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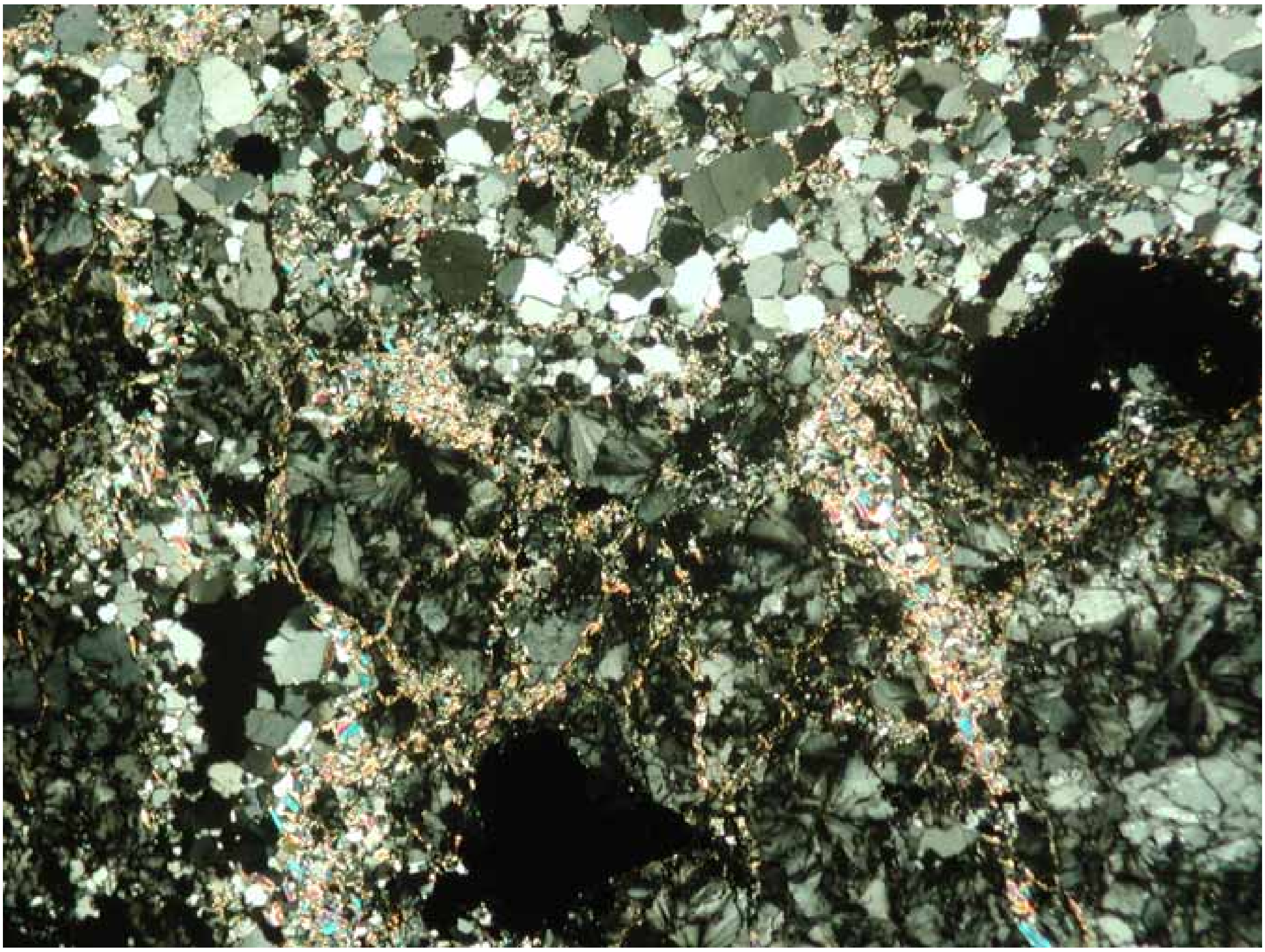

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Lithostratigraphy of the Mesoproterozoic Oftefjell group, central Telemark, Norway

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Abstract

The c. 1.15 Ga old Oftefjell group counterparts the lower part of the traditional Bandak group within the Mesoproterozoic Telemark supracrustal belt in southern Norway. It represents a 1 – 4 km thick continental sedimentary-volcanic rift sequence deformed and metamorphosed under the greenschist facies during the Sveconorwegian orogeny. A regional angular unconformity separates it from the underlying Vindeggen group, whereas its contact with the overlying Høydalsmo group is so much sheared that its nature is open. The group starts with the Svinsaga formation (150 – 200 m) characterized by basal talus breccias and conglomerates overlain by debris-flow and fluvial quartzites and conglomerates. The 1155 ± 3 Ma old Ljosdalsvatnet formation and its likely correlative, the Robekk porphyry, overlie the Svinsaga formation. The quartzitic Hornlitjørn formation and the Langelinutane formation of vocaniclastic conglomerates and quartzites with interbedded felsic and mafic metalava units overlie the Ljosdalsvatnet formation. Three fault-separated, large, porphyry bodies, the Stemmetjørn, Breidlandsnutane, and Bergstøylnutane formations**,** occupy the middle part of the group. They may originally have formed a single unit. The extensive massive – amygdaloidal metabasalts with minor metasedimentary interbeds of the Oftevatnet formation close the Oftefjell sequence.

The Ljosdalsvatnet formation can be correlated with the Brunkeberg formation of similar age, but the part above it is not straightforwardly correlative with any other sequence in the southern part of the Telemark belt.

Key words: Telemark, Vestfjorddalen, Sveconorwegian, lithostratigraphy, porphyry, basalt, conglomerate, quartzite, peperite

1. Introduction

Central Telemark in southern Norway is known for the rather well-preserved Mesoproterozoic volcanic-sedimentary belt named collectively as Telemark supracrustals (Sigmond et al., 1997). Brief outlines and complexity of their geology have been known since Dons' (1960a, b) classical works. He subdivided them into the traditional Rjukan, Seljord, and Bandak groups. Recent studies (Laajoki et al., 2002; Laajoki, 2002, 2006, in print; Laajoki & Lamminen, 2006) have shown that this subdivision was right in principal points, but that the Telemark sequence includes other significant lithostratigraphic breaks. Laajoki et al. (2002) used one of them for reclassifying Dons' Bandak group into the Oftefjell (older) and Høydalsmo groups. This paper gives a field documentation and informal lithostratigraphic classification of the former group, which comprises the Svinsaga and Ofte formations of the Bandak group on Nilsen's and Dons' (1991) and Dons' (2003) 1: 50 000 maps. Because of inadequate outcrops, uncertainties caused by complex tectonics, and lack of sufficient geographic names standard recommendations for lithostratigraphic classification (Nystuen 1986, 1989) can be followed only in part. The paper is part of the recent lithostratigraphic studies carried out in the southern part of the Telemark belt (Laajoki et al., 2002; Laajoki 2002, 2005, 2006, in print, subm.; Laajoki & Lamminen, 2006). The reader is referred to them for closer information of the diverse volcanic and sedimentary units and unconformities within this unique Mesoproterozoic rock record in the SW part of the Fennoscandian Shield.

All the rocks of the Oftefjell group are metamorphic, for they were metamorphosed under the greenschist facies during the Sveconorwegian orogeny, but for simplicity's sake, meta-prefix will not be used systematically in the rock names. The terms "quartzite" and "volcaniclastic" are used, respectively, as a loose field rock name to light, quartz-rich metasandstones (cf. Howard, 2005) and as a descriptive name to deposits composed of significant amount of volcanic particles (Fisher, 1961).

2. Geological setting and regional lithostratigraphy

The study area belongs to the Mesoproterozoic (c. 1.5 Ga to <1.12 Ga) sedimentary-volcanic Telemark supracrustals belt (Sigmond et al. 1997), which occupies the northern part of the Sveconorwegian Telemark sector (Bingen et al., 2005) or block (Andersen, 2005) of the Southwest Scandinavian Domain (Gaál & Gorbatschev, 1987) of the Fennoscandian (Baltic) Shield (Fig. 1). The c. 10 km wide Mandal-Ustaos fault zone (Sigmond, 1985) with the Kalhovd fault (Dons et al., 2004) as its western limit (Fig. 2) separates the Telemark sector from the Hardangervidda sector (Fig. 1, Bingen et al., 2005). In contrast to most of the metamorphic Precambrian crust in South Norway, the Telemark supracrustals are relatively well preserved. They comprise two major lithostratigraphic entities: the Vestfjorddalen (c. 1.5 Ga to <1.155 Ga) and Sveconorwegian (c. 1.155 Ga – 1.0 Ga) supergroups separated by the sub-Svinsaga unconformity (legend in Fig. 2 & Fig. 3, Laajoki, in print).

The *Vestfjorddalen supergroup* forms the core of the Telemark belt and comprises: (1) the Tuddal formation (is in fact of a group rank) of c. 1.5 Ga felsic volcanites (Dahlgren et al., 1990; Sigmond, 1998, Bingen et al. 2005), and (2) the c. 2 km thick dominantly metabasaltic volcanic-sedimentary Vemork formation (is in fact of a group rank) (Laajoki & Corfu, subm.), and (3) the sedimentary Vindeggen group c. 5 km thick with several quartzite and two mudstone formations (Laajoki, in print).

The c. 1.15 – 1.1 Ga *Sveconorwegian supergroup* rims unconformably the Vestfjorddalenian core in the west, south and east. It includes the Oftefjell group, the main target of this paper, and the coeval, 1155 ± 2 Ma old Brunkeberg formation (Laajoki et al., 2002), whose basement is unknown. The sub-Røynstaul unconformity (Laajoki & Lamminen, 2006; cf. section 5.11) separates the former from the overlying sedimentary-volcanic Høydalsmo group, whereas the quartzite-dominated Lifjell group lies unconformably on the Brunkeberg formation (Laajoki, 2006a, b). The youngest units include the Eidsborg formation deposited on the Høydalsmo group in the southwest and west, the Skogsåa formation and the Heddal group above the Vindeggen and Lifjell groups in the east (Figs. 2 & 3).

Many, mainly hidden, faults subdivide the bedrock of the study area into several lithostratigraphic-structural domains (Fig. 2, for definitions see Laajoki, in print). The Oftefjell group occupies the northern part of the Bandakian domain and the eastern part of the Øyfjell domain. Diverse quartzitic-conglomeratic metasedimentary units and felsic as well as mafic metavolcanites characterize it.

3. Previous lithostratigraphic studies

Bugge (1931) included the porphyry and greenstones north and around Høydalsmo (Fig. 2) into his Bandak group. He described in detail the petrography of a porphyry north of Ofte, of which a chemical analysis was also given. Dons (1960a) established the angular unconformity between his Seljord and Bandak groups. He demonstrated that a unit of basal conglomerate and quartzite occurred under Bugge's Ofte porphyry, but their distribution was not shown on the appended map neither on the Kviteseid map (Neumann & Dons, 1961). On the Rjukan map, the porphyry overlying the basal conglomerate was called the Robekk porphyry (Dons, 1961). Dons' and Jorde's (1978) Skien map illustrated several porphyry bodies with intervening metabasalt, conglomerate and quartzite units within the Bandak group in the area between Ofte and Ljosdalsvatnet. Later on, the basal Bandak quartzite unit was called the Svinsaga formation and the Ofte formation was shown to contain both acid and basic volcanites (Nilsen & Dons, 1991). The Åmotsdal map sheet (Dons, 2003), of which a preliminary version was available already in 1998, gave distribution of diverse lithological units within the Ofte formation, but all the porphyries were labelled under the "Ofte porphyry". Laajoki et al. (2002) demonstrated that a major unconformity occurs above the Ofte formation and subdivided Dons' (1960a) Bandak group into the Oftefjell group, which comprised Dons' Svinsaga and Ofte formations, and the Høydalsmo group, which included the rest of the traditional Bandak group. The Ofte formation was no more treated as a single unit, but was subdivided into several individual units (Fig. 4 in Laajoki et al., 2002), of which the porphyry above the Svinsaga formation was called the Ljosdalsvatnet formation. It was dated to be 1155 ± 3 Ma old. Laajoki and Lamminen (2006) published an updated map of the Ljosdalsvatnet area with many new unit names applied in this study. Laajoki (in print) gives a detailed documentation of the sub-Svinsaga unconformity and Köykkä and Laajoki (2006a, b) have published preliminary results of the ongoing studies of the Svinsaga formation. Lamminen and Andersen (2006) have given detrital zircon U-Pb dating results which put part of the sub-Røynstaul unconformity in a new light (section 5.11).

4. Definition, distribution and structural features of the Oftefjell group

The Oftefjell group is defined to comprise the supracrustal rocks lying in its type area between the Vindeggen and Høydalsmo groups from which it is separated by the sub-Svinsaga (Laajoki, in print) and sub-Røynstaul (Laajoki & Lamminen, 2006) unconformities, respectively. It occurs in four structurally different areas. (1) At the northern margin of the Bandakian domain, it defines the northern margins of three larger upright folds: the Hommesnip syncline, the Dalana anticline (a D_4 structure in Edwards' 1998 classification), and the Selvatn syncline (Figs. 4 & 6). Only the two lowermost units of the Oftefjell group, the Svinsaga and Ljosdalsvatnet formations occur in this area (Fig. 6). (2) West of the Selvatn syncline, around and south of Ljosdalsvatnet, the group is most complete and has an E-W structural grain (Figs. 5a & d). (3) West of

Ljosdalsvatnet the units of the group are N-S trending (Figs. 5a – c). The boundary between these two areas is defined by several N trending faults of the Vikvatnet shear zone, of which the Landsverk fault (Fig. 5c) and the Ofteelvi shear zone (Fig. 5b) may define the eastern boundary of the Mandal-Ustaos fault zone. In the northern part of the Øyfjell domain, the rocks are so much faulted and sheared that it is difficult to distinguish them from younger rocks (section 7). (4) In the Brattefjell area (Fig. 2), an outlier of the group cut by a major fault occurs (Dons, 2003; Dons et al., 2005; Laajoki, in print, Köykkä & Laajoki, subm.). In addition, small outliers of the Svinsaga formation occur upon the Vindeggen group in the Hovundvarden and Åmotsdal domains (Laajoki, in print).

5. Lithostratigraphy of the Oftefjell group

Because the felsic volcanites in the area are nonstratified and metamorphism has destroyed primary features in the mafic metalavas, the lithostratigraphic subdivision of the Oftefjell group was based mainly on the study of the metasedimentary units. The volcanic rocks were mapped only near their contacts and along the road E134 (Fig. 5a). Their regional distribution was taken from previous maps (Nilsen and Dons, 1971; Dons 2003). Consequently, all the felsic volcanite rocks are described as porphyries without any reference to their volcanic/subvolcanic or lava/pyroclastic origin. The basic volcanic rocks were labelled as metabasalts, if they displayed primary lava features, or as metabasites, in the cases their volcanic vs. subvolcanic origin was not certain.

The type area of the group lies around and south of Lake Ljosdalsvatnet (Fig. 5), but its lower contact and basal unit, the sub-Svinsaga unconformity and Svinsaga formation, are best exposed on the limbs of the Selvatn syncline (Fig. 6) and the Dalana anticline and in the Brattefjell area (Laajoki, in print; Köykkä & Laajoki, subm.). Fig. 7 gives lithostratigraphic columns with informal unit names and approximated unit thicknesses for different parts of the Oftefjell group.

5.1. Lower contact of the Oftefjell group

The sub-Svinsaga unconformity defines the lower contact of the Oftefjell group with the Vindeggen group (*op. cit.*).

5.2. Svinsaga formation

The 150–200 m thick Svinsaga Formation deposited unconformably on the Vindeggen group (*op. cit.*) starts the Oftefjell group. It forms a continuous unit at the northern margin of the Selvatn syncline (Fig. 6), from which it can be followed to south of Ljosdalsvatnet (Fig. 5a). It also occurs in the Brattefjell area and as small outliers on the Vindeggen group (Laajoki, in print). Its general sedimentology is under study (Köykkä & Laajoki, 2006b). The formation is characterized by its basal talus breccias and conglomerates and debris-flow deposits in its lower part (Köykkä & Laajoki, 2006a; Köykkä & Laajoki, subm.). The main part consists of trough-cross bedded (Fig. 8a) or parallel laminated typically pink quartzite with quartzite-clast conglomerate beds (Fig. 8b) or quartzite-pebble layers. The quartzite clasts are well-rounded and often hematite-coated. The lack of volcanic clasts distinguishes the formation from other quartzite units within the Oftefjell group. The formation represents a periglaciofluvial, gravelly, braided-river depositional environment affected by talus breccia input (Köykkä & Laajoki, 2006b).

5.3. Ljosdalsvatnet and Robekk formations

The porphyry overlying the Svinsaga formation east of Ljosdalsvatnet is called the Ljosdalsvatnet formation (Laajoki et al., 2002). The formation continues to the Bandakian domain where it overlies the Svinsaga formation along the limbs of the Selvatn syncline and the Dalana anticline. It is, however, important to note that the Svinsaga/Ljosdalsvatnet contact has not been found exposed. A small porphyry body west of Ljosdalsvatnet separated by a fault from the main body is also included in this formation (Fig. 5b). The formation is seemingly monotonous consisting solely of a rather homogeneous plagioclase- and quartz-phyric porphyry within which no epiclastic or pyroclastic interbeds have been found. No continuous section across the formation is available, but as the formation is rather thick and extensive it is unlikely that it would represent a single volcanic event. The U-Pb zircon age of the porphyry sample collected from its type locality is 1155 ± 3 Ma (Laajoki et al., 2002). The rock dated is quartz- and feldspar- phyric, but the latter phenocrysts and the groundmass have been altered to sericite aggregates and to a sericite-rich and carbonate-bearing mass, respectively.

East of Brattefjell, c. 25 km NNE from Ljosdalsvatnet, a 1 x 4 km porphyry body cut by the Marigrønutan fault overlies the Svinsaga formation (Fig. 2). Dons (2003) included it into his Ofte formation, but following his previous usage (Dons, 1961) it is called here the Robekk formation. Also this unit consists of a monotonous porphyry.

5.4. Hornlitjørn formation

The subdivision of the sedimentary-volcanic sequence above the Ljosdalsvatnet formation south and west of Ljosdalsvatnet is difficult, for the area is forest covered, the outcrops are often small and it is difficult to determine whether the volcanites are extrusive or subvolcanic. Top determinations show, however, that the sedimentary rocks are facing everywhere to the south. That is why the sedimentary part above the Ljosdalsvatnet formation is subdivided simply into the lower quartzitic part and the mixed quartzite-conglomerate part, named the Hornlitjørn and Langelinutane formations, respectively. The Hornlitjørn formation comprises the parallel-laminated or trough cross-bedded sericite quartzite overlying the Ljosdalsvatnet formation. Their contact is gradual for the porphyry passes via a sericite-rich rock with volcanic quartz and quartz-amygdale clasts and relics of granophyric groundmass (Fig. 8c) to a sericite quartzite indicating that the porphyry was exposed to weathering before the deposition of the quartzite. This weathering crust is labelled as the sub- Hornlitjørn unconformity in Figs. 3 and 7. Because synsedimentary volcanism seems to have been common in the area (sections 5.7 and 5.9), it is possible that hydrothermal alteration processes had a role in formation of this crust.

The formation is 150-200 m thick SE of Ljosdalsvatnet. West of this lake, it overlies a small porphyry body offset dextrally by an N-S trending fault from the main part of the Ljosdalsvatnet formation (Fig. 5b). Petrographically, the quartzite is a microcline- and sericite-bearing quartz-rich arenite. Thin beds containing pink quartzite and felsic volcanite clasts occur locally. If the latter clasts are missing (Fig. 8d) the rock is hard to distinguish from pebbly Svinsaga quartzites (section 7)

The Hornlitjørn formation does not occur in the Bandakian domain, but a monomictic, *in situ* type felsic vocaniclastic conglomerate with a scanty sericite-schist matrix (Fig. 8e) occurs in the upper contact of the Ljosdalsvatnet formation on the eastern flank of the Selvatn syncline. This may represent either the sub- Hornlitjørn unconformity or the sub-Røynstaul unconformity (section 5.11).

5.5. Nystøyl porphyry

The c. 1 x 1 km felsic volcanic body south of the Hornlitjørn formation, studied only briefly, is named the Nystøyl porphyry (Fig. 5d). *In situ*-type conglomerates near its upper contact indicates that it was exposed to erosion during the sedimentation of the Langelinuten formation (next section). The rock is plagioclase phyric (Fig. 8f). Its groundmass has mostly been recrystallized, but relics of granophyric texture can be seen.

The minor porphyry body within the shear zone west of Ljosdalsvatnet (Fig. 5b) is correlated with the Nystøyl porphyry, for it has metamorphosed the underlying minor quartzite unit correlated with the Hornlitjørn formation (section 5.4). The small porphyry unit NW of Ljosdalsvatnet cut by the Skogsheim fault (Fig. 5c) is also included in this porphyry family. In theory, it could, however, belong to the Ljosdalsvatnet formation or even to the Tuddal formation exposed on the opposite side of the fault. Minor sandstone relics and veins upon the porphyry (Fig.8g) prove that it has been exposed to erosion before the extrusion of the Hovde metabasite (section 5.7).

5.6. Langelinutane formation

The Hornlitjørn formation passes to and the Nystøyl formation is surrounded by a c. 500 m thick sequence of conglomerates, pebbly quartzites, and quartzites mapped as the Langelinutane formation. Conglomerates are more abundant, contain more felsic volcanic clasts, and are coarser-grained in the lower part of the formation. Near the upper contact of the Nystøyl formation, the conglomerate is almost monomictic containing only solitary quartzite or schist/metabasite clasts among the dominant felsic volcanite clasts. In the upper part of the conglomerate, opaque-rich stripes occur (Fig. 9a). They contain pebbles of felsic volcanite in which quartz phenocrysts are surrounded by sericite-rich rims (Fig.9b) interpreted as altered groundmass. This is a similar feature observed at the felsic lava/basalt contact in the Vemork formation (Fig. 13g in Laajoki & Corfu, subm.) indicating that the dark stripes represent altered thin basaltic intrusions expelled from the overlying Nystøyl metabasite (next section). The conglomerates rich in felsic volcanite clasts dominate also the part above the Nystøyl metabasalt. They include mass-flow conglomerates (Fig. 9c) interbedded with pebbly-cobbly sandstones and cross-bedded lithic sandstones (Fig. 9d). The latter may contain abundant granophyric or spherulitic clasts in sericite-rich matrix. The amount of volcanic clasts and their sizes decrease upwards and the uppermost part consists of feldspathic quartzite (section 5.9). The formation abuts Ofteelvi, which most likely follows a shear zone. This causes that its correlation with Hovdevatnet formation on the other side of the river (Fig. 5b) is uncertain.

5.7. Nystøyl, Hovde, Sopanstad and other minor metabasite units

A few tens of meters thick metatabasite units occur around the Nystøyl porphyry (Fig. 5d), S and SSW of Hovdevatnet (Hovde metabasite in Figs. 5b & c) and NW of the Stemmetjørn porphyry (Sopanstad metabasite, Fig. 5a). The rocks are metamorphosed to sericite-carbonate-epidote-opaque rocks and have often lost completely their primary textures. Consequently, they may represent either volcanic or subvolcanic rocks. The metabasite south of the Nystøyl porphyry is classified as lava, named the Nystøyl metabasalt, for it contains abundant amygdales and the primary trachytic texture has locally been preserved (Fig. 9e). At its lower contact, the metalava has been mingled with the volcaniclastic conglomerate that separates it from the Nystøyl porphyry indicating that this part may represent a fluidal peperite (Fig. 9f). The conglomerate near the lava looks homogeneous out, which may be due to the induration caused by the lava. Solitary lava fragments in it may represent blocky juvenile lava clasts. A similar mingled rock occurs also at the eastern contact of the metabasite at station 3026 (Fig. 5d). Petrographic evidence of its peperitic origin includes: (1) opaque rich, dense margins of the metabasite fragments (Figs. 9g & h) which may represent chilled margins enriched in iron by hydrothermal alteration during the peperite genesis, (2) very irregular lava/sediment contacts (Fig. 9h) and (3) opaque-rich rags, which may represent metamorphosed basaltic glass or chilled lava fragments, in a siltstone, whose bedding has been disturbed or homogenized (Fig. 9i) (cf. White et al., 2000; Skilling et al., 2002).

The Hovde metabasite (Figs. 5b & c) may represent a part of the Nystøyl metabasalt transposed parallel to the Vikvatnet shear zone. The narrow, c. 3 km long Sopanstad metabasite separated by a thin quartzite unit from the Stemmetjørn porphyry may also be a lava unit, but it has been altered completely. A metabasite dike with porphyry fragments at the northern part of the Stemmetjørn porphyry proves, however, that subvolcanic basic intrusions are also present.

5.8. Hovdevatnet formation

The quartzite units south and north of Hovdevatnet cut by the NW trending Kråkebøtjørn and Skogsheim faults (Figs. 5a-c) are included in the formation named after this lake. The thickness of the formation varies greatly. Provided that tectonic repetition has not taken place, the formation is c. 500 m thick SW of the Kråkebøtjørn fault, but becomes thinner and dies out southwards. Between this fault and the Skogsheim fault and west of the Landsverk fault the thickness is less than 100 m. This may have been attributed to tectonic movements within the Vikvatnet shear zone. In the south (Fig. 5b), the formation overlies a felsic volcanite, which may be correlated with the Nystøyl formation, whereas north of Hovdevatnet it overlies the Hovde metabasite (Fig. 5c). The Landsverk fault separates it from the Kultankriklan-type conglomerate in the east (Fig. 5c). The formation starts with fluvial conglomerates and pebbly-cobbly quartzite beds with quartzite and less common felsic volcanite pebbles and cobbles (Fig. 10a) overlain by or interbedded with a trough cross-bedded, microcline-bearing quartzite. In the middle part, wave ripples (Fig. 10b), mud layers, and mudstone rip-ups occur indicating a basinal environment, whereas cross-bedded quartzites or pebbly quartzites dominate again the upper part. The fault-bounded thin slice NE of the Skogsheim fault consists of microcline quartzite with solitary quartzite pebbles or pebble trains (Fig. 10c).

The narrow, c. 2 km long, west facing microcline-bearing quartzite unit with solitary quartzite pebbles underlying the Bergstøylnutane porphyry (Fig. 5a) is considered as a thrust-bounded slice cut from the upper part of the Hovdevatnet formation. It is possible, that the quartzite-pebble quartzite in Heimveglinuten, 20 km N of Hovdevatnet (Fig. 11 in Laajoki & Lamminen, 2006), may also belong to this formation, but it could also represent the Svinsaga formation (Dons, 2003).

5.9. Stemmetjørn, Breidlandsnutane, and Bergstøylnutane porphyries

The three large porphyry units overlain by the Oftevatnet formation named from the west to the east are: (1) the dome-like Stemmetjørn porphyry (c. 2 x 2 km), which underlies the main part of the Oftefjell mountain. (2) The N-S trending Breidlandsnutane porphyry (1 x 9 km), and (3) the Bergstøylnutane (1 x 3 km) porphyry. Originally, they may have represented a single volcanic complex, but as they are separated by tectonic zones this cannot be proved by mapping only. The bedding, top observations and the nature of the quartzite/porphyry contact indicate that the Stemmetjørn porphyry has flowed upon the Langelinutane formation or has intruded into its upper part. The contact zone is marked by mingling of the porphyry and the quartzite (Fig. 11a). It is interpreted as a peperitic on the basis of spherulites within the very outer margin of the porphyry and infiltration of sedimentary material along the cracks and microcracks into the spherulite zone (Fig. 11b). These indicate chilling of the porphyry against the quartzite and mobility of the sediment material during emplacement of the porphyry, respectively (cf. Kokelaar, 1982; White et al., 2000; Skilling et al., 2002). The abundance of the spherulites points to Lofgren's (1971) "spherulitic cooling stage". Its growth conditions are typified by more water or a slower cooling rate and higher temperature than those of the glassy stage, whose products are dominated by undevitrified glass with widely spaced spherulites. The lower contacts of the other two porphyries have not been found exposed, but bedding and top observations indicate that they overlie the Hovdevatnet formation. All the porphyry units consist of quartz- and feldspar-phyric volcanic rocks (Fig. 11c), but they have not been studied in detail.

5.10. Oftevatnet formation

A metabasalt unit c. 1 km thick closes the Oftefjell group. Nilsen and Dons (1991) and Dons (2003) mapped it as units 21 and 15 of their Ofte formation, respectively. It is named in this study the Oftevatnet formation after the lake on the shores of which it is well exposed. In its main southern distribution area from Oftevatnet to north of Bergstøylnutane, the formation overlies the Stemmetjørn, Breidlandnutane, and Bergstøylnutane porphyries, but its contacts with them have not been found exposed. It consists dominantly of massive or amygdaloidal metabasalts, which have been altered completely to epidote-chlorite-opaque rocks. A c. 10 m thick sedimentary interbed is visible in one road cut (Figs. 11d, e). A poorly exposed vocaniclastic conglomerate (Fig. 11f) similar to those in the Langelinutane formation near the eastern upper contact of the Oftevatnet formation east of the Stemmetjørn massive is named the Luråsen conglomerate (Fig. 5e). Because it occurs near a major shear zone, it could represent a tectonic slice of the Langelinutane formation, but as a similar conglomerate occurs also c. 1 km south of this place, between the Oftevatnet metabasalts and the topmost tuffites (next section), it is considered to overlie the Oftevatnet metabasalts. A small porphyry body occurs near the Li farm, N of Bergstøylnutane (its size is exaggerated in Fig. 5a). In this area and SE of Oftevatnet the topmost part of the formation contains a few metres thick tuffite beds separated by a metabasite (Fig. 11g).

According to Dons (2003) the Oftevatnet formation (his unit 15) continues north of Vehuskjerring granite (Fig. 2).

5.11. Upper contact of the Oftefjell group

Based on the lower contact of the distinctive Kultankriklan conglomerate, Laajoki and Lamminen (2006) considered that a major regional angular unconformity occurs between the Oftefjell and Høydalsmo groups. Recent Detrital zircon U-Pb-studies studies have shown, however, that Kultankriklan conglomerate may represent the basal part of the Eidsborg formation (Lamminen & Andersen, 2006; Lamminen et al., subm) and so the unconformity under it (Laajoki & Lamminen, 2006) can not represent the Oftefjell group/Høydalsmo group contact, but the sub-Eidsborg unconformity. This can easily be accepted in the cases where the Kultankriklan conglomerate is separated by an angular unconformity from the underlying rocks, for instance around Kultankriklan self (Fig. 6). The conglomerate occurs, however, also at the boundary between the Ljosdalsvatnet and Røynstaul formations in Fjellet and Trolltjørnnuten, in the hinge zone of the Selvatn syncline (Fig. 6). In Fjellet, it seems to have a sedimentary contact with the Ljosdalsvatnet formation (Fig. 10g in Laajoki & Lamminen, 2006), whereas in

Trolltjørnnuten the bedding in the conglomerate seems to abut the Selvatnet syncline. This exceptional position of the Kultankriklan conglomerate can be explained in two ways: (1) the conglomerate happened to deposit unconformably on the Ljosdalsvatnet/Røynstaul contact or (2) it was deposited unconformably on the former unit and the latter unit was brought tectonically into juxtaposition with the conglomerate and the Ljosdalsvatnet formation. The tectonic model seems more likely, because lower parts of the Røynstaul formation has been foliated (Fig. 12a) and sheared (Fig. 12b) along both flanks of the Selvatn syncline and even sheath-fold like structures occur (Fig. 12c). Furthermore, basic subvolcanic intrusions with quartzite clasts (Fig. 12d) have been intruded along or near the Røynstaul formation/Oftevatnet formation boundary. They have caused epidotization of the surrounding rocks, which has dissolved this boundary. Because the foliation follows the flanks of the Selvatn syncline (Fig. 5e) it is older than this structure. It may counterpart Edwards' (1998) S_3 foliation whose original east-west structural trend was disturbed by main Sveconorwegian D_4 deformation producing folds with north-south trends including the Selvatn (Edwards' western) syncline. Consequently, it is possible that the contact between the Oftefjell and Høydalsmo groups is a folded D_3 fault or thrust zone, which joins the sub-Eidsborg unconformity in Fjellet and cuts it west of Trolltjørnnuten. The *in situ* breccia above the Ljosdalsvatnet formation in Fig. 8e could also indicate the sub-Eidsborg unconformity, but the distinctive features of the Kultankriklan conglomerates are missing leaving this a speculative interpretation.

SE of Oftevatnet, where the bedding trend turns to southwest (Fig. 5e), the contact between the topmost tuffite of the Oftevatnet formation and a quartzite of the Røynstaul formation is slightly erosional, but seemingly conformable (Fig. 12e). However, a large structural discordance seems to occur between the Oftefjell and Høydalsmo groups south of Oftevatnet where the faults and fold structures within the former are N-S trending whereas the Røynstaul and younger formations within the latter defines a complex interference fold structure (Figs. 4 & 5a).

At the eastern limb of the Dalana anticline, where the Oftefjell group consists only of the Svinsaga and Ljosdalsvatnet formations (Fig. 4), the Kleiv marmor occurs as a thin discontinuous unit between the Ljosdalsvatnet and Røynstaul formations. Dons (2003) included it in the upper part of his Ofte formation. In addition to carbonate rocks, it contains, however, also conglomeratic parts with both quartzite and felsic volcanite clasts up to boulder size, on the basis of which it is considered as a basal unit of the Røynstaul formation representing a significant change in volcanic/sedimentary environment.

The Oftevatnet formation /Røynstaul formation contact has been folded openly within the Buvatnet basin (Fig. 4). The Bikkestaulnuten-type polymictic conglomerates with quartzite and both felsic and mafic volcanite clasts define it (Lamminen & Laajoki, 2006). The small porphyry body near Li (Fig. 5a) passes gradually to this type a conglomerate indicating a weathering period before the deposition of the Røynstaul formation. It is, however, possible that the Bikkestaulnuten conglomerate and the overlying rocks represent the Eidsborg formation. Their depositional ages should be determined by detrital zircon U-Pb method.

In conclusion, due to the intense and complex deformation of the bedrock and the lack of reliable outcrop observations, the actual nature of the upper contact of the Oftefjell group is not known in certain. It might be that most of the Høydalsmo group of the Bandakian domain is allochthonous in relation to the Oftefjell group.

6. Age frame of the Oftefjell group

Because it is not known when the Vindeggen group was folded and when the deposition of the Svinsaga formation was started, no absolute lower age limit can be given for the Oftefjell group. It is, however, reasonable to assume that it is close to 1155 ± 3 Ma, which is the age of the Ljosdalsvatnet porphyry (Laajoki et al., 2002). The age of the Dalaå formation of the Høydalsmo group is 1150 ± 4 Ma (*op. cit.*). These age results indicate that the Oftefjell sedimentation and volcanism took place during a few million years around 1155 Ma ago (Fig. 3).

7. Discussion

The sedimentary-volcanic evolution of the Oftefjell formation around, south and west of Ljosdalsvatnet (Fig. 5a) can be subdivided into three main stages:

(1) The mainly fluvial - periglaciofluvial stage which produced the Svinsaga formation upon the folded Vindeggen group (Köykkä & Laajoki, 2006b). No evidence of volcanic activity to have taken place during this stage is known and volcanic clasts are missing in the Svinsaga conglomerates.

(2) The volcanic-sedimentary stage which started with the Ljosdalsvatnet felsic volcanism followed by siliciclastic sedimentation (the Hornlitjørn, Langelinutane, and Hovdevatnet formations) with minor felsic (the Nystøyl porphyry) and basaltic volcanism (the Nystøyl metabasalt, Hovde, Sopanstand and other metabasites). The peperite occurrences prove that at least the mafic volcanism was synsedimentary. Abundant felsic material in the

conglomerates around the Nystøyl porphyry suggests that it was exposed to erosion, which indicates that it represents either a lava or a shallow-level intrusion.

(3) The closing bimodal volcanic stage, which started with voluminous a period of felsic volcanism (the Stemmetjørn, Breidlandsnutane, and Bergstøylnutane porphyries) and was closed by extensive basaltic volcanism with minor associated siliciclastic sedimentation (the Oftevatnet formation). The peperites at the lower contact of the Stemmetjørn porphyry indicate that this stage started during or shortly after the deposition of the Langelinutane, and Hovdevatnet formations.

The Oftefjell group in the Selvatn area (Fig. 6) comprises only the Svinsaga and Ljosdalsvatnet formations. This may be a primary feature the Ljosdalsvatnet area representing a sedimentary-volcanic rift basin and the Selvatn area its shoulder apt to syn-rifting erosion. Another choice is that this difference is due to the later deformation treated in section 5.11.

Correlation of the Oftefjell formation north of Ljosdalsvatnet is difficult due to the intense shearing and faulting associated with the Vikvatnet shear zone and similarity of the quartzites of the Oftefjell group and the Røynstaul formation. For instance, Dons (2003) considered the small quartzite unit N of Vikvatnet as assumed Svinsaga formation. It is included in this study in the Røynstaul formation (Fig. 4) because it contains felsic volcanic clasts, but it could also represent e.g. the Hovdevatnet formation. The small quartzite unit north of Svinefjell is included in the Oftefjell group, for it lies under the sub-Røynstaul unconformity (Laajoki & Lamminen, 2006), but does it represent the Svinsaga formation (Dons, 2003) or does it lie higher in the Oftefjell stratigraphy is an open question. On the Frøystaul map sheet, several quartzite belts occur some of which are assumed to belong to the Svinsaga formation, some to the Ofte formation and some to the Røynstaul formation (Dons et al., 2004). Their division is not, however, possible on the lithological criteria only. An example of this problem in given in Fig. 12f where a foliated microcline quartzite from Svinefjell included in the Røynstaul formation contains well-rounded, hematite coated orthoquartzite pebbles. Lithologically it is identical to a pebbly Svinsaga quartzite.

It is difficult to correlate unconformities developed on felsic volcanites without distinctive earmarks. For instance, an *in situ* breccia conglomerate at the western margin of the Heidalsnutan domain in Fig. 12g lies upon the porphyry Dons (2003) mapped as the Tuddal formation (Fig. 4). Being separated by a fault from the quartzite in the west included in the Røynstaul formation it could in theory reflect either the sub-Heddersvatnet (Laajoki, 2005), sub-

Svinsaga (Laajoki, in print), sub-Hornlitjørn (cf. Fig. 8e), or sub-Røynstaul (Laajoki & Lamminen, 2006) unconformity. The jig-saw-fit of some of the fragments refers to frost action, which has been reported from the breccias above the sub-Svinsaga unconformity (Köykkä & Laajoki, subm.).

In the southeast, the Oftefjell group fades out south of Liervatnet (Fig. 4). This is attributed to fault tectonics (Laajoki, 2006a). On the basis of their similar ages, it is likely that the Ljosdalsvatnet and Brunkeberg formations represent coeval felsic volcanism (Fig. 3) and, consequently, the sub-Hornlitjørn and sub-Lifjell unconformities could represent same period of weathering. The overlying sequences are, however, quite different (*op. cit.*), which refers to different geotectonic settings.

All the peperite observations described above represent lower contacts of the igneous unit in question, on the basis of which alone extrusive *vs.* intrusive origin of the units cannot be solved. Their geotectonic position and sedimentary-volcanic environment of the group will be treated in connection with the results of the geochemical analyses of Oftefjell volcanites under process. In this connection it is sufficient to say, that the dominantly alluvial-fluvial nature of the sedimentary units, abundance of coarse sediments, and lack of any evidence of marginal or marine environment point to a continental rift or back-arc setting , cf. Brewer's et al.'s (2002) model for the overlying part of the traditional Bandak group (Høydalsmo group in this study).

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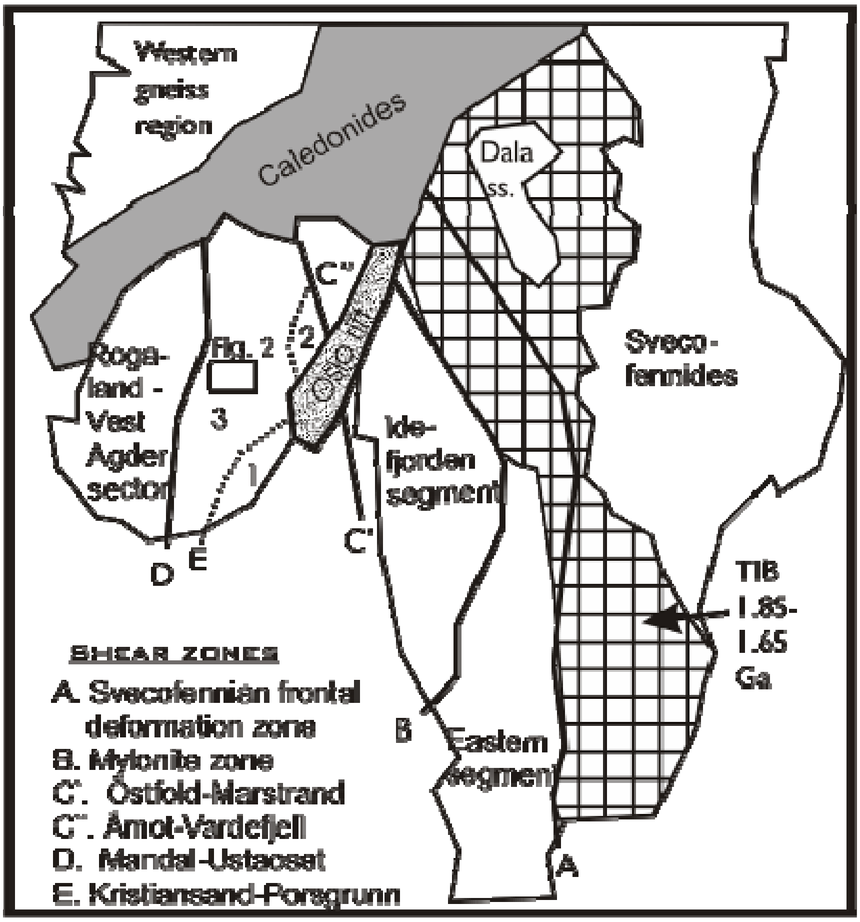

Fig. 1. Sketch map of the Sveconorwegian province (modified from Bingen et al., 2001). The area of Fig. 2 is framed. Numbered sectors west of the Oslo rift: (1) Bamble, (2) Kongsberg, (3) Telemark.

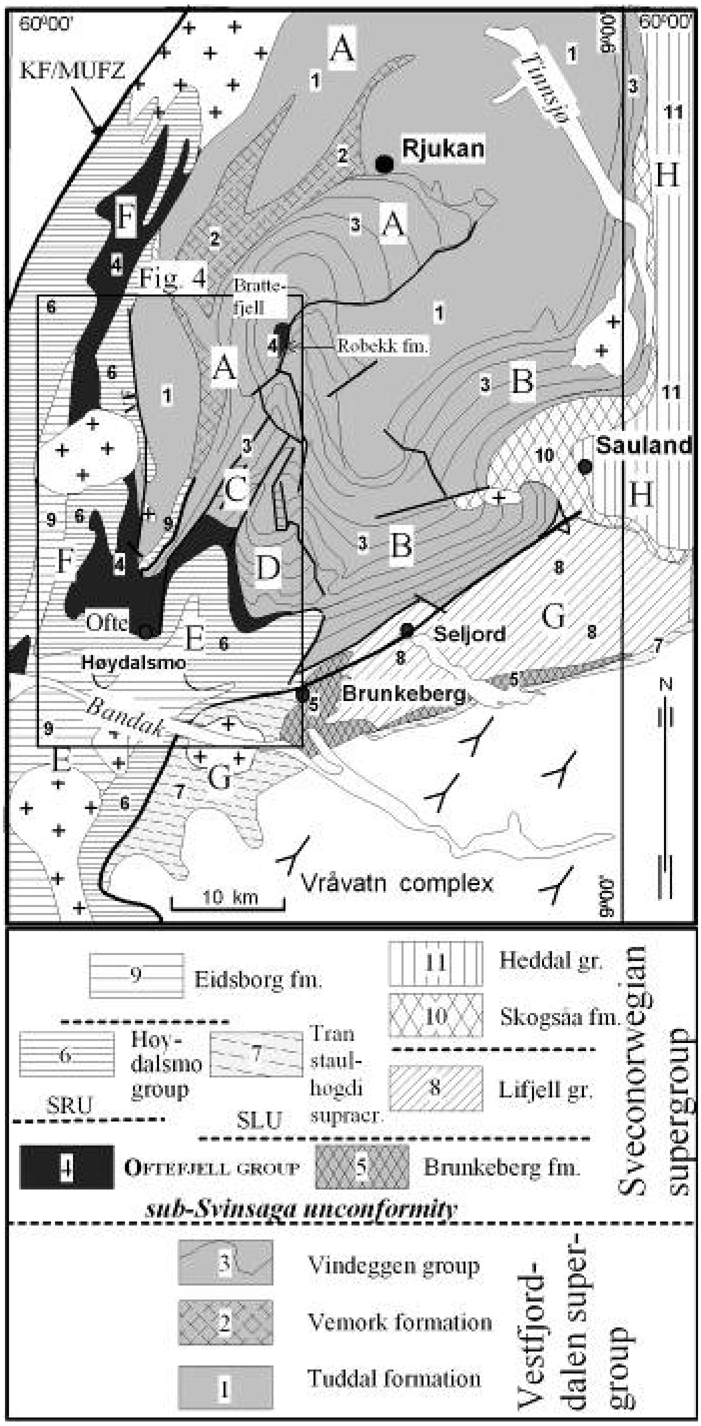

Fig. 2. Simplified geological map of the southern part of the Telemark supracrustals (in part after Dons & Jorde, 1971). Area of Fig. 4 is framed. Note the location of the Robekk formation in the centre of the map. Capital letters A- F refer to lithostratigraphic-structural domains: A = Mefjell, B = Hjartdal, C = Åmotsdal, D = Hovundvarden, E = Bandakian. F = Øyfjell. G = Seljord. H = Sauland. KF/MUFZ, SLU, SRU, & VF = Kalhovd fault of the Mandal-Ustaos fault zone (in upper left corner), sub-Lifjell and sub-Røynstaul unconformities (in the legend), and Vikvatnet shear zone, respectively. Crosses mark post-tectonic and other granitoids.

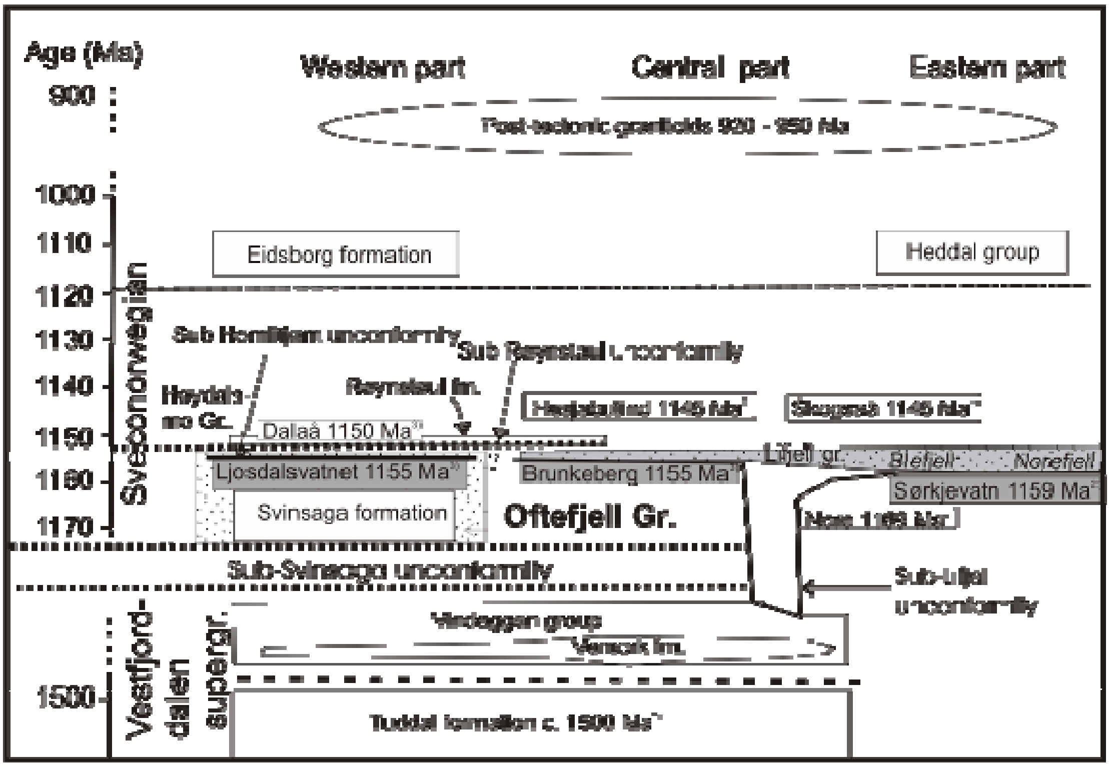

Fig. 3. Schematic chronostratigraphy of the dated igneous and associated sedimentary units across the southern part of the Telemark supracrustals showing the relative position of the Oftefjell group (stippled). Note that the age of the sub-Svinsaga unconformity is not known and that the history of the Oftefjell group between the sub-Hornlitjørn and sub-Røynstaul unconformities covers only a few million years. Age references. 1) Dahlgren et al. 1990, Sigmond, 1998. 2) Bingen et al. 2003. 3) Laajoki et al. 2002. Limits of error c. ± 2 – 8 Ma. For the present status of the sub-Røynstaul unconformity see the text.

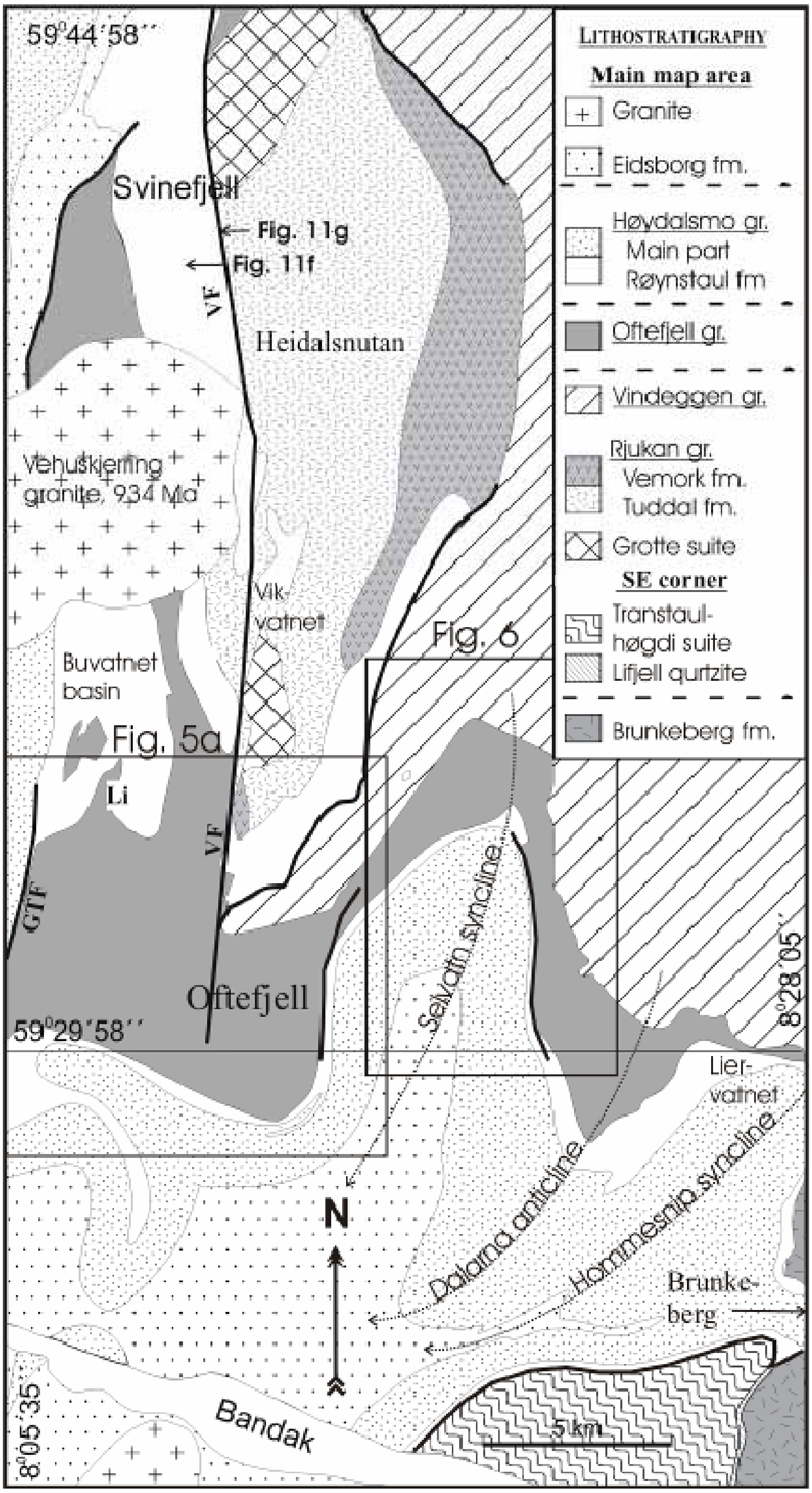

Fig. 4. Geological map of the main distribution area of the Oftefjell group (in part after Nilsen & Dons, 1991 and Dons, 2003). Areas of Figs. 5a & 6 are framed and locations of Figs. 11f-g are shown. GTF = Grønlitjørn fault, VF = Vikvatnet shear zone.

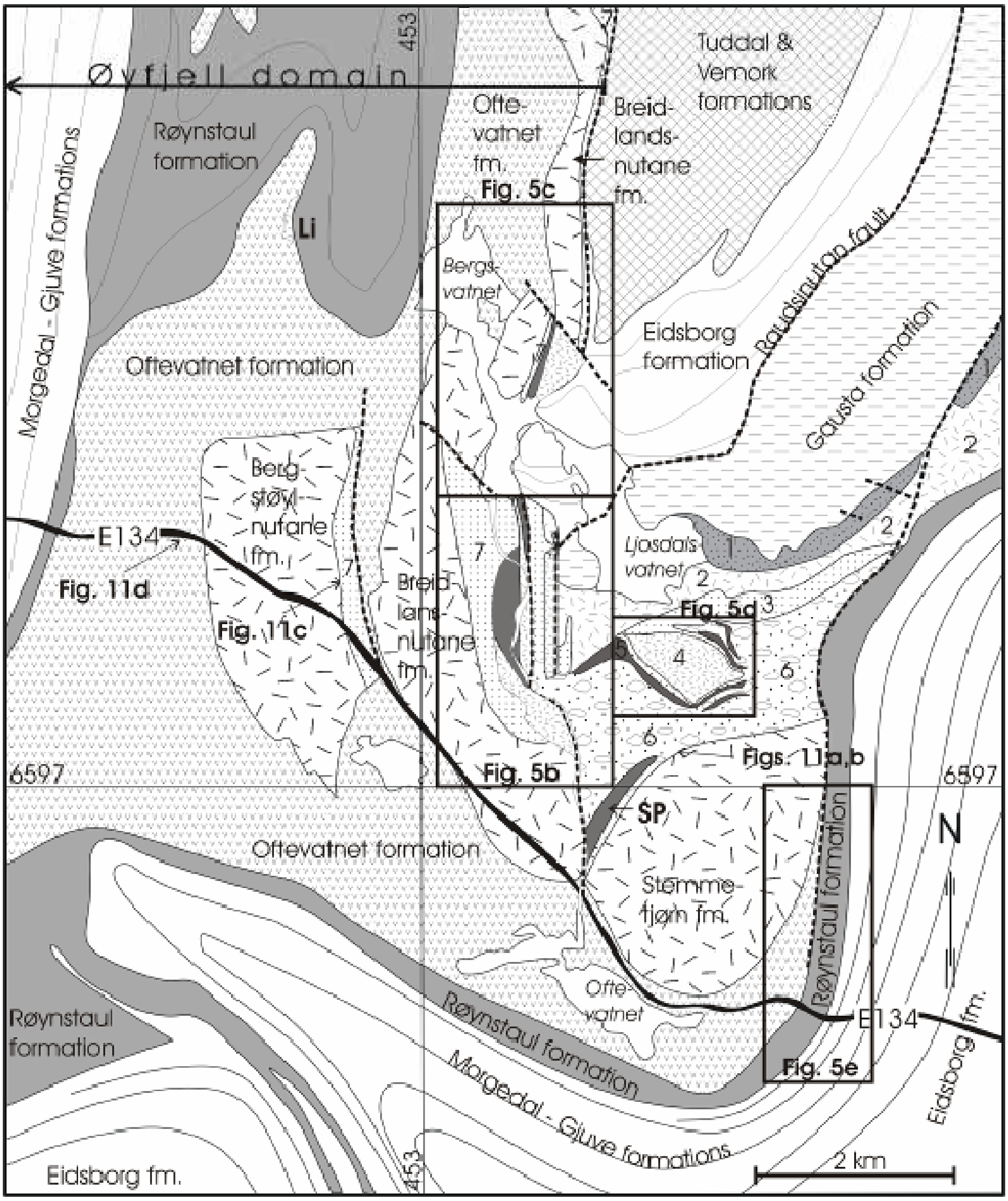

Fig. 5a Geological map of the Ljosdalsvatnet - Oftevatnet area. Areas of maps in Figs. 5b-e are framed. The Vikvatnet shear zone is defined by the N trending faults in the centre of the figure. The Bandakian domain comprises the folded southern part occupied by the Røynstaul formation (gray) and younger formations and the Øyfjell domain the area west of the Vikvatnet shear zone. Locations of Figs. 11a-d are shown. Numbered units of the Oftefjell group around Ljosdalsvatnet: 1. Svinsaga, 2. Ljosdalsvatnet, 3. Hornlitjørn, 4. Nystøyl porphyry, 5. Nystøyl metabasalt, 6. Langelinuten, and 7. Hovdevatnet formations. For minor units west of Ljosdalsvatnet see Figs. 5b & c. Dark gray = unnamed metabasite units. Form and broken lines indicate bedding and fault, respectively. SP = Sopanstad metabasite. Representation of the Eidsborg formation NW of Ljosdalsvatnet is based on recent datings of detrital zircons (Lamminen & Andersen, 2006).

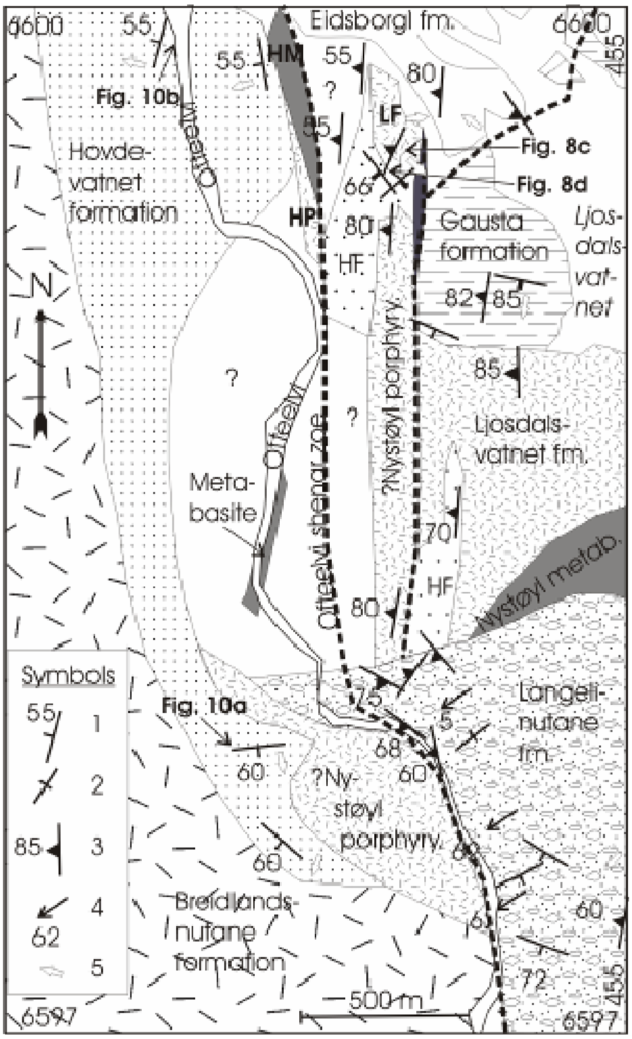

Fig. 5b. Detailed geological map of the Vikvatnet shear zone south of Hovdevatnet. Locations of Figs. 8c, d & 10a, b are shown. HF, HM, HP, LF, MD = Hornlitjørn formation, Hovde metabasite, Hovde porphyry, Ljosdalsvatnet formation, metadiabase, respectively. Symbols: 1. Bedding & dip. 2. Vertical bedding. 3. Foliation & dip. 4. Lineation & plunge. 5. Top direction.

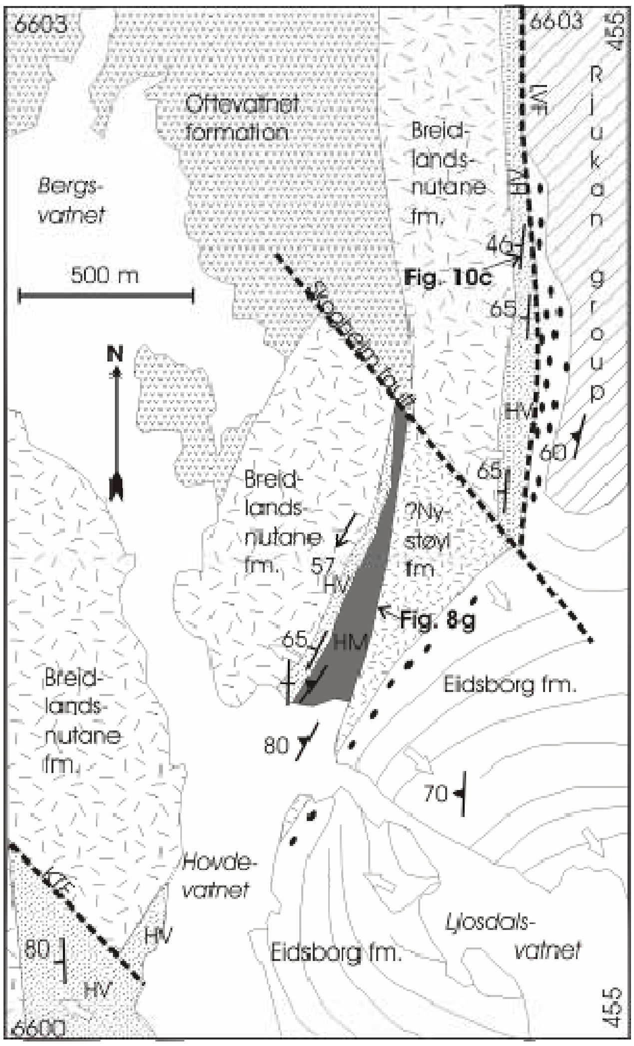

Fig. 5c. Detailed geological map of the Vikvatnet shear zone north of Ljosdalsvatnet. Locations of Figs. 8g & 10c are shown. HV = Hovdevatnet formation. HM = Hovde metabasite. KTF = Kråkebøtjørn fault. LVF = Landsverk fault. Black ellipsoids indicate Kultankriklan-type conglomerate of the Eidsborg formation. For symbols see Fig. 5b.

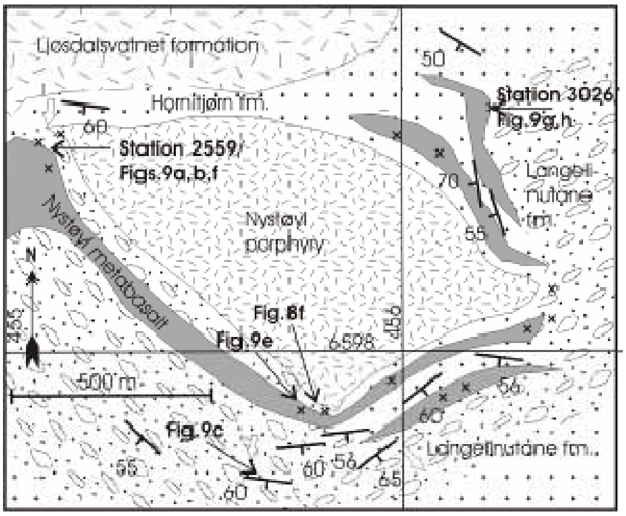

Fig. 5d. Partial geological map of the surroundings of the Nystøyl porphyry. For location and symbols see Figs. 5a & 5b, respectively. Stipples and ellipsoids within the Langelinutane formation indicate quartzite and conglomerate dominated parts, respectively. Locations of Figs. 8f, 9a - c & 9e - i are shown.

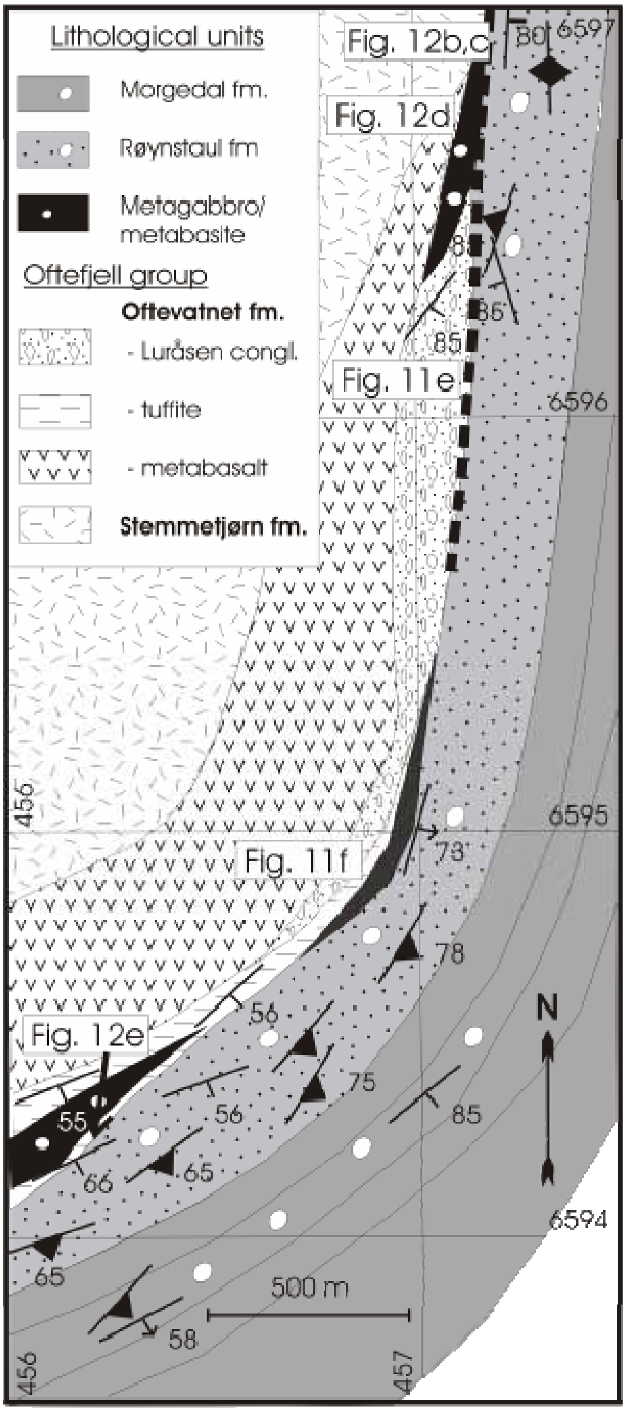

Fig. 5e. Partial geological map of the contact zone between the Oftefjell and Høydalsmo groups at the SW part of the Selvatn syncline. Note how foliation follows the fold structure defined by the bedding in the Røynstaul and Morgedal formations. For location and symbols see Fig. 5a & 5b, respectively. Locations of Figs. 11e, f & 12b-e are shown. Note that the distribution of the Luråsen conglomerate is arbitrary.

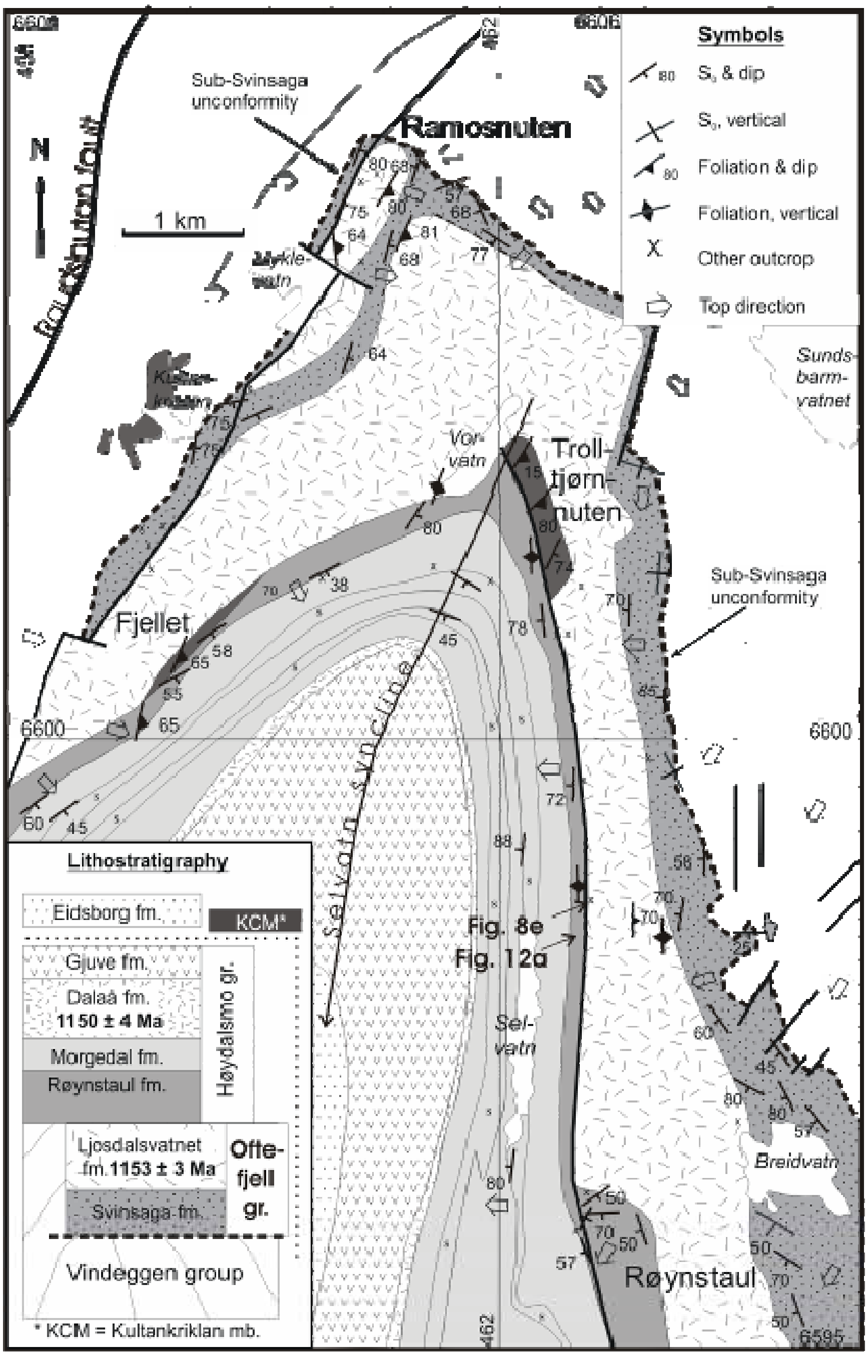

Fig. 6. Geological map of the Selvatn area (in part after Dons, 2003). Locations of Figs. 8e and 12a are shown. Thick lines indicate a fault/shear zone. Note the small relics of the Kultankriklan-type conglomerate (dark gray) around Kultankriklan, in Fjellet and Trolltjørnnuten.

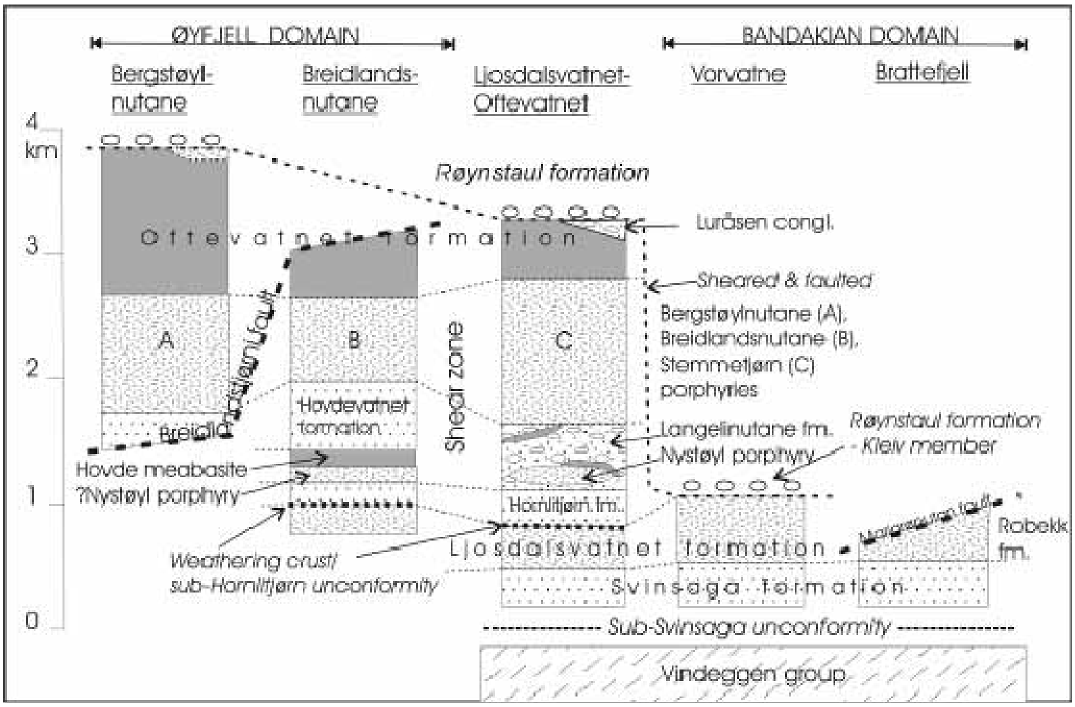

Fig. 7. Lithostratigraphic columns of the Oftefjell group. Thicknesses are approximated.

Fig. 8a. Trough cross-bedded quartzite with typical pink colour and….

Fig. 8b. …. quartzite-pebbly quartzite of the Svinsaga formation, Hovundfjellet.

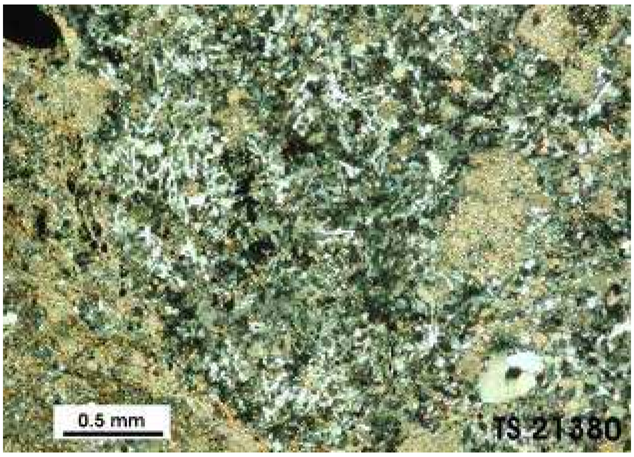

Fig. 8c. Photomicrograph of in situ weathered/ altered Ljosdalsvatnet porphyry with patches of relics of granophyric texture (white and gray) and fine grained sericite domains. Thin section Oy21380/station 5568. Two polars.

Fig. 8d. Quartzite pebbles in the quartzite of Hornlitjørn formation, W of Ljosdalsvatnet. Note the well rounded and hematite coated quartzite pebble below the compass.

Fig. 8e. Monomictic, in-situ-type conglomerate with a scanty sericite-rich matrix upon the Ljosdalsvatnet formation, N of Selvatn. For location see Fig. 6 and for discussion see sections 5.4 & 5.10.

Fig. 8f. Large plagioclase phenocrysts in the Nystøyl porphyry.

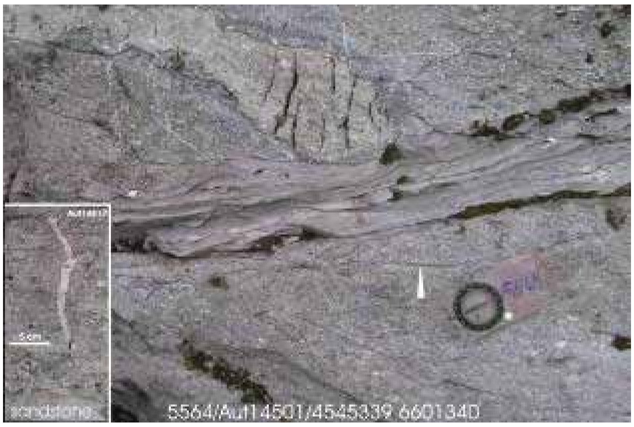

Fig. 8g. Sandstone relics and dikelets (arrow and the inset) above the ?Nystøyl porphyry. NW of Ljosdalsvatnet. For location see Fig. 5

Fig. 8. Lithologies of the Svinsaga (a-b), Hornlitjørn (c-e), and Nystøyl (f) formations of the Oftefjell group. Number series on the photographs give station and file numbers and UTM coordinates in this order. The plate of the compass used as a scale is 6.5 x 12.5 cm.

Fig. 9a. Volcaniclastic conglomerate upon the Nystøyl porphyry with opaque-rich stripes interpreted as altered basalt seams (see Fig. 9b).

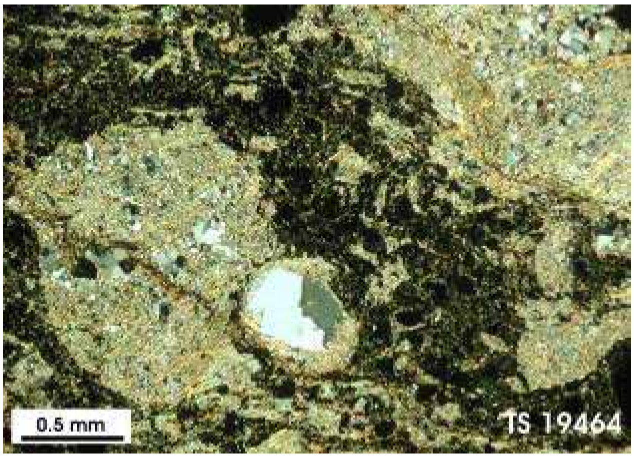

Fig. 9b. Photomicrograph of an opaque-rich stripe in Fig. 9a with felsic volcanite clasts whose groundmass has been altered to sericite-rich mass. Thin section Oy19464. Two polars.

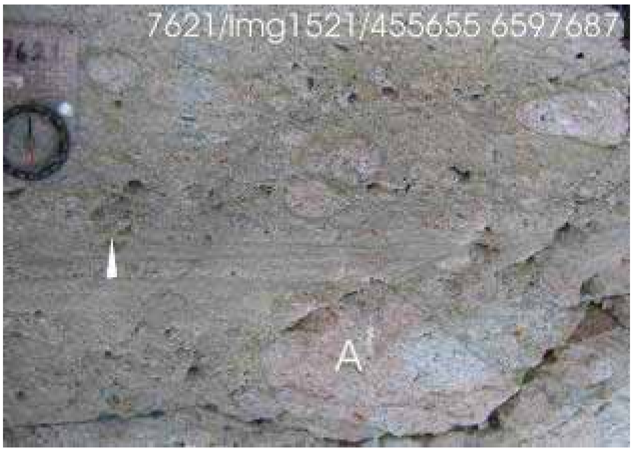

Fig. 9c. Volcaniclastic mass-flow conglomerate c. 150 m above the Nystøyl porphyry. Note the angular felsic volcanite cobble (A) and thin graded layers showing top up (arrow).

Fig. 9d. Trough cross-bedded volcanic sandstone.

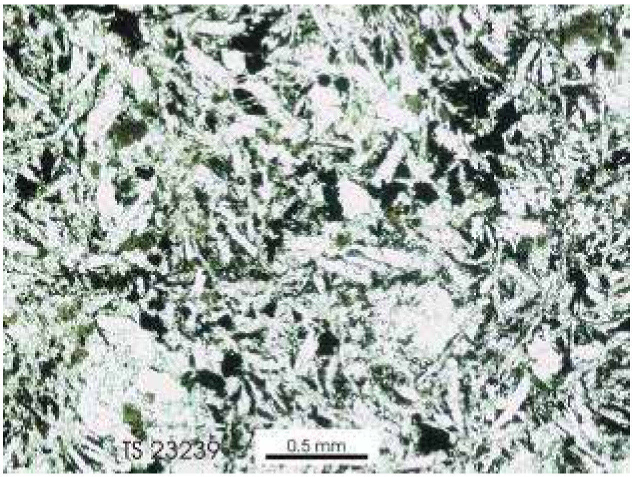

Fig. 9e. Photomicrograph of the Nystøyl metabasalt with well-preserved trachytic texture. The primary mafic minerals have been altered to opaques, epidote, chlorite, sericite and carbonate. Thin section Oy23239/station 7620. One polar.

Fig. 9f. Nystøyl metabasalt (dark) mingled with a vocaniclastic conglomerate (light) of the Langelinutane formation. Note the metabasite "flame" (above the compass) and tongues (lower part) and plastic mingling of the rocks with irregular contacts (arrow).

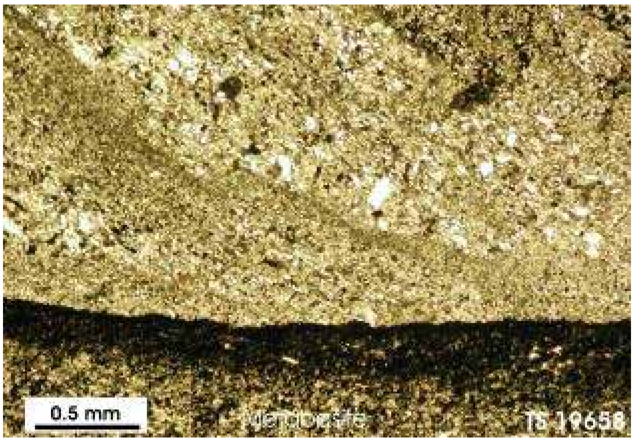

Fig. 9g. Photomicrograph of peperite-like texture of the Nystaul porphyry at station 3026 NE (see the text).Thin section Oy19658. Metabasite (lower part) with an opaque-rich margin in contact with a siltstone showing undisturbed graded lamination. One polar.

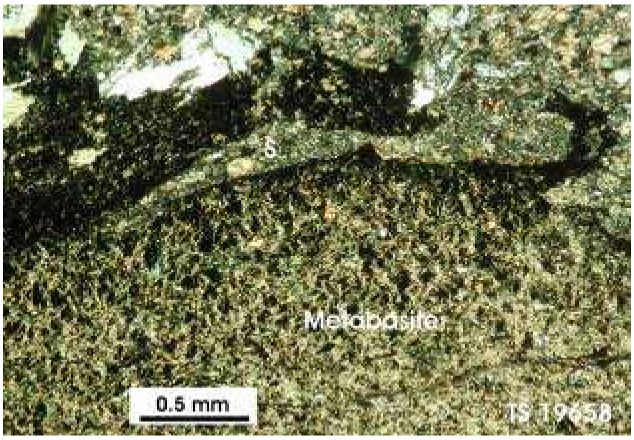

Fig. 9h. The same contact as in Fig. 9g showing siltstone wedges and …

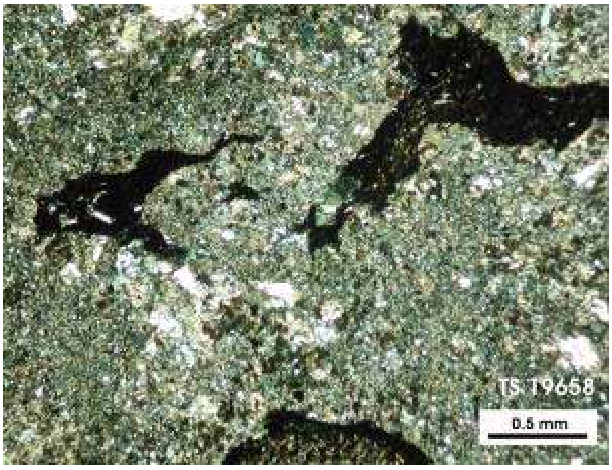

Fig. 9i. …flame-like metabasite "rags". The metabasite has been altered to opaque- and sericite-rich rock and has lost its primary texture. Two polars.

Fig. 9. Lithologies of the Langelinutane formation and peperitic contact phenomena of metabasite in the Nystøyl area. For locations see Fig. 5d.

Fig. 10a. Quartzite bed overlain by a foliated conglomerate bed with quartzite pebbles and cobbles and a few felsic volcanite clasts (F). The inset displays a hematite-coated quartzite cobble common in all quartzite units of the Oftefjell group.

Fig. 10b. Wave-rippled quartzite seen from below. Middle part of the Hovdevatnet formation. Hovdevatnet dam.

Fig. 10c. Parallel-laminated microcline quartzite with a quartzite pebble train (arrows).

Fig. 10. Lithologies of the Hovdevatnet formation. For locations see Fig. 5b.

Fig. 11a. Mingling of quartzite (Qt) and porphyry (P) at the Langelinutane formation/Stemmetjørn formation contact. Oftefjell.

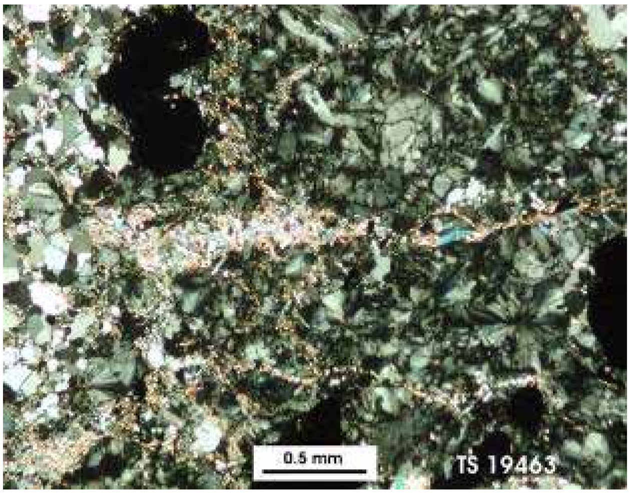

Fig. 11b. Photomicrograph of the rock in Fig. 11a showing closed sheaf feldspar spherulites (terminology after Lofgren, 1974) in outer margin of the Stemmetjørn porphyry. Note how the sericite-rich sedimentary material infiltrated from the quartzite on the left fills the microfractures in the spherulite. Thin section Oy 19463. Two polars

Fig. 11c. Quartz-feldspar porphyry. Huka.

Fig. 11d. C. 10 m thick metasedimentary bed (for detail see Fig. 11e) between metabasalt flows. Skinand/E134.

Fig. 11e. Detail of the sandstone in Fig. 11d showing tectonic transposition of sandy parts (light brown) of the graded beds parallel to the foliation.

Fig 11f. Polymictic, clast-supported vocaniclastic Luråsen conglomerate with abundant felsic volcanite (f) and less common quartzite (q) clasts and mafic fragments.

Fig. 11g. Topmost, thinly laminated tuffite of the Oftevatnet formation. Note the minor erosional troughs (arrows) indicating top up.

Fig. 11. Lithologies of the Stemmetjørn (a-b), Bergstøylnutane (c) and Oftevatnet formations (d, e). For locations of Figs. 11a-d, and Fig. 11e & f, see Figs. 5a and Fig. 5e, respectively.

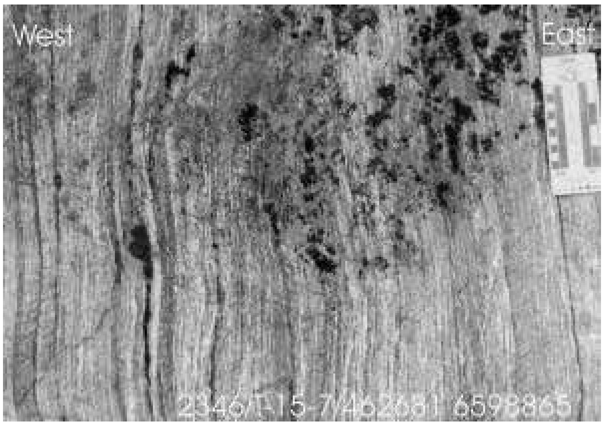

Fig.12a. Pervasively foliated Røynstaul quartzite on the eastern flank of the Selvatn syncline, west of the conglomerate in Fig. 8e

Fig. 12b. Sheared and….

Fig. 12c ....(sheath) folded Røynstaul formation on the western flank of the Selvatn syncline.

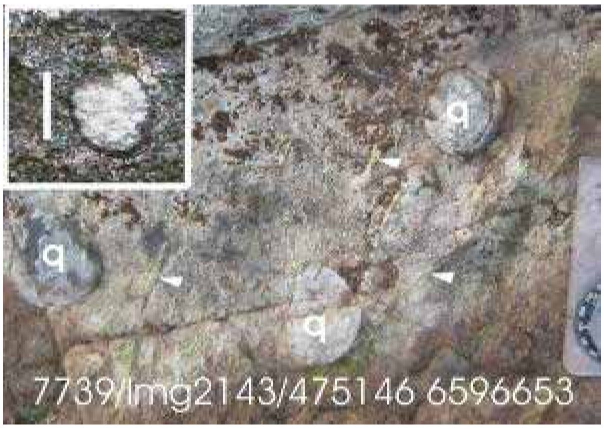

Fig.12d. Quartzite clasts (q) in a fine grained metabasite with epidote veinlets (arrows). The inset show a quartzite clast (bar = 2 cm) with a reaction rim in a metagabbro.

Fig. 12e. A likely erosional contact between the tuffite of the Oftevatnet formation and a quartzite of the Røynstaul formation.

Fig. 12f. Quartzite pebbles (q) in a foliated microcline quartzite. Svinefjell.

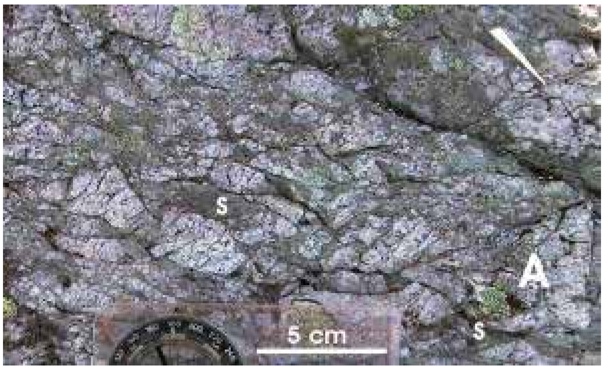

Fig. 12g. In situ-breccia conglomerate upon a porphyry of the Tuddal formation (cf. Fig. 8e). Note scanty sericite schist matrix (s), sharp-edge fragments (A), and jigsaw fit of some of the fragments (arrow).

Fig. 12. Photographs related to the contact zone between the Oftevatnet and Røynstaul formations formation (a-e), a pebbly quartzite of the Røynstaul formation east of Svinefjell (f), and a basal breccia conglomerate of unknown age (g. For locations see Figs. 4 (f & g), 5e (b-e), and 6