Lithostratigraphic correlation of the Salangen (Ofoten) and Balsfjord (Troms) Groups: evidence for the post-Finnmarkian unconformity, North Norwegian Caledonides.

MARK G. STELTENPOHL, ARILD ANDRESEN & JAMES F. TULL

Steltenpohl, M.G., Andresen, A. & Tull, J.F. 1990: Lithostratigraphic correlation of the Salangen (Ofoten) and Balsfjord (Troms) Groups: evidence for the post-Finnmarkian unconformity, North Norwegian Caledonides, *Nor. geol. unders. Bull. 418*, 61-77.

Detailed mapping around Ofotfjorden (68-69°N) demonstrates many tectonostratigraphic and lithostratigraphic similarities with the Caledonian allochthons in the Balsfjord area, 150 km to the north. Lithostratigraphic similarities are particularly striking between the nonfossiliferous Salangen supergroup (Ofoten) and the fossiliferous Upper Ordovician-Silurian Balsfjord Group. Both groups occur at an equivalent level in the respective nappe stacks. The lower contact of both groups is erosional, lying above a basement containing mafic-ultramafic igneous complexes that have been interpreted as ophiolite fragments; the Salangen supergroup lies above the upper part of the Narvik Group (Bjørkvik nappe) and the Balsfjord Group overlies the Lyngen Gabbro/Ophiolite. Relatively thick marble sequences, including both calcite and dolomite marbles, and distinctive carbonate pebble diamictites, quartzites, breccias, conglomerates, and mica schists are present in both groups at similar stratigraphic levels. Syntectonic granitoids and pretectonic metadolerites intruded both groups. The combined depositional, magmatic and tectonostratigraphic similarities strongly support that the Upper Ordovician/Silurian post-Finnmarkian basin recognized within the nappe pile in Balsfjord extended much further south into the Ofoten nappes. This implies that at least the upper part of the Narvik Group is of pre-Scandian age.

Mark G. Steltenpohl, Department of Geology, Auburn University, Auburn, AL 36849, U.S.A.
Arild Andresen, Department of Geology, University of Oslo, P.O. Box 1047, Blindern, 0316 Oslo 3, Norway
James F. Tull, Department of Geology, Florida State University, Tallahassee, FL 32306, U.S.A.

Introduction

Large portions of the north Norwegian Caledonides contain rocks of uncertain age and tectonic affinity. The depositional ages of units within the metamorphic cover allochthons, presumed to range from Late Precambrian (Riphean - Vendian) to Early Silurian (Roberts & Gee 1985), are poorly constrained because high degrees of metamorphism and strain have obliterated any possible faunal evidence. In fact, no ages relating to deposition, fossil or isotopic, are known for any of the metamorphic cover allochthons in the extensive region between Balsfjord and the general area depicted at the bottom of Fig. 1. Additionally, relatively few isotopic age determinations relating to igneous or metamorphic events have been published for this region (Roddick 1977, Dallmeyer & Andresen 1984, Hodges 1985, Steltenpohl et al. 1988). Consequently, little is known about the absolute timing of orogenic evolution in this large portion of the Caledonides.

The problem becomes more critical considering recent studies (Tull et al. 1981, Steltenpohl & Bartley 1984, Andresen & Bergh 1985, Andresen et al. 1985, Steltenpohl 1985, 1987) which indicate that this region lies within the transitional area between the Late Cambrian - Early Ordovician 'Finnmarkian' and the Late Silurian to Early Devonian 'Scandian' orogenic zones (Roberts & Gee 1985). One way of constraining the extent and relations between these orogenic zones is to trace fossiliferous units from their type areas (e.g., Balsfjord, Kåfjord, Sulitjelma) into areas, like Ofoten, where strong metamorphic and deformational effects preclude fossil age determinations. A

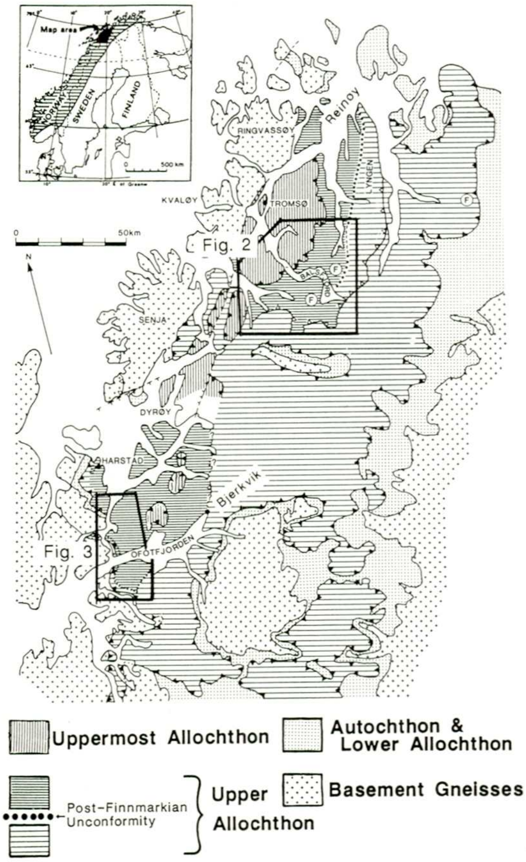

Fig. 1. Simplified tectonic map of the Ofoten-Troms regions of the north Norwegian Caledonides illustrating the known extent of the Salangen supergroup and Balsfjord Group and the study areas depicted in Figures 2 and 3. F in circles represent known fossil localities.

lack of detailed studies in the intervening areas, however, does not presently allow for physical connection of units in Ofoten with fossiliferous rocks in the region. An alternative solution, utilized herein, is correlation of distinctive lithologies and rock sequences. We argue that the unconformity at the base of the Salangen Group (Gustavson 1966) corresponds with that at the base of the fossiliferous Ordovician-Silurian Balsfjord Group (Olaussen 1976, Binns & Matthews 1981, Bjørlykke & Olaussen 1981, Andresen & Bergh 1985, Bergh & Andresen 1985), which allows for straightforward regional correlation of rock units between Ofoten and Balsfjord.

The purpose of this report is twofold: 1) to present new, detailed descriptions on the stratigraphy of the highly deformed and metamorphosed (kyanite-grade) Salangen supergroup (Evenes and Bogen Groups: Foslie 1941, Vogt 1942, Steltenpohl 1987), and 2) to compare the petrography, petrology, lithology, and lithostratigraphy of the Salangen supergroup with that of the biotite/garnet-grade rocks of the Upper Ordovician-Silurian Balsfjord Group (Bjørlykke & Olaussen 1981, Binns & Matthews 1981, Andresen & Bergh 1985).

Tectonostratigraphic context

Studies dealing with Caledonian tectonics have grouped the allochthonous units into four main thrust complexes, the Lower, Middle, Upper, and Uppermost Allochthons (Gee & Zachrisson 1979, Roberts & Gee 1985). The Lower and Middle Allochthons contain Late Proterozoic (Riphean and Vendian) to Silurian miogeoclinal metasediments, locally in depositional contact with allochthonous Precambrian basement gneisses. These rocks are interpreted to have been deposited along the rifted margin of Baltica, which bordered the Iapetus Ocean to the east. The Upper and Uppermost Allochthons comprise a number of thrust sheets of eugeoclinal character (Stephens & Gee 1985). Included within these nappes are ophiolite fragments, island arc assemblages, and back-arc basin sequences (Sturt 1984, Stephens 1988). Both the Salangen and Balsfjord Groups, which are the focus of this report, are considered to be part of the Upper Allochthon (Figs. 1, 2, & 3).

The nappe stack in Balsfjord (Fig. 2) contains, from bottom to top, the Normannvik and Lyngen Nappes (Upper Allochthon) and the Tromsø Nappe Complex (Uppermost Allochthon). The Lyngen Nappe comprises the Balsfjord Group, Lyngen Gabbro, and a sequence of greenschist-facies metasediments and metavolcanics (Koppangen formation) that lie structurally underneath the gabbro. Thrusts, which correspond to steep metamorphic gradients, separate the Lyngen Nappe from the underlying Normannvik Nappe and the overlying Tromsø Nappe Complex (Andresen et al. 1985). The Nordmannvik Nappe contains relict granulite-facies assemblages (Andresen & Bergh 1985, Bergh & Andresen 1985), and the Tromsø Nappe Complex contains eclogites and high-pressure granulites (Krogh et al. 1990). Sandwiched between these two high-

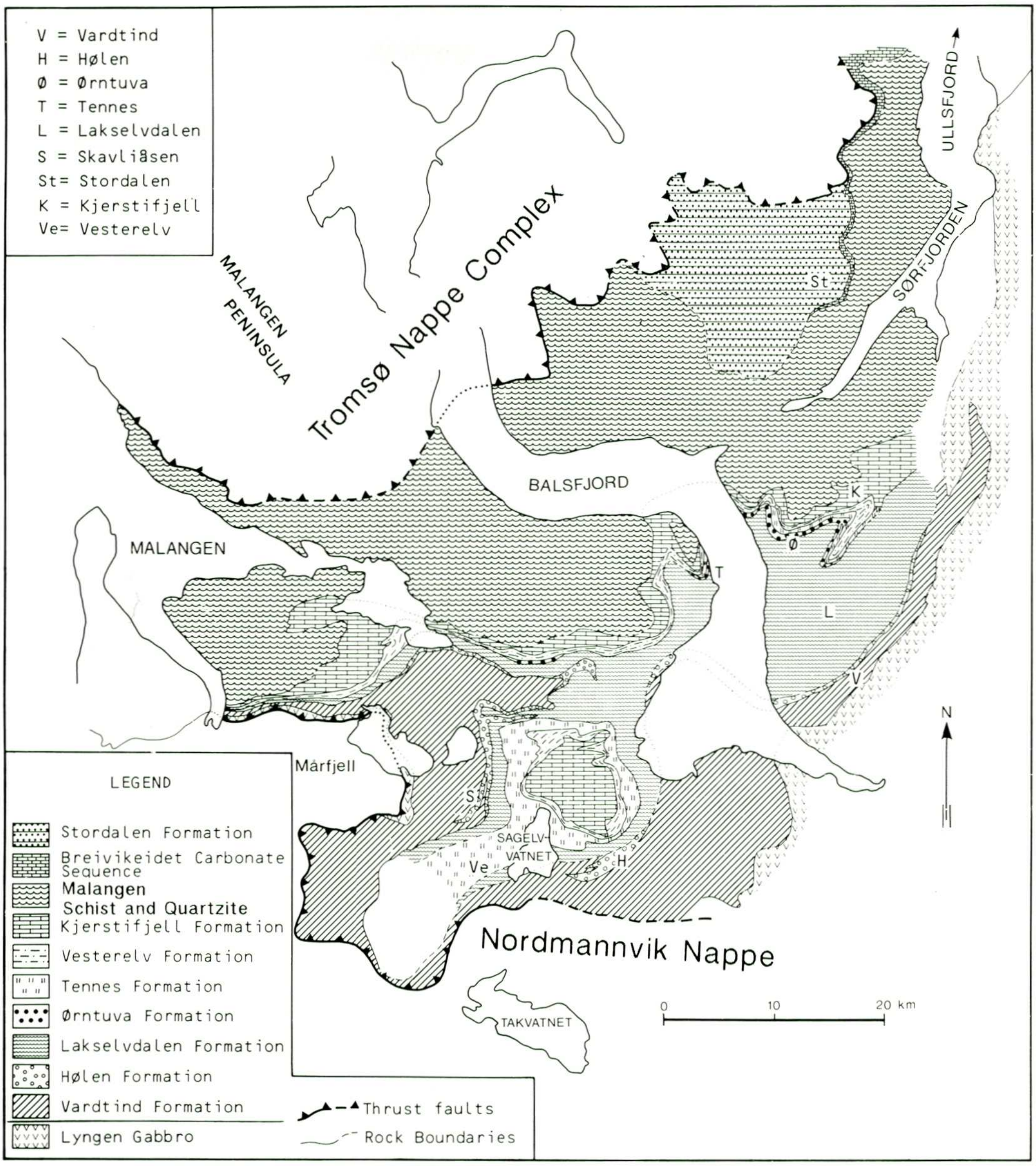

Fig. 2. Geologic map of the Balsfjord area (Troms) with emphasis on the lithostratigraphy of the Balsfjord Group (after Andresen & Bergh 1985). See Figure 1 for location.

grade nappes over a large area is the fossiliferous greenschist-facies Balsfjord Group, locally containing a lower amphibolite-facies assemblage. We believe the Balsfjord Group corresponds to the Salangen supergroup located 100 km to the south in Ofoten. The stratigraphy of the Balsfjord Group (Figs. 2 and 4) has been described by Binns & Matthews (1981), Bjørlykke & Olaussen (1981), Andresen & Bergh (1985), Bergh & Andresen (1985) and Minsaas & Sturt (1985). Despite earlier disagreements concerning the structural position of the Balsfjord Group relative to the overlying and underlying units, it is now well established that a regional unconformity separates the Balsfjord Group from the underlying Lyngen Gabbro (Minsaas & Sturt 1985). The same authors interpret the Lyngen Gabbro as the layered cumulate portion of an ophiolite fragment. Geochemical data (Fuller 1986) from a dike complex along the eastern margin of the gabbro support this interpretation.

The Ofoten nappe stack (Fig. 3) comprises, from bottom to top, the Narvik, Salangen (both of the Upper Allochthon), and Niingen (Uppermost Allochthon) Groups (Gustavson 1966, 1972). In Ofoten a thrust separates Precambrian basement gneisses and their discontinuously preserved cover units from the overlying Narvik Group. The Narvik Group contains mostly schists and gneisses that constitute a melange of rock types, including sheared mafic and ultramafic rocks that have been interpreted as fragments of obducted oceanic crust (Boyd 1983, Barker 1984, Crowley 1985, Hodges 1985). Numerous types of felsic plutonic rocks intrude these units (Steltenpohl et al. 1988). Hodges (1985) and Barker (1986), recognizing the lithologically complex nature of the Narvik Group, suggested that it contains several internal thrust sheets of variable metamorphic grade. The Salangen Group (Gustavson 1966) contains two lithologically distinct assemblages called the Evenes and Bogen Groups (Foslie 1941, Vogt 1942). The Evenes Group unconformably overlies the upper units of the Narvik Group and constitutes a more than 3 km thick sequence of calcite and dolomite marble with minor metaconglomerate, metadiamictite and pelitic schist (Tull et al. 1981, 1985, Steltenpohl et al. 1985, 1986). In contrast to the Narvik Group, the Evenes Group is a coherent lithostratigraphic package that lacks felsic intrusives. The Bogen and Niingen Groups, which lie successively above the Evenes Group, are composed dominantly of schists intruded by numerous granitoid bodies. The Bogen Group is more calcareous, containing thin marbles and calcschists, neither of which is known to occur in the Niingen Group. Tectonic contacts mark the boundaries between the Evenes and Bogen Groups and the Bogen and Niingen Groups (Steltenpohl 1987). Each of the Ofoten allochthons contain kyanite-zone assemblages (kyanite + garnet + biotite and kyanite + staurolite + garnet + biotite, both in association with quartz, white mica, and plagioclase). Migmatites are locally preserved in the Narvik and

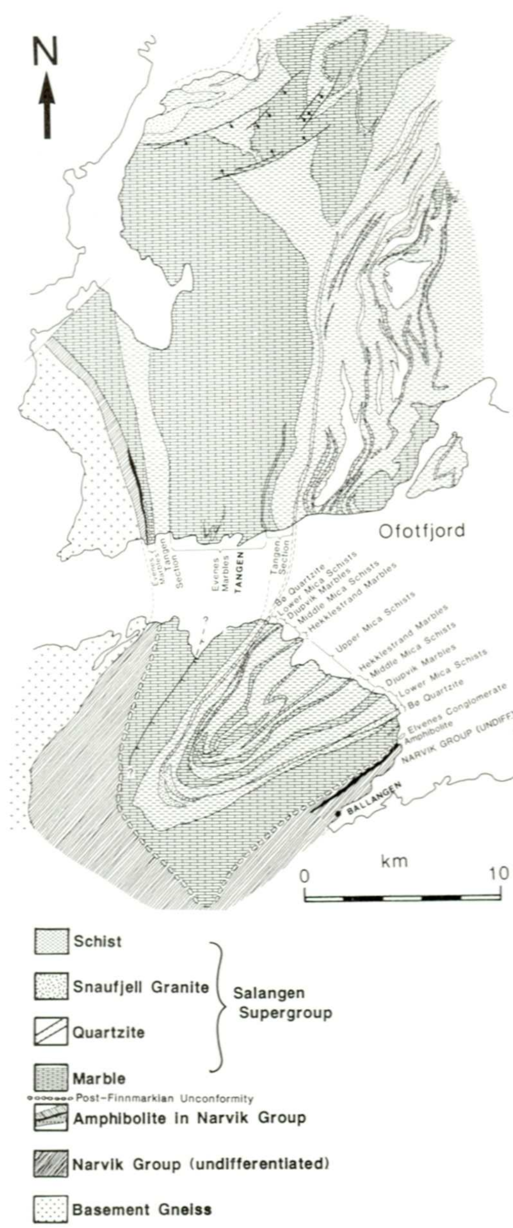

Fig. 3. Lithologic map of the Salangen supergroup (Ofoten) (after Steltenpohl 1983, 1987). See Figure 1 for location.

Niingen Groups (Hodges 1982, Steltenpohl unpubl. data). Quantitative thermobarometric studies on the metapelites (see Steltenpohl and Bartley 1987) resulted in P-T estimates that plot along a linear trend ranging from

443°C, 6.9 kb to 688°C, 10.6 kb. There is no systematic variation of P-T estimates between allochthons except for the investigated part of the Narvik Group, which yielded systematically higher temperatures and pressures (Steltenpohl & Bartley 1987). The thermobarometric estimates, therefore, corroborate kyanite-grade metamorphism having affected each of the western Ofoten nappes.

Most recent studies have concluded that pre- or syn-kyanite-grade thrusts correspond to the boundaries between the western Ofoten nappes (Bartley 1984, Hodges 1985, Steltenpohl 1987). This interpretation is based on a lack of variation in metamorphic grade and structural development between individual nappes combined with a lack of recognition of retrogressive deformation zones along their contacts. As described below (see Salangen supergroup lithostratigraphy), however, this contrasts with observations along the eastern limb of the Ofoten synform where post-kyanite-grade metamorphic emplacement of the nappes is reported (Boyd 1983, Barker 1984, 1986, 1989). This discrepency is not presently understood perhaps because, (1) exposures containing the thrust contacts are rare, (2) a great deal of the intervening area lies beneath the Ofotfjord, and (3) the critical area around Bjerkvik has not yet been mapped in detail.

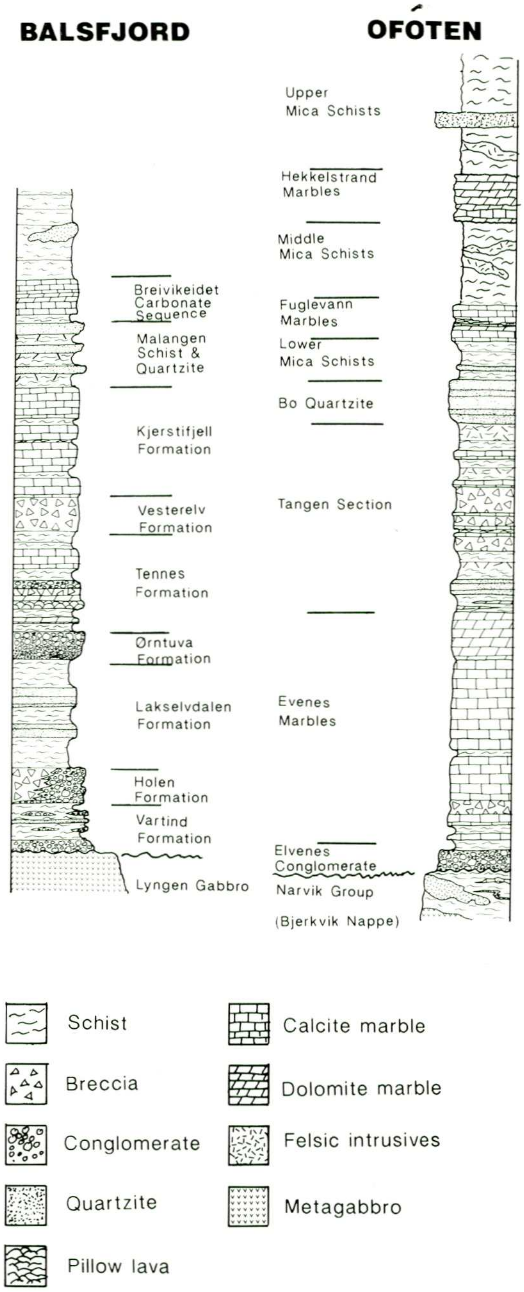

Fig. 4. Simplified columnar sections through the Balsfjord Group and Salangen supergroup. Not to scale.

Balsfjord Group Lithostratigraphy

Various lithostratigraphic terms have been reported for the different units within the Balsfjord Group, depending upon author and area under discussion (Randall 1971, Binns & Matthews 1981, Bjørlykke & Olaussen 1981, Minsaas & Sturt 1985, Andresen & Bergh 1985). Based on available data, Andresen & Bergh (1985) proposed a revised but *informal* lithostratigraphy for the entire region underlain by the Balsfjord Group. This lithostratigraphy is summarized below (Fig. 4). The reader is referred to Bjørlykke & Olausson (1981), Minsaas & Sturt (1985) and Bergh & Andresen (1985) for detailed information.

Vartind formation. The Vartind/Bjørndalsfjell formation is dominated by phyllites and chlorite schists that characteristically contain several discontinuous metaconglomerate units. Clasts of gabbro and metabasalt, most probably derived from the underlying Lyngen Gabbro (Minsaas & Sturt 1985), dominate the lowermost metaconglomerate horizons but exotic volcanic and plutonic rocks occur higher up in the formation. The metaconglomerates are interbedded with texturally and compositionally very immature metasandstones. Various primary sedimentary structures (current ripples, flaser bedding, normal grading, parallel lamination) are common. Minsaas & Sturt (1985) interpreted this part of the Balsfjord Group as interbedded debris flow and sheet flow deposits. A thin serpentinite/soapstone layer is present at several localities just below the base of the overlying Hølen formation.

Hølen formation. The Hølen formation is a conglomerate/breccia unit of variable thickness (0-50 m), sorting, and composition. It is commonly clast supported, with well-rounded pebble-sized quartzite and angular marble clasts as the dominant clast lithology. Carbonate clasts characteristically dominate the lower part whereas the upper part contains mostly quartzite clasts. At some localities, jasper fragments appear to be enriched in the transitional zone between the marble and quartzite dominated portions of the conglomerate. An essentially monomict carbonate breccia with clasts up to 1 m across occurs locally. Both pink calcite marble clasts and green fuchsite-bearing clasts are present (Andresen & Bergh 1985). The Hølen formation interfingers with dark calcareous schists dominating the lowermost part of the overlying Lakselvdalen formation and is apparently discontinous toward the southwest (Bergh & Andresen 1985).

Lakselvdalen formation. The Lakselvdalen formation comprises mainly calcareous chlorite schist, graphitic-chlorite-white mica schist, and metasandstone. Minor volumes of calcite marble, dolomite marble, variably sorted metasandstone and metaconglomerate (grit) occur in the upper part of the formation. Fining-upward sequences present within some units imply deposition from turbidity currents. There appears to be a lateral facies change from coarse to fine material from east to west. The direction of fining indicates a probable eastern source. Most of the fossils recovered from the Balsfjord Group are from the Lakselvdalen or overlying Tennes formation (Fig. 4).

Ørntuva formation. A coarse clastic, generally coarsening upward sequence named the Ørntuva formation overlies the Lakselvdalen formation. The Ørntuva formation is dominated by an essentially monomict quartzite conglomerate with minor metasandstone beds restricted to its stratigraphically lower parts.

Tennes formation. The Tennes formation comprises mainly light-gray to white, laminated, fine-grained flinty dolomite and brownish-green, laminated, sandy carbonate-rich chlorite schist. Other common lithologies are pink and white calcite marble, dark-gray dolomite marble, intraformational metabreccias in carbonates, metaconglomerates, graphitic schists, metamorphosed pillow lavas and chlorite schists. A distinctive characteristic of the Tennes formation is its rapid lateral facies and thickness variations. Its greatest thickness occurs around Sagelvvatn where it is 300-500 m thick. Outside this area its characteristic lithologies may locally be absent. Although tectonic strain accounts for some of this thickness variation, most of it is considered to be syndepositional in nature. It is, however, not clear whether this pretectonic thickness variation is due to non-depositon or erosion in some areas. The fossils recovered from the Tennes formation (i.e., Mosberg formation of Bjørlykke & Olaussen 1981) include tabulate corals belonging to Halysitidea. Most corals are poorly preserved, but one halysitid with large coralites resembles the Upper Llandovery (Adarere) species Cateripora maxineae (Fisker-Benzon) and Catenipora distans (Fichwald) (Bjørlykke & Olaussen 1981).

Vesterelv formation. A matrix supported metaconglomerate (metadiamictite) with yellowish-white and gray metadolomite fragments dominates the overlying Vesterelv formation. The frequency of clasts varies stratigraphically throughout this section but no well-developed sorting or layering was observed. The clasts are angular and range in size from less than 5 mm to 10 cm across. Clasts of light-gray dolomite predominate but calcite marble pebbles and oolitic dolomite clasts are also present. At a few localities, metadiamictite is observed interbedded with dark-gray to black graphitic marble, a lithology constituting the bulk of the overlying Kjerstifjell formation.

Kjerstifjell formation. The Kjerstifjell formation is dominated by a dark gray to black graphitic calcite marble. A few thin layers of fine-clastic material, now metamorphosed to a garnet-biotite schist, are interbedded with the black marbles. The Kjerstifjell formation reaches a structural thickness of up to 200 m.

Malangen schist & quartzite. The uppermost part of the Balsfjord Group at Malangen contains garnet-mica schist, chlorite schist, and quartzite with minor amounts of amphibolite and 'garbenschiefer'. Different types of crossbed stratification occur locally in the quartzites. This entire sequence of rocks, which is at least 1000 m thick, was named the 'Malangen schist and quartzite' by Andresen & Bergh (1985). So far, little detailed work has been carried out within this sequence around Balsfjord although petrographical data from the most dominant lithologies have been described by Landmark (1973), Kristensen (1983) and Bergh & Andresen (1985).

Breivikeidet carbonate sequence. Northward along strike from Balsfjord (Fig. 2), at least two more lithotectonic units have been mapped above the 'Malangen schist and quartzite sequence' but below the thrust at the base of the Tromsø Nappe Complex. These units are called the 'Breivikeidet carbonate sequence' and the Stordalen formation (Andresen & Bergh 1985). The former is composed of gray calcite marble and white dolomite marble. These lithologies are well exposed in the steep cliffs of Reinøy (Fig. 1) further north (Binns 1978, Velvin 1984). Stromatolites reported by Binns (1975) are from dolomites within the Breivikeidet carbonate sequence. Some of the marbles are very pure dolomite marbles and have been investigated for commercial use both around Breivikeidet-Sjursnes and on Karlsøy.

Igneous rocks. Igneous or meta-igneous rocks within the Balsfjord Group metasediments are 1) a few bodies of serpentinite, 2) metaquartz diorite, 3) thin (from a few cm up to 10 m thick) metadolerite dikes, 4) metagranite dikes, and 5) a single trondhjemite body. The serpentinites appear to be restricted to the Vardtind formation (Bergh & Andresen 1985). Their low structural position supports that they may represent tectonic slices from the ultramafic portion of the underlying Lyngen Gabbro. The only major trondhjemite body occurs at Balsfjord Church at Tennes (Binns & Matthews 1981), where it intrudes schists of the Lakselvdalen formation. It is a leucocratic, white, chlorite-white mica-quartz-plagioclase rock with a weakly developed foliation. This foliation corresponds to the earliest foliation in the country rock, thus indicating a pre-tectonic emplacement age for the trondhjemite. Minor dikes and bodies of slightly more melanocratic metadiorites were observed southwest and west of Ullsfjord around Sjursnes in the Malangen schist and quartzite sequence. Pre-tectonic metadolerites are particularly common on the east side of Ullsfjord (Munday 1974, Minsaas 1981). Recent mapping on Reinøy by Velvin (1984) demonstrates, however, that mafic dikes intruded the Balsfjord Group at various stages during its tectonometamorphic evolution. Velvin (1984) also described syntectonic (post-D1 and pre-D2) garnetiferous metagranite bodies in the garnet-mica schist stratigraphically above the Breivikeidet carbonate sequence on Reinøy. A Rb-Sr wholerock study of the largest metagranite body on Reinøy has yielded an isochron age of 431 ± 7 My (Lindstrøm 1988).

Salangen Supergroup Lithostratigraphy

The 'Salangen Group' contains two lithologically distinct assemblages, a lower marble dominated sequence called the Evenes Group and an upper sequence of schists with minor marble units intruded by granite sills called the Bogen Group (Vogt 1942, Foslie 1941, 1942, Gustavson 1966, Steltenpohl & Bartley 1984, Steltenpohl 1987). We use the informal term, Salangen supergroup, to refer to the combined Evenes and Bogen Groups. The nature of the contact between the two groups is poorly understood. In western Ofoten, Steltenpohl & Bartley (1984) and Steltenpohl (1987) suggested that it is tectonic, although direct structural evidence for a thrust in western Ofoten has not been observed. As discussed below, in some areas the Bogen Group is allochthonous with regard to the Evenes Group, but it is interpreted to have originated as an upward (and/or westward?) continuation of the same stratigraphic package.

The known areal extent of the Salangen supergroup and our interpretation of correlations into other areas are illustrated in Figure 1. The data presented below and in Figure 3 are based on our detailed mapping of the Evenes and Bogen Groups in the hinge zone (Steltenpohl 1983, Tull et al. 1985, Andresen

& Tull 1986) and along the western limb of the Ofoten synform (Steltenpohl 1985). Boyd (1983) suggested that the rocks along the eastern limb of the synform at Bjerkvik (Fig. 1), which correspond to the same tectonostratigraphic level as the Evenes Group on the western limb, in part belong to a separate nappe called the Bjerkvik nappe (Boyd & Søvegjarto 1983). They based this distinction in part upon the contrasting metamorphic grades between the over- and underlying kyanite-grade Bogen and Narvik Groups, respectively, and the 'lower-grade' (greenschist-facies) Bjerkvik nappe. Boyd (1983) reported postmetamorphic faults bounding the Bjerkvik nappe. The present authors note, however, that no detailed description of either the lithologic units or the metamorphic mineral assemblages of the Bjerkvik nappe has been published. On the preliminary map-sheet Skjomen, Boyd & Søvegjarto (1983) included 2 units in the Bjerkvik Nappe, a mafic complex and conglomerate (Elvenes conglomerate). Barker (1984, 1986), mapping in detail about 10 km northward along strike of Bjerkvik, reported a structural and metamorphic break at the top of his Kvernmo Nappe (Narvik Group) where kyanite-grade gneisses are overlain successively by greenschist-facies 'sheared' metavolcanics, a 'sheared' granitoid layer, a biotite-grade marble-schist sequence representing the base of the Salangen Group (Evenes Group), and locally kyanite-bearing units interpreted as the Bogen Group. Although the intervening area has not been mapped, the lower part of the Bjerkvik Nappe and the greenschist-facies rocks in Barker's area have similar rock types, are of lower metamorphic grade than units above and below them, and lie at the same tectonostratigraphic level, implying a probable lateral link. Additionally, our reconnaissance observations around Bjerkvik indicate many lithologic similarities (e.g. metaconglomerates and graphitic marbles) with rocks of the Evenes Group, along the western limb of the Ofoten Synform, although the metamorphic grade differs markedly. This is consistent with our detailed mapping in the core of the synform which demonstrates a relatively simple continuation of Evenes Group rock units around the fold hinge. The present authors believe that these relationships indicate increasing metamorphic grade of Evenes Group rocks traversing westward from the eastern to the western limb of the synform.

Our interpretation of the lithostratigraphy of the Salangen supergroup is illustrated in Figure 4. True stratigraphic thicknesses are unknown because the units have been strongly modified by ductile intraformational folds and local tectonic slides. Stratigraphic 'up' indicators are preserved only locally in the Evenes Group, indicating both right way up and inverted compositional layering, which reflects local overturning due to folding. The depositional contact with the underlying Narvik Group (Gustavson 1966, Tull et al. 1981, 1985), however, indicates that the sequence as a whole is both structurally and stratigraphically upright. Rock unit names in Figure 4 are informal and were modified from Foslie (1941, 1949), Juve (1967), Gustavson (1966, 1969, 1972) and Steltenpohl (1983, 1985, 1987). The following description of the lithologic units proceeds upwards from the base of the Evenes Group.

Evenes Group

Elvenes conglomerate. The base of the Evenes Group is marked by the Elvenes conglomerate (Gustavson 1966). The best exposures of this unit are found in roadcuts along highway E6, approximately 2 km southwest of Ballangen (Fig. 3), where it is approximately 30 m thick. At this locality an approximately 10 m thick carbonate and schist sequence, the Sjurvatnet schist of Hodges (1985), makes up the lowermost part of the formation.

Above this sequence two distinct conglomerate facies are recognized (Foslie 1941). Both are polymictic matrix-supported diamictites; one has an amphibolite matrix and the other has a matrix of calcareous schist. The average size and shape of the clasts in the amphibolite-matrix conglomerate are larger and more angular than those of the calcareous-schist conglomerate. The two lithofacies appear to be gradational and discontinuous along strike; stratigraphic relationships between the two are often difficult to decipher. The amphibolite-matrix facies appears to be the stratigraphically lowest unit at most localities.

The amphibolite-matrix facies of the Elvenes conglomerate (Fig. 5) contains clasts of (in decreasing abundance) trondhjemite, metagabbro, calcite or dolomite marble, and orthoamphibolite. The dark green to black matrix is composed of hornblende-andesine-clinozoisite-biotite-quartz, indicating lower amphibolite-facies conditions of metamorphism. The clasts range in size from less than 1 cm to nearly 1 m in length. Some of the trondhjemite clasts are angular, which combined with the generally large size of clasts, indicates deposition close to the source area. Southwest of Bjørkasen, a few kilometers south of Ballangen, the conglomerate lies in depositional contact with a tabular trondhjemite body in the underlying Narvik Group/Bjerkvik Nappe.

The calcareous-schist-matrix facies of the conglomerate contains clasts of quartzite, granite, and calcite and dolomite marble, in order of decreasing abundance (Fig. 6). The matrix contains the assemblage muscovite-biotite-calcite-quartz. In outcrop the matrix has a distinctive pitted appearance due to weathering of calcite grains. Exposures of this facies can be observed on both limbs of the Ofoten synform along the south shore of Ofotfjord, and along the western limb north of Ofotfjord (Fig. 3).

Evenes marble sequence. Overlying the Elvenes conglomerate is a thick sequence of marbles that form the bulk of the Evenes Group. The marbles are dominantly medium- to coarse-grained, light- to dark-gray, banded calcite marbles. Medium- to coarse-grained banded white varieties or medium-grained dark-gray to blue and black graphitic types with rather thin (less than several meters thick) pink or fuchsite-bearing green varieties occur locally. The banded marbles are composed of layers generally less than 4 cm thick; rare 50 cm thick layers are composed almost entirely of calcite (approximately 90% of the mode is calcite, dolomite is only a minor constituent). These layers are separated by thin (less than 3 mm thick) mica-rich (white mica and biotite, the latter is commonly phlogopitic) laminae. Accessory amphibole, quartz, chlorite, clinozoisite, plagioclase, rutile, apatite, graphite, zircon, sphalerite, pyrite, chalcopyrite, and galena were observed in the mica-rich layers. In schistose marbles, mica may account for as much as 15% of the mode. The micas are scattered throughout the rock and dimensionally aligned. Dolomitic marbles are interspersed throughout the Evenes marble sequence but predominate in the upper portions (Figs. 3 and 4). Most are gray-banded varieties, although white-banded or massive units locally predominate. The dolomitic marbles are commonly non-laminated, having a phyllitic appearance due to the fine grain size. Commonly, the phyllitic dolomite marbles have large (less than

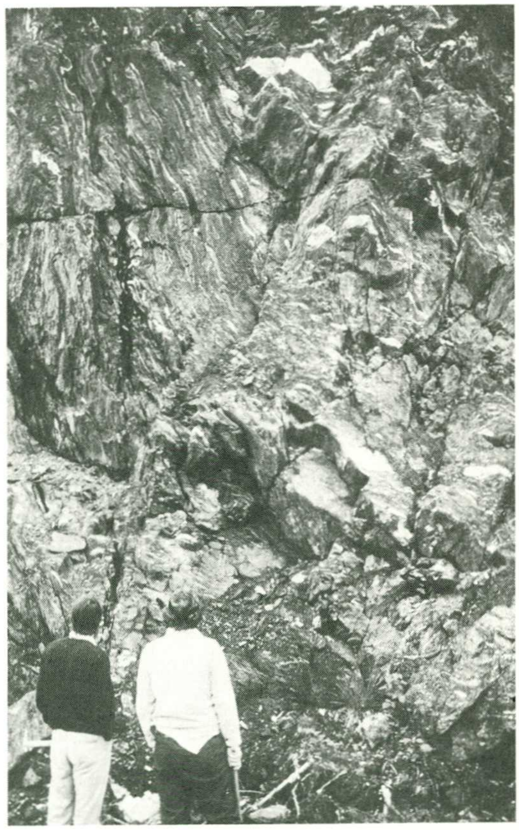

Fig. 5. Mafic—matrix facies of the Elvenes conglomerate. Most of the lightcolored clasts are trondhjemite. Gabbroic clasts occur only sporadically.

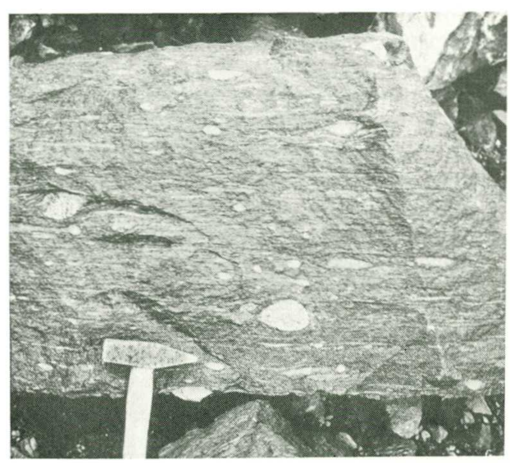

Fig. 6. Carbonate-matrix facies of the Elvenes conglomerate as it appears south of Ballangen along the E6. The least deformed clasts are nonfoliated and with a granitic composition. The remaining clasts are composed dominantly of quartzite and marble.

5 mm) sulfide grains (generally pyrite or chalcopyrite), which give the rock a spotted appearance upon weathering. The same accessories present in the calcite marbles are found in the dolomite marbles.

Intercalated with the marbles are minor, thin (generally less than 10 m thick) discontinuous mica schist layers. The mica schists are variable in composition but generally contain the assemblage garnet-biotite-white mica-plagioclase-kyanite-staurolite. The two-mica schists are gray in color, commonly stained rusty brown, and have no discernable internal layering. The lepidoblastic fabric is defined by dimensionally oriented white mica (<1 mm). Generally, the two-mica schists are quartz rich (ca. 40% of the mode). Accessory amounts of hornblende, rutile, tourmaline, apatite, zircon, zoisite, chlorite, carbonate, and opaques are present. Distinctive diamictite units (carbonate-pebble metapelites) are present at several stratigraphic levels within the Evenes marble sequence (Tull et al. 1985, Steltenpohl 1987). The diamictites contain clasts of yellowish-white, sugary-textured dolomite marble with rare scattered clasts of coarse-grained white calcite marble and orthoquartzite. The matrix is composed of calcareous schist. Few clasts are angular; most are rounded and elongated (X:Y:Z axial ratios are roughly 25:5:1, indicating plane strain).

Rare dolomite breccias also occur within the Evenes marble sequence. The clasts are composed of fine-grained light-gray dolomite. The matrix is also composed of dolomite but is darker, reflecting a higher concentration of graphite.

Intercalated with mica schists near the base of the Evenes marbles is a banded quartzite unit with thin, approximately 1-2 cm thick, compositional layers. The alternating layers of metapsammite and metapelite suggest graded bedding. The upward decrease in SiO_2 content indicates that stratigraphic 'up' is also structural 'up'. These probable graded beds, along with another exposure recognized in the overlying Tangen sequence described below, represent the only mesoscopic primary top and bottom features recognized in the Salangen supergroup of western Ofoten.

Tangen sequence. The Tangen sequence lies above the uppermost light-gray and white dolomite marbles of the Evenes marbles but below the Bø quartzite. This sequence is particularly well exposed along the shoreline near Tangen (Fig. 3). The Tangen sequence contains various types of distinctive mica schist. Two-mica schists, much like those described from the Evenes marble sequence, are most abundant and are complexly intercalated with other types of schist. In general, the mica schists of the Tangen sequence are more muscovite-rich than schists intercalated with the Evenes marbles. It was not possible, however, to differentiate the various schists at the scale of mapping (1:20,000).

'Garbenschiefer' is the next most abundant lithology in the Tangen sequence. It is persistent both laterally and vertically but the contacts with the surrounding garnet two-mica schists are diffuse. The 'garbenschiefer' is characterized by large hornblende porphyroblasts (up to 5 cm in length) growing randomly within the plane of schistosity. Garnet, hornblende, white mica, biotite, quartz, carbonate, and plagioclase are the major constituents. The hornblende porphyroblasts contain inclusions of quartz and are variably replaced by biotite and chlorite.

Biotite schists of the Tangen sequence are well-layered, with alternating dark and light laminae composed mostly of biotite and polygonized quartz, respectively. Minor garnet and muscovite are also present. Poikiloblastic plagioclase rarely occurs and contains inclusions of quartz, biotite and epidote. Garnet two-mica schists commonly grade into garnet-muscovite schists. The muscovite schists are relatively homogeneous without discernable compositional layering. The rock is composed dominantly of muscovite, with minor quartz, biotite, garnet, chlorite, tourmaline, opaques and zircon. Graphite is locally abundant, but may be dispersed throughout the rock. The muscovite schists commonly grade into and alternate with quartz-rich muscovite schists and graphite schists described below.

Thin (<5 m thick) matrix-supported metadiamictite units with fine-grained yellowish-white and gray metadolomite clasts (Fig. 7) occur at several levels within the Tangen sequence. The matrix is mostly carbonate schist. Clasts are mostly rounded and elongated with X:Y:Z axial ratios similar to those of the clasts in diamictites on the Evenes marbles. Commonly, the diamictites are bedded with dark-gray to black graphitic marble.

Several thin (<10 m thick), discontinuous carbonate schist matrix conglomerates (Fig.

8) occur in the Tangen sequence. The matrix of these rocks is similar to the carbonate schist facies of the Elvenes conglomerate but it is more carbonate rich and the clasts are different (medium- to coarse-grained quartzite and marble, and fine-grained gray dolomite marble). The abundance of marble clasts in these conglomerates combined with the lack of other lithic clast types suggest that they are intrabasinal deposits.

Fine-grained graphite-rich phyllitic dolomite marbles, similar to those described for the Evenes marbles, are commonly associated with light-gray to white banded varieties. These rocks have a spotted appearance due to weathering of sulfides. Near Tangen, the dolomitic marbles are isoclinally folded with highly attenuated limbs and isolated hinge regions, a structural feature responsible for the discontinuous occurrence of many lithologies in this unit.

Dark-green to black amphibolites are volumetrically minor, generally less than 1.5 m thick units scattered throughout the Tangen sequence. They are concordantly interlayered with the enveloping metasediments. The amphibolites commonly contain aligned hornblende but no conspicuous foliation was observed. Idioblastic crystals are commonly less than 2-3 mm long producing a nematoblastic texture. Garnet may or may not be present. Other consituents of the amphibolites are plagioclase

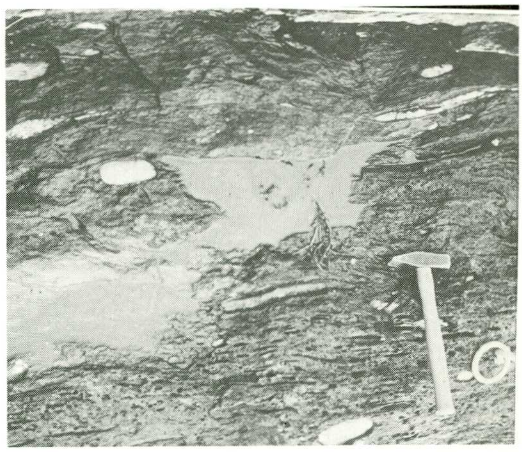

Fig. 7. Metadiamictite of the Tangen sequence. Light-colored rounded clasts are composed of fine-grained dolomite marble.

(oligoclase-andesine), biotite, carbonate, clinozoisite, epidote, tourmaline, zircon, rutile, and opaques.

Grey to black graphite schists of the Tangen sequence are generally thin units, less than 3 m thick, composed dominantly of muscovite and containing substantial amounts of graphite. Quartz layers, approximately 1 mm thick, are locally present and contain minor plagioclase, myrmekite, rutile, chlorite, opaques, and

Fig. 8. Carbonate-matrix conglomerate of the Tangen sequence folded about a late-phase, post-thermal peak, recumbent fold hinge. Long dimension of the photograph is approximately 3 m.

minor microcline. Rarely associated with the graphite schists are distinctive, black, thin (1-3 cm thick) but extremely competent dolomite + quartz layers. These layers characteristically form ridges in the less resistant graphite schists and commonly have tensional gashes filled with hydrothermal quartz. A distinctive, thin (8-10 m thick), feldspathic quartzite occurs near Tangen (Fig. 3). The quartzite is well-layered with quartz-rich bands, less than 3 cm thick, separated by phyllosilicate-rich parting laminae, approximately 1 mm thick. It is characterized in outcrop by relatively large biotite porphyroblasts which give the rock a spotted appearance. The quartzite layers behave as itacolumite or flexible sandstone; the flexibility is produced by interlocking quartz grains. The rocks are mineralogically distinct because of abundant orthoclase (up to 25%), a phase that is rare in any of the other metasedimentary units of the Evenes and Bogen Groups. Muscovite is generally finer grained and more abundant than biotite. Accessory minerals are plagioclase and carbonate.

A thin (<3 m) orthoquartzite unit, similar in appearance to the Bø quartzite (see below) is also present in the Tangen sequence. It is composed of poorly defined layers (<1 cm) of quartz separated by concentrations of small white mica grains. The quartzite is discontinuous along strike due to extreme boudinage. A pronounced rodding lineation was commonly observed.

Bogen group

The overall lithologic makeup of the Bogen Group is illustrated in Figure 4. In general, the Bogen Group differs lithologically from the underlying Evenes Group in that the former 1) is dominated by schists rather than marbles, 2) does not contain conglomerates or breccias, and 3) contains several types of felsic intrusions, none of which have been recognized in the Evenes Group.

Bø quartzite. A distinctive quartzite and key marker unit throughout Ofoten was referred to as the Bø quartzite by Foslie (1941) and Vogt (1942). It is generally about 15 m thick but its thickness varies from less than 1 m to more than 200 m. It is a well-foliated, medium-grained quartzite with muscovite-rich laminae, which cause the rock to split into slabs 5-10 cm thick. In outcrop the quartzite is buff or bleached tan in color; fresh samples are light gray. Petrographically, the quartzite is granoblastic with polygonal quartz intergrowths and small idioblastic mica grains at triple points. Quartz domains are separated by laminae containing muscovite, biotite, plagioclase, carbonate, amphibole, tourmaline, and chlorite. A detailed description of the Bø quartzite was given by Gustavson (1966).

Lower mica schist. Lower mica schist refers to a thick schist sequence above the Bø quartzite and below the Fuglevann marbles. It has a structural thickness of about 550 m. A garnet biotite-white mica-quartz-plagioclase schist is the dominant lithology. This rock type is interlayered with other types of mica schist and amphibolite similar to those described for the Tangen sequence. In addition to these lithologies, the Lower mica schists also have staurolite-bearing garnet-muscovite schists and calc-schists. Biotite schists in the lower mica schist sequence commonly are less quartz-rich than those of the Tangen sequence. Both the biotite schists and the calc-schists are more iron-rich than similar rocks in the Tangen sequence, as evidenced by the large amounts of opaque minerals which, upon weathering, stain the rock brown. Rare staurolite-bearing garnet-muscovite schists contain only minor amounts of fine-grained, brown pleochroic biotite and essentially no plagioclase. The calc-schists are very distinct in outcrop because of their pitted appearance, reflecting substantial concentrations of calcite (locally up to 50% of the mode). Gradational transition into schistose marbles (> 50 % calcite) is common. Green biotite, quartz and minor muscovite are the most abundant minerals after calcite. Other minerals are epidote, magnetite, hematite, plagioclase, tourmaline, and chlorite.

Fuglevann marble. Gustavson (1966) referred to the lowest group of marbles lying structurally above the Bø quartzite as the Fuglevann marble. South of Ofotfjord, this group of marbles is approximately 200 m thick but thins sharply northwards. Marbles of this sequence are generally medium- to coarse-grained, gray-banded or schistose calcite marbles, very similar to those described for the Evenes marble. Thin discontinuous layers, less than 3 m thick, of garnet-mica schist and/or calc-schist are intercalated throughout the Fuglevann marble. Rare, 1-2 m thick lenses of white sugary textured, dolomite marbles were observed.

An abundance of iron ore minerals is apparent as thin, 1-2 mm thick, hematite/magnetite-rich bands disseminated within the marble layers. Specular hematite zones were locally observed. These iron-rich zones appear to be randomly dispersed throughout the Bogen Group but more frequently occur in the Fuglevann marbles. The iron ores within the Bogen Group were commercially exploited during the early 1900's and have been described in detail by Foslie (1949) and Gustavson (1966).

Middle mica schist. An approximately 400 m thick schist sequence, the Middle mica schist, overlies the Fuglevann marble. These schists are petrographically similar to the Lower mica schists; the only difference being the presence of rare kyanite-bearing garnet-mica schists and absence of staurolite porphyroblasts. Kyanite is fine-grained (less than 0.1 mm) and occurs as inclusionfree porphyroblasts enveloped by coarse-grained white mica, which forms the dominant schistosity in the rock. Garnets are quite large (up to 1 cm) in the kyanite-bearing mica schists. In other samples lacking kyanite, garnet rarely contains fine-grained staurolite inclusions.

Hekkelstrand marble. Above the Middle mica schist is a relatively clean marble sequence, approximately 150 m thick, dominated by dolomitic marbles. This sequence is referred to as the Hekkelstrand marble, which is well exposed in the Hekkelstrand marble quarry on the east limb of the Ofoten synform (Fig. 3). The Hekkelstrand marble is a pure carbonate sequence lacking significant intercalations of metapelites.

A white, fine-grained, sugary-textured dolomite marble, approximately 75 m thick, constitutes one of the more distinct units in the Bogen Group. It has considerably less quartz than the dolomite marbles of the Evenes Group. In the structurally lower portion of the dolomite marble, a 10 m thick layer has a faint gray and white banding resulting from variable concentrations of graphite. The remainder of the marble sequence is made up of an approximately 40 m thick gray banded and white coarse-grained calcite marble, petrographically identical to those described for the Fuglevann marbles. Rare graphite schists and amphibolites, like those recognized in the Evenes Group, are also present. A distinctive, less than 3 m thick, interlayered amphibolite marble unit is composed of alternating bands of amphibolite and white and pink coarse-grained calcite marble.

Upper mica schist and Djupviknes quartzite. Overlying the Hekkelstrand marble is another sequence of schists, approximately 370 m thick, containing a thin but distinct orthoquartzite unit near the structural base. This Upper mica schist unit is succeeded by coarse-grained gneisses and schists of the Niingen Group north of Ofotfjorden. The contact between the Bogen Group and the Niingen Group was interpreted as a thrust by Gustavson (1966) and Steltenpohl (1985, 1987). The Upper mica schists are very similar to the two-mica schists that occur elsewhere within the Bogen Group. The Upper mica schists contain Pb-Zn deposits described in detail by Juve (1967). The Djupviknes quartzite is a very clean orthoquartzite, which has no discernable layering in outcrop. Finegrained mica, carbonate, garnet, chlorite, tourmaline, zircon, and opaques are present in only accessory amounts.

Igneous rocks.

Significant contrasts exist in the distribution and types of igneous rocks present in the Evenes and Bogen Groups. Both groups contain rare, thin (<1 m), polydeformed tabular amphibolites that cross-cut the compositional layering but have the same metamorphic lineations and foliations as the surrounding metasediments. These amphibolites are interpreted to represent pre- to syntectonic mafic dikes. These dikes are similar in appearance and petrography to the interlayered amphibolites present in the Tangen sequence. Whereas the mafic dikes are the only igneous rocks thus far recognized in the Evenes Group, Steltenpohl (1985) and Steltenpohl et al. (1988) have described three types of felsic intrusives within the Bogen Group at Skånland. These are the Snaufjell and Dragvik granites and the Skogoy quartz monzonite. The felsic intrusives occur as dikes and/or sills and are differentiated based upon field relations, petrography, and geochemistry. Rb-Sr whole-rock dating of the garnetiferous Dragvik granite has yielded an age of 427 ± 6 My (Lindstrøm 1988, Steltenpohl et al. 1988). A discussion of these felsic intrusives and other granitoids in the Ofoten region is the subject of a forthcoming paper.

Comparison of Salangen Supergroup and Balsfjord Group Lithologies

In discussions of the regional geology of northern Norway, workers have traditionally correlated the Balsfjord Group with the Salangen supergroup (Gustavson 1966, Landmark 1973, Binns 1978). The basis for this correlation, in most cases, has been the presence of extensive carbonate sequences in both groups and the apparent lower metamorphic grade of both groups compared to rocks structurally above and below.

Among the most distinctive and laterally extensive lithologies in the Balsfjord area are the metadiamictites of the Vesterelv formation. These diamictites are lithologically identical to the metadiamictites reported at several stratigraphic levels within the Salangen supergroup, particularly within the Evenes marbles and the Tangen sequence (Fig. 4). Petrographically similar metadiamictites have not been reported from any of the overlying or underlying tectonic units within the Upper Allocthon in either the Ofoten or the Troms regions. We interpret the Vesterelv metadiamictites to correspond to those of the Tangen sequence. This correlation is preferred because the Tangen metadiamictites are interlayered with graphitic schists and not bluish-gray carbonates as is the case for the metadiamictites associated with the Evenes marbles.

The black graphitic calcite marbles present in the upper part of the Tangen sequence may correspond to the graphitic marbles of the Kjerstifjell formation (Fig. 4). The variety of lithologies present in the Tennes formation implies correlation with the lower parts of the Tangen sequence. An influx of siliciclastic material into the basin, as indicated by the presence of the Bø quartzite and Lower mica schist in the Ofoten area, may correspond to that recorded by the Malangen schist and quartzite in the Balsfjord area. This siliclastic influx was apparently choked off during a period of deposition of clean carbonate rocks in both areas, reflected in the Breivikeidet carbonate sequence and Hekkelstrand marble sequence. Petrological and chemical similarities between these dolomite marbles have long been recognized, as is demonstrated by their mutual exploitation by mining companies (Hekkelstrand Quarry, and proposed quarrying at Breivikeidet, Karlsøy and Sjursnes). The combined Fuglevann marbles and Middle mica schist may correlate with the Malangen schist and quartzite sequence, although the latter locally contains marbles.

It may seem surprising that the above lithostratigraphic correlation implies that the thick Evenes marbles may have no direct correlative carbonate sequence in the Balsfjord area, as this was the fundamental basis for earlier correlations of the two sequences. The carbonate breccia facies of the Hølen formation, as well as the general lithology of marble clasts in the lower part of the Hølen formation, indicate that they may have been derived from a nearby carbonate shelf. The calcareous turbidite material making up the Lakselvdalen formation (Olsen 1983) may have been derived from the same source. We tentatively suggest that the Evenes marbles represent the remains of an extensive carbonate shelf which, to the north, was eroded of material now represented by the carbonate clastics in the Hølen formation.

In addition to the lithostratigraphic similarities mentioned above, intrusives into the Salangen and Balsfjord Groups are markedly similar. Both groups contain pretectonic, possibly also syntectonic metadolerites, and syn-tectonic garnetiferous granites occur in the stratigraphically upper parts of both groups. Although the intrusives occur at somewhat different stratigraphic levels, the overlap in Rb-Sr whole rock ages favors their correlation.

The Salangen and Balsfjord Groups thus represent a thick shelf sequence dominated by carbonate and pelitic lithofacies. Coarse siliclastic rocks are very minor and volcanic rocks are rare to absent. If the proposed correlations are correct, then this shallow shelf sequence contained Paleozoic sedimentary rocks as young as Llandovery and they covered an extensive region of the northern Scandinavian Caledonides.

The Balsfjord/Salangen unconformity

Regional unconformities, such as that at the bases of the Balsfjord Group and Salangen supergroup, are extremely rare within the Upper and Uppermost Allochthons. Where such unconformities are recognized (e.g., Vestlandet) they are approximately of the same age (Sturt 1984, Thon 1985). The Balsfjord/ Salangen unconformity indicates that the two cover sequences, which are at approximately the same tectonic level in the nappe stack, were deposited in the same or contiguous basins at approximately the same time.

The Salangen/Balsfjord Group basin developed stratigraphically above a regional erosion surface that had penetrated plutonic rocks from various crustal levels. The unroofing of the Lyngen Gabbro and upper Narvik Group/ Bjerkvik nappe trondhjemites and gabbros implies significant uplift of the pre-Salangen/ Balsfjord Group basement prior to basin formation. Rocks within each of these basement complexes have been interpreted as ophiolite fragments (Boyd 1983, Crowley 1985, Hodges 1985, Minsaas & Sturt 1985). The unconformity below the Elvenes conglomerate is approximately concordant with units in the underlying Narvik Group, cutting downward toward the southwest at only a low angle. South of Ofotfjorden, where the unconformity is exposed around the hinge of the Ofoten synform (Tull et al. 1985, Andresen & Tull 1986) pre-Salangen supergroup folding is not readily apparent, unless it occurred at a scale larger than the exposed region of the unconformity. The tectonic history of the Narvik Group prior to the unconformity is poorly understood due to strong metamorphic and structural overprinting (Barker 1984, Crowley 1985, Hodges 1985, Steltenpohl 1987). Clearly, part of the sequence had been intruded by felsic and mafic plutonic rocks (Steltenpohl et al. 1988). However, we have not unequivocally identified either foliated lithic clasts in the Elvenes conglomerate, or folds in the Narvik Group that are truncated by the unconformity. Thermobarometric studies in the Narvik Group give equivocal results as to whether or not parts or the entire sequence experienced pre-Salangen supergroup dynamothermal events (Steltenpohl & Bartley 1987). Thus, it is not known whether the Narvik Group experienced significant orogenic activity other than plutonism prior to formation of the pre-Salangen supergroup unconformity. The presence of the plutonic lithic clasts in the Elvenes conglomerate, which appear to have been derived from the upper Narvik Group, however, requires significant regional uplift and unroofing prior to deposition of the Salangen supergroup.

An Upper Ordovician-Silurian depositional age for the Salangen supergroup requires that deformation and metamorphism in these rocks postdated the Finnmarkian orogeny as defined by Sturt et al. (1978) and are related to the Scandian event. The occurrence of 427 My syn-tectonic granitoids in the Bogen Group (Lindstrøm 1988, Steltenpohl et al. 1988) restricts the ages of deposition and metamorphism to post-Early Silurian. Late Ordovician/ Early Silurian fossils from the basal units of the Balsfjord Group imply a pre-Upper Ordovician depositional age for the underlying uppermost tectonic unit within Narvik Group (Bjerkvik nappe, Boyd & Søvegjarto 1983). In light of the recently identified thrusts and nappes within the Narvik Group, one cannot exclude the possibility that some of these nappes also have Finnmarkian depositional, igneous, and metamorphic ages. This is indicated by recent Sm-Nd and ^{40}Ar - ^{39}Ar isotopic studies of the Narvik Group by Crowley (1985) and Tilke (1986). Recent studies (Andresen, unpubl. data) indicate that large porphyroclasts/ tectonic lenses within blastomylonitic gneisses of the Narvik Group around Skjomenfjord contain granulite-facies (Grt+Cpx) mineral assemblages. Because the foliated matrix of these 'blastomylonites' contains kyanite-grade assemblages, possibly reflecting final equilibration during the Scandian event, these granulite lenses are interpreted as having formed during an early Caledonian tectonometamorphic event. Steltenpohl & Bartley (1987) reported thermobarometric evidence supporting an early highgrade metamorphic event in the Narvik Group that was retrograded during Scandian kyanite-grade metamorphism. Recognition of the pre-Upper Ordovician unconformity in the Ofoten area is also consistent with the interpretation of Sturt (1984) and Thon (1985), who recognized a regional unconformity within exotic terranes of the Upper Allochthon in other portions of Norway that postdated Finnmarkian ophiolite obduction. Apparently, a post-Finnmarkian basin of considerable size existed prior to the final collapse of the Iapetus Ocean in Late Silurian-Early Devonian time.

In conclusion, rocks lying directly above the unconformity, in both the Balsfjord and Evenes Groups, are remnants of the same lithostratigraphic package. We recommend that these units, which are depicted as separate entities on earlier maps of this region, be assigned to a single lithostratigraphic package.

Acknowledgements
This work was partially supported by National Science Foundation grant EAR-8107525 to J.M. Bartley, NAVF grant D.47.31/035 to Arild Andresen and awards from the Reynolds Foundation, McCarthy Foundation, Norges Geologiske Undersøkelse, University of Tromsø, University of North Carolina Department of Geology, University of Alabama Graduate Research Council, University of Alabama, Geological Society of America and Sigma Xi to Steltenpohl. Thanks go to L.F. Wood who provided technical help in producing this report. This is publication No. 116 in the Norwegian ILP-project.

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Manuscript received October 1989; revised typescript March 1990; accepted May 1990.