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Lithostratigraphy of the lower part of the Mesoproterozoic Lifjell group, central Telemark, Norway.

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Abstract

The Lifjell group comprises the conglomerates and quartzites deposited either on the porphyries of the 1155 ± 3 Ma Brunkeberg formation or quartzites of the ≥ 1 155 – ≤ 1500 Ma Vindeggen group. Because regional deformation has destroyed most of the primary sedimentary structures and several faults cut the bedrock correlation of different parts of the group is difficult. That is why only an informal lithostratigraphic classification of the group across its whole distribution area can be established. The group starts with the Vallar bru formation and the Heksfjellet conglomerate dominated by intensely deformed quartzite-clast conglomerates with felsic volcanite clasts in their lower parts. The Bjørndalen mixed rock with solitary quartzite clasts in mafic schist is interpreted as a diabase intruded into a Vallar bru conglomerate probably during the soft-sediment - semi-indurated stage. The lower conglomeratic part is overlain by a parallel-laminated quartzite with local conglomeratic sericite-quartzite members. The topmost conglomerate unit above an intra-Lifjell hiatus/unconformity contains solely quartzites clasts in a scanty sericite-schist matrix. It is overlain by a heterolithic - sericitic quartzite unit. The scanty sedimentary features preserved indicate that the part of the Lifjell group studied consists of two fan delta – basinal sequences separated by an intra-Lifjell hiatus/unconformity.

Occurrence of garnet and problem of how to distinguish deformed conglomerates from tectonic pseudoconglomerates and breccias are discussed.

Key words: Telemark, Vallar bru, Grunningsdalen, Heksfjellet, Seljord, Bjørndalen, lithostratigraphy, conglomerate, breccia, quartzite, garnet.

1. Introduction

The Precambrian bedrock in Central Telemark, southern Norway, is known for the rather well-preserved Mesoproterozoic volcanic-sedimentary belt named collectively as the 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 press; 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, the sub-Lifjell unconformity (Laajoki, 2006) for reclassifying Dons' Seljord group into the Vindeggen (older) and Lifjell groups. This paper gives a field documentation and informal lithostratigraphic classification of the conglomeratic lower part of the Lifjell group, of which the conglomerates in Seljord and Hesteskodiket (Werenskiold, 1910; Bugge, 1931; Dons, 1960b), in Lifjell (Werenskiold, 1910, Dons, 1960b), as well in Heksfjellet (Törnebohm, 1889; Werenskiold, 1910)) have been know since long ago, but without any closer description (for the history see Laajoki et al., 2002).

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; Andersen & Laajoki, 2003; Andersen et al., 2004; 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 (Baltic) Shield.

All the rocks of the Lifjell group are metamorphic, for they were metamorphosed under the greenschist facies, in part also in the amphibolite facies, during the Sveconorwegian orogeny, but for simplicity's sake, meta-prefix will not be used systematically in the rock names. The term "quartzite" is used as a loose field rock name (cf. Howard, 2005).

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 Shield (Fig. 1). The c. 10 km wide Mandal-Ustaos(et) fault zone (Sigmond, 1985) 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).

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), (2) the c. 2 km thick volcanic-sedimentary Vemork formation (is in fact of a group rank) with abundant metabasaltic units (Laajoki & Corfu, subm.), and (3) the sedimentary Vindeggen group c. 5 km thick with several quartzite and two mudstone formations (Laajoki, in press).

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 and the coeval, 1155 ± 2 Ma old Brunkeberg formation (Laajoki et al., 2002), whose basement is unknown. The sub-Røynstaul unconformity (Laajoki & Lamminen, 2006) separates the former from the overlying sedimentary-volcanic Høydalsmo group, whereas the Lifjell group lies unconformably on the Brunkeberg formation and the Vindeggen group (Laajoki, 2006). 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).

Numerous faults subdivide the bedrock of the study area into several lithostratigraphic-structural domains (Fig. 2, for definitions see Laajoki, in press). The Lifjell group occupies SE part of the

Telemark belt within the Seljord domain. Its boundary with the gneisses and granitoids in the south is tectonic (Laajoki, 2006).

3. Distribution and general lithostratigraphy of the lower part of the Lifjell group

The southern part of the traditional Seljord group (Dons, 1960a, b), which overlie unconformably the Brunkeberg formation and the Vindeggen group, was remapped by Laajoki et al. (2002) as the Lifjell group. The sub-Lifjell (Laajoki, 2006) and sub-Heddal (Laajoki, 2002) unconformities define its lower and upper boundaries, respectively. It forms a NE trending quartzite mountain belt about 130 km long and 30 – 50 km wide between the Brunkeberg-Heksfjellet tectonic zone and the Vråvatnet complex (Figs. 2 & 4). The group consists mainly of quartzites, but conglomerates are common in its lower part exposed on the NW and SE margins of the Seljord domain (Figs. 2, 4 & 5). Both the areas are, however, so much deformed and unevenly exposed that no regional lithostratigraphic subdivision with a good continuous type section can formally be done. That is why lithostratigraphic studies were concentrated in the areas the units are best exposed (Figs. 6 – 10). Fig. 11 gives generalized lithostratigraphic columns with informal unit nomenclature. The sequence to be described comprises the Vallar bru formation and the Heksfjellet conglomerate overlain by diverse quartzite and conglomerate units. Its estimated maximum thickness is about 700 m in Grunningsdalen.

4. Heksfjellet-Nordfjell area

The best locality where the Lifjell group can be seen to lie unconformably on the Vindeggen group is the eastern flank of Heksfjellet (Figs. 4 & 6; Laajoki, 2002; Laajoki et al., 2002). Two units can be separated (Fig. 11):

(1) *The Heksfjellet conglomerate* starts with a fracture - *in situ* breccia zone developed above the Upper Brattefjell formation of the Vindeggen group (Figs. 9 & 10a in Laajoki, 2002; Fig. 6d in Laajoki et al., 2002). The fractures are filled by sericite quartzite (Fig. 12a). The quartzite clasts are exceptional containing tiny garnet around quartz grains (section 14). This basal part passes to a

typical Heksfjellet conglomerate with both quartzite and felsic volcanite cobbles and boulders in a sericite quartzite matrix whose amount varies from place to place. The 1498 ± 6 Ma age of one of the porphyry clasts refers to the Tuddal formation as the source (Laajoki et al., 2002). The size of the clasts and the relative amount of the volcanite clasts decrease upwards. The amount of the matrix varies (Fig. 12b) and thin sericite quartzite interbeds or lenses may occur (Fig. 12c) in the middle-upper part of the unit. The conglomerate can be followed along the poorly exposed and faulted Slåkådalen valley to the surroundings of Slåkåvatnet (Fig. 6). Northeast of the lake, the lowermost conglomerate may represent a deformed *in situ* breccia (Fig. 12d), whereas southwest of it a few metres thin clast-supported conglomerate interbed with only quartzite clasts occur between parallel laminated orthoquartzites (Fig. 12e). Quartzite interbeds at least a few metres thick occur on both sides of Slåkåvatnet. The conglomerate is everywhere highly stretched (Fig. 12f) the stretching lineation plunging shallowly to the east (Fig. 6). Volcanite clasts are rare and seem to occur in the middle part of the conglomerate, where also a quartzite bed with low-angle cross-bedding and solitary quartzite clasts interbedded with matrix-supported quartzite-cast conglomerate was detected (Fig. 12g). This is the only locality where top direction (black arrow on the map in Fig. 6) pointing towards the topographically overlying main Lifjell quartzite at Nordfjell could be determined.

(2) The parallel-laminated *Høymyråsen quartzite* overlies the Heksfjellet conglomerate on the eastern flank of Heksfjellet. It is intruded by metadiabases and overlain by the Skogsåa porphyry, from which it is separated by the sub-Heddal unconformity (Laajoki, 2002). The Slåkådalen fault (Fig. 12h) separates it from the main Lifjell quartzite in the SE. It is possible that the Høymyråsen quartzite can be connected with the quartzite interbed in the Slåkåvatnet area.

5. Grunningsdalen

Grunningsdalen is a deep, poorly exposed valley furrowed by the Grunnåi River. It defines approximately the SW part of the Slåkådalen - Grunningsdalen fault. The presence of the fault is inferred by the narrow wedge of the Brunkeberg formation between the Vindeggen group in the NW and the Vallar bru formation in the SE (Fig. 7). The SE wall of the valley offers the best place where the lithostratigraphy of the lower part of the Lifjell group can be studied. Even it is, however, so unevenly exposed and deformed that no continuous section can be measured. Based on the section from Grunnåi to Grimaren (Figs. 7 and 11), the following informal units can be established:

(1) The *Vallar bru formation*, which consists of stretched Vallar bru conglomerates lying via the sheared unconformity upon the Brunkeberg formation (Fig. 17e in Laajoki, 2006). The unconformity represents a Hesteskodiket-type transitional contact (*op. cit.*), but the intense shearing hampers its exact location. The Vallar bru conglomerate (> 100 m) is everywhere highly deformed showing evidence of at least two stages of deformation; local D_1 flattening, D_2 stretching and folding, which counterparts Richards' (1998) regional D_2 and D_3 stages. These have modified the original shapes of the quartzite clasts (Figs. 13a, b). The basal part of the conglomerate is "bimictict" in the sense that it contains both felsic volcanite and diverse quartzite clasts (Fig. 17e in Laajoki, 2006), but the amount of the former decreases rather rapidly upwards. The scanty matrix contains abundant felsic volcanic material in lower parts, but becomes sericite-richer upwards. The conglomerates are poorly sorted containing clasts from small pebbles to large boulders, but due to intense strain the clast sizes can determined only arbitrarily. As a whole, the formation fines upwards, for clast-supported cobble - boulder conglomerates are common in the basal parts whereas pebble - cobble conglomerates, some of which are matrix supported (Fig. 13c), occupy upper parts, where pebbly sericite quartzites may also occur.

(2) The *Årstaul quartzite* (c. 400 m) is a monotonous unit of glassy, blue, parallel laminated, recrystallized orthoquartzite, in which wave ripples have locally been seen.

(3) The *Grunnåi membe*r (c. 50 m) is considered as an interbed or a lense within the Årstaul quartzite. In Geitekyrja, a breccia occurs which is considered to indicate the base of this unit. Here a gray opaque-rich and sericite-chlorite schist fills deformed fractures in a orthoquartzite or surrounds cigar-like quartzite fragments. The schist contains abundant well-rounded accessory zircon and apatite and some tourmaline (Fig. 13d). The member itself consists of foliated and in part sheared pebbly sericite quartzite (Fig. 13e) and gray biotite-sericite schist rich in tiny epidote.

(6) The highly deformed *Grimaren conglomerate member* consists of quartzite-clast conglomerate (n x 10 m). Its lower contact with the Årstaul quartzite is marked by an irregular fracture network

within the upper margin of the Årstaul quartzite (Fig. 13f), which passes to a tightly packed conglomerate (Fig. 13g). This lowermost zone is considered as an intra-Lifjell *in situ* breccia developed on the Årstaul quartzite (see section 15). Like the Vallar bru formation, the main part of the member consists of conglomerate deformed twice, but the clasts comprise solely diverse quartzite (Fig. 13h). The upper contact is exposed well on the NW slope of Venelinuten (Fig. 13i), where the Grimaren conglomerate is overlain abruptly (Fig. 13j) by the parallel laminated orthoquartzite of the main Lifjell range (Figs. 13k).

6. Bjørgenuten, Seljord city and Raudbergnuten

The lower part of the Lifjell group in Bjørgenuten and around the Seljord city has been folded and faulted in a complex way (Fig. 16 in Laajoki, 2006) with the consequence that the sub-Lifjell unconformity and the basal part of the Vallar bru formation have been deformed (Fig. 17 in *op. cit.*). Locally, however, the transitional sub-Lifjell unconformity (Fig. 14a) and the basal Vallar bru conglomerate with abundant felsic volcanite clasts (Fig. 14b) are visible. The lithostratigraphic position of the classical Vallar bru conglomerate outcrop in the Seljord city (stop 8 in Dons, 1960b) is problematic. It has a fault contact with the Brunkeberg formation in the north (Fig. 14c), but the contact with the blue orthoquartzite in the south is gradational, dips about 60° to the north (Fig. 14d), and is marked by a folded fracture system filled by sericite-rich material (Fig. 14e). No top determinations can be made in the outcrops south of the contact, but the orthoquartzite dips shallowly to the north (Fig. 16a in Laajoki, 2006) indicating that it probably underlies the conglomerate. This and the lack of volcanite clasts in the conglomerate (Fig. 14f) refer to that the conglomerate could be correlated with the Grimaren conglomerate or the upper Vallar bru conglomerate in the Vigdesjå area (next section) and that the fractures in the contact could represent the intra-Lifjell hiatus (section 15). Thin beds of quartzite-clast conglomerate occur within the blue parallel-laminated quartzite both south and north of Vallar bru; e.g. the Lønnestad conglomerate (Fig. 11, Fig. 16a in Laajoki, 2006).

Laajoki (*op.cit.* Fig. 12) published a cross section of Raudbergnuten showing the problematic relationship between the Lifjell and Vindeggen groups and photographs of quartzite breccias of the Vallar bru formation. No typical Vallar bru conglomerate was found in this area. After the work referred to above, a c. 30 m wide breccia zone was detected on the SW flank of Raudbergnuten. The breccia topographically above the quartzite previously included into the Lifjell group resembles an *in situ* conglomerate (Fig. 14g), but otherwise the zone consists of highly deformed breccia (Fig. 14h). More studies are needed to find out the origin and significance of this zone.

8. Vigdesjå area

This is a highly deformed area characterized by stretched Vallar bru conglomerates covering wide areas around and north of Vigdesjå Lake (Fig. 8). It is likely that the conglomerate consists of 3-4 thrust sheets whose boundaries are, however, difficult to locate. Because of the faults, the thickness of the Vallar bru formation is unknown, but it should be several tens of meters (Fig. 14i). In spite of the strong deformation, the transitional unconformity between the Brunkeberg and Vallar bru formations and Hesteskodiket type pebbly vocaniclastic sandstone – conglomerate have been preserved in the classical Hesteskodiket and nearby localities (stop 11 in Dons, 1960b; Fig. 13 in Laajoki, 2006). On the basis of detrital zircon geochronology, de Haas et al. (1999) concluded, that the maximum depositional age of the conglomerate is 1453 ± 46 Ma. Above the Vallar bru conglomerate, the lithostratigraphy is briefly similar to that in Grunningsdalen. Namely, a typical basal Vallar bru conglomerate with felsic volcanite material passes upwards to quartzite-clast conglomerate with quartzite interbeds (Fig. 11). The thickest quartzite unit, the *Bøjeåi member,* consists of a blue, glassy, parallel-laminated orthoquartzite (Fig.14j). Locally, *in situ* breccia has developed at the quartzite/conglomerate contact (Fig. 14k, see section 15). In spite that the enveloping conglomerates are highly strained, quartzite interbeds may show rather well preserved parallel-lamination or in one case even planar cross-bedding (Fig. 14l). The upper part of the Vallar bru formation consists of quartzite – sericite quartzite with solitary quartzite clasts or thin quartzite-clast conglomerate beds. The sequence is overlain topographically by the *Juvrefjell quartzite,* which consists of a monotonous blue, glassy quartzite similar to the one in Fig. 14j, but the parallel lamination has been preserved only locally. The quartzite has been thrust upon the Vallar bru formation along the Juvre fault (Fig. 14m) which leaves its exact lithostratigraphic position open. The quartzite above the fault surface in Fig. 14m is an orthoquartzite with some biotite. It also contains accessory tiny garnet (see section 14).

9. Bjørndalen

The lower part of the Lifjell group in Bjørndalen, a narrow valley north of Juvrefjell, forms a small syncline, whose SE and NW margins are defined by the sub-Lifjell unconformity and the Jåfjell fault, respectively (Fig. 9). The area is exceptional as it contains a mixed rock within the Vallar bru formation and a thin, but significant conglomerate member within the overlying quartzite. Unfortunately, due to the lack of locality names, the name Bjørndalen appears in most of the units.

9.1. Basal conglomerates at Station 7350

The transitional unconformity between the Brunkeberg formation and the Vallar bru formation is well visible at station 7350, in SW part of Bjørndalen (Figs. 14c and 14d in Laajoki, 2006). The Hesteskodiket-type conglomerate above the transitional zone contains variable amounts of both solitary felsic volcanite clasts (Fig. 15a) and quartzite (Fig. 15b) clasts. This is overlain sharply by a Vallar bru-type, clast-supported, quartzite-clast conglomerate (Fig. 15c).

9.2. Bjørndalen mixed rock

At station 927 (Fig. 9), the Vallar bru conglomerate is overlain (or intruded, see below) by a heterogeneous mafic rock with solitary quartzite clasts (Fig. 15d). Because the origin of the rock is unsure it is called simply a mixed rock. It contains lighter and darker irregular layers or bands (Fig. 15d). The host rock comprises four different domains all of which contain metamorphic garnet and accessory tourmaline: 1) lighter patches rich in sericite and opaques, 2) dark domains or fragments rich in opaques with chlorite and sericite, 3) felsic domains rich in plagioclase and with abundant garnet and accessory apatite, and 4) quartzitic parts with abundant garnet and plagioclase near their margins (Fig. 15e). The contact of the host rock with the Vallar bru conglomerate is sharp (Fig. 15f). The rock filling the interspaces of the quartzite clasts of the conglomerate is rich in opaques, sericite, and plagioclase and garnet, but quartzitic domains also occur. The quartzite clasts in direct contact with the mixed rock are recrystallized orthoquartzites, but their marginal parts are finer-grained than the inner parts of the clasts and contain abundant plagioclase and accessory tourmaline. A rock similar to the host rock occurs at the contact of a metadiabase at station 930 (Fig. 9). It is pervasively foliated consisting of steel gray opaque-rich and biotite- and garnet-porphyroblastic epidote-chlorite- quartz schist bands. At station 946 (Fig. 9), a mixed rock occurs between the

Brunkeberg formation and the Vallar bru conglomerate and contains more and bigger quartzite clasts than at station 927. It also contains dark opaque-rich layers and fragments. At station 942, the mixed rock occurs between the Brunkeberg porphyry and a metadiabase.

At station 4479, the Hesteskodiket-type conglomerate has been pervasively sheared (Fig. 14e in Laajoki, 2006) and contains sericite- and opaque-rich band, chlorite porphyroblasts, and abundant anhedral garnet porphyroblasts some of which have nucleated in plagioclase-phenocryst clasts (Fig. 15g). This may represent sheared contact zone between the Brunkeberg porphyry and the mixed rock. The latter occurs as a thin layer between the Brunkeberg porphyry and the Vallar bru conglomerate in the eastern part of Hill 657 (Fig. 9). Locally the rock is massive, but contains solitary quartzite boulders.

Because metamorphism has destroyed the primary texture of the mafic host rock and its dark fragments, it is difficult to determine their origins. The abundance of opaques, sericite and chlorite as well as presence of abundant garnet refers to a basaltic composition. This is supported by the fact that metadiabases and metabasalts in the area have in most cases altered to opaque- and sericite-rich rocks. The occurrence of the host rock near contacts of metadiabases at stations 930 and 942 also refer to a close connection between these rocks. The sharp contact in Fig. 15f seems to be more likely either extrusive or intrusive than sedimentary. All the quartzite clasts in the mixed rocks are petrographically similar to those in the Vallar bru conglomerate, from which they have most likely been derived from. Consequently, the rock can be considered as a mixture of Vallar bru conglomerate and basaltic magma. Because it occurs both under, above, and within the Vallar bru conglomerate, it might present a sill intruded along the Brunkeberg/Vallar bru contact. The fact that the host rock does not occur as dykes in the conglomerate and does not contain conglomerate clasts, but only solitary quartzite pebbles and cobbles, indicates that the conglomerate was unconsolidated or poorly consolidated during the intrusion of the magma. Consequently, the rock could be a subvolcanic peperite, but as the critical characteristics are missing the use of this genetic term is avoided (cf. White et al., 2000; Skilling et al., 2002).

9.3. Bjørndalen quartzite

A monotonous blue, recrystallized quartzite overlies the Vallar bru conglomerate. Both the rocks are deformed, but their contact is likely sedimentary (Figs. 16a and b). The quartzite is totally recrystallized, but parallel-lamination has been preserved rarely (Fig. 16c, cf. Fig. 14h). Thin mudstone layers occur locally.

9.3 Upper Bjørndalen conglomerate

This is a thin unit (c. 1 m) above the Bjørndalen quartzite with station 7457 as it type locality, where it starts with a fracture zone (Figs. 16d, e) passing to an *in situ* breccia (Fig. 16f). Note that although the quartzite fragments are roundish they do not represent ancient gravel, for they are still attached to their basement. Both the fracture fill and matrix of wider interspaces between the fragments are rich in sericite, epidote and opaques. The real conglomerate above the fracture zone consists solely of quartzite clasts in scanty sericite-schist matrix and is overlain by a quartzite breccia (Fig. 16g). It is difficult to determine is the breccia sedimentary or tectonic (see section 14). At station 7355, 300 m to the NE from station 7457, a conglomeratic rock occurs above the blue Bjørndalen quartzite (Fig. 16h). In this case, however, the scanty matrix contains abundant epidote and some tremolite, whereas sericite is missing.

9.4. Bjørndalen sericite quartzite

The part above the Bjørndalen upper conglomerate is poorly exposed. Above the conglomerate at station 7457, a highly deformed epidote- and opaque-rich sericite schist mineralogically similar to the matrix in the conglomerate occurs. The rock contains solitary orthoquartzite pebbles (Fig. 16i). A similar, strongly foliated rock occurs also above the conglomerate at station 7355, but it contains better preserved parts which display graded bedding (Fig. 16j). Brecciated sericite quartzite occurs also along the Jåfjell fault (Figs. 16k, l).

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10. Åmtveit

The lower part of the Lifjell group in the Åmtveit area is both structurally and lithostratigraphically similar to that in the Bjørndalen area (Fig. 10 in Laajoki, 2006). The upper conglomerate has not been found there, but a sericite quartzite with folded pelitic layers (Fig. 16m) occurs in a close association with or overlies the blue quartzite which may be correlated with the Bjørndalen quartzite.

11. Nystaulvatnet area

Laajoki (2006) gave arguments for why the conglomerates and sericite quartzites deposited on the Vindeggen group in the structurally complex Nystaulvatnet area might be correlated with those in the Åmtveit and Bjørndalen areas. He also published many photographs of breccias and conglomerates of the Vatnelian member considered to belong to the basal part of the Lifjell group. The overlying sericite quartzite was mapped as the Nystaulvatnet member, which contains both relatively well preserved (Fig. 16n) and highly strained parts (Fig. 16o).

12. SE margin of the Telemark supracrustals

Laajoki (2006) demonstrated that the southeastern margin of the Telemark supracrustals is tectonic consisting of two tectonic slices (Fig. 5). The lower part of the Lifjell group has been preserved only within and above the Gardvik tectonic unit, where the strongly deformed Hesteskodiket-type conglomerates occur attached to the Brunkeberg formation (Fig. 18 in *op. cit.*) veined by thin pegmatite veins (Fig. 17a) and are overlain by intensely deformed Vallar bru-type conglomerates and conglomeratic sericite quartzites and schists. Hesteskodiket-type conglomerates differ from those within the Brunkeberg – Heksfjellet tectonic zone by containing cobbles-boulders of coarse-grained granitoids/felsic volcanites (Fig. 17b) of unknown source and by displaying mass-flow beds (Fig.17c).

The most varied sequence occurs in the forest-covered Høystaultjørni area (Fig. 10). Its units are described away from the Brunkeberg formation that is from the SSE to the NNW. It is possible, that the tight folding visible in pelitic parts may have repeated some of the units tectonically. Although the outcrops are small, it can be seen that the sequence above the Brunkeberg porphyry starts with a transitional unconformity and Hesteskodiket-type conglomerates. This is overlain by a matrix-supported conglomerate where quartzite clasts up to boulder size lie in a sericite-quartzitic matrix. Thin mica schist and quartzite beds occur in upper part of the conglomerate. The next unit consists of a quartzite followed by a tightly folded heterolith with a few cm thick quartzite portion draped by thin pelite layers (Fig. 17d) and pervasively foliated sericite quartzite with flattened or stretched quartzite pebbles and cobbles (Fig. 17e). The second main conglomerate unit starts with gray microcline- and biotite-bearing quartzitic schist with solitary quartzite cobbles followed by matrix-supported quartzite-boulder conglomerate and a quartzite-pebble conglomerate with quartzite wedges (Fig. 17f). The rest of the sequence mapped consists of a blue, glassy quartzite with thin, isoclinally folded heterolithic units (Fig. 17g). The sequence described resembles the part of the lower Lifjell group exposed within the Brunkeberg – Heksfjellet tectonic zone, but due to the deformation it is not possible to do any closer correlation between these areas c. 10 km apart.

A distinctive feature of the SE margin is strongly deformed matrix-supported conglomerates – conglomeratic quartzites, which may counterpart either the Grimåsen or Grimaren member in Grunningsdalen. The Gravali conglomerate (Fig. 5d in Laajoki, 2006) consists of a stretched matrix-supported quartzite-boulder conglomerate (Fig. 17h). The stretched quartzite-cobble sericite quartzite in Høgåsåsen (Fig. 17i), c. 10 km, east of Høystaultjørni, resembles the one in Fig. 17e, but it occurs structurally above the gneissic quartzite of the Åsekollen tectonic unit. Fig. 17j displays an extremely strained conglomeratic sericite-quartzite where the clasts have been first flattened and then folded tightly. It occurs structurally above the strained Hesteskodiket-type conglomerate in Årmotdalen (Figs. 18d and 18e in Laajoki, 2006).

13. Conglomerate vs. pseudoconglomerate and sedimentary breccia vs. tectonic breccia

To distinguish a conglomerate from a pseudoconglomerate produced by tectonic processes or to distinguish a tectonized sedimentary breccia from a tectonic breccia in deformed bedrock may be difficult, cf. Singh (1968) *vs*. Roberts (1969). The fact that most of the conglomerate and sedimentary breccias in the study area contains solely quartzite clasts or quartzite fragments in quartzite matrix and are associated with quartzites similar to the clasts in conglomerates makes this question even more problematic. Proper interpretation of the genesis of the rock is of utmost importance in establishing the lithostratigraphic/ tectonostratigraphic order of the rock sequences in the area.

If an *in situ* breccias is only moderately deformed it can easily be identified as sedimentary on the basis of its matrix and undisturbed or slightly disturbed jigsaw fit of its fragments (Fig. 9d in Laajoki, 2006). If the rock has been strongly deformed it can, however, be mixed with a tectonic breccia. This is the situation in the Nystaulvatnet and Grenjusnetten areas, where Laajoki (*op. cit.*) used the petrography of the fracture fill of and "exotic" clasts in basal breccias as a proof for their sedimentary origin. Part of the breccias was considered as tectonized *in situ* breccias (Figs. 9g and 11e in *op. cit.*). Fig. 18a gives an example of a complex breccia, which may also represent a tectonized *in situ* breccia.

Deformed oligomictic quartzite-clast conglomerates with quartzitic matrix may also be difficult to distinguish from tectonically brecciated quartzite. Being polymictic, the Vallar bru conglomerate in Fig. 18b represents a relatively simple case, but the origin of the c. 2 m thick breccia developed in an orthoquartzite of the Lifjell group (Figs. 18c, d) is not that simple. It consists of one quartzite type only and the fractures are thin (~ 1 mm) and are mainly continuous and parallel to the bedding plane observed in nearby outcrops (Fig. 18d). In a section oblique to the regional stretching lineation the rock shows some conglomeratic features and the fracture surfaces are wavy (Fig. 18c). The fractures are filled by abundant opaques, muscovite and chlorite with accessory apatite. This assemble resembles the fracture fillings in the sedimentary *in situ* breccias in the Grenjusnetten area and in Geitekyrkje (Fig. 13d), but detrital zircon seems to be missing. The relatively abundant apatite, which occurs both within and outside the fractures, indicates that the fill could be hydrothermal or metamorphic. The Grimaren conglomerate in Venelinuten is locally so highly pressed that it could easily identified as a tectonic breccia, but bulbous appearance of some of the clast and their cup-like moulds reveals that it is a conglomerate (Fig. 18e).

On the basis of the lack of matrix and the homogeneity of the fragments, the rock from the lower part of the Heksfjellet conglomerate in Fig. 18f is interpreted as a deformed quartzite interbed. However, deformation of clasts in conglomerates may produce similar structures (Figs. 13b & 18g). Figs. 18h – 18j give examples of deformed rocks from the shear zone between the blue orthoquartzite and the Vallar bru conglomerate in Bjørgenuten. The bulbous structure in Fig. 18h resembles conglomerate, the lack of matrix and homogeneity of the clasts refer, however, to a tectonic origin as do also the lozenge form of many of the fragments in Fig. 18j. The rock in Fig. 18i represents an intermediate form between these two. Because this zone is poorly exposed and does not contain parts which could easily identify as conglomerates their tectonic origin is not totally excluded, but as similar structures occur within the sheared Grimaren conglomerate (Fig. 18k) sedimentary origin seems more likely.

The third problem is to distinguish extremely deformed matrix supported conglomerates from pelitic rocks with solitary quartzite interbeds. Fig. 18l gives a view of a quartzite clast- bearing sericite quartzite subparallel to the local F_2 fold axis. This could be interpreted as a rock where more competent quartzite layers have been fragmented. The view oblique to the F_2 fold axis reveals, however, that the fragments are strained quartzite clasts (Fig. 18m). If the folded quartzite clast in Fig. 17j were taken out of its context, it could be interpreted as a fragment of a folded quartzite layer. The rock in Fig. 18n represents an extremely flattened quartzite-clast conglomerate from the SE margin of the Lifjell group. The lens like quartzite domains with flattened edges and lack of fold closers distinguish it from the isoclinally folded heterolith in Fig. 17g. The banded lower part of the rock could not be interpreted as a strained conglomerate without the help of the upper part. The view oblique to lineation in Fig. 17o confirms that the rock is a strained conglomerate. The scanty matrix is a opaque-rich muscovite schist with some plagioclase and abundant accessory epidote.

14. Occurrence of garnet

In a metamorphosed sedimentary rock it is important to detect whether a garnet is detrital or a new metamorphic mineral. Garnet is rather common in the schists, mixed rocks and in some of the metadiabases (Fig. 19a) in Bjørndalen, between the Jåfjell and Hill 657 faults (Fig. 9), but is missing from similar rocks south of the latter fault. On the basis of their S_i/S_e relations and euhedral forms, these garnets are clearly porphyroblasts indicating that this tectonic slice represents a higher metamorphic unit than the Juvrefjell quartzite SE of the Hill 657 fault. Usually, an older unit is thrust over younger, which indicates that the Juvrefjell quartzite is younger than the Brunkeberg formation supporting the idea that that the Juvrefjell quartzite does not represent a tectonic slice of the Upper Brattefjell formation exposed NE of the Jåfjell fault with which it is lithologically almost identical.

In the case when garnet occurs in orthoquartzite its origin is more difficult to determine because S_i/S_e relations are barely visible. The garnet in the Juvrefjell quartzite above the Juvre fault (Fig. 8) is a good example of this. It occurs in two surroundings: 1) associated with tourmaline in thin muscovite-rich seams (Fig. 19b) or 2) as solitary anhedral grains in orthoquartzite (Fig. 19c). Because the former association may be interpreted as a fracture fill deposited from hydrothermal – metamorphic fluids moving along the fault surface also the latter garnet may be metamorphic. In the Heksfjellet *in situ* breccia, garnet occurs as porphyroblasts in the muscovite-schist matrix and as tiny grains between quartz grains in quartzite clasts (Fig. 19d).

15. Discussion

Laajoki (2006) attributed the sub-Lifjell *in situ* breccias above the Vindeggen group in Heksfjellet to frost action, whereas the gradational sub-Lifjell unconformity above the Brunkeberg formation was considered erosional, but problematic. In the Heksfjellet-Brunkeberg tectonic zone (Fig. 4) , the lithostratigraphy of the lower part of the Lifjell group can briefly be subdivided into four parts (Fig. 11): 1) the lower conglomerate units with occasional quartzite interbeds (the Vallar bru formation and the Heksfjellet conglomerate), 2) the lower quartzitic part (Høymyråsen, Årstaul, Bøjeåi, and Bjørndalen quartzites) with conglomeratic interbeds (Grimåsen member and Lønnestad conglomerate), 3) the upper conglomerate units above an intra-Lifjell *in situ* breccia (Grimaren, Upper Vallar bru, and Upper Bjørndalen conglomerates), and 4) Bjørndalen sericite quartzite. Because the pervasive and ubiquitous deformation has destroyed almost all primary sedimentary structures no profound sedimentological synthesis can be done. The thickness and coarseness of the lower conglomerates refer either to an alluvial fan on to a fan delta. The locally preserved parallel lamination (Figs. 14j and 16c) and wave ripples in the overlying quartzite indicate a beach or shallow water basinal setting, which supports the latter choice. The *in situ* breccias above the quartzite (Figs. 13e-f, 14k, and 16d-f) prove that the lower quartzites were indurated and likely exposed to subaerial erosion before the formation of the upper conglomerates. Consequently, they mark an intra-Lifjell hiatus or a minor intra-Lifjell unconformity, above which the upper conglomerates and the heterolithic - sericitic Bjørndalen quartzite (Figs. 16j – l) seem to represent another fan delta – basin sequence.

The part exposed in the south is so much deformed that no closer sedimentological analysis can be done. The basal conglomerate seems to be thinner and heterolithic quartzites more common than in the north. This indicates that the southern sequence may represent a more distal part of the lower northern fan delta complex.

Andersen et al. (2004) considered the Blefjell quartzite, c. 25 km to the NE from Heksfjellet, as a more metamorphic correlative of the Lifjell group. This was based on the lithological similarities between the Vallar bru and Surtetjørn formations, which both overlie porphyries, which have within error limits identical ages; 1155 ± 2 Ma (Brunkeberg formation, Laajoki, et al., 2002) and 1159 ± 8 Ma (Sørkjevatn formation, Bingen et al., 2003), respectively. No other conglomerate-quartzite occurrences correlative with the lower part of the Lifjell group is known in Central Telemark.

16. Recommendation

The lower part of the Lifjell group treated in this paper offers a unique target for those specialists in structural geology who would like to study how quartzites, quartzite-clast conglomerates and solitary quartzite-clasts in a quartzite matrix behave in polyphase deformation.

Acknowledgements

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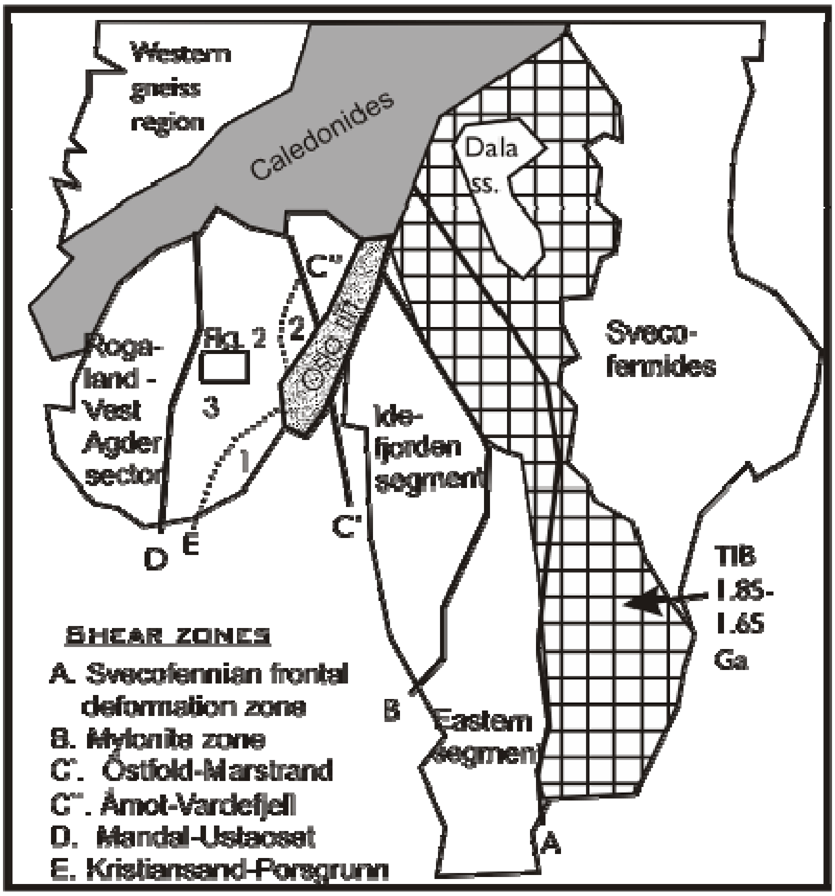

Fig. 1. Sketch map of the Sveconorwegian province (modified from Bingen et al., 2001). The area covered by Fig. 2 is framed. Numbered sectors west of the Oslo rift: (1) Bamble, (2) Kongsberg, (3) Telemark. TIB = Transscandinavian Igneous Belt.

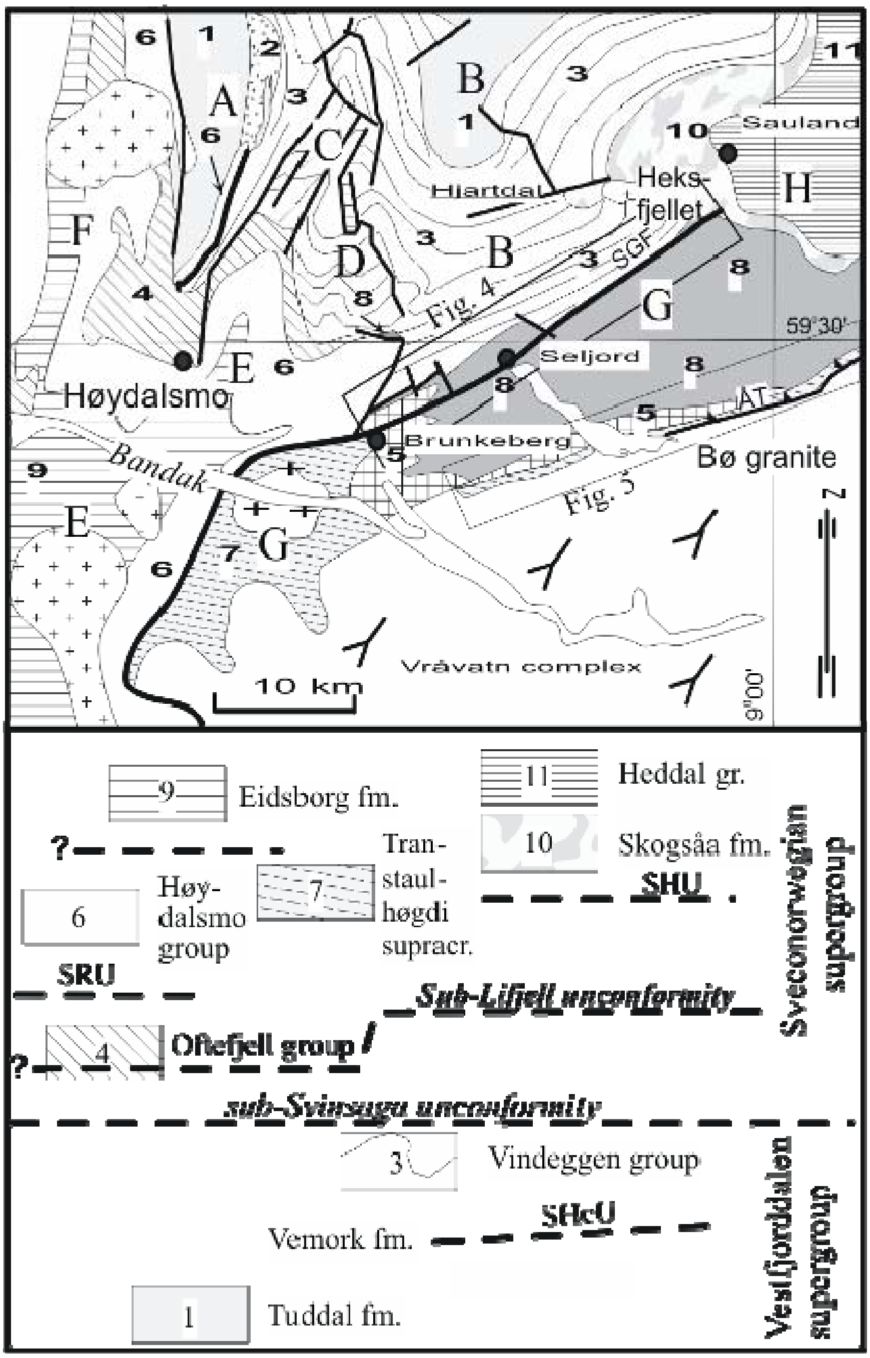

Fig. 2. Simplified geological map of the southern part of the Telemark supracrustals (in part after Dons & Jorde, 1978) (modified from Laajoki, 2006). Areas of Figs. 4 & 5 are framed. Thick lines on the map and hatched lines in the legend refer to a major fault or a shear zone and an unconformity, respectively. Unconformities in the legend: SHeU = sub-Heddersvatnet, SHU = sub-Heddal, SRU = sub-Røynstaul. Note that the sub-Lifjell unconformity may continue within the Oftefjell group. SGF = Slåkådalen-Grunningsdalen fault. ÅT = Åseåa thrust. Capital letters A – H refer to the lithostratigraphic-structural domains discussed in the text.

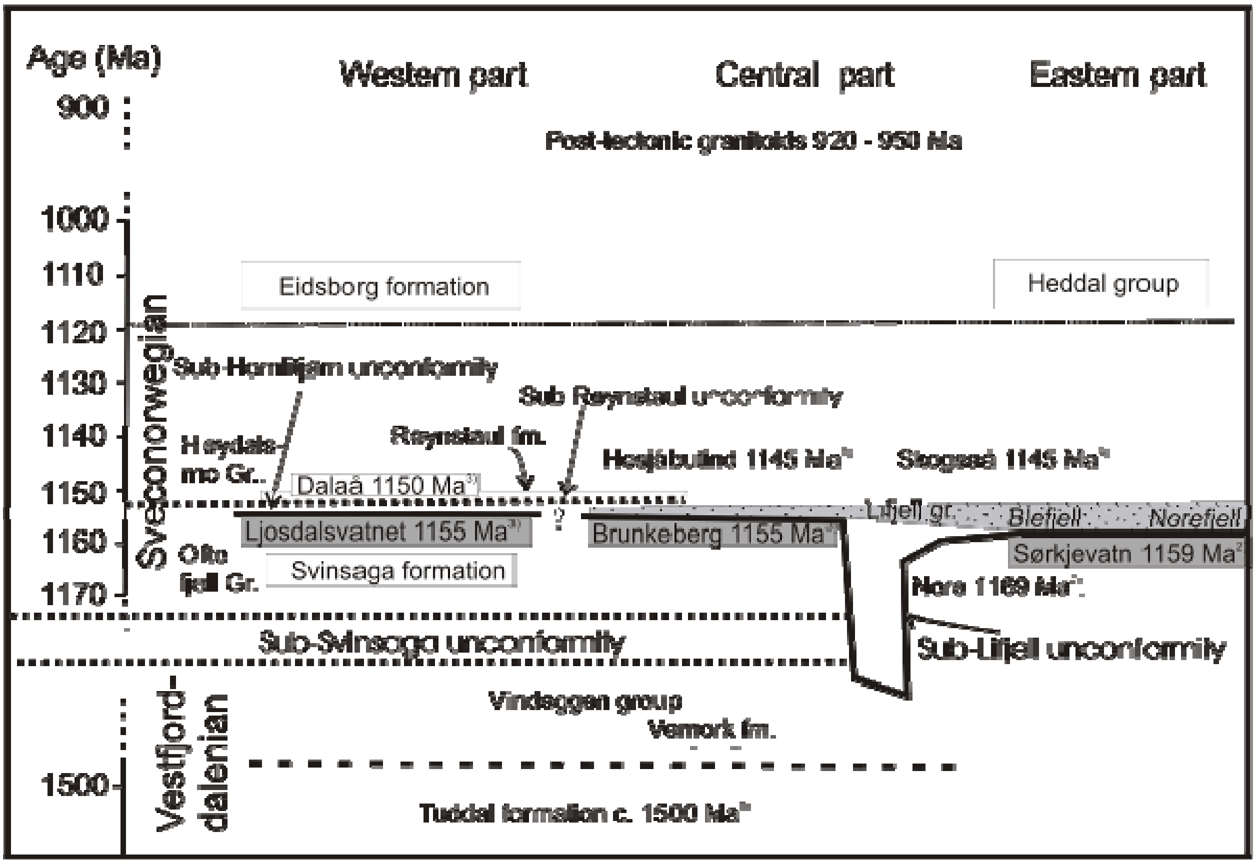

Fig. 3. Schematic chronostratigraphy of the dated igneous and associated sedimentary units in the southern part of the Telemark supracrustals. Note how the sub-Lifjell unconformity (heavy line) erodes the c. 1 155 Ma volcanic porphyry units (dark grey) and the Vindeggen group and is overlain by the Lifjell-Blefjell-Norefjell quartzites (grey). Other unconformities are shown by dashed lines. 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.

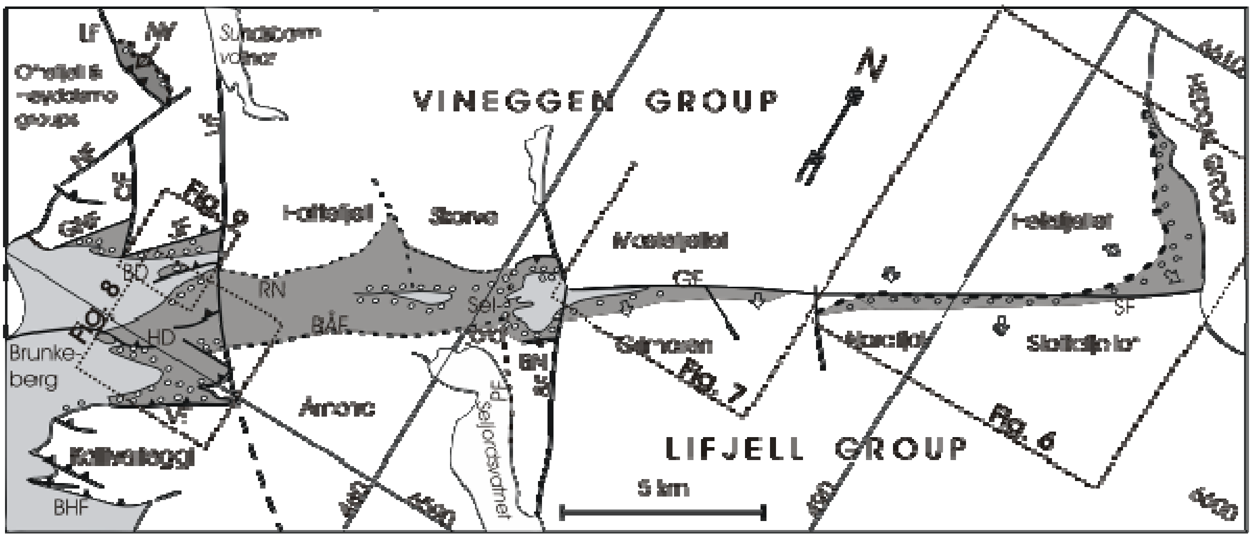

Fig. 4. Approximate distribution of the lower Lifjell group (dark gray) within the Brunkeberg – Heksfjellet tectonic zone (modified from Laajoki, 2006). Light gray = Brunkeberg formation. Arrows indicate top directions. Major faults (teeth indicate dip direction): BF, BHF, BÅF, GF, GNF, JF, LF, NF, OF, PF, SF, UF and VF = Borkebudalen, Båstjörnhovet, Bygdaråi, Grunningsdalen, Grenjusnetten, Jåfjell, Lier, Nonnetten, Ordalen, "Proposed", Slåkådalen, Ubydalen, and Vigdesjå faults, respectively. Geographic localities: BD = Bjørndalen, BN = Bjørgenuten, HD = Hesteskodiket, RN= Raudbergnuten. Areas of Figs. 6 - 9 are framed. UTM coordinates are used (Also in all other maps and cross sections).

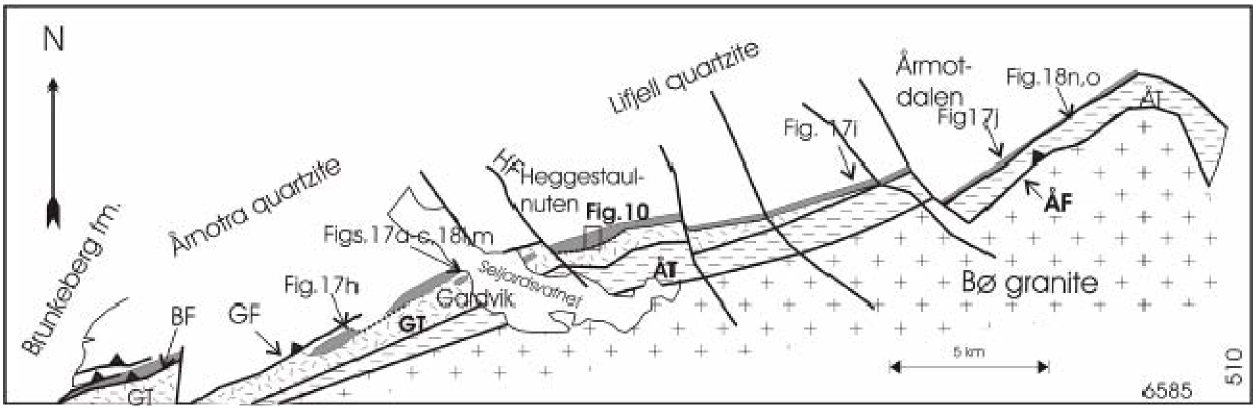

Fig. 5. Simplified geological map of the SE margin of the Telemark supracrustals showing approximate distribution of the sheared lower part of the Lifjell group (gray) (modified from Laajoki, 2006). GT & ÅT = Gardvik and Åsekollen tectonic units, respectively. BF, GF, HF, & ÅF = Båstjørnhovet, Gravalifjellet, Heggenes, and Åseåa faults (thick lines), respectively. Their verified dip directions are indicated by black teeth. Area of Fig. 10 is framed and locations of Figs. 17a-c, h-j & 18l-o are shown.

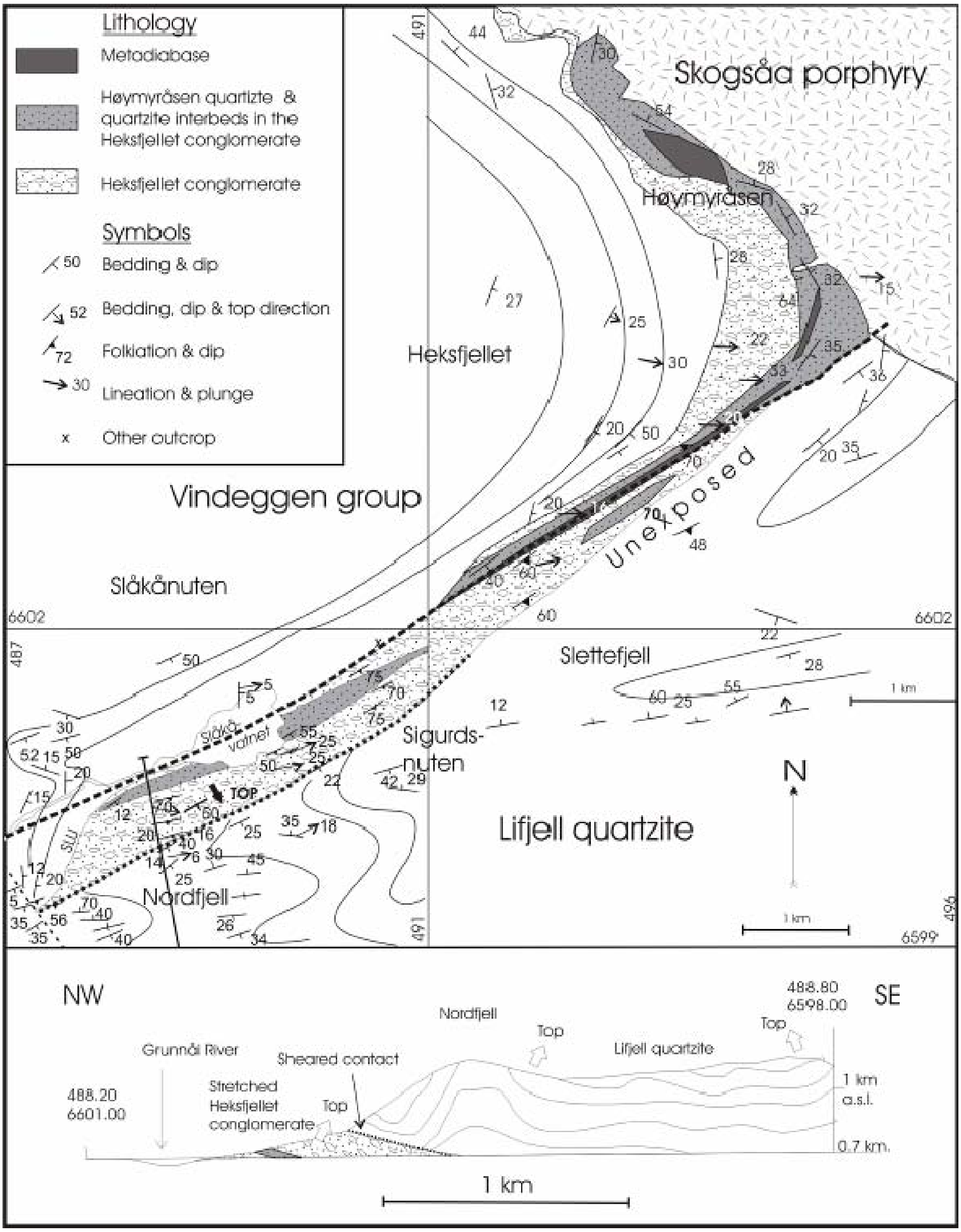

Fig. 6. Geological map of the Heksfjellet-Nordfjell area and Grunnåi-Nordfjell cross section along the line in the lower left corner of the map. See Fig. 12g for the only top observation within the Heksfjellet conglomerate.

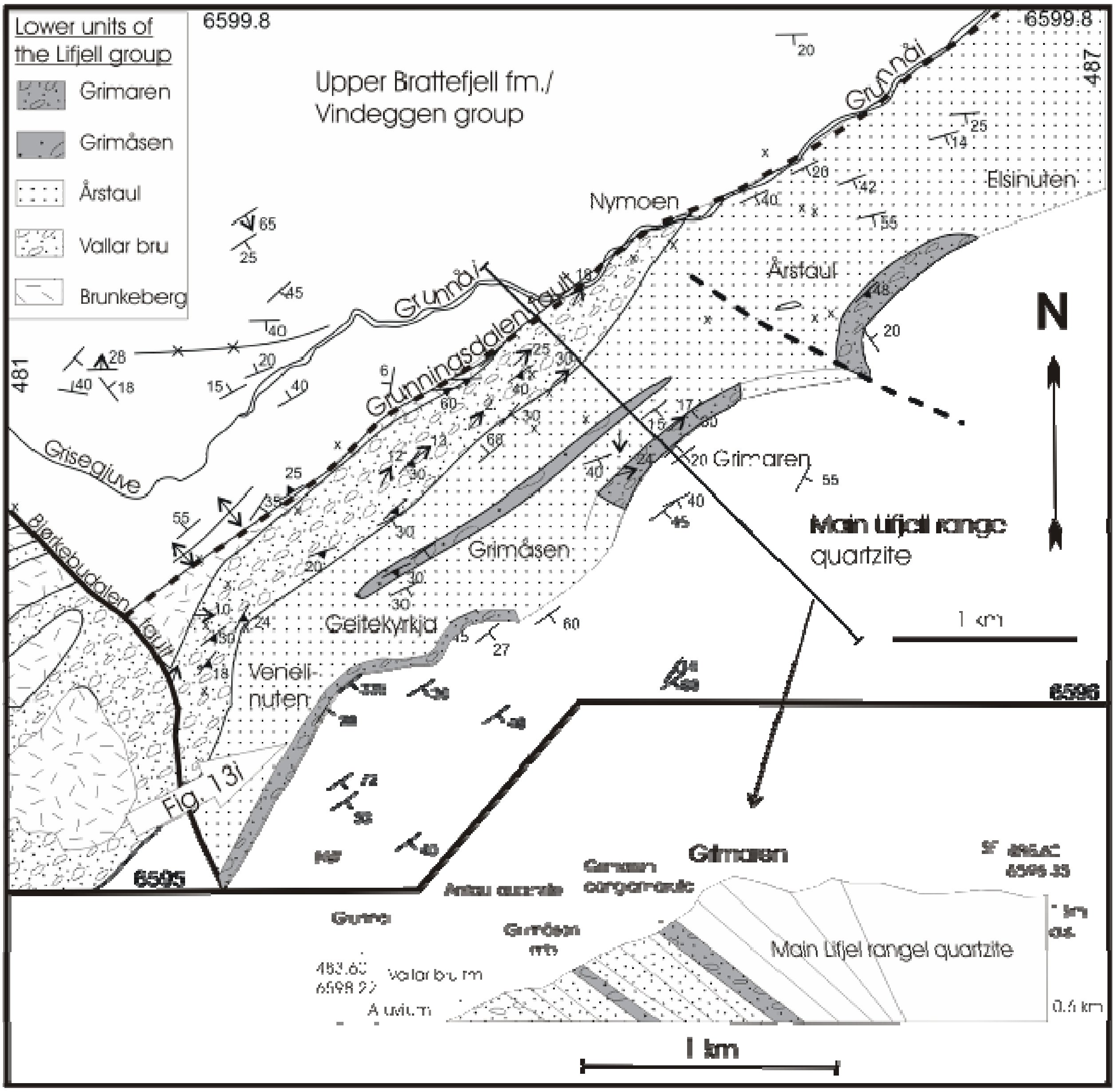

Fig. 7. Geological map of the Grunningsdalen area and a cross section from Grunnåi to Grimaren. For the symbols see Fig. 6. Arrow SW of Venelinuten shows the view direction in Fig. 13i.

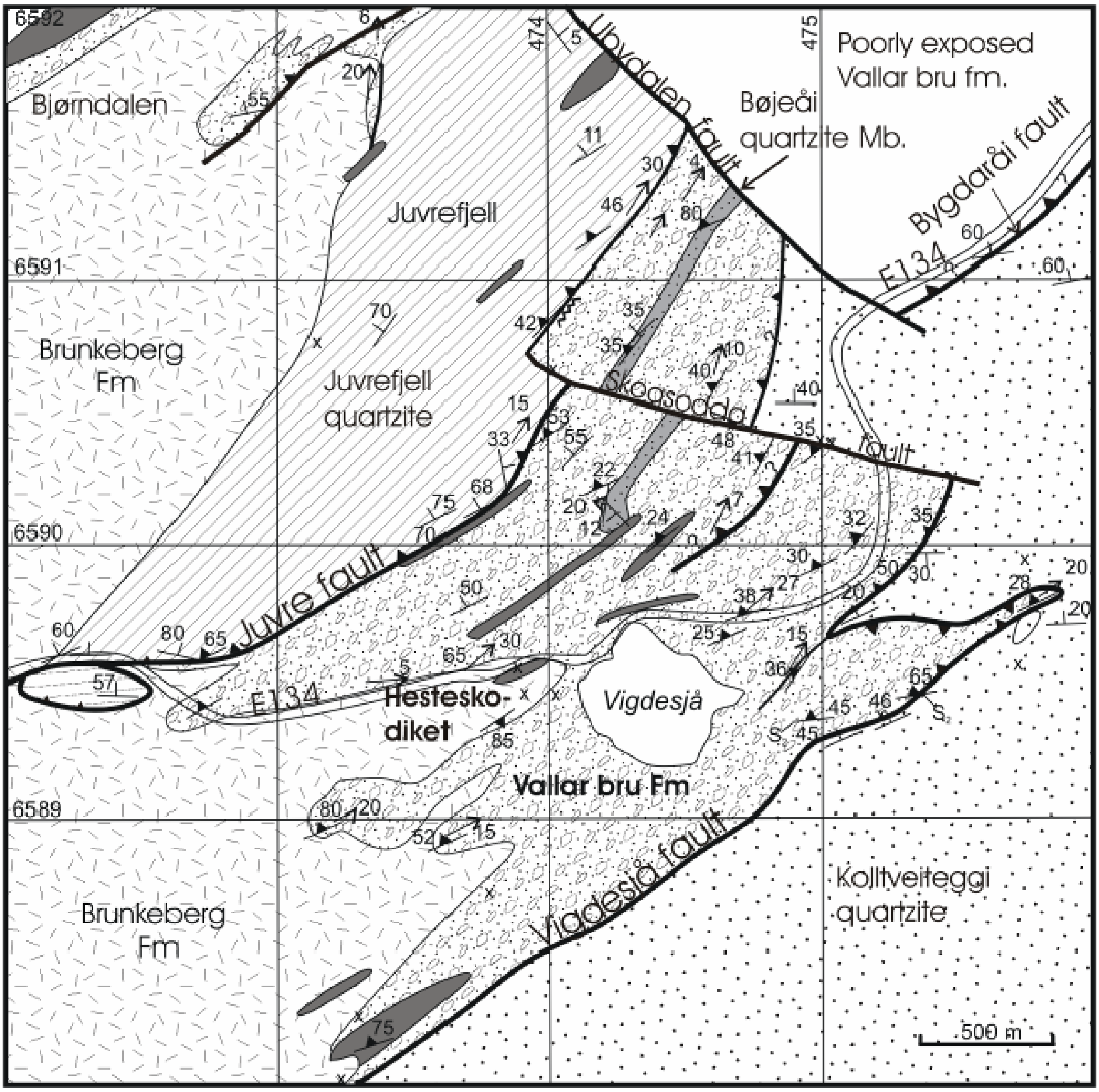

Fig. 8. Geological map of the Vigdesjå - Juvrefjell area. For the symbols see Fig. 6.

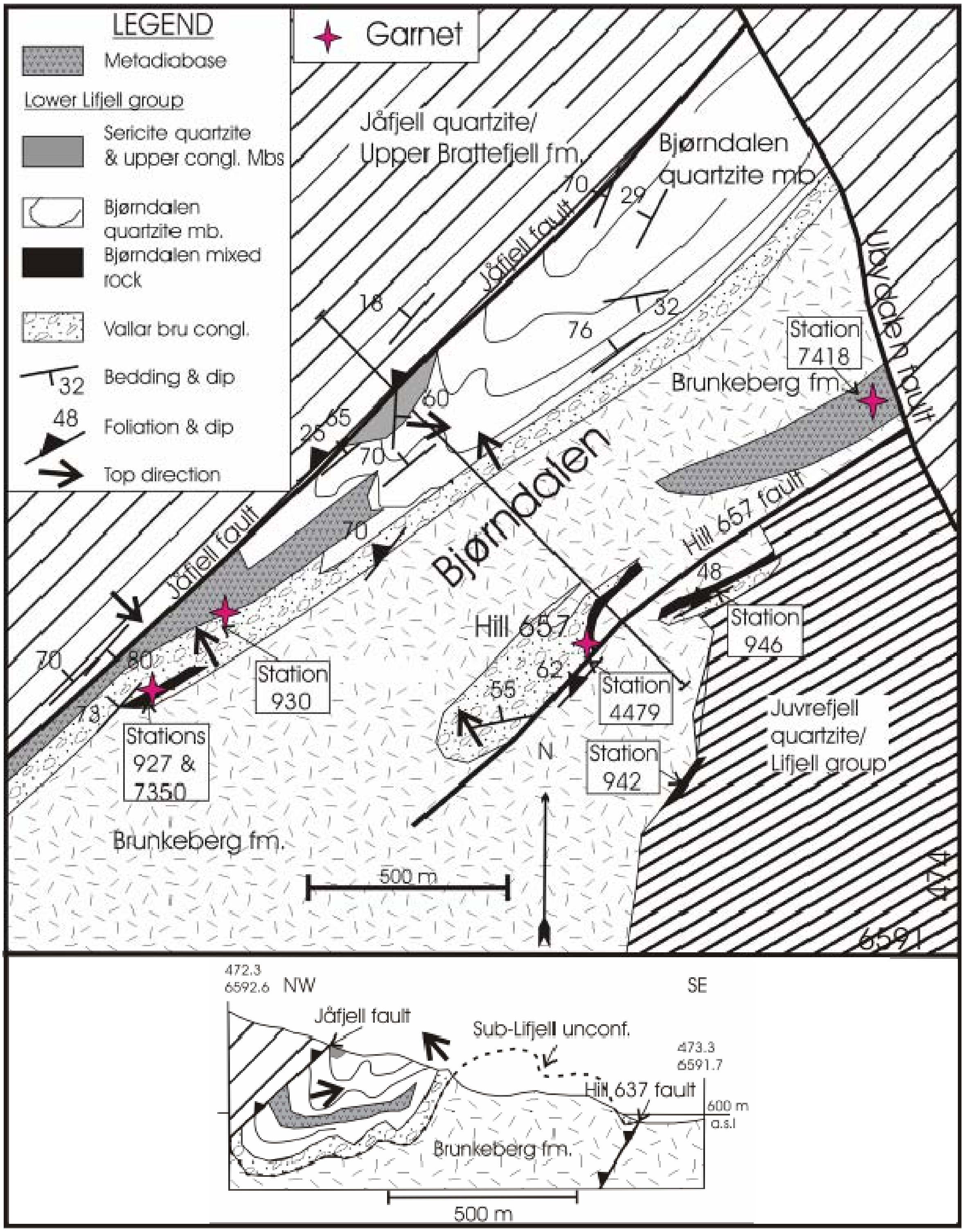

Fig. 9. Geological map and cross section of the Bjørndalen area (modified from Laajoki, 2006). Stars indicate distribution of garnet.

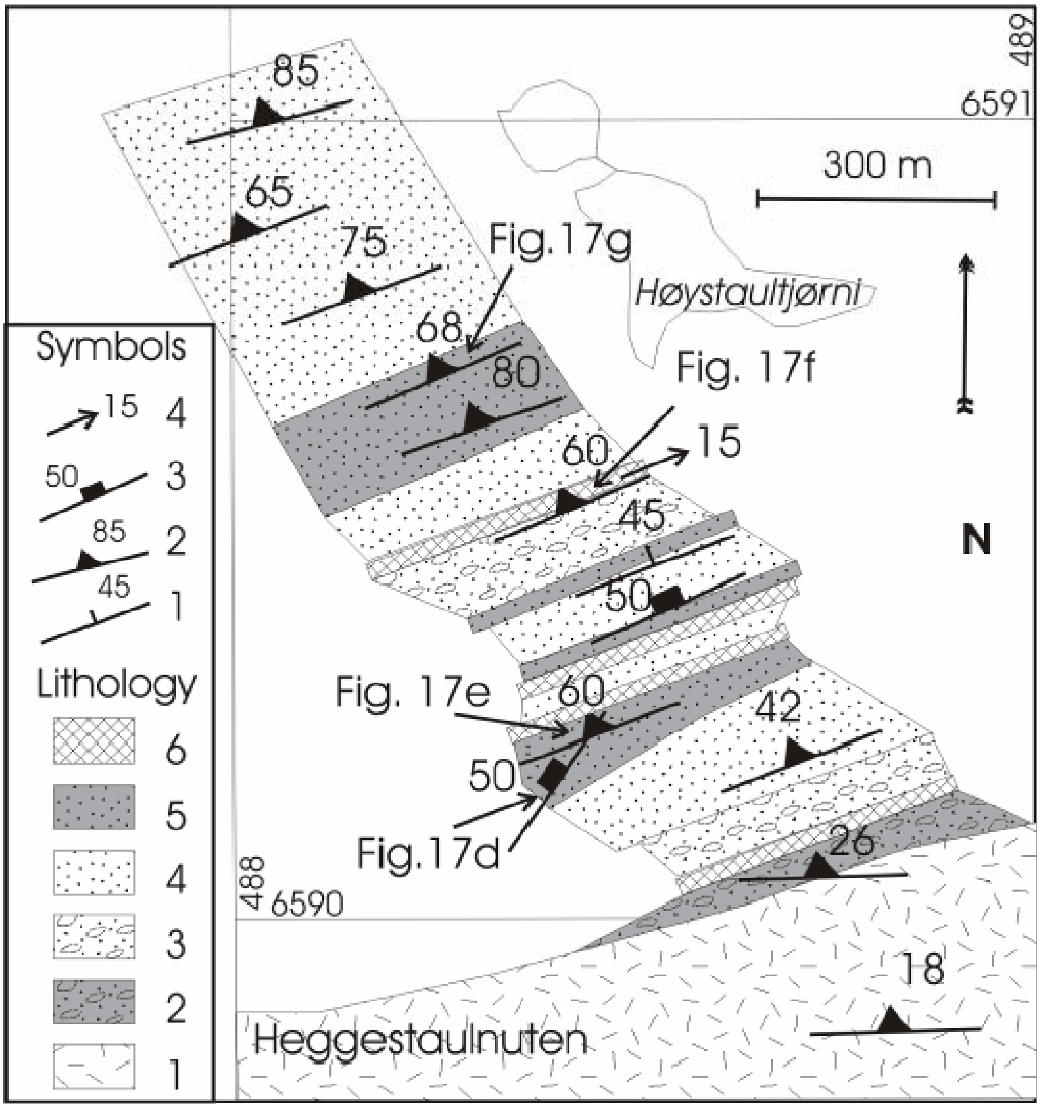

Fig. 10. Geological map of the Høystaultjørni area. Lithology: 1. Porphyry of the Brunkeberg formation. 2. Hesteskodiket-type conglomerate. 3. Vallar bru-type conglomerate. 4. Quartzite. 5. Heterolith. 6. Metadiabase. Symbols: 1. Bedding & dip. 2. Foliation & dip. 3. Axial plane & dip. 4. Stretching lineation & plunge. Locations of Figs. 17d-g are given.

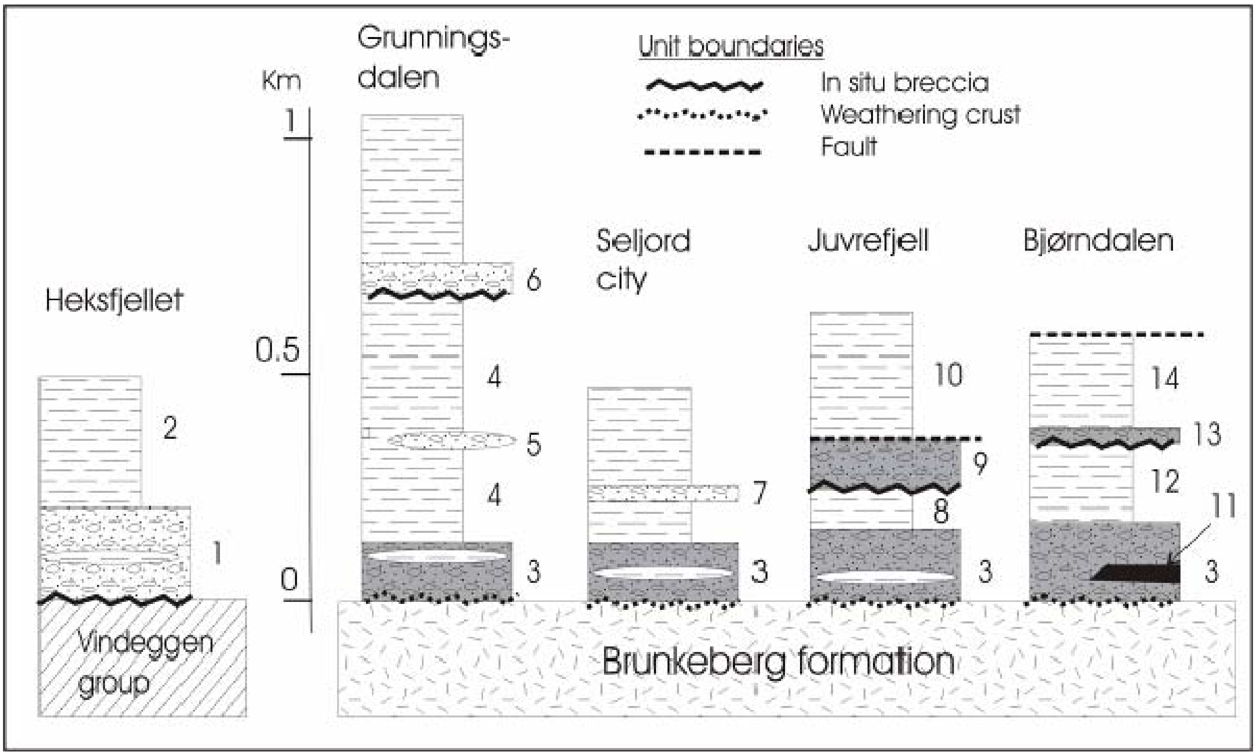

Fig. 11 Lithostratigraphic columns of the lower part of the Lifjell group. Note that thicknesses are very arbitrary. Units discussed in the text: 1. Heksfjellet conglomerate. 2. Høymyråsen quartzite. 3. Vallar bru formation conglomerate with quartzite interbeds. 4. Årstaul quartzite. 5. Grimåsen member. 6. Grimaren conglomerate member. 7. Lønnestad conglomerate. 8. Bøjeåi quartzite member. 9. Upper Vallar bru conglomerate. 10. Juvrefjell quartzite. 11. Bjørndalen mixed rock. 12. Bjørndalen quartzite. 13. Upper Bjørndalen conglomerate. 14. Bjørndalen sericite quartzite.

Fig. 12a. In situ breccia developed upon the Upper Brattefjell quartzite (on the right) of the Vindeggen group. Note the concave fractures filled by sericite-quartzite matrix (arrows). The hammer handle is 60 cm.

Fig. 12b. A matrix-supported boulder conglomerate. Heksfjellet.

Fig. 12c. A thin sericite quartzite interbed in the Heksfjellet conglomerate. Clasts are quartzite. Heksfjellet.

Fig. 12d. A likely in situ breccia. SE of Slåkåvatnet. The compass plate in all photographs is 6.5 x 12.5 cm.

Fig. 12e. Clast-supported quartzite-clast conglomerate interbed. SW of Slåkåvatnet.

Fig.12f. Stretched Heksfjellet cobble conglomerate seen along the plunge of the lineation (L = 100°34°, S = 148°/50°). Clasts are solely quartzite.

Fig. 12g. Quartzite interbed with low-angle cross-bedding and solitary quartzite clasts overlain by matrix-supported quartzite-clast conglomerate. N slope of Nordfjell

Fig. 12h. Slåkådalen fault between the Høymyråsen quartzite (on the right) and the main Lifjell quartzite. Kyrkjegjuvet/Mjella River.

Fig. 12. Photographs of the Heksfjellet conglomerate. Number series in all photographs give station number, file number, and UTM coordinates in this order. Structural geological codes used in the photographs: AP = axial plane, F = fold axis, L = lineation, S = foliation, S_0 = bedding.

Fig. 13a. Quartzite boulder in the Vallar bru conglomerate deformed twice.

Fig. 13b. Sheared quartzite-clast conglomerate above the conglomerate in Fig. 13a

Fig. 13c. Deformed sericite quartzite with quartzite boulders and cobbles. Upper part of the Vallar bru formation.

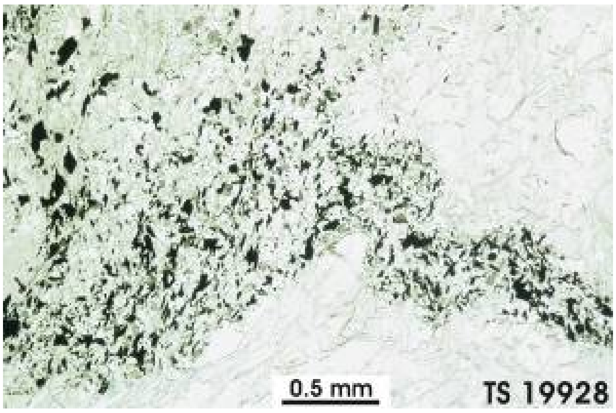

Fig. 13d. Sericite- and opaque-rich fracture fill with abundant tiny grains of accessory apatite, tourmaline and zircon (rounded, high relief) in the Geitekyrkje breccia.

Fig. 13e. Solitary quartzite clasts (q) and thin quartz veins (qv) in deformed sericite quartzite of the Grimåsen member

Fig. 13f. Deformed contact between the Årstaul quartzite (on the right) and the Grimaren conglom-

erate member. The contact is interpreted as an in situ breccia. The loose boulder on the left was taken from the conglomeratic part. Grimaren.

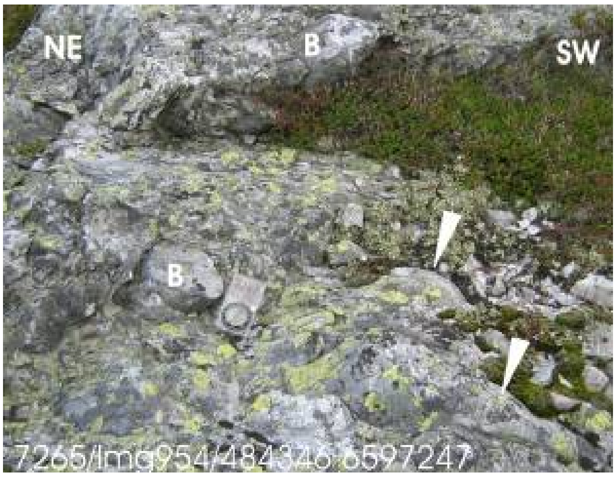

Fig. 13g. Quartzite boulders (B) in the basal part of the Grimaren conglomerate member. Note the billow-like quartzite bodies (arrows) which may represent pre-Grimaren weathering forms. Grimaren.

Fig. 13h. F_2-folded quartzite-clast conglomerate near the upper contact of the Grimaren conglomerate. Venelinuten.

Fig. 13i. Grimaren conglomerate member overlain by the openly folded quartzite of the main Lifjell range.

Fig.13j. Upper contact of the Grimaren conglomerate member. Venelinuten

Fig. 13k. Parallel laminated Lifjell orthoquartzite about 1 m above the Grimaren conglomerate. Venelinuten.

Fig. 13. Lithologies of the lower part of the Lifjell group in Grunningsdalen.

Fig. 14a. Hesteskodiket-type transitional unconformity with solitary quartzite pebbles (arrow) in felsic volcanite detritus and pegmatitic veins (pg).

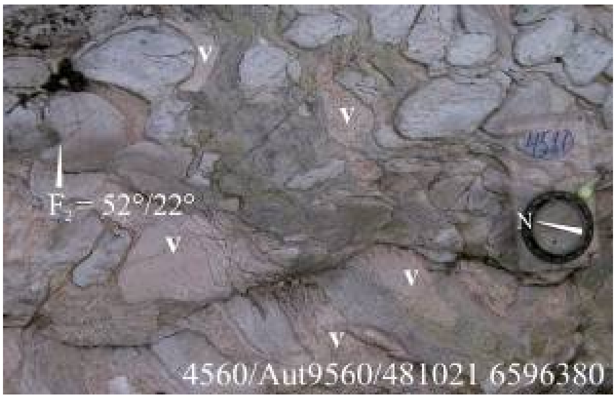

Fig. 14b. Conglomerate from the lower part of the Vallar bru formation with both felsic volcanite (V) and quartzite clasts deformed twice.

Fig. 14c. Fault between the classical Vallar bru conglomerate and the Brunkeberg formation.

Fig. 14d. View of the contact between the blue orthoquartzite and the Vallar bru conglomerate.

Fig. 14e. Close-up of the quartzite/conglomerate contact in Fig. 14d with folded in situ-type weathering fractures. The lineation plunges about 35° away from the viewer.

Fig. 14f. Quartzite-clast conglomerate from the classical Vallar bru outcrop. Note that volcanite clasts are missing, F_2 folding of the clasts, and the pebbly layer (p) indicating relict bedding.

Fig. 14g. ?in situ breccia.

Fig. 14h. A likely tectonic quartzite breccia structurally above the breccia in Fig. 14g.

Fig. 14i. A mountain wall of deformed Vallar bru conglomerate, south of Juvrefjell.

Fig. 14j. Glassy, parallel laminated quartzite of the Bøjeåi member.

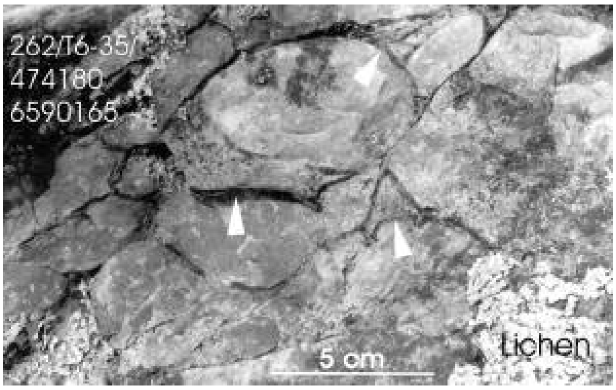

Fig. 14k. In situ breccia above a quartzite in upper part of the Vallar bru formation south of Juvrefjell. Arrows point to scanty sericite-rich matrix. Boundaries of some of the in situ quartzite fragments are delineated by a marker.

Fig. 14l. Planar cross-bedding in a quartzite (S_0 = 322°/25°) overlain by a deformed quartzite-pebble train.

Fig. 14m. SW-end of the Juvre fault between the Juvrefjell quartzite and c. 3 wide metabasite. A Vallar bru conglomerate occurs just outside the left lower corner of the photograph.

Fig. 14. Lithologies of and faults within the lower part of the Lifjell group in Bjørgenuten (a-b), Seljord City (c-f), Raudbergnuten (g-h), and Vigdesjå area (i-m).

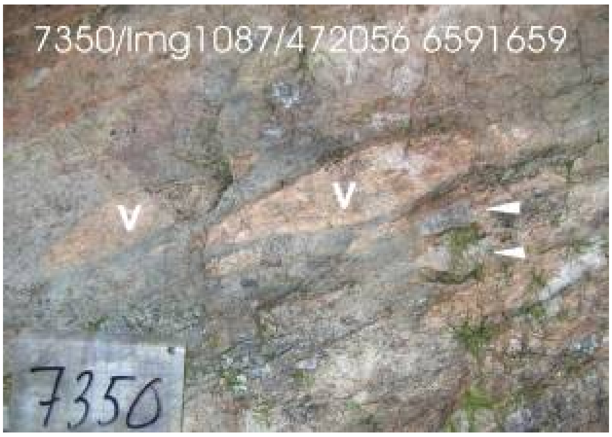

Fig. 15a. Flattened felsic volcanite clasts (v) with minor quartzite clasts (arrows) in the Hesteskodiket-type conglomerate.

Fig. 15b. Deformed quartzite clasts (q) in the Hesteskodiket-type conglomerate.

Fig. 15c. Stretched, clast-supported Vallar bru-type conglomerate with dominantly quartzite clasts above the conglomerate in Fig. 15b

Fig. 15d. Solitary quartzite clasts in the Bjørndalen mixed rock with darker fragments and siliceous portions (s).

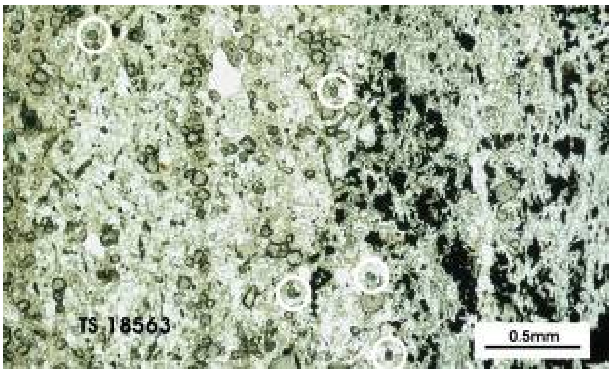

Fig. 15e. Microphotograph of the host rock of the Bjørndalen mixed rock with a garnet- and plagioclase-rich domain with tiny tourmaline grains (encircled) and an opaque-sericite-chlorite rich domain (on the right). One polar.

Fig 15f. Sharp contact between the Vallar bru-type conglomerate and the Bjørndalen mixed rock.

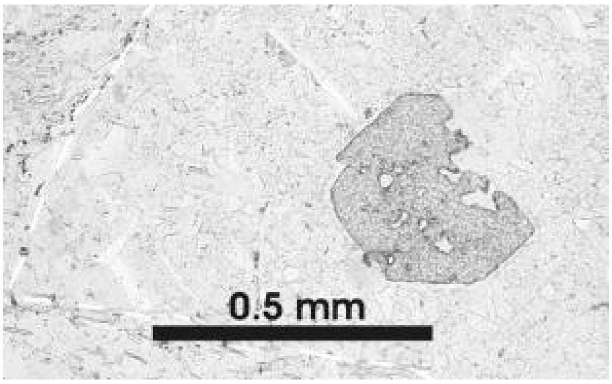

Fig. 15g. Anhedral-euhedral garnet porphyroblast in a plagioclase-phenocryst clast. One polar. Station 4479.

Fig. 15. Lithologies of the Vallar bru formation in Bjørndalen.

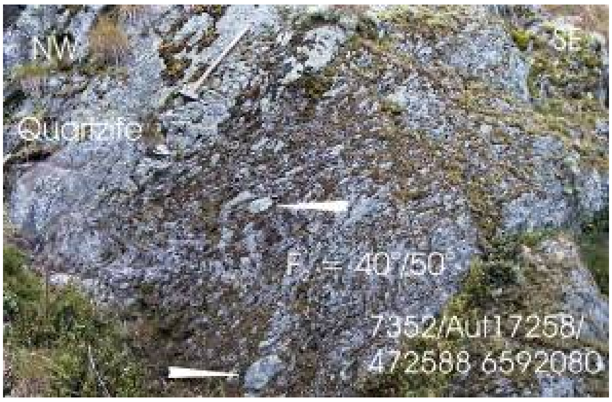

Fig.16a. F_2-folded Vallar bru formation conglomerate overlain by the Bjørndalen quartzite.
Arrows point to larger quartzite clasts.

Fig. 16b. Close-up of the contact in Fig. 16a.

Fig. 16c. Parallel-laminated Bjørndalen quartzite.

Fig. 16d. Fracture zone in the upper part of the Bjørndalen quartzite. Arrows point to thin fractures. M = wider fractures filled by sericite schist.

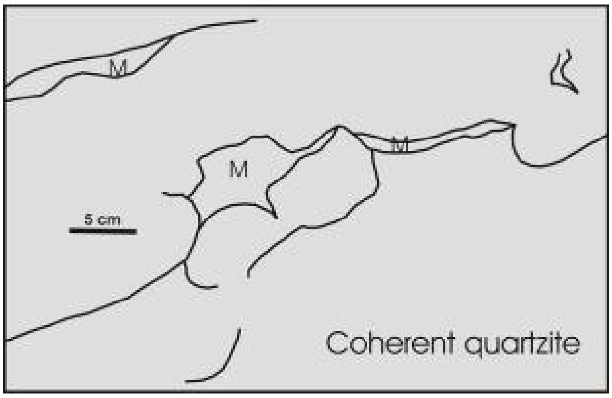

Fig. 16e. Line drawing of the fracture system in Fig. 16d.

Fig. 16f. In situ breccia above the Bjørndalen quartzite. Note the rounded shape of the quartzite fragments.

Fig. 16g. Upper Bjørndalen conglomerate with quartzite clasts in a scanty sericite-schist matrix (dark) overlain by a quartzite breccia (inset)

Fig. 16h. Conglomeratic rock in upper part of the Bjørndalen quartzite at station 7355.

Fig. 16i.. Sericite schist - quartzite with solitary quartzite-pebbles (arrows) and thin quartz veins above the Upper Bjørndalen conglomerate. Folded older foliation is shown by white lines

Fig. 16j. Graded-bedded sericite-quartzitic rock above the conglomeratic rock in Fig. 16h.

Fig. 16k. The Jåfjell fault zone developed in the Bjørndalen sericite quartzite.

Fig. 16l. Close-up of the brecciated Bjørndalen sericite quartzite within the Jåfjell fault zone. Note the tube-like form of the quartzite fragments in comparison with the bulbous nature of the quartzite fragments in Fig. 18h

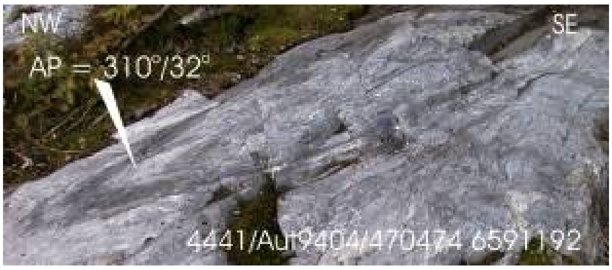

Fig. 16m. Folded sericite quartzite with dark pelitic layers near the Grenjusnetten fault.

Fig. 16n. Hematite-laminated sericite quartzite of the Nystaulvatnet member.

Fig. 16o. Sheath folds with horizontal axes in a sericite quartzite of the Nystaulvatnet member. Arrow points to the nose of a fold defined by pelitic layers

Fig. 16. Lithologies of the units above the Vallar bru formation in Bjørndalen (a-l) and in Åmtveit (m) and the Nystaulvatnet member (n-o).

Fig. 17a Folded pegmatite veins and epidote stripes (yellowish) in the Brunkeberg porphyry or in its detritus.

Fig.17b . A 25 cm long granitoids boulder in the Vallar bru-type conglomerate.

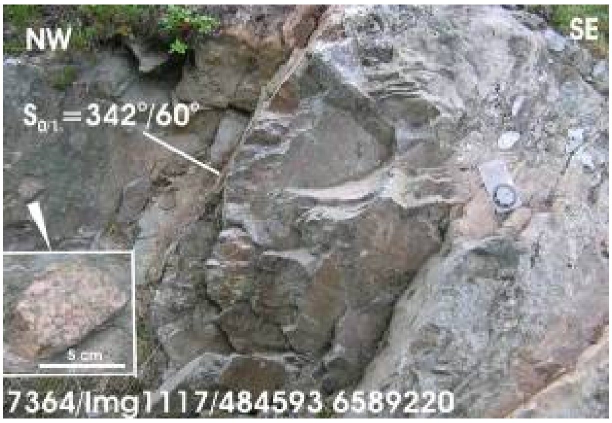

Fig. 17c . Poorly defined bedding in Hesteskodiket-type conglomerate - debris flow. Inset gives a close-up of a coarse-grained felsic cobble

Fig. 17d, Tightly folded heterolith.

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Fig. 17e. Deformed quartzite with both extremely flattened (white stripes) and stretched quartzite clasts. Note the folding of the clast in the lower left corner of the photograph.

Fig. 17f. Quartzite-pebbly conglomerate with quartzite (sand) wedges (s). q = quartzite pebble.

Fig. 17g. Isoclinally folded heterolith. The arrows point to fold closers. h) i) j)

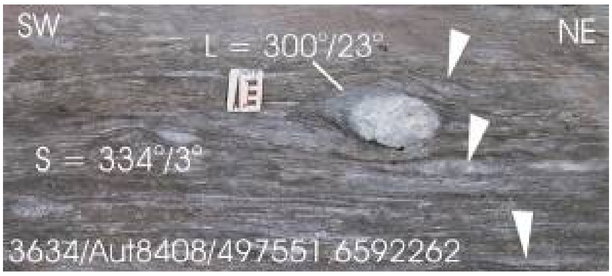

Fig. 17i. Conglomeratic micaceous quartzite with both stretched and flattened (arrows) quartzite clasts.

Fig. 17h. Stretched Gravali conglomerate.

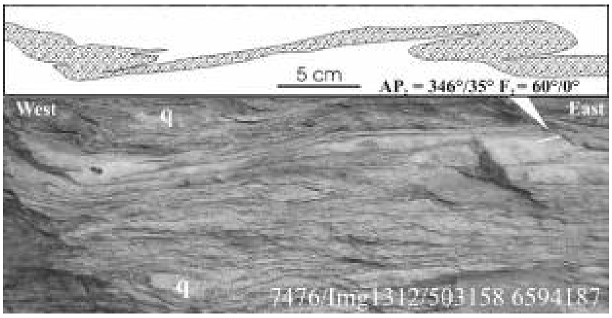

Fig. 17 j. F_2-folded quartzite clast in a conglomeratic micaceous quartzite.

Fig. 17. Lithologies of the lower part of the Lifjell group in Gardvik (a-c), Høystaultjørni (d-g), Gravali (h), Høgåsåsen (i), and Årmotdalen (j).

Fig. 18a. Tectonic breccia, which may have been developed upon a sedimentary breccia. Vatnelian.

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Fig. 18b Clast-supported quartzite-clast conglomerate folded twice with a few bluish quartzite clasts (arrows). South of Vigdesjå.

Fig. 18c. Brecciated orthoquartzite viewed nearly parallel to regional lineation and vertical to bedding. Slettefjell.

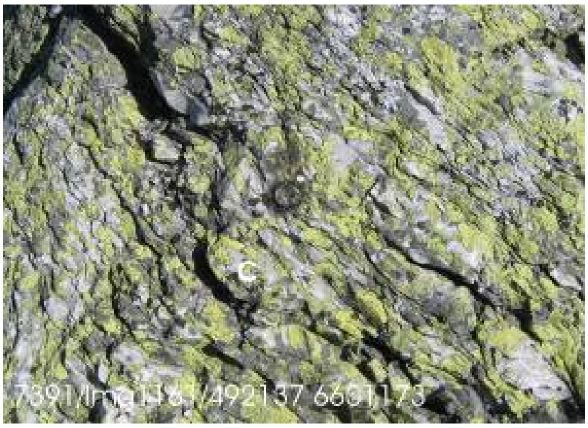

Fig. 18d. Oblique view of the breccia in Fig. 18c.

Fig. 18e. Deformed Grimaren conglomerate resembling seemingly a tectonic breccia, but the bulbous structure and bowl-like mould above the compass reveal its sedimentary origin.

Fig. 18f. Sheared quartzite (or a conglomerate) interbed in the Heksfjellet conglomerate, SE of Slåkåvatnet.

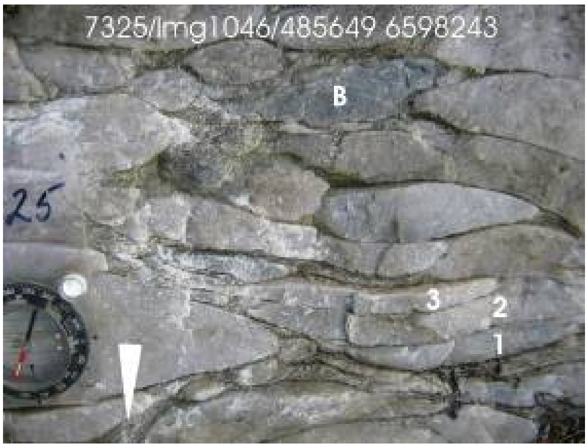

Fig. 18g. Deformed Grimaren conglomerate north of Årstaul with scanty sericite-schist matrix (arrow), one bluish quartzite clast (B) and one quartzite clasts split into three parts (numbers 1 -3).

Fig. 18h. Bulbous,

Fig. 18i. semibulbous, and

Fig. 18j. Lozenge quartzite fragments, in a shear zone above the Vallar bru conglomerate in Bjørgenuten

Fig. 18k. F_2*-folded and sheared Grimaren conglomerate with rolled quartzite clasts.*

Fig. 18l. View subparallel and

Fig. 18m. oblique to lineation, in a matrix-supported quartzite-clast conglomerate in Gardvik. B = quartzite boulders

Fig. 18n. Lens-like quartzite clasts (L) in an extremely deformed Vallar bru- type conglomerate in Stokkland. The arrows point to flattened edges of quartzite clasts. Note the pseudobedding defined by extremely deformed quartzite clasts in the lower part of the photograph.

Fig. 18o. Oblique view of the conglomerate in Fig. 18n.

Fig. 18. Photographs of sedimentary conglomerates vs. tectonic breccias.

Fig. 19a. *Garnet-rich domains (G) in a metadiabase. Bjørndalen.*

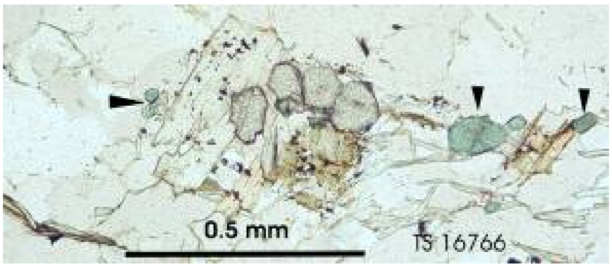

Fig. 19b. *Microphotographs of garnet and tourmaline (arrows) in a mica-rich seam and*

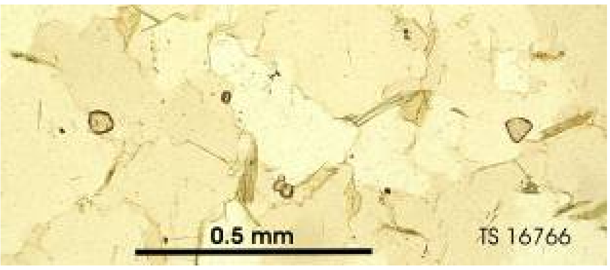

Fig. 19c. *Solitary anhedral garnet grains (high relief), in the Juvrefjell quartzite above the Juvre fault in Fig. 14m. One polar*

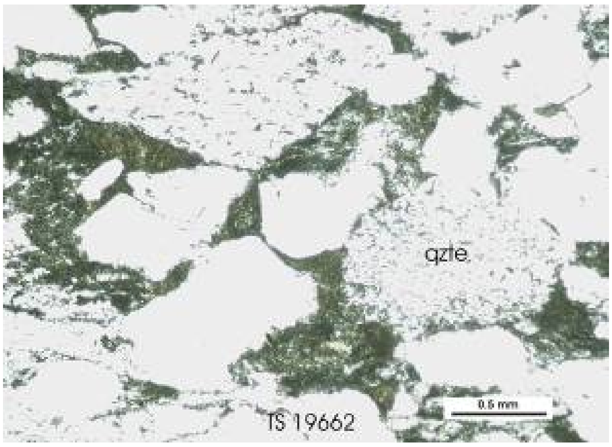

Fig. 19d. *Microphotograph of an in situ quartzite fragment of the Heksfjellet conglomerate where garnet fills the interspaces between quartz and quartzite (qzte) clasts and occurs even within the latter clasts.*

Fig. 19. Occurrence of garnet. Thin section (TS) numbers are given.