Alvdalen Area

Introduction

In this area the dominant structure is the major Jonndalen synclinal core, trending ENE-WSW through Folldal, deflected by large-scale D4 deformation into a NNE-SSW trend to the north of Alvdal. As in the Dovre area the Ordovician core is flanked on the north and south by the Heidal correlatives, i.e. Gula and Hummelfjell respectively.

The northern limb of the belt is a continuation of the inverted limb seen on Svarthovda. A large subsidiary anticline in the hinge-zone of the Jonndalen Syncline is responsible for the prominent re-entrant of Heidal Gp. south of Einunnfjell (Map 4).

The D2 recumbent fold has been refolded by a system of large upright folds during D3, the most conspicuous of which is the elongate dome of the Einnunenfjell Anticlinorium and numerous smaller folds in the Ordovician sequence . The trend of these swings from NNE-SSW to ENE-WSW around the Alvdal bend.

In the N-S belt the largest D3 structure is a West-facing monocline between the Hummelfjell and Hersjø Gps flanked on the west by a more symmetrical, upright synform. This in turn passes west into a system of large and small upright folds with the same NNE-WSW axial trend. The form of the large monocline is mirrored in the attitude of D2 minor folds which deflect from a gentle WNW orientation to a steep attitude, in a NNE-SSW girdle.

Between Folldal and Alvdal in the lower limb of the D2 syncline of the core the only significant volcanic sequence is close to the southern margin near Alvdal (loc. 4.2.). Elsewhere only sporadic thin greenstone and trondhjemite bands or acid and basic tuffs occur in the slate-turbidite dominated sequences.

The Folldal Volcanics reappear to the north of the Folla River, west of Plassen, and continue north as a thick sequence including volcanogenic sediments (Hersjø Volcanics of Rui 1972), all the way to the north of the TNC.

The large massif of Tronden is one of the highest mountains in the region. This is formed from a layered gabbro/ultramafic sheet beneath which Heidal (= Hummelfjell) Gp. rocks are bent into an elongate syncline. The Trondfjell body was emplaced subsequent to polyphase deformation in the Heidal Gp., but prior to the main deformation of the Sel Gp. (Wellings 1996).

The innermost core of the Jonndalen Syncline is located within the Setershoi Conglomerate, which is up-sequence from the Folldal Volcanics. This is confirmed by sedimentary structures i.e. channels, cross-bedding and flames, especially in the upper and lower part of the Setersjø Fm. in Vangrøftdal. In the large syncline the stratigraphy of the upper limb matches that of the lower limb, except that the Hersjø (= Folldal) Volcanics are essentially missing from the lower limb.

North of Savalen, on the western margin of the Meråker Belt and in the Røros area of the eastern margin, the shale (phyllite) facies of the Lower Sel passes laterally into a greywacke-sandstone dominated sequence with marked increase in thickness.

In the Høsa Valley, south of Røros, a development of porphyritic and non-porphyritic mafic volcanics interbanded with black phyllites occurs in the lower part of the Sel Gp., similar to the situation found at Alvdal and mentioned above.

4.5. Localities - Alvdal district (Map 4).

Loc. 4.1. 150m. West of Moskardet Farm on Route 29. Map sheet 1619 III Alvdal Grid Ref. 6730 9720.

The road cuts through a large subsidiary core of the Jonndalen Syncline (D2). Coarse-grained garnet-staurolite-mica schist is the typical Heidal Gp lithology. The progressive strike-swing along this road to the East is a consequence of the large symmetrical Einunnfjell Antiform (D3).

Loc. 4.2. Small track in the seter system on the knoll Brottet. Grid Ref. 7890 8820, 6 km. West of Alvdal

Flaggy amygdaloidal greenstones with relict pillows. These volcanics occur close to the base of the Sel Gp..

Loc. 4.3. *Brekkebekken.* Forestry track running north from Plassen. At Loc. (8150 9360) are typical pale-grey banded psammite and quartz schist of the Hummelfjell (= Heidal) Gp. On the western side of this track (8135 0415) there are several outcrops of black slate-phyllite (Lower Sel Gp.). On the prominent ridge to the west of the track extensive outcrops of the Otta Conglomerate occur. Large channel structures give the westerly polarity of the sequence. On low ground to the NW of the ridge (8135 9465) the westernmost devlopments of the conglomerate belong to the Skardshoi facies i.e. pebbles of quartzite and vein quartz in a quartz sand matrix. At (8150 9500) roadside outcrops are typical Lower Sel black phyllite of the succeeding 9501) sequence.

Loc. 4.4. *Brennåsen Kennels.* Map sheet 1619 III Alvdal. Grid Ref. 8410 0000. An exploratory pit in Otta Conglomerate. Prominent bedding in serpentine/talc conglomerate, sandstone and siltstone shows well preserved sedimentary structures with normal polarity. 100m. to the north the western developments of the conglomerate belong to the To facies.

Loc. 4.5. *Fåsteinen.* Map sheet 1619 IV Kvikneskogen. Grid Ref. 8800 0650. Large lens of ultramafite (Hartzburgite/Dunite) sited between the Heidal and Sel Gps.On the Seter track (8750 0665) the To Conglomerate facies outcrops. The main Fåsteinen knoll 500m. to the SE is a lens of serpentinised Hartzburgite and chrome-bearing dunite (ophiolitic upper mantle section = VO). Banding in some situations trends at varying angles to the long axis of the lens and the general tectonic grain. On the southern margin (8800 0630) typical members of the Hummelfjell (= Heidal) Gp., i.e. pale-grey, flaggy psammite and garnet-mica schist dip westwards beneath the ultramafite. On the northwestern margin the unconformity is preserved at two places (8780 0640) and (8735 0610). At the first of these the surface of unconformity has been exhumed on a steep face, the unconformity is directly overlain by serpentine conglomerate and relict onion-skin weathering is preserved in the immediately subjacent ultramafic. At the second locality. The unconformity is overlain by Sel Gp. phyllites, sandstones/grits and two facies of the conglomerates (both Otta and Skardshoi types). Between the Fåsteinen knoll and To Conglomerate (on the track) are numerous outcrops of silver phyllite and grey sandstone (low crystallinity) typical of the Sel Gp.

OS - RØROS DISTRICT

Loc. 4.6. *Vangroftdalen.* Map sheet 1620 III Dalsbygda.

a) Bekketrøa. Grid Ref. 1000 3440.
   Polymict conglomerate (Setersjø Conglomerate). This outcrops at the junction of the track to Setersjøen and the main valley road, and intemittently for 3.5. km. in the deep ditch of the track. Well preserved channel structures indicate westerly polarity. The clast population includes augen-gneiss, various granites, amphibolites, greenstone and psammite.
b) At two localities on the side track to the ski-jump (Grid Refs. 1025 3505; 0980 3520) outcrops of sandstone and phyllite with lenses of polymict and mud-flake conglomerate display load casts and flame structures with easterly polarity. This indicates that the band of conglomerate is one-sided and forms the innermost part of the core of the Jonndalen Syncline in this area.

c) Myrtrøvollen Farm (Grid Ref. 0520 3815). Large roadside outcrop of pillowed greenstone. Although flattened the indications are of easterly polarity. These are part of the Hersjø (= Folldal) Volcanic Fm.

Loc. 4.7. Bridge to Osmovollen Seter. Grid Ref. 0005 3945.
In the river there is a thick sequence of turbiditic sediments, e.g. grit, sandstone and black slate-phyllite. In many beds grading is well preserved, while occasional channel structures can be discerned. These all indicate easterly polarity. This is part of a wide development, though aerally restricted, of a facies of the Lower Sel Gp. lithologically distinct from the the typical Åsli Fm. It probably represents a submarine fan deposit.

4.9. Day 5. RØROS-STUGSJØ-TYDAL AREA.

Introduction

In this district the lower part of the Sel Gp. is a quite different facies from that developed SW of Røros and traceable to the Otta-Vågåmo district. The phyllite-dominant sequences of the south give way rapidly along strike to a sandstone-calc sandstone/turbidite assemblage. Thus amphibole (tremolite-actinolite) is a commonly developed mineral in both arenaceous and pelitic lithologies. Dominant lithologies include thick- and thin-bedded, pale and dark grey sandstone (+/- amphibole); garbenschiefer; grey and black phyllite.

In the upper, i.e. western, limb of the Jonndalen Syncline the corresponding change in facies has a less limy character, represented by a sandstone-turbidite-black phyllite assemblage. This facies persists only as far as the lake Øyungen where it reverts to the phyllite dominant facies (+/- conglomerate and limestone) seen in the Vågåmo-Alvdal area to the south. The turbidite facies in the lower limb, however, persists northwards to beyond Tydal.

In the ground north and east of Røros the recumbent Jonndalen Syncline passes from the steeper attitude of the Østerdalen sector into a sensibly flat rolling attitude closer to its original pre-D3 disposition. As a result, the outcrop widens dramatically. The inverted limb, delineated by the Hersjø (= Fundsjø/Folldal) Volcanic Fm. on the Kjølifjell massif, extends some 20. Km. Eastwards from the steep Østerdalen Belt.

In this area the effects of tranverse extension are dramatically displayed (Gee et al. 1994). While late or post-orogenic extensional faults have been recorded in this region as far south as Tesse and the Jotun massif, the most dramatic in the present area is the one which defines the easten margin of the TNC from Rien, south of Stugsjø, northwards to the Grong-Olden Culmination (Map 5). In the Stugsjø area this fault juxtaposes members of the Lower Sel Gp. with Precambrian basement of the autochthon or lower nappes.

To the northwest of Stugsjø the Hersjø Volcanic Fm. outcrop of Kjølifjell is terminated by another such fault. As a result of this the volcanics and structurally overlying Lower Sel of the upper limb of the Jonndalen Syncline are juxtaposed with the Lower Sel of the lower limb, and come very close to being in contact with the underlying Hummelfjell (= Heidal) Gp. in one of the two large inliers of Heidal-type psammite-garbenschiefer-calc schist association.

Structurally the Røros-Stugsjø area is dominated at sub-area level by open D4 folds , superimposed on the regional D2 fabric. Larger D3 folds are difficult to discern in this area. From the Røros 'flat-belt' there is a rapid down-bend along Østerdalen into the north-south strike of the belt, persisting south to Alvdal. D2 minor structures emphasise this in their reorientation from typical WNW-ESE trend and gentle attitude to steep plunges distributed in a NNE-SSW girdle, over the crest of the D3 Østerdalen Monocline.

In this general N-S belt, all the way to the northern tip of the TNC, the Gula-Meråker (= Heidal-Sel) contact along the western margin of the Meråker Belt has caused difficulties for authors, and the ambiguity has somewhat bedevilled interpretation. Some authors have cited the contact at the base of the Fundsjø Fm., while others have recognised a distinctive sequence between the volcanics and the typical high-grade Gula Gp., i.e. the Gudå Gp. (Wolff 1967b) or Åsli Fm. (Bjerkgård and Bjørlykke 1994), but nevertheless included it as a division of the Gula Gp. As a result the tectonothermal break, identified in the Otta-Vågåmo area, has been missed or misinterpreted and the Gula Gp. is commonly taken to represent a single series with a progressive E-W increase in metamorphic grade.

At Hegset Dam in Tydal (Map 5) it is difficult to see how this ambiguity can be sustained. Over a few metres (2-3 m.) rocks pass abruptly from Amphibolite Facies (kyanite-staurolite-garnet mica scists of coarse-grain) to Greenschist Facies phyllites and sandstones. The attitude is steep but patterns are in other respects similar to the Otta-Vågåmo area. Another difficulty arises from interpretation of the polarity of the pillowed greenstones of the Hersjø Fm. at Hegset. Horne (1979) claimed that they face West into the high-grade Gula Gp. and so the contact must be tectonic. It is the present authors contention based on polarity indicators and the consistent stratigraphic relationships south to Vågåvatn, that the volcanics young eastwards and the contact with the Gula Gp. is the same unconformable one as seen elsewhere.

In the Ålen-Holta valley area significant volcanism commenced earlier than further south, i.e. Folldal-Dovre, so typical Åsli (= Lower Sel) Fm. black phyllites and grey sandstone are thin and rapidly become associated with and inter-bedded with sub-aerial to shallow water greenstones. This is similar to the Høsa valley, south of Røros, and Brottet near Alvdal (see Day 4). It is one of these slate-interbeds that yielded the Tremadoc fossils (Rabdopora flabelliforme) at Nordaunevoll.

4.10. Localities Røros-Stugsjø-Tydal area (Map 5).

Loc. 5.1. Just south of Rugdalen Halt on route 30. Map sheet 1720 III Røros

Grid Ref.1900 5765.
Gently dipping, well-bedded dark grey quartz sandstones, schistosity is parallel to bedding. Current bedding indicates normal polarity.

Loc. 5.2. Glåmos power plant. Map sheet 1720 III Røros. Grid Ref. 2590 5170. Two flows of pillowed greenstone. The pillows are too strongly deformed for determination of polarity. They are, however, situated on the right-way up lower limb of the Jonndalen Syncline.
Loc. 5.3. Evavollen Seter, northern shore of Aursunden. Grid Ref. 3645 5250. Thick-bedded amphibole-bearing sandstone and silver phyllite. These are typical of the Lower Sel Gp. in the Røros district.

Loc. 5.4. Langvikåsen. Map sheet 1720 I Stugsjø. Grid Ref. 4450 6100 (1.5 km. West of Rien).
Outcrop of grey schistose sandstones and quartz schists, of the Lower Sel Gp. in roadcut-on the Brekken-Stugsjø road.

Loc. 5.5. Mustjern. Grid Ref. 4275 7380. Small layby on eastern side of road. Sandy and pelitic garbenschiefer (Lower Sel Gp.)with lineated or random amphiboles. Small flame structures display easterly (normal) polarity.

Loc.5.6. Storbekken-Vassmyra. Grid Ref. 4950 8100.
In the stream to the west of the bridge on the Nesjøen road quartz-biotite sandstone is interbanded with garbenschiefer (Lower sel Gp.). Amphiboles define a strong lineation (D2).

Loc. 5.7. Hamnadalen. Grid Ref 4840 8290.
50 m. below the bridge over the river the major normal fault which delimits the eastern margin of the TNC crosses the stream. This is the most prominent of the extensive listric normal faults which affect the TNC. A thin zone of mylonite is developed from the acid gneiss protolith in the footwall. Upstream the gneiss develops prominent diaphthoreic chlorite. Downstream from the small waterfall Lower Sel Gp. sandstone forms the hanging-wall. Some bands of the sandstone are conspicously amphibole-bearing. In the Sel rocks a feature of the fabric is the system of thin, westerly dipping cataclastic zones with veins of pseudotachylite.

Loc. 5.8. Arnevollen. Grid Ref. 4300 8245.
Long roadcut just north of the large layby on the Tydal road, at the northern end of Stugsjø. Interbanded thin grey sandstone and amphibole bearing pelite are conspicuously affected by a system of small listric faults, consistently downthrowing to the west. These are part of the extensional collapse system of normal faults so widespread in the TNC.

Loc.5.9. Gorge of the Tya River. Grid Ref. 3875 8555.
In the high cutting on the Tydal road banded white psammite alternates with garnet mica schist. To the south of this the sequence includes garbenschiefer, calc psammite, and garnet hornblede mica schist. These are lithologically

typical of the Heidal Gp., occurring in a large inlier.

Loc. 5.10. Hegset Dam. Map sheet 1721 III Tydal. Grid Ref. 2040 0000. Contact zone of the Gula (= Heidal) Gp. and Gudå (= Lower Sel) Gp. The actual contact (unseen) occurs 700 m. west of the dam on the side of a small access road to the base of the dam. The Gula Gp. to the West is predominantly coarse-grained kyanite-staurolite-garnet mica schists and schistose quartzites.

The Sel Gp. comprises low crystallinity dark grey to black phyllite and semi-phyllite, sandstone, Skardshoi-type conglomerate and pale marble. Beneath the dam the thin Lower Sel Gp. metasedimentart sequence is succeeded by pillow lavas of the Hersjø (= Folldal) Volcanic Fm.

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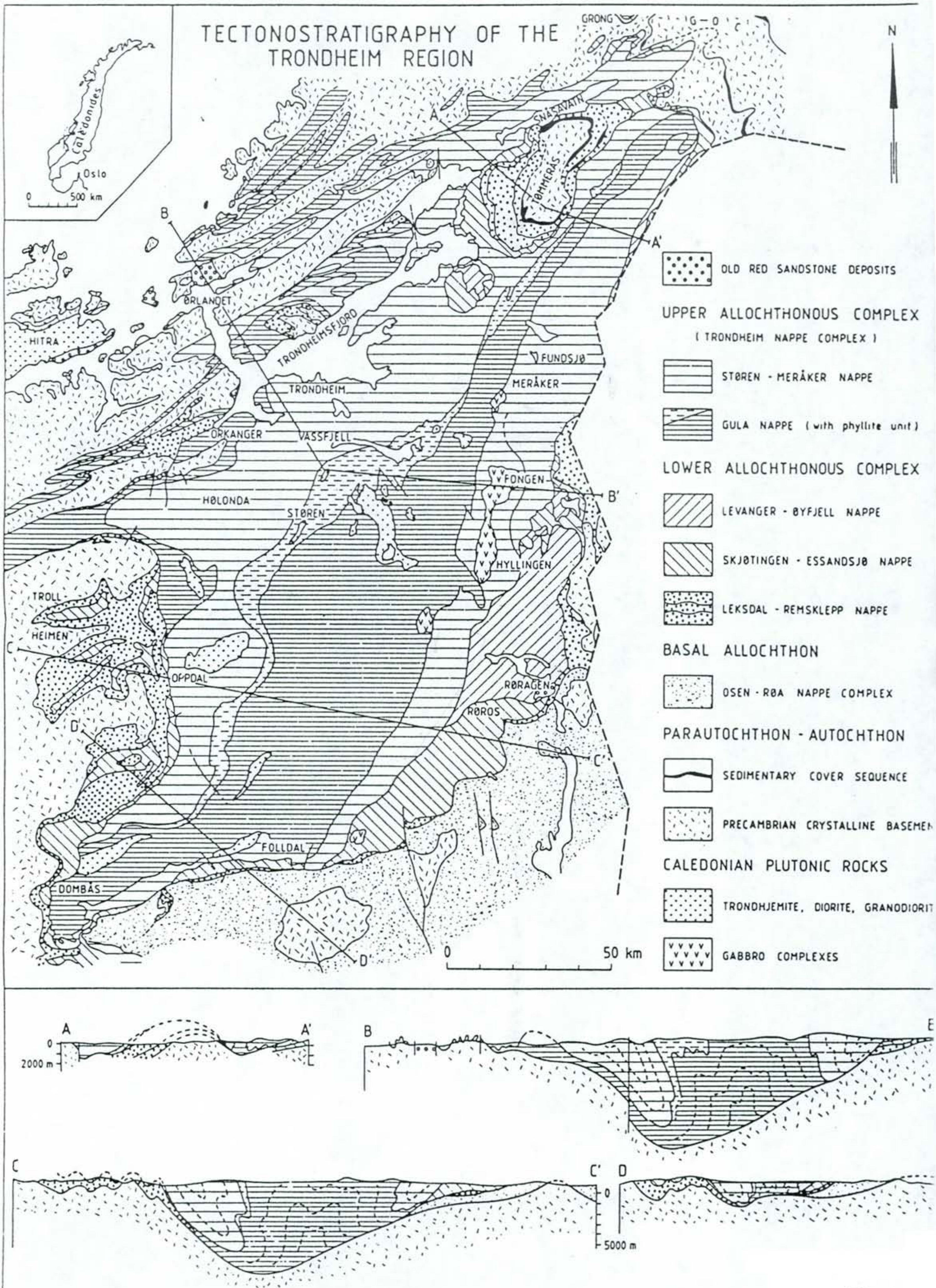

TECTONOSTRATIGRAPHY OF THE TRONDHEIM REGION
Caledonides
Oslo
0 500 km
N
GRONG
G - O - C
SNÅSAVATN
TØMMERÅS
ØRLANDET
HITRA
TRONDHEIMSFJORD
TRONDHEIM
FUNDSJØ
MERÅKER
ORKANGER
VASSFJELL
FONGEN
HØLONDA
STØREN
HYLLINGEN
TROLL
HEIMEN
OPPDAL
RØRAGEN
RØROS
FOLLDAL
DOMBÅS
0 50 km
OLD RED SANDSTONE DEPOSITS
UPPER ALLOCHTHONOUS COMPLEX
(TRONDHEIM NAPPE COMPLEX)
STØREN - MERÅKER NAPPE
GULA NAPPE (with phyllite unit)
LOWER ALLOCHTHONOUS COMPLEX
LEVANGER - ØYFJELL NAPPE
SKJØTINGEN - ESSANDSJØ NAPPE
LEKSDAL - REMSKLEPP NAPPE
BASAL ALLOCHTHON
OSEN - RØA NAPPE COMPLEX
PARAUTOCHTHON - AUTOCHTHON
SEDIMENTARY COVER SEQUENCE
PRECAMBRIAN CRYSTALLINE BASEMEN
CALEDONIAN PLUTONIC ROCKS
TRONDHJEMITE, DIORITE, GRANODIORIT
GABBRO COMPLEXES
A
A'
0
2000 m
B
B'
C
C'
D
D'
0
5000 m

Fig. 1

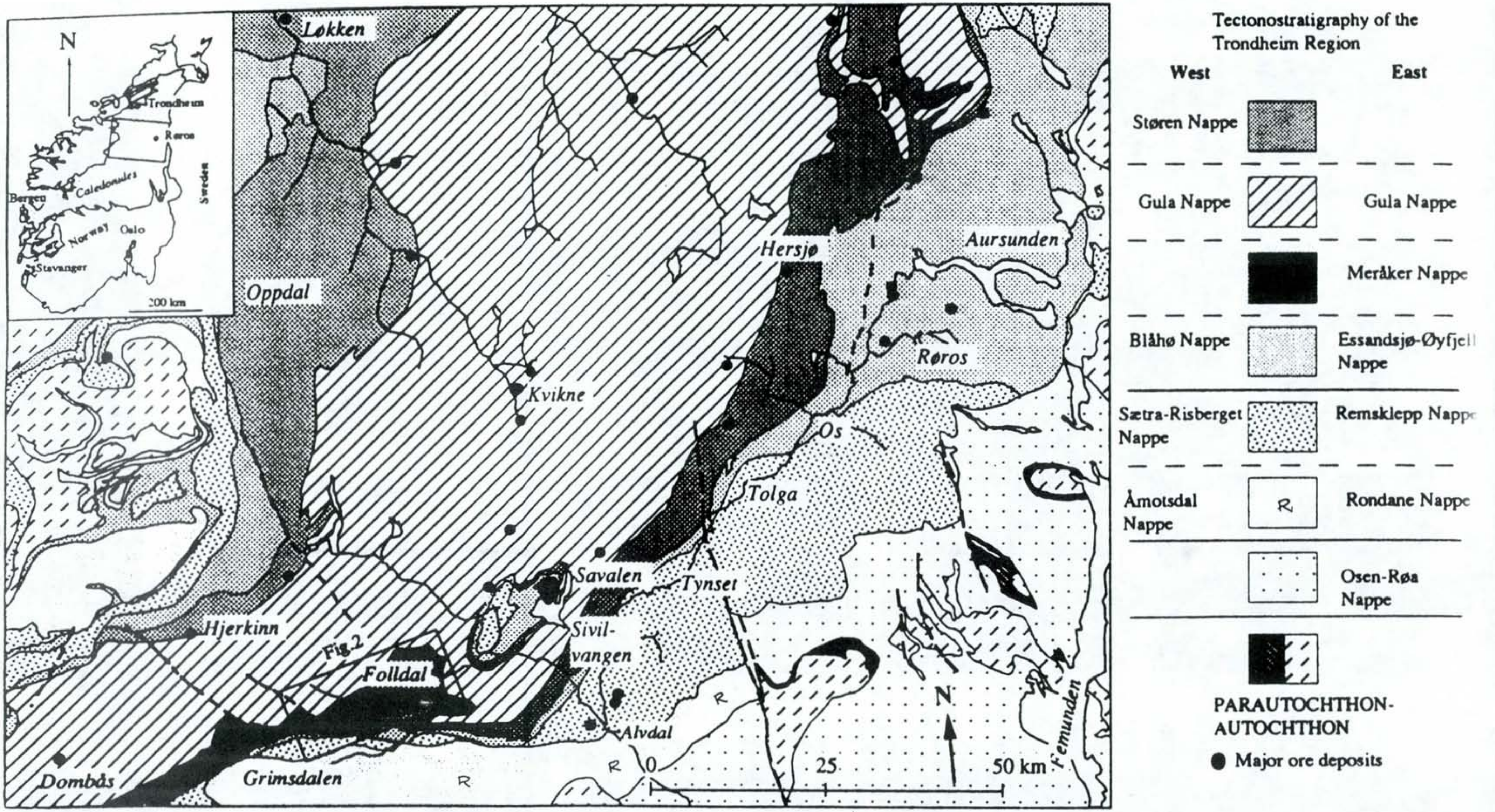


Fig. 2. Tectonostratigraphic map of the southern part of the Trondheim Region (modified from Nilsen 1988).

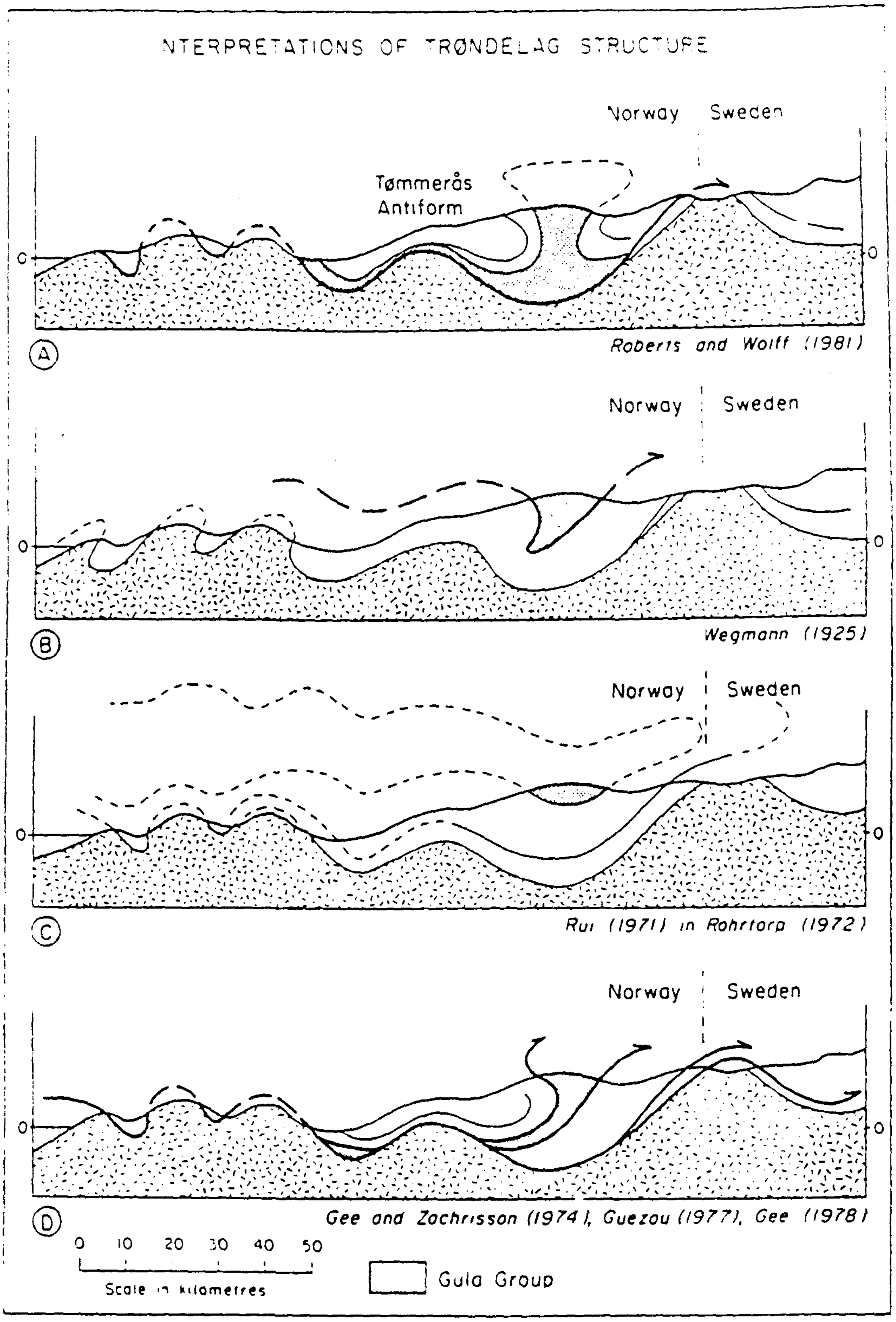


Fig. 3. Sketch sections illustrating alternative interpretations of the Trøndelag structure along a WNW–ESE line through the Tømmerås Antiform and Trøndelag Synform

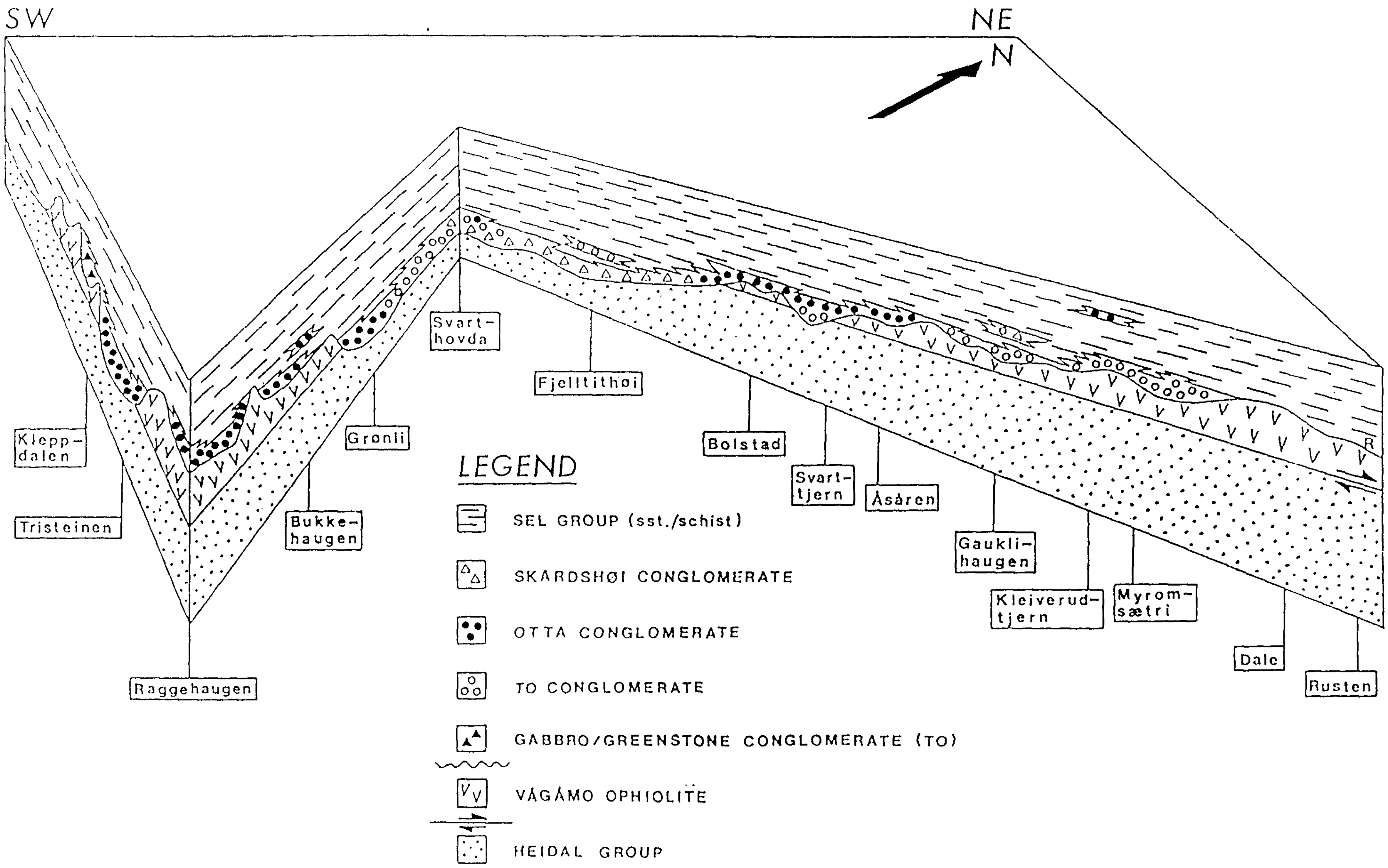

SW
NE
N
Klepp-dalen
Tristeinen
Raggehaugen
Bukke-haugen
Grønli
Svart-hovda
Fjelltithøi
Bolstad
Svart-tjern
Åsåren
Gaukli-haugen
Kleiverud-tjern
Myrom-sætri
Dale
Rusten
R
LEGEND
SEL GROUP (sst./schist)
SKARDSHØI CONGLOMERATE
OTTA CONGLOMERATE
TO CONGLOMERATE
GABBRO/GREENSTONE CONGLOMERATE (TO)
VÅGÅMO OPHIOLITE
HEIDAL GROUP

Fig. 4

TABLE A. NAPPE STRATIGRAPY

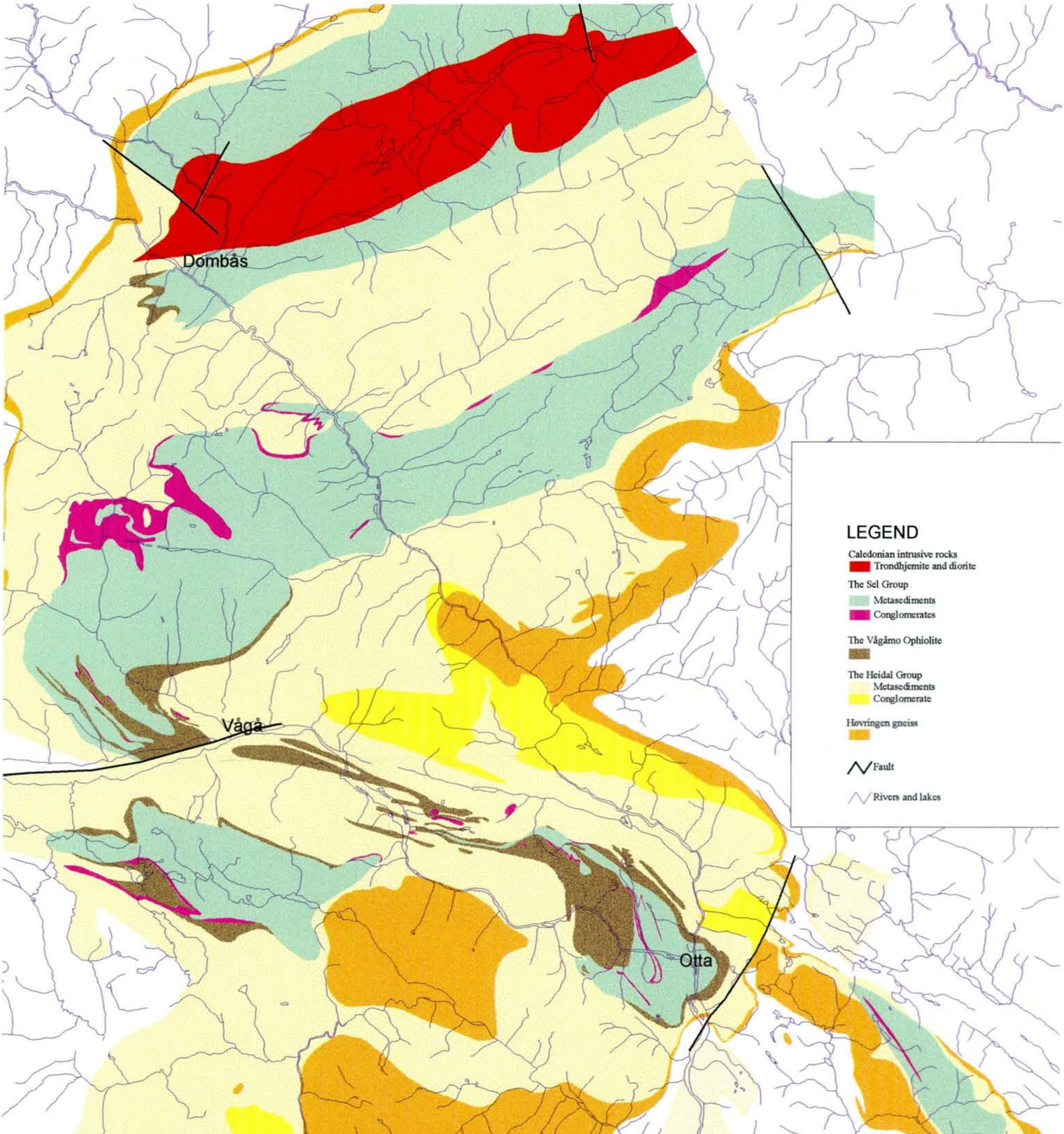
	GEE ET AL. (1985)	PRESENT AUTHORS	
UPPER ALLOCH.	STOREN / MERÅKER (KÖLI)	TRONDHEIM NAPPE	OTTA NAPPE
	GULA (SEVE)		
	ØYFJELL (KÖLI)	MERÅKER BELT	
	EQUIVALENT OF L. TÄNNFORS	MERÅKER BELT	
	ESSANDSJØ (SEVE)	GULA BELT	
	REMSKLEPP	PZ. BASEMENT	
	SPARAGMITE		

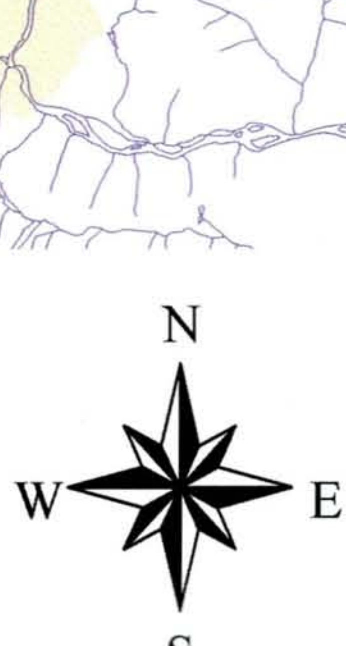
POLARITY	LITHOSTRATIGRAPHY ØSTERDALEN	OTTA	STRATIGRAPHIC AGE	RADIOMETRIC AGE	STRATIGRAPHIC AGE (RUI, 1972)
	GULA GP.	HEIDAL Gp.	U. PRECAMB.	509	CAMBRIAN
Y	ÅSLI FM.	L. SEL Gp.	TREMADOC		TREMADOC
Y	HERSJØ FM.	—	ARENIG	488±2	TREM. - ARENIG
	KJURUDAL FM.	—	MID ORDOVIC.		
CORE OF JS (Y / ⅄)	SETERSHØ FM.	—	MID ORDOVIC.		MID ORDOVIC.
⅄	RØROS FM.	L. SEL Gp.	LLANVIRN		U. ORD. - SIL.
	VÅGÅMO OPH.	VÅGÅMO OPH.	CAMBRIAN ?		—
⅄	HUMMELFJELL Gp.	HEIDAL GP.	U. PRECAMB.		SILURIAN
	HOVRINGEN GN.	HOVRINGEN GN.	M. PROTEROZOIC	1180±1	CALEDONIAN ?

TABLE B. COMPARATIVE STRATIGRAPHY IN THE EAST OF THE T.N.C.

	OTTDALEN	RØROS	MERÅKER
OTTA NAPPE	SEL GP.	KJURUDAL GP. Sporadic greenstone congl.	KJOLHAUGEN GP. SULÅMO GP. L. Fundsjø Conglomerate
	Quartzite, limestone, graphitic phyllite, mica & calc silicate schists Volcanics	HERSJØ GP.	FUNDSJØ GP.
	Skardshoi - To - Otta Conglomerates	limestone schist with quartzite conglomerate	limestone GUDÅ FM. Gudå Conglom.
	VÅGÅMO OPHIOLITE Ottdalen thrust	ULTRAMAFICS	GULA GP.
	Sporadic quartz conglomerate calc schist, garbenschiefer, marble psammite, mica schist HEIDAL GP. Psammite, quartzite, mica schist Sporadic basal conglomerate	GULA GP. [HUMMELFJELL GP.]	
	HOVRINGEN GNEISS CPX.	GNEISS	
	otta	Thrust	
	SPARAGMITE	SPARAGMITE	

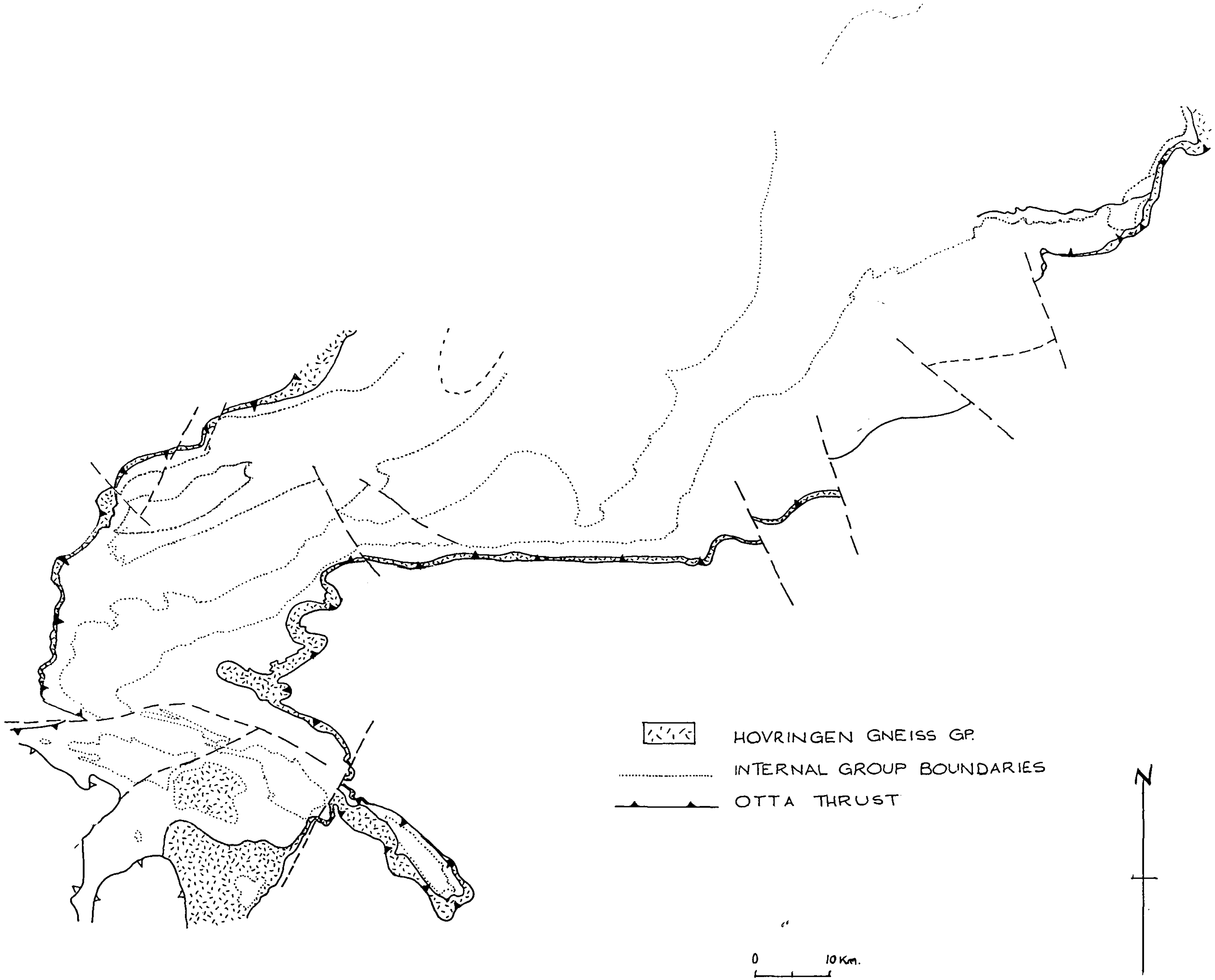
TABLE C. LITHO- AND TECTONOSTRATIGRAPHY OF THE OTTA NAPPE





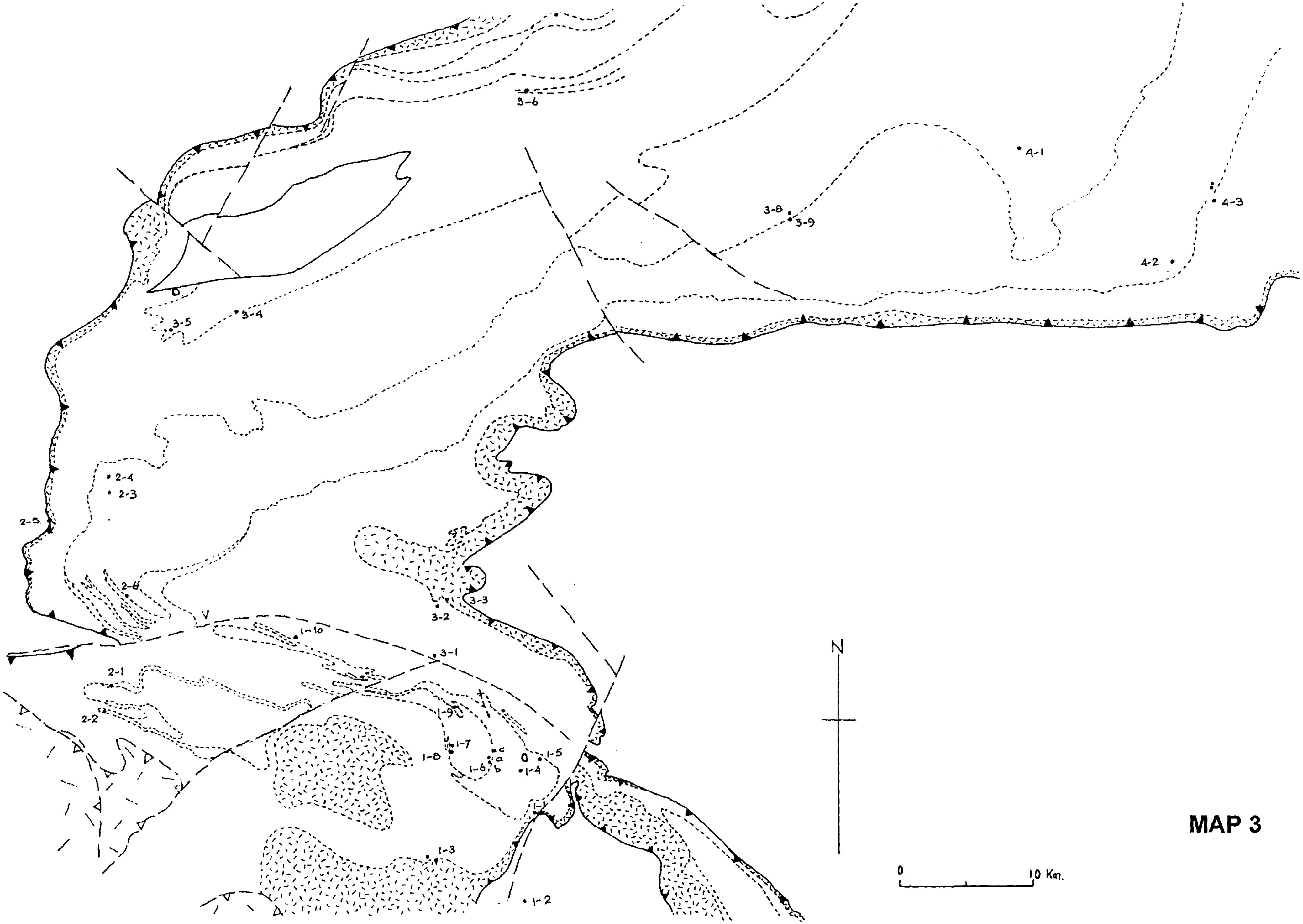
Geological map of the Otta-Dombås area
Scale 1:200 000

Map 1



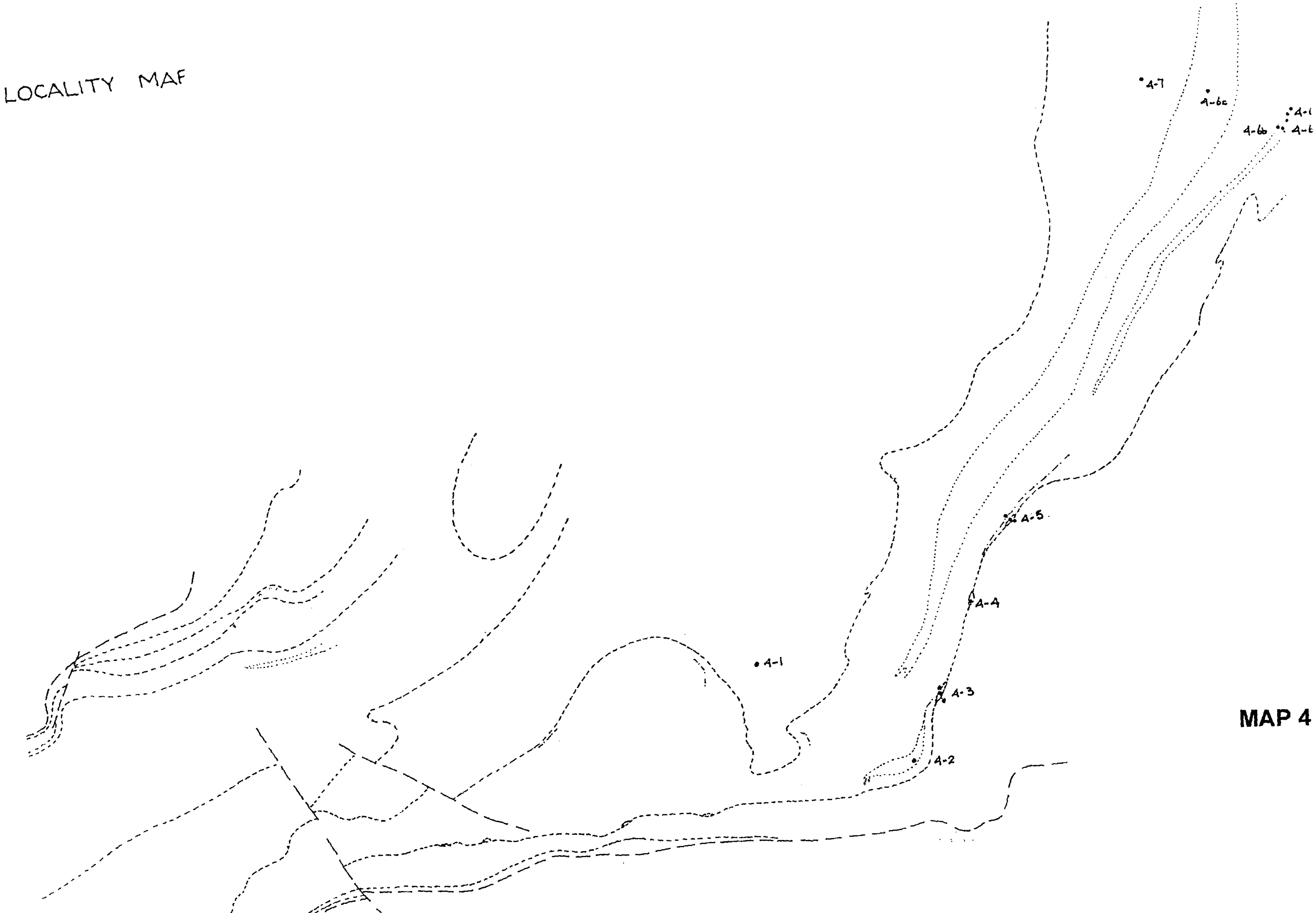
MAP 2

GENERAL OUTLINE OF THE OTTA NAPPE



MAP 3

LOCALITY MAP



MAP 4

MAP 5

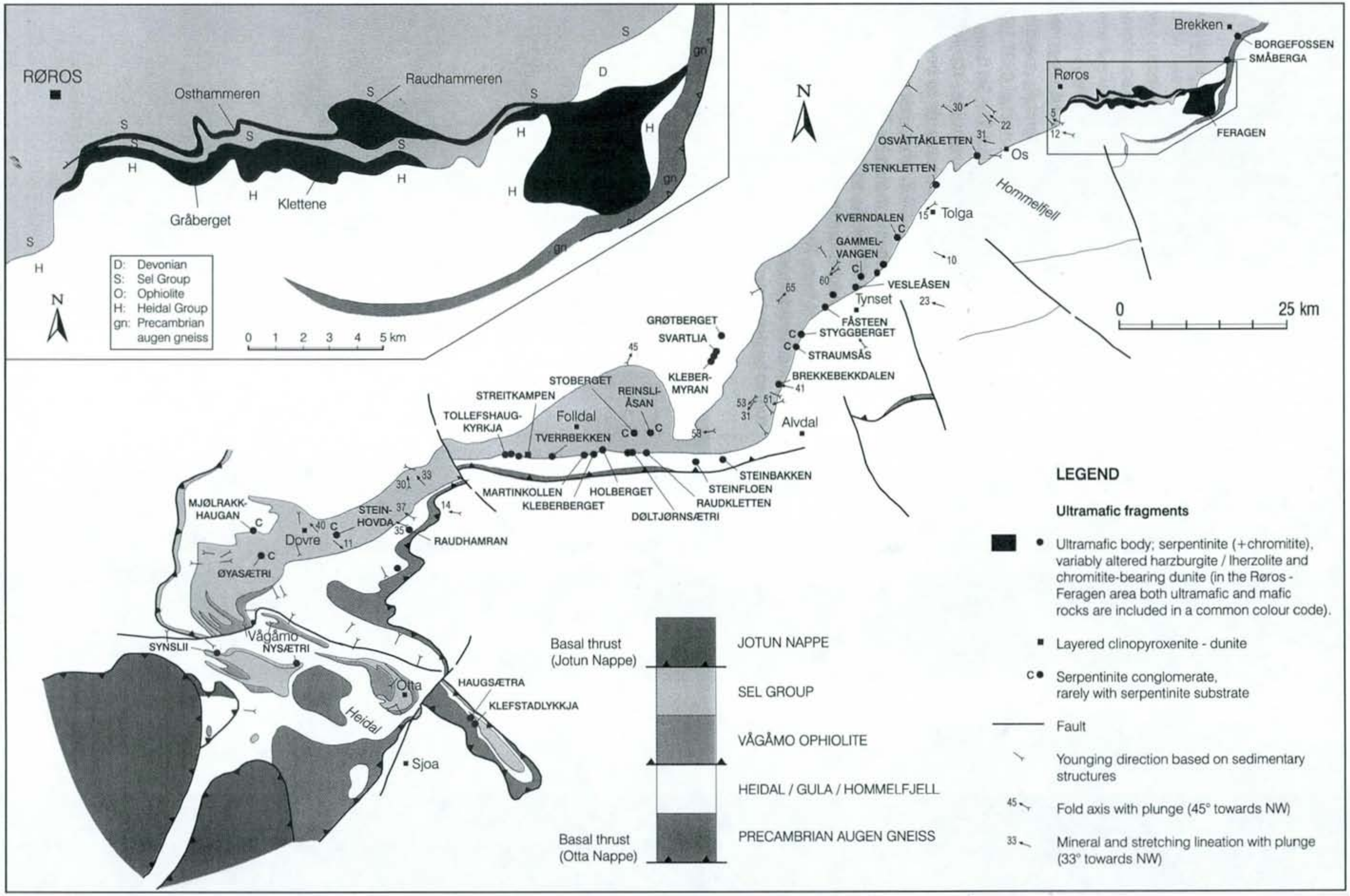


Fig. 1. Geological sketch map of the Vågå - Røros tract showing the locations of the ultramafite bodies.

MAP 6
(From Nilsson et al. 1997, Fig. 1)

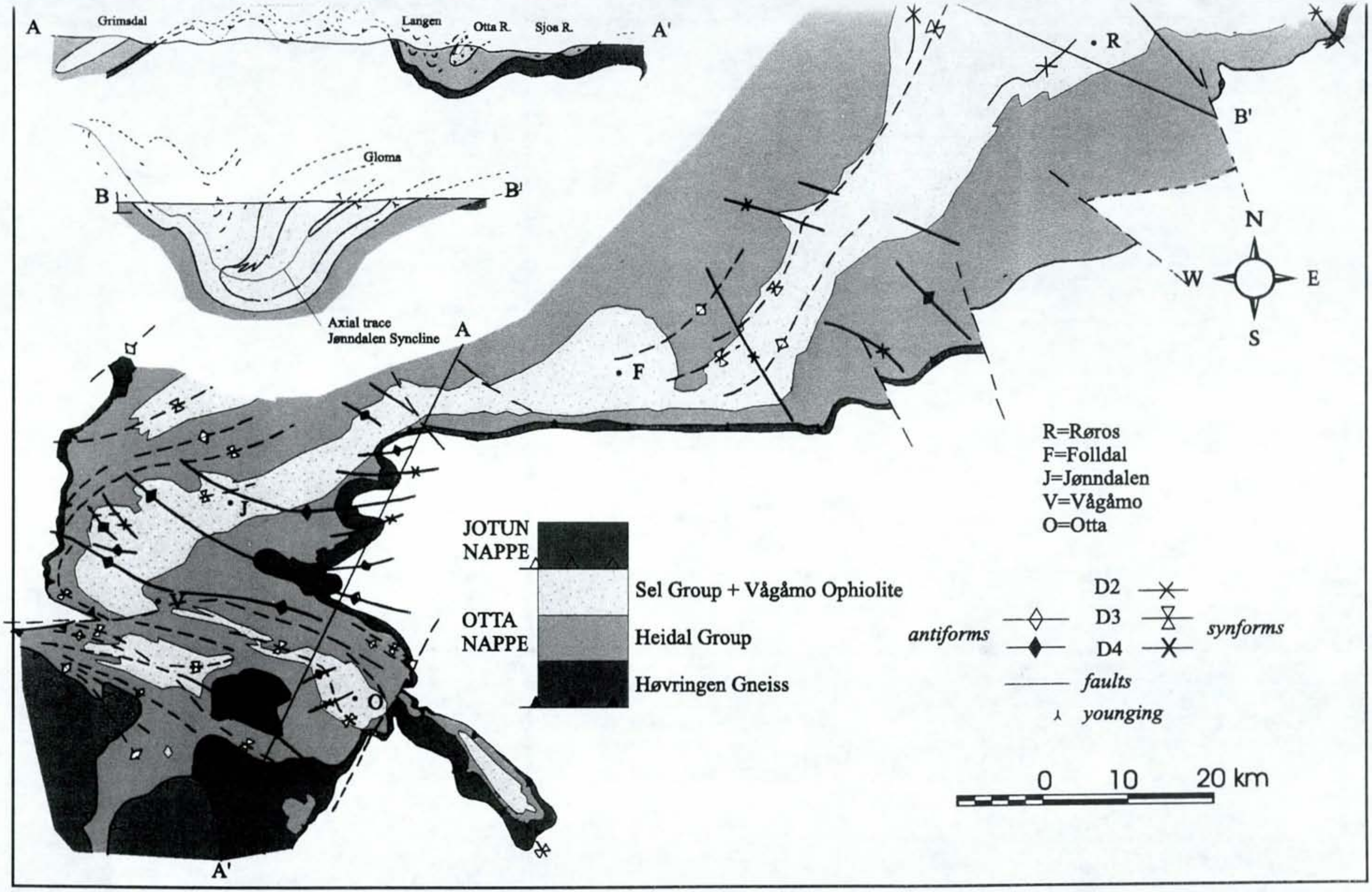


Fig 1. Simplified geological map of Otta-Røros Tract, emphasizing D3 and D4 folds, and with cross-sections A-A′ and B-B′.

MAP 7
(From Sturt & Ramsay 1997, Fig 1)