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The Neoproterozoic Valdres Group - depositional conditions and stratigraphical developments in the Mellane and Grønsenn-knippa sections, Valdres, Southern Norway

Henning Dypvik[1,8], Even Stokkebekk[2], Eirik N. Nordeng[3], Rikke Ø. Småkasin[4], Kathrine Sørhus[5], Andrew C. Morton[6,7], Roy H. Gabrielsen[8]

[1] Department of Geosciences and Department of Technology Systems, University of Oslo, P.O. Box 1047, NO 0316 Oslo, Norway
[2] Equinor ASA, P.O. Box 8500, NO 4035 Stavanger
[3] Rambøll Norge, P.O. Box 427, Skøyen, 0213 Oslo
[4] Multiconsult Norge AS, P.O. Box 265 Skøyen, NO 0213 Oslo, Norway
[5] NCC (Nordic Construction Company), Østensjøveien 27, NO 0661 Oslo, Norway
[6] Department of Geology and Geophysics, University of Aberdeen, AB24 3UE, UK
[7] CASP, West Building, Madingley Rise, Cambridge, CB3 0UD, UK
[8] Department of Geosciences, University of Oslo, P.O. Box 1047, NO 0316 Oslo, Norway

E-mail corresponding author (Henning Dypvik) henning.dypvik@its.uio.no

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The youngest part of the Valdres Group of south-central Norway (mainly the Neoproterozoic Rundemellen unit, Tonian – Cryogenian?) has been sedimentologically and stratigraphically studied and sampled at the Skarvemellen and Rundemellen sections at Mellane (Øystre Slidre) and Grønsennknippa (Vestre Slidre). The goal was to shed light on the depositional conditions and possible stratigraphical correlations to time-equivalent formations in the better-known Hedmark Group to the east. It is hoped that this approach will also help establish an improved basis to understand the related metamorphic Valdres Group units to the west and north of the study area. Depositional environments have been interpreted from sedimentary field data and observations, supported by petrographical, geochemical and mineralogical analyses.

Coarse clastic sedimentary rocks of braided stream/alluvial fans dominate the Valdres Group. The studied succession at Grønsennknippa starts with massive pebbly conglomerates with well-rounded clasts and interbedded sandstone units, unconformably overlying crystalline basement. This package is overlain by sandstones of various alluvial affinity, interrupted only by one conglomerate horizon and

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one diamictite unit. The latter is possibly correlative to the diamictite recognised in the Valdres Group at Mellane and may represent a tillite correlatable to the Moelv Tillite (Marinoan glaciation). The Mellane section is more dominated by sandstones and subordinate conglomerates than those at Grønsennknippa. Mineralogical composition and field observations of the Grønsennknippa and Mellane sections indicate relatively short transport distances of the texturally immature sediments. The petrography also reflects a later metamorphic phase (varying greenschist facies) that overprints the original mineralogy.

Comparison between the Valdres Group at Mellane and Grønsennknippa sections indicates that the Grønsennknippa succession exhibits an originally more immature mineralogical and textural signature than those at Mellane. The Grønsennknippa sections are more feldspar-rich and dominated by coarse-grained detritus. This may reflect different positions with respect to the source area/basin margin. In this study, the Valdres Group at Grønsennknippa and Mellane is compared with selected fluvial/alluvial formations of the Hedmark Basin, revealing comparable depositional environments and stratigraphic developments. The occurrence of possible tillites at stratigraphical levels comparable to the Moelv Tillite are of particular interest. The petrographical composition and heavy mineral distribution support comparable sediment sources from mainly Sveconorwegian formations in both the Valdres and Hedmark basins.

Introduction

The Valdres Group (former Valdres sparagmite) of the Valdres Basin, located in central southern Norway, has been studied for about two hundred years, initiated as early as in 1829 by Esmark (Esmark, 1829). The correlatable Hedmark and Engerdalen basins, which are the most intensively investigated, are located to the east of the Valdres Basin (Fig. 1). The aim of the present paper is to update the local stratigraphy of key sections in the Valdres Basin to correlate with greater confidence these Neoproterozoic (Tonian–Cryogenian) successions with those of the Hedmark Basin, and furthermore to improve the descriptions and explanations of their sedimentological and petrographical developments. Finally, we discuss possible source areas and post depositional alterations.

Esmark (1829) introduced the term sparagmite for the coarse-grained feldspathic successions in the Valdres and Hedmark basins. These Neoproterozoic formations have been the target of numerous studies, research projects, excursions, etc. (Figs. 1, 2 & 3). In particular, the Hedmark Group of the Hedmark Basin, from the eastern regions of southern Norway, has received considerable attention (e.g., Bjørlykke et al., 1976; Nystuen, 1982, 1987; Bockelie & Nystuen, 1985; Nystuen et al., 2008; Bjørlykke & Olesen, 2018). The Valdres Group of the Valdres Basin (Figs. 1, 2 & 3) has been less frequently visited since the time of the pioneers (Esmark, 1829; Kjerulf, 1873, 1879; Kjerulf & Dahl, 1866; Törnbohm 1873, 1882; Bjørlykke, 1905; Goldschmidt, 1916; Vogt, 1928; Bugge, 1939; Holtedahl, 1959; Strand, 1959; Kulling, 1961). Subsequently significant contributions were presented by e.g., Loeschke (1967), Nickelsen (1967), Loeschke & Nickelsen (1968), Hossack (1968, 1972, 1976, & 1978), Nickelsen (1974), Heim et al. (1977), Hossack et al. (1985) and Nickelsen et al. (1985).

This paper presents new stratigraphical information and sedimentological discussions of key sections from the less metamorphosed, uppermost unit (Rundemellen unit of Mellane and Grønsenn-knippa) in the Valdres Group (Figs. 1, 2 & 3), focusing on sedimentological appearance, petrographical composition (in appendix), and regional stratigraphical correlation to the Hedmark Group (Figs. 1 & 2). The present data will establish an improved basis for future comparison with the correlatable formations of higher metamorphic grade to the west and north. The first results of our study group were published

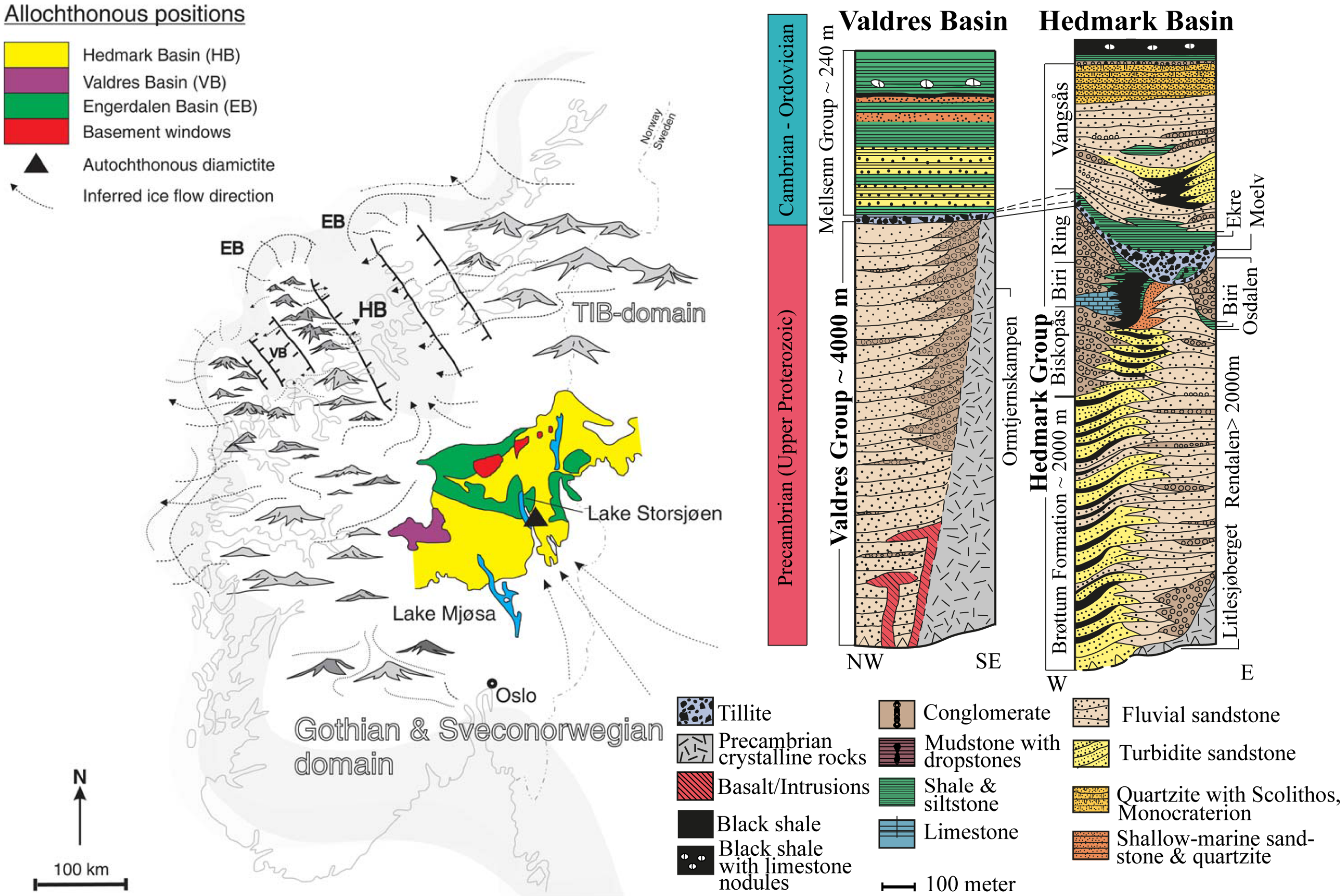

Figure 1. Geological/tectonic sketch, with Neoproterozoic basins (Valdres Basin and Hedmark Basin) included in predrift position along with a geological mark of their present locations is shown to the left. Based on Nystuen & Lamminen (2011). To the right stratigraphical correlation chart between the Valdres and Hedmark Group stratigraphies, based on Kumpulainen and Nystuen (1985). The formations are indicated on the left of the Hedmark Basin column. TIB= Trans-Scandinavian Igneous Belt. Paleofaults separating HB and VB.

by Stokkebekk et al. (2019), who documented the discovery of the probable Precambrian microfossils (acritarchs) in the Rundemellen section at Mellane, and described possible diamictite occurrences at the Grønsennknippa section. The original results of our project can be found in the following master's theses: Nordeng (2018), Småkasin (2017), Stokkebekk (2018), and Sørhus (2017).

This paper presents the sedimentological development at two sites represented by four sections, namely at Mellane (referred to as the Rundemellen and Skarvemellen sections) and Grønsennknippa (sections #2a and #4a of this study; Figs. 2, 4 & 5). These are easily accessible, well-known localities of the least altered units of the Valdres Group. The present contribution is based on field and laboratory analyses performed in the period 2015–2019, with the main goal of gaining new sedimentological and stratigraphical information through analysing sedimentary and petrographical characteristics to re-evaluate depositional conditions and paleoenvironments. In the study, the uppermost stratigraphical formations of the Valdres Group have been the target of our combined investigations. This includes sandstones and conglomerates of the so-called Rundemellen unit at Mellane (Figs. 2 & 3) (Nickelsen, 1967; Loeschke & Nickelsen, 1968).

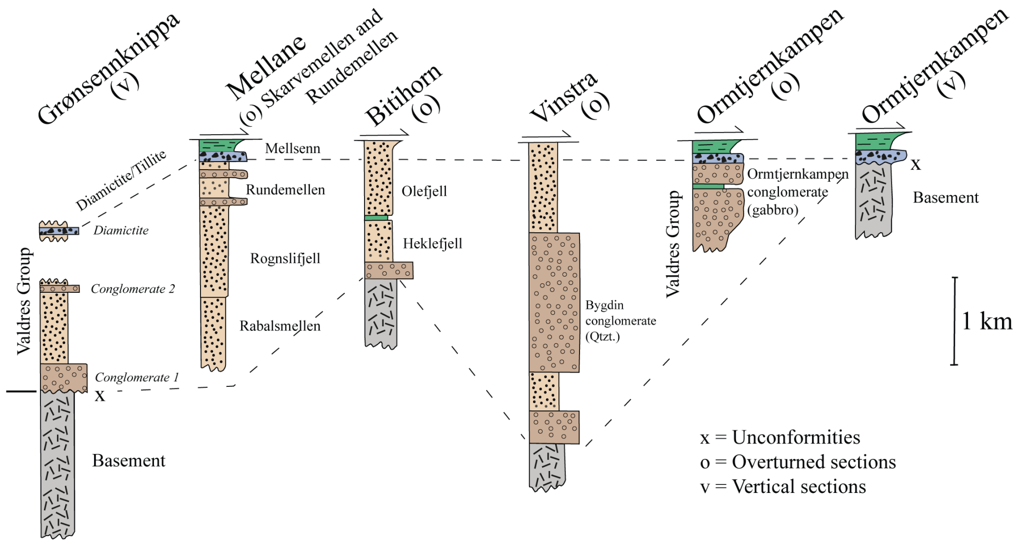

Figure 2. A correlation overview sketch of the sections of the Valdres Group mentioned in the text (from Nickelsen et al., 1985; Stokkebekk, 2018). Diamictite in Grønsennknippa section is also referred to as Conglomerate 3 (FA 5).

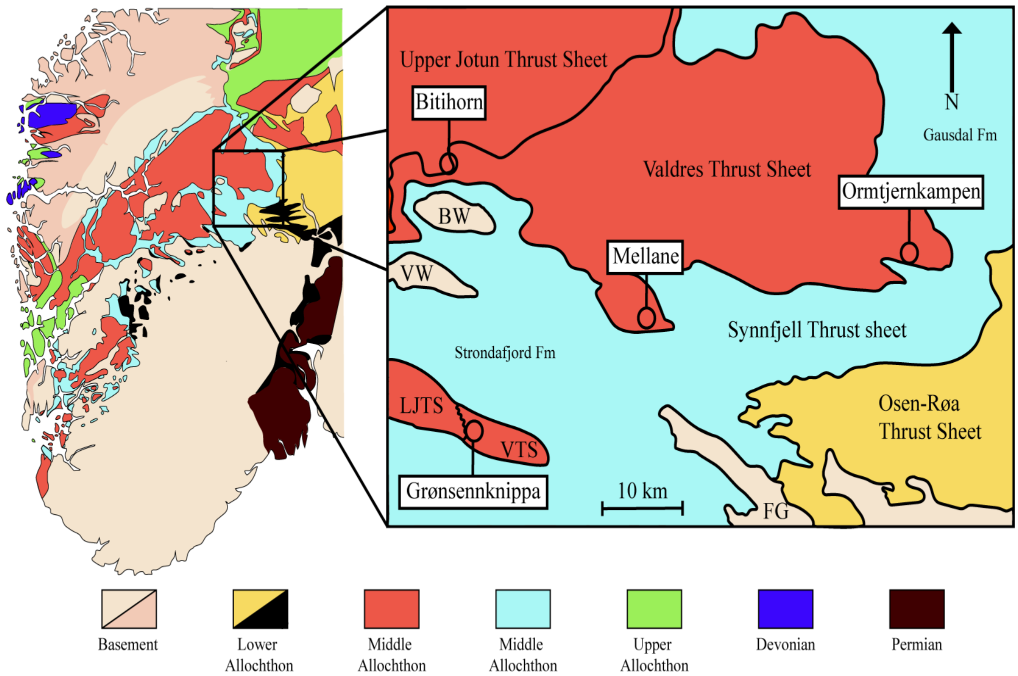

Figure 3. Geological overview map with the studied areas included: Mellane (Skarvemellen, Rundemellen) and Grønsennknippa, as well as the Bitihorn and Ormtjenkampen referred to in text. This figure is modified from Ramberg et al. (2013) and Nickelsen et al. (1985). LJTS=Lower Jotun Thrust Sheet, VTS= Valdres Thrust Sheet, BW= Beito Window, VW= Vang Window. FG= Foreland gneisses.

Geological history

The Mesoproterozoic supercontinent Rodinia formed during the Sveconorwegian orogeny (1140–960 Ma), creating an important clastic source area for the Neoproterozoic sedimentary strata of the Hedmark and Valdres basins (Bockelie & Nystuen, 1985; Lamminen et al., 2015) (Figs. 1, 2 & 3). The rifting of Rodinia (750–600 Ma) during the late Riphean resulted in two new continents, Baltica and Laurentia, eventually creating the Iapetus Ocean (Kumpulainen & Nystuen, 1985). Continued seafloor spreading increased the separation of Laurentia and Baltica (Murphy et al., 2004; Cawood & Pisarevsky, 2006; Li et al., 2008).

The Valdres and Hedmark basins were among several rift basins established at the western margin of Baltoscandia, dominated by coarse clastic sedimentation in grabens with NW–SE to NNE–SSW trending graben axes (Bockelie & Nystuen, 1985; Kumpulainen & Nystuen, 1985; Nystuen, 1987) (Figs. 1, 2 & 3). At least five rift basins evolved along the Baltoscandian margin as a result of the late Riphean rifting (750–600 Ma) (Gee & Sturt, 1985; Gee et al., 2008; Lamminen et al., 2015), including the Valdres and Hedmark, in addition to the Risbäck, Tonsåsfjellet and Engerdalen basins. The basins possess different types of fill, including fluvial to deep marine successions, and Kumpulainen & Nystuen (1985) suggested that the basins were established along a crustal dome along the Baltoscandian margin. Later during the Caledonian orogeny, the rift basins were thrust southeastwards as nappes by several hundred kilometres to their present positions (Kumpulainen & Nystuen, 1985; Hossack & Cooper, 1986; Nystuen & Lamminen, 2011) (Figs. 1 & 3). The suggested displacements of these rift basins have been discussed and disputed by, amongst others, Bjørlykke et al. (1976) who claim the Hedmark Basin to be in place.

The Hedmark Basin is the largest and best studied of these rift basins and contains a several thousand-metre-thick sedimentary succession (Bjørlykke et al., 1976; Bockelie & Nystuen, 1985; Kumpulainen & Nystuen, 1985; Nystuen et al., 2008; Bjørlykke & Olesen, 2018). Bockelie & Nystuen (1985) suggested that the Valdres and Hedmark basins developed through comparable geological events from the late Precambrian to the Cambrian times, as reflected in their correlative depositional successions dominated by immature, coarse-grained, feldspathic arenites (Figs. 1, 2 & 3).

Using field appearance and petrographical composition (Loeschke & Nickelsen, 1968), the Valdres Group at Mellane can be subdivided into three units called the Rognslifjell, Rabalsmellen and Rundemellen units (Fig. 2). Based on the capping diamictite formation (Diamictite in Fig. 2), the units may be correlated with the lower part of the Hedmark Group (Brøttum, Biskopåsen, Biri, Ring and Moelv formations) (Bockelie & Nystuen, 1985; Kumpulainen & Nystuen, 1985) (Fig. 1). Nystuen (1987) claimed that the Valdres Basin successions depict a continental basin created by block faulting and possibly attaining up to 6000 m in thickness.

The Caledonian Orogeny represents the closing of the Iapetus Ocean and on the regional scale it is dominated by ESE-vergent thrusting and overprinted by top-WNW extensional translation, particularly in its western part. The major nappe units can be grouped into a series of allochthons: a Lower (e.g., Osen-Røa, Synnfjell nappes), a Middle (e.g., the Valdres and Kvitvola nappes), a Middle/Upper (e.g., the Jotun Nappe), and the so-called Uppermost Allochthons (Bockelie & Nystuen, 1985; Gee et al., 1985; Lamminen et al. 2015) with proposed top-SE/ESE contractional displacements of up to about 400 km (Rice, 2005; Gee et al., 2010) (Figs. 1 & 3). The Caledonian stacking of thrust sheets resulted in several repetitions of Proterozoic- to Silurian-aged sedimentary strata intermixed with pre- and syn-sedimentary crystalline rocks (Roberts & Gee, 1985). The discussion of the Valdres Group as a separate nappe unit was initiated by Kulling (1961).

The Hedmark and Valdres basin successions are parts of the Lower (Osen Røa) and Middle (Valdres, Kvitvola) Allochthons, respectively (Bockelie & Nystuen, 1985; Hossack et al., 1985; Nickelsen et al., 1985; Roberts & Gee, 1985; Hossack & Cooper, 1986; Nystuen et al., 2008; Lamminen et al., 2011; Bjørlykke & Olesen, 2018) (Figs. 1 & 3). Both are overlain by the Jotun Nappe (Loeschke & Nickelsen, 1968; Hossack, 1972; Bockelie & Nystuen, 1985; Roberts & Gee, 1985; Bryhni & Sturt, 1985; Hossack et al., 1985; Lamminen et al., 2011; Lamminen et al., 2015) (Figs. 1, 2 & 3), which belongs to the Middle Allochthon of the Scandinavian Caledonides, while the Upper and Uppermost Allochthons are absent in this area (e.g., Roberts & Gee, 1985; Corfu et al., 2014; Roffeis & Corfu, 2014).

The basement rocks surrounding the Valdres and Hedmark basins consist of Proterozoic crystalline rocks, similar to those found in the autochthonous basement below the nappes and in western Norway (Figs. 1 & 3). The so-called Western Gneiss Region (WGR) is associated with the Trans-Scandinavian Igneous Belt (TIB) (Lamminen et al., 2015). Pyroxene granulites in the upper Jotun Nappe may be correlated with WGR or even more westerly lithologies, closer to the Proterozoic plate margin (Gorbatchev, 1985). The status of these rocks when referring to the Valdres Group remains enigmatic (Corfu & Heim, 2020). Hossack (1972) described granitic and gabbroic rocks underlying the Valdres Group in the Jotun Nappe at Grønsennknippa. Extra-formational volcanic clasts have been found in both the Valdres and Hedmark basin successions (Figs. 1, 2 & 3). Larger successions of metarhyolite of «Telemarkian» age (about 1500 Ma) exist in the basement southwest of the study area (Torske, 1977; Gabrielsen & Sigmond, 2004). The nappes likely originated on the western margin of Baltica (e.g., Roffeis & Corfu, 2014; Kumpulainen et al., 2021), and a source for metarhyolite clasts in the autochthonous basement would thus require westward transport. In addition, this setting is a likely candidate for the host of large volumes of metarhyolites that are preserved in the Dyrskard Allochthon (Andresen & Gabrielsen, 1979; Gabrielsen et al., 1979; Gabrielsen, 1980), which may have originated in the same region (Roffeis & Corfu, 2014).

The Neoproterozoic age of the Valdres Group is fairly well established (Loeschke, 1967; Nickelsen, 1967; Heim et al, 1977; Nickelsen et al., 1985; Nystuen & Lamminen, 2011; Stokkebekk et al., 2019), but the amount of displacement is still a topic of discussion (Hossack et al., 1985; Kumpulainen & Nystuen, 1985; Bjørlykke et al., 1976).

After the break-up of Rodinia, Baltica was centred on the equator, before drifting towards the South Pole (Torsvik & Cocks, 2005). At about 616 Ma, Baltica was positioned very close to the South Pole and the Moelv Tillite was deposited during this time as a consequence of the Marinoan glaciation. The Caledonian Orogeny started at about 425 Ma, but by that time Baltica had drifted back towards lower (southern) latitudes.

Stratigraphical setting

Hedmark Group stratigraphy – background for comparison to the Valdres Group

The Hedmark Group of the Hedmark Basin is well understood, and consequently represents a reasonable foundation and background for this investigation of the Valdres Group and further comparison of the two groups. The lower and central parts of the Hedmark Group consist of a sandstone-dominated turbidite succession more than 5 km thick (Brøttum Formation). This is succeeded by mass-flow deposits of the Biskopåsen Conglomerate, which is followed by the carbonates and sandstones of the Biri Limestone and the sandstones of the Ring Formation (Fig. 1). Together with the stratigraphically overlying Moelv Tillite (on top of the Ring Formation), the Biskopåsen Conglomerate has been suggested to represent one of two glacial periods of the so-called Marinoan glaciation (Bjørlykke et al., 1976; Bockelie & Nystuen, 1985; Kumpulainen & Nystuen, 1985; Kumpulainen et al., 2021). These Precambrian glaciers covered large parts of Baltica (Kumpulainen & Nystuen, 1985) and advanced westwards into the rift basins of Baltoscandia. The Moelv Tillite has been recognised as a tillite horizon, while the Biskopåsen Conglomerate may represent distal, reworked glaciofluvial deposits of an older glaciation/earlier ice sheet (Bjørlykke et al., 1976). The upper part of the Hedmark Group, above the Moelv Tillite, is a fairly mature succession of shales, sandstones and quartzites (Bjørlykke et al., 1976).

In the Hedmark Group, the Vangsås Formation, capped by the Ringsaker Quartzite, forms the uppermost part, just below the Cambro–Ordovician succession (Fig. 1). Similar widespread quartzitic formations have not yet been discovered in the Valdres Group, except for a few quartz-rich arkoses far down in the succession, but Loeschke (1967) described the so-called Mellsenn Quartzite as a possible correlatable equivalent to the Ringsaker Quartzite/Ekre Shale/Vangsås Formation in the Hedmark Basin (Fig. 1). Consequently, we suggest a possibly long break in sedimentation and/or massive erosion after the diamictite deposition (Conglomerate 3) in the Valdres Basin, in sharp contrast to the thick succession of post-glacial and fluvial to shallow marine beds succeeding the Moelv Tillite in the Hedmark Basin (Figs. 1 & 2). This may be the result of tectonic movements and reflect local rift-control of sedimentation, leading to great stratigraphical variations between the different rift basins.

Valdres Group stratigraphy

The Valdres Group succession at Grønsennknippa and Mellane localities consist mainly of arkosic sand- and siltstones with a few interbedded conglomerates and conglomeratic sandstones, generally classified as braided stream deposits (Figs. 2 & 3) (Bockelie & Nystuen, 1985; Kumpulainen & Nystuen, 1985). The Valdres Group successions have immature, feldspathic lithologies, and display large variations in grain size. Nickelsen et al. (1985) claimed that this reflects depositional environments controlled by active faulting, probably close to the continental margin of Baltica. Based on the overall tectono-stratigraphical position and the lithological developments, a correlation with the Hedmark Group is evident, not least due to the presence of the Moelv Tillite and other diamictites on top of the Valdres Group (Figs. 1 & 2).

The Valdres Group at the Mellane area (Fig. 2), which is tectonically inverted, can be divided into three main local units, starting from the bottom: the Rabalsmellen, Rognslifjell and Rundemellen units (Loeschke, 1967; Loeschke & Nickelsen, 1968). Several conglomerate layers of variable thickness (conglomerates 1, 2, and 3) are present.

i) **The Rabalsmellen unit** (about 1000 m in thickness) is the oldest unit of the Valdres Group at Mellane and consists of alternating coarse- and fine-grained sandstone beds, and a few beds enriched in heavy minerals. Well-developed conglomeratic deposits have not been observed in this unit (Fig. 2) (Nickelsen, 1968; Loeschke, 1967; Loeschke & Nickelsen, 1968).

ii) **The Rognslifjell unit** (about 1350 m in thickness) displays upwards coarsening, poorly sorted, coarse-grained feldspar-rich sandstones with several conglomerate layers (Loeschke, 1967) (Fig. 2). It is recognised as a tri-colour arkose (violet to pink feldspar, and white quartz in a greenish matrix).

iii) **Conglomerate 1** (about 10 to 30 m in thickness) separates the Rognslifjell and Rundemellen units. The conglomerate carries clasts of up to 5 cm in diameter, commonly quartzite and rhyolite clasts.

iv) **The Rundemellen unit** (about 650 m in thickness), consists of finer-grained lithologies and displays a more homogeneous composition than the units below (Fig. 2) (Loeschke, 1967; Loeschke & Nickelsen, 1968). The often tri-colour sedimentary rocks are better sorted, and richer in quartz than the Rognslifjell unit below (Nickelsen, 1967; Loeschke & Nickelsen, 1968). Volcanic rock fragments appear in the Rundemellen conglomerates (Conglomerates 2 and 3 of this study) (Loeschke, 1967) as in, for example, the Biskopåsen Conglomerate of the Hedmark Group. In the lower part of the Rundemellen unit a possible microfossil (acritarch) was recently discovered in the Rundemellen section (Stokkebekk et al., 2019).

v) **Conglomerate 2** (about 2 m in thickness) occurs in the middle of the Rundemellen unit. The conglomerate displays a matrix composition comparable to the surrounding sandstone.

vi) **Conglomerate 3** (from a few centimetres to about 3 m in thickness) is the uppermost conglomerate and marks the boundary between the Neoproterozoic Valdres Group and the succeeding 240 m thick Cambrian to Ordovician Mellsenn Group (Loeschke, 1967; Loeschke and Nickelsen, 1968). Conglomerate 3 has been classified as a breccia and diamictite, possibly representing a tillite, but a mudflow/density flow origin is also possible. Conglomerate 3 contains a large diversity of commonly subangular clasts in a matrix-supported setting.

Deposits of undisputable marine/deep-marine origin comparable to the Brøttum and Biri formations of the lower part of the Hedmark Group (Fig. 1) were not discovered in the present project. However, it should be mentioned that some calcareous horizons (sugary marble) have been reported at Heklefjell, near Bitihorn, NW of Beitostølen (Hossack, 1976) (Figs. 2 & 3). Based on the diamictite occurrences and acritarch correlation, it is reasonable to suggest that Conglomerate 3 is correlatable to the Moelv Tillite. If this tillite interpretation of Conglomerate 3 is correct, it may point to significant glacial erosion and depositional hiatuses developing in the Valdres Group before deposition of the Cambro–Ordovician Mellsenn Group (Fig. 2). The hiatuses in the Valdres Group are significant when compared to the apparently continuous deposition of the Hedmark Group. This potentially makes the regional correlation of the Valdres Group successions problematic.

Methods

The Rundemellen unit was studied in detail at three sections (Rundemellen, Skarvemellen and Grønsennknippa) and logged at scales 1:100 and 1:50 (locally at 1:20), in 2016 and 2017 (Figs. 1, 2, 3, 4 & 5). All the main lithologies were measured and sampled, and gamma-ray measurements (at Grønsenn-knippa) were acquired in the field along the key sections (Figs. 4 & 5) (RadEye B20). The main sedimentological syntheses are presented later in the main text, while general petrographical composition of the different units are presented and discussed in the appendix.

The conventional gamma ray measurements at Grønsennknippa did not display any large variations and are consequently not included in the present paper, but these data and all additional original data are available in the master theses of Nordeng (2018) and Stokkebekk (2018).

The laboratory analyses of the present study include X-ray diffraction (XRD), and thin section/optical analyses of selected rock samples after impregnation with blue-stained epoxy. The average mineralogical data from point counting in thin-section analysis are presented in Table 1. The general sample descriptions and petrographical raw data along with the results of XRD and additional SEM analyses are to be found in Nordeng (2018), Småkasin (2017), Stokkebekk (2018) and Sørhus (2017).

Key lithologies were also sampled for heavy-mineral analysis to search for detailed and possible new provenance information. Heavy-mineral separations and analyses were executed on a few samples from selected stratigraphical levels. The average values are presented in Table 2, while single sample results are presented in Nordeng (2018), Småkasin (2017), Stokkebekk (2018) and Sørhus (2017).

The studied sediments are occasionally (but not always) strongly deformed by thrusts and associated fault-propagation folds. The folds are generally cylindric and the strata could therefore be rotated around the fold axes and back into original positions to determine lineations and sedimentological transport vectors (Fig. 6).

Table 1. Average mineralogical composition (%) as determined in point counting of thin sections. The quantitative XRD results are shown in Figures 8, 9 and 11. Single values point-counting analysis and semiquantitative XRD analysis of each sample are to be found in Nordeng (2018), Småkasin (2017), Stokkebekk (2018), and Sørhus (2017).

Location	Sample	Quartz	K-feldspr	Plag	Rock frags	Matrix	Misc
Rundemellen							
FA1 Cgl sst middle		77,85	5,60	1,35	3,50	10,45	1,15
FA 2 sst lower		62,33	8,86	2,59	3,51	21,20	1,40
FA 3 ss upper		16,25	6,35	0,85	0,45	68,45	7,65
FA 4 Diamict.		33,50	26,60	2,70	2,50	24,00	10,70
Skarvemellen							
FA1 Cgl sst middle		58,92	7,62	5,08	4,52	20,84	3,22
FA2 sst lower		57,63	10,33	5,64	4,31	20,26	2,03
FA 3 sst upper		27,53	3,53	3,17	1,17	54,43	10,47
FA 4 Diamict.	Ska 13-16	32,00	9,00	5,30	6,00	44,80	3,30
Grønsennknippa							
FA1 Cgl middle		35,62	9,15	2,80	2,92	42,60	6,72
FA 2 sst lower		39,08	14,92	2,87	1,72	35,35	5,70
FA 3 sst upper		40,35	15,60	4,20	7,70	28,55	3,23
	GRØ 4a-46-17	41,20	24,20	1,70	2,70	27,70	2,20
	GRØ 4a-49g-17	43,50	11,50	5,50	1,70	36,20	1,40
	GRØ 4a-58b-17	24,50	13,20	4,00	0,70	50,20	7,20
FA 4 cglsst upper		36,40	16,30	3,73	1,70	38,03	3,60
Diamictite	GRØ 5-26-17	32,20	16,00	2,50	17,50	30,50	1,50

Table 2. Average heavy mineral results of samples from Rundemellen (Rund), Skarvemellen (Ska), Grønsennknippa (Grø) and the Hedmark Group. Hedmark Group: Ring 0= Ring Formation, Rin 2-15=Brøttum Formation, BK 1: Biri chalk (Biri Formation), MB 1= tillite from Moelv Brygge. Analysis was conducted on the 63–125 µm fraction of the samples with minerals identified by petrographic microscopy following Mange & Maurer (1992). At = anatase, Ap = apatite, Ca = calcic amphibole, Cp = clinopyroxene, Ep = epidote, Gt = garnet, Mo = monazite, Op = orthopyroxene, Ru = rutile, Sp = titanite (sphene), To = tourmaline, Zr = zircon. R = rare (< 0.5%).

Location	Sample	At	Ap	Ca	Cp	Ep	Gt	Mo	Op	Ru	Sp	To	Zr
Rundemellen	Rund 1-5-16		2,0				0,5			1,5			96,0
	Rund 1-7-16			0,5	0,5	1,0		R					98,0
	Rund 1-8-16		2,0	1,0					1,0			0,5	95,5
	Rund 2-8-16		4,0									0,5	95,5
	Rund 2-6-16					2,9	1,0						95,1
	Rund 2-5-16					1,8							98,2
Skarvemellen	Ska 2-4-16		27,5	R	R					0,5			72,0
	Ska 6-16		1,0									R	99,0
	Ska 8-16		17,0									5,0	78,0
	Ska 10-9-16		21,5									2,5	76,0
	Ska 2-12-16									4,5			95,5
Hedmark Group	Ring 0		73,5				1,5	0,5		R	R	1,0	23,5
	Rin 2-15		49,0									1,0	50,0
	BK 1		32,4	5,9						2,9		32,4	26,4
	MB 1	0.5	75,5		R		R	R		0,5		0,5	23,0
	GRØ 2a-3-17		3,7			24,7	25,9				42,6		3,1
	GRØ 2a-12c-17					76,8	9,3				11,6		2,3
	GRØ 2a-17-17		14,8			59,3	7,4				14,8		3,7
Location	GRØ 4a-1-17		11,0			77,5					8,5		3,0
Grønsennknippa	GRØ 4a-6-17					70,5	1,5				18,0		10,0
	GRØ 4a-18-17		12,5			66,5	1,0				14,0		6,0
	GRØ 4a-27a-17					79,5	3,5				14,0		3,0
	GRØ 4a- 36-17		6,5			59,0	1,0				28,5		5,0
	GRØ 4a-44-17		5,5			57,5	3,0		1,0		29,0		4,0
	GRØ4a-49g-17		6,5			46,5	2,0				39,0		6,0
	GRØ 4a-54-17		7,5			19,0	4,5				61,5		7,5
	GRØ 4a-58b-17		1,6			48,5	0,8				43,5		5,6
	GRØ 4a-60-17		6,5			38,0	2,0				48,0		5,5
	GRØ 5-13-17		4,5			50,0	6,0				28,5		11,0
	GRØ 5-26-17		4,0			17,0	2,5				72,0		4,5
	GRØ 5-26-17		4,00			17,00	2,50				72,00		4,50

Results

Facies associations

In the field logs the investigated successions have been subdivided into five overall facies associations (FA1 to FA5) (Figs. 4 & 5).

i) **Facies association 1:** Massive conglomerate association, with a thickness of 1–10 m in upwards-fining successions separated by thin medium to very coarse sandstone beds. The conglomerates are grain supported. Imbrications are identified and show an easterly transport direction in FA1 at Grønsennknippa (Figs. 5 & 6). FA1 is only identified at Grønsennknippa.

ii) **Facies association 2:** Conglomerate and sandstone association, commonly parallel-bedded, in sets ranging from 10 cm to 6 m. The conglomerates in FA2 are mainly dominated by rounded clasts in grain-supported texture. FA2 displays small-scale cyclic variations in lithology, alternating between conglomerates and sandstones, with both upwards-coarsening and upwards-fining successions. These beds are periodically disrupted by possible mass- and sheet-flood events, represented by sediments with poorly developed sorting and matrix-supported texture. Imbrication with an easterly transport direction is present, but rarer than in FA1 (Figs. 5 & 6). FA 2 is identified mainly at Grønsennknippa, with only occasional occurrences at Rundemellen and Skarvemellen.

iii) **Facies association 3:** Bedded sandstone-dominated association, often reddish stained with parallel lamination and cross-bedding present. The bed thickness varies from about 10 cm to about 3 m, while the grain size varies between medium- to very-coarse-grained sand. Sedimentary structures, such as parallel and mainly trough cross-stratification, are more common at Mellane compared with Grønsennknippa, where the sandstones are mostly homogeneous and structureless (Figs. 4 & 5).

iv) **Facies association 4:** Pebbly sandstone conglomerates, up to 20 m in thickness composed of 20 cm to 2 m thick beds of matrix-supported, moderately sorted sediments with dominantly rounded clasts. Some FA4 units are recognised by the high component of angular clasts, which could potentially represent mass flow deposits (Figs. 4 & 5). The clast/matrix ratio is approximately 50/50, with evenly distributed clast sizes.

v) **Facies association 5:** The thin breccias of FA5 (stratigraphically labelled Conglomerate 3) belongs to a diamictite of possible tillite or mud/mass-flow origin (Figs. 4, 5 & 7). Clasts are angular and the texture is matrix-supported in these poorly sorted beds which are between 10 cm and 2 m in thickness. The diamictite at Grønsennknippa is overall matrix-supported, poorly sorted and with a variety of angular to well-rounded clasts. The number of clasts varies significantly along the exposed section where the breccia was observed with both upper and lower boundaries towards homogeneous sandstone. The clasts of FA5 show greater diversity in lithology, shape and size of clasts compared to FA4. At Grønsennknippa FA5 has quartzite, feldspar, granitic and gabbroic clasts with a wide spectrum of colours, such as greenish grey, red and white. (More in paragraphs below and discussion paragraph 5.2.3).

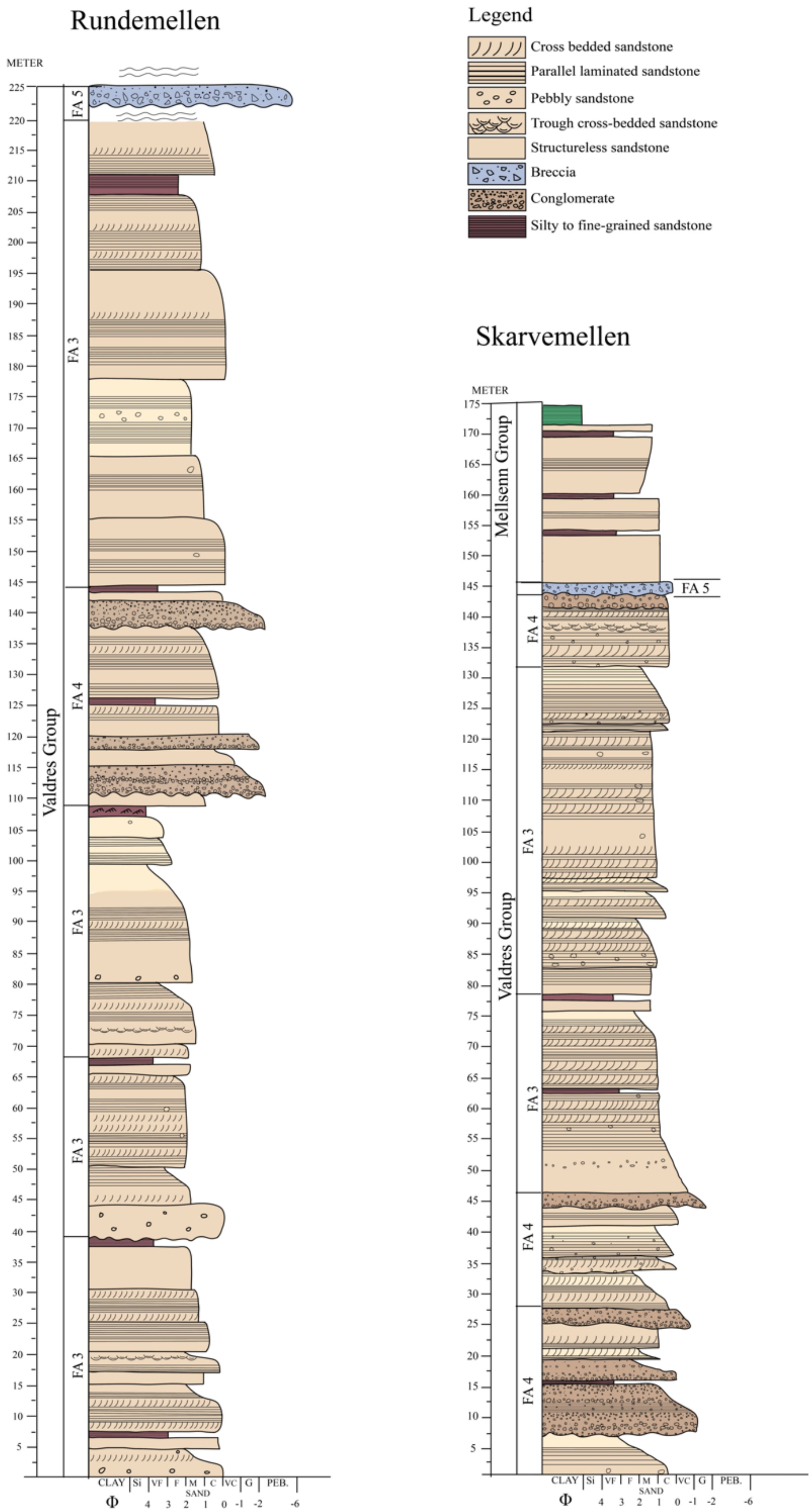

Figure 4. General lithological logs from the Rundemellen and Skarvemellen site at Mellane (Småkasin, 2017; Sørhus, 2017). The main facies associations are marked. The FA5 breccia (diamicton) is poorly sorted and matrix-supported, while the other conglomerates are generally clast-supported, somewhat better sorted and consist of rounded clasts. The successions show stacked braided stream deposits, with some coarser possible mass-flow deposits interspersed. Conglomerate 2 at level 140m in Rundemellen section and 25m in Skarvemellen section.

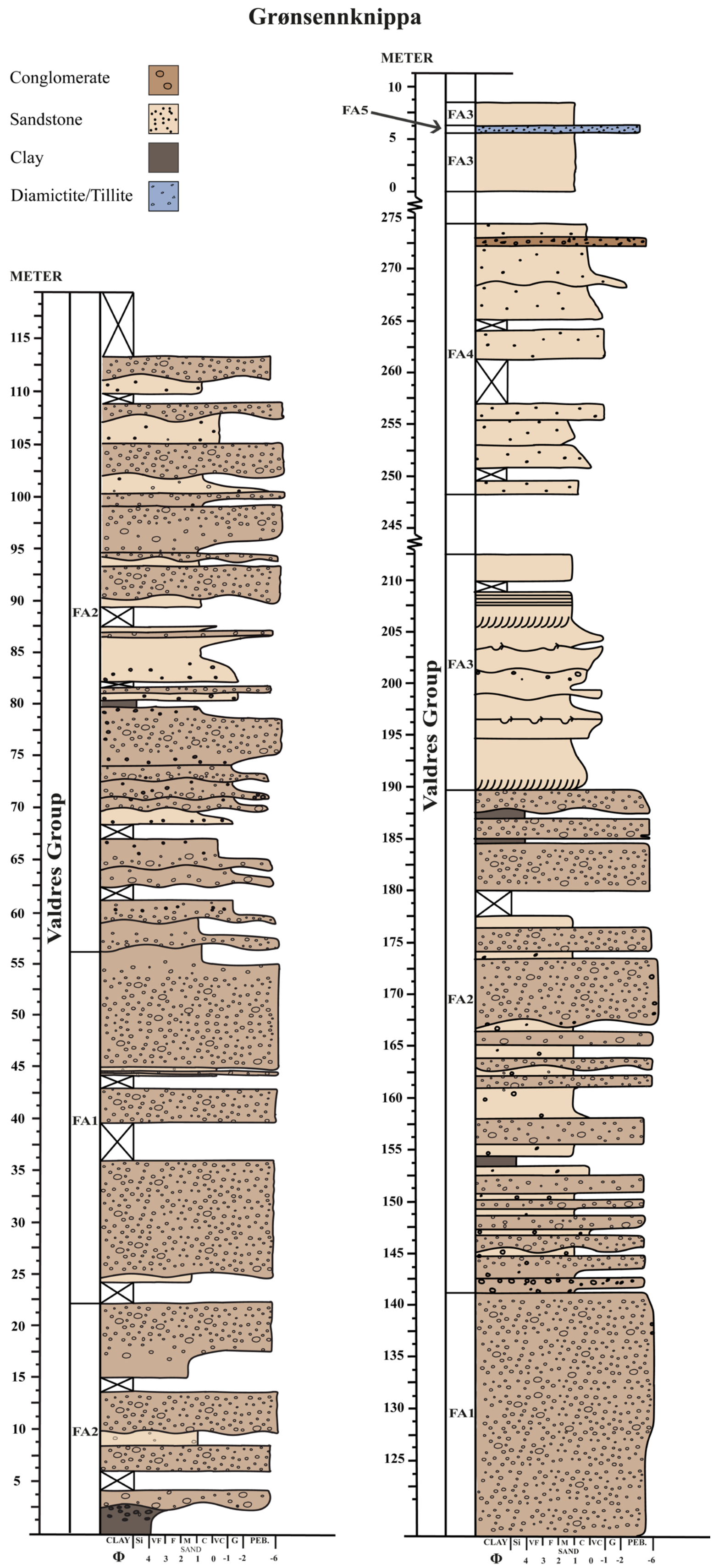

Figure 5. General lithological logs of the two sections (2a and 4a) at Grønsennknippa (Nordeng, 2018; Stokkebekk, 2018). Section 4a to the right and 2a to the left. The main facies associations are marked. Note the dominance of FA1 and FA2 in comparison to the Mellane logs shown in Figure 4. The FA 5 breccia (diamicton) is poorly sorted and matrix-supported, while the other conglomerates are generally clast-supported, somewhat better sorted and consist of rounded clasts. The successions show stacked braided stream deposits, with some coarser possible mass-flow deposits interspersed. In section#4a, cgl.1. 0-112m, and in section#2a cgl.1. from 125m -190m and cgl 2. at 275m.

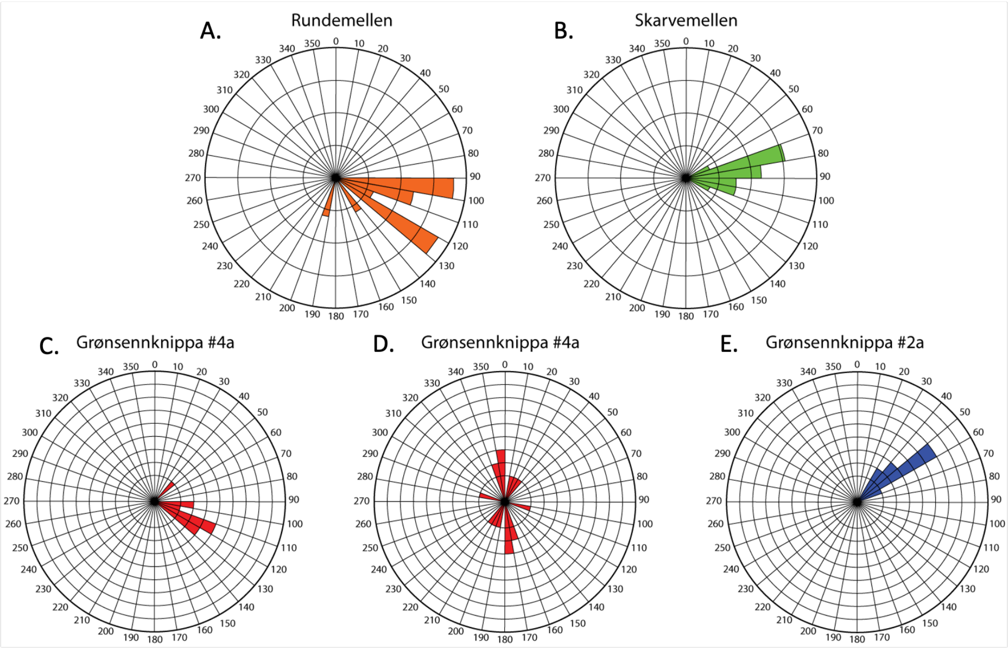

Figure 6. Paleocurrent measurements corrected for secondary, structural rotation (horizontal fold axis assumed) from cross-bedding in Rundmellen (A) and Skarvemellen (B) sections (upper figures) transported towards the east (Småkasin, 2017; Sørhus, 2017). The lower plots from Grønsennknippa display clast imbrication, flute casts and channel base paleocurrent directions from sections 4a and 2a. (C) Section 4a displays an overall ESE transport from clast imbrication observations, while section 2a (figure E) displays ENE transport direction from clast imbrication observations. (D) Paleocurrent directions from channel orientation and sole marks in the sandstone unit indicate north–south and south–north directions and were only observed in the interval 196–204 m in section 4a.

Outcrop description and field observations

Field observations will be presented separately from each of the main sections in this study (Skarvemellen, Rundemellen and Grønsennknippa), while the overall geological synthesis is the main topic of the discussion. The main petrographical information is presented in the appendix.

Mellane – the Skarvemellen outcrop section

The studied Skarvemellen section is 170 m thick and covers parts of the Rundemellen unit stratigraphy, dominated by feldspathic sandstones (see appendix) and dispersed conglomeratic formations (Figs. 2, 3 & 4) (Småkasin, 2017). Three conglomeratic beds are present in this unit; labelled Conglomerate 1, Conglomerate 2, and Conglomerate 3 (Figs. 4 & 7). In the Skarvemellen section, however, the logging started at the level of Conglomerate 2, while Conglomerate 3 forms the uppermost stratigraphical horizon of the Rundemellen unit. The Valdres Group succession at Skarvemellen is tectonically inverted and stratigraphically overlain by the Cambrian Mellsenn Group, which will not be discussed in this paper.

Conglomerate 2 and associated sandstones beds commonly display fining-upwards successions, ranging from 1 to more than 7 m in thickness, above an erosional base (Figs. 4 & 7). They are around 2 to 10 metres in total thickness. The conglomerate intervals carry about 50% clasts in which shale, granite and rhyolite fragments predominate. In addition, there are quartzites, and lithoclasts composed of quartz and various feldspars. Shale clasts are more common in the lower part. The fine-grained matrix

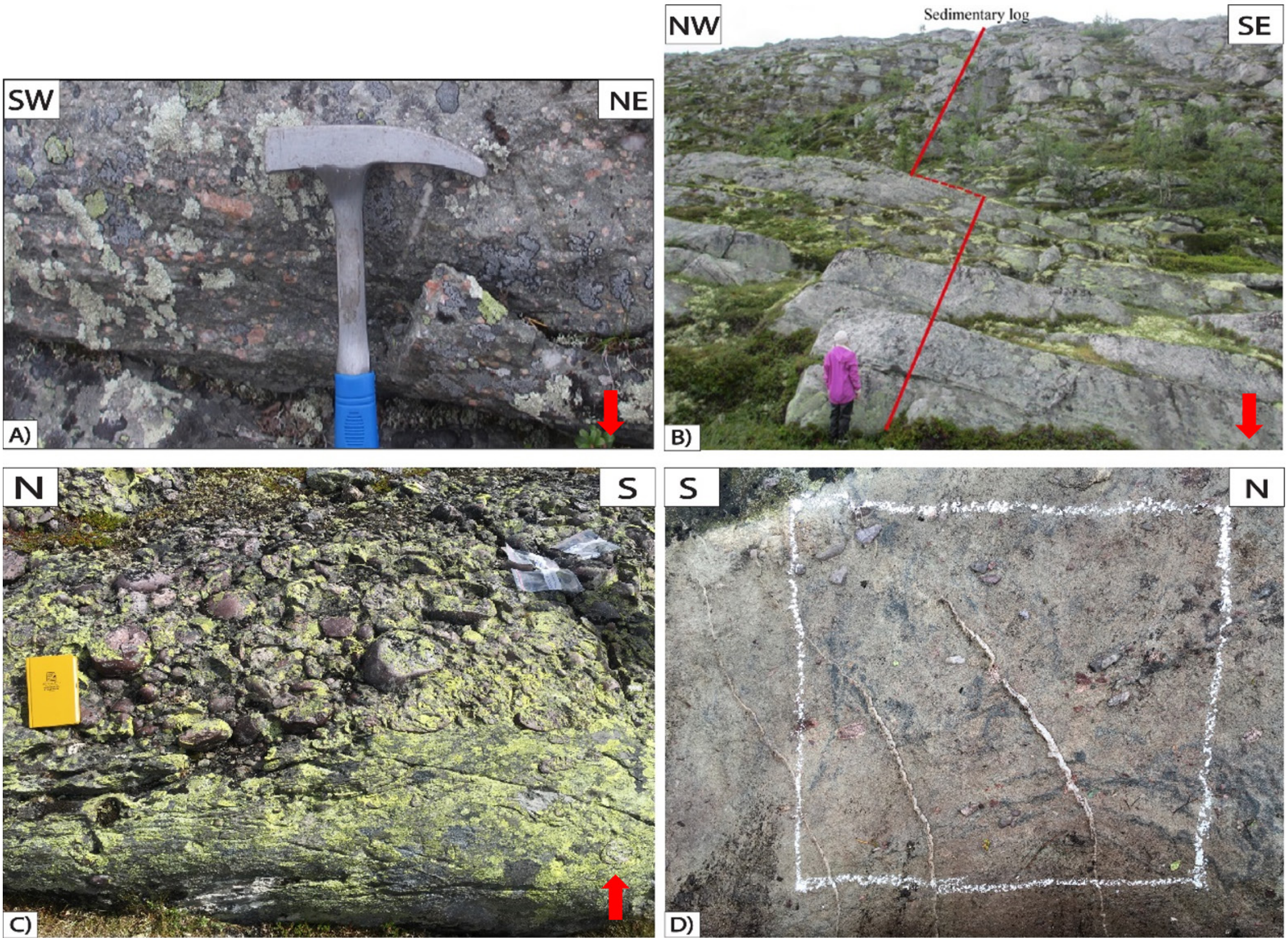

*Figure 7. The upper left photo (A) shows beneath surficial lichens and algae, a poorly sorted matrix-supported texture of the diamictite (Conglomerate 3) at Skarvemellen. Red arrow points at base of diamictite. The photo to the upper right (B) displays the typical outcrop expression of the sandstones in the Skarvemellen section. Log trace indicated by red line. A conglomeratic zone at level 167 m (FA 2, Fig. 5) in Grønsennknippa section 4a is shown at the lower left (C). The down-cutting features are about 20–30 cm deep. The largest clast is 20 cm in diameter. The lower right figure (D) shows the possible diamictite exposed in section 4a (FA 5, level 6, Fig. 5). The chalk line marks the area (50cm * 50cm) of clast counting (see Nordeng, 2018 and Stokkebekk, 2018 for details).*

is richer in feldspar and quartz than the surrounding sandstones (see appendix). Conglomerate 2 is composed of rounded clasts and is to a large extent grain-supported. Erosional boundaries and deposits with elongated, weakly deformed clasts are common, as also noted by Loeschke (1967).

The sandstones (FA2, FA3 and FA4) that make up most of the succession in the Skarvemellen section are commonly reddish in colour, with pebble content less than 30%. They are structureless to parallel-bedded and normally consist of coarse- to medium-grained sandstone, with frequent erosional boundaries (Figs. 4 & 7). The dispersed clasts range from 0.5 cm to about 30 cm in diameter. Some trough crossbedding has been found and, as with the conglomerates, fining-upwards developments are also common. The sandstone intervals are 1 to 6 m thick and composed of individual beds ranging from 10 to 40 cm in thickness. Transport directions have been measured in cross-bedded units from the Skarvemellen section, demonstrating transport towards due E, after tectonic reconstruction (horizontal rotational axis) (Fig. 6) (Småkasin, 2017). Scattered shale/silt layers of thickness from a few cm to about 50 cm appear within the sandstones.

Conglomerate 3 at the top of the Rundemellen unit is poorly sorted and only about 20 cm in thickness, rich in angular to subangular fragments from 0.3 to 4.0 cm in size, in a matrix-supported texture (see # 5.2.3.). It is dominated by quartz and feldspar clasts and can be classified as a diamictite (Figs. 4 & 7) (see appendix).

Mellane – the Rundemellen outcrop section

A 240 m thick succession of the Rundemellen unit was logged at the Rundemellen mountain (Figs. 2, 3 & 4) (Sørhus, 2017). It is dominated by sandstones and conglomerates, and is capped by Conglomerate 3. At this location the Valdres Group is succeeded by the Cambrian Mellsenn Group (Figs. 2 & 4).

The grain-supported conglomerates (Conglomerate 1 and Conglomerate 2) (FA1, FA2 and FA3) at Rundemellen consist of rounded to subrounded clasts, in contrast to Conglomerate 3 (FA5), which is more poorly sorted, matrix-supported, and rich in angular to subangular fragments. The conglomerates 1 and 2 normally range from about 2 to 5 m in thickness and are commonly grain-supported and poorly to moderately sorted. Together with the associated sandstones they often display fining-upwards developments. The matrix of the conglomerates appears similar to the surrounding sandstones, rich in quartz and feldspar. Quartzites, rhyolites, shales, granites and gneisses are common clasts in the coarser-grained beds (appendix).

Some conglomerate clasts are imbricated, indicating an easterly direction of transport, supporting the E to SE transport directions measured on the crossbedding in the sandstones (Figs. 4 & 6).

The average clast size in the conglomerates varies, the largest clasts measured ranging between 4 and 7 cm in diameter. Individual beds within the conglomerates commonly have an erosional base. The conglomerates normally occur along the base of upward-fining units, succeeded by parallel-laminated and cross-bedded sandstones. They are often capped by fine-grained units and, in a few cases (Conglomerates 1 and 2), almost silty beds. Asymmetrical ripples were observed in one fine-grained bed. Fine-grained sandstones/siltstones (often 0.3–1 m thick) are found between the coarser sandstones with erosional contact to the overlying conglomerates.

The poorly sorted Conglomerate 3 is recognised by its matrix-supported texture. The thickness of the deposit is unknown because Conglomerate 3 at Rundemellen was only encountered in scattered, loose boulders. The comparable stratigraphic unit was, however, found *in situ* at Skarvemellen (Fig. 7). The clasts in the Rundemellen version of Conglomerate 3 are mainly composed of quartzite, feldspars and volcanic rock fragments. Most clasts are less than 6 cm in length, and are mostly angular to subangular, although sub-rounded clasts are also present. The matrix is dark grey and similar in composition to the surrounding sandstones. The Rundemellen Conglomerate 3 is feldspar-rich and carries more matrix than that at Skarvemellen, but the general matrix composition appears similar in the field sections (see appendix).

Grey to pinkish feldspathic sandstone benches of the Rundemellen unit have a thickness of 2 to 5 m at the Rundemellen site. They are coarse-grained and partly pebbly (normally less than 30 % clasts), but some finer-grained and almost silty parts are present too. They are poorly to moderately sorted and commonly found in fining-upwards successions. The clasts are dominated by quartzites, but rhyolite and shale clasts are also present (see appendix). Imbrication of the clasts was seen in this unit (Fig. 6). The sandstone units are often structureless/homogeneous-to-laminated, but both trough and tabular cross-beds are present. The crossbedding and imbrication show sediment transport towards E/ESE (Fig. 6). Erosional boundaries between the different sandstones beds are common. Some thin, dark layers enriched in heavy minerals can be observed.

The Grønsennknippa outcrop section

The Valdres Group successions at Grønsennknippa are found with discordant primary contact to a crystalline granitic and gabbroic basement. The succession includes several distinct fold duplexes with flat to steeply-dipping strata defining anticlines at the leading edge of each duplex (Nordeng, 2018; Stokkebekk, 2018). Care was taken to avoid logging sequences containing thrust faults.

Two sedimentary sections of a possible Rundemellen correlatable unit were described and sampled at Grønsennknippa (Figs. 2 & 5). One section was 275 m (#4a) and the other 265 m (#2a) in thickness. In addition, an 8 m thick section approximately 533 m to the east of section 4a was measured. Sections 4a and 2a are dominated by sandstones and conglomerates (Conglomerates 1 and 2), but a few fine-grained silt/fine-sand units are also present (Nordeng, 2018; Stokkebekk, 2018). In section 4a, a minor exposure of Conglomerate 3 was found (Figs. 5 & 7).

The clast-supported conglomerate units (Conglomerates 1 and 2) are up to about 20 m in thickness with average clast sizes from 3 to 6 cm, the largest observed clast being 35 cm in diameter. The clasts have been slightly elongated/deformed tectonically. Some grain contacts show evidence of pressure solution in the form of a limited number of concave – convex sutured clast boundaries (see appendix). The conglomerates and conglomeratic sandstones are normally structureless and homogeneous, but imbricated quartz clasts do occur. Erosive and non-erosive basal boundaries are commonly found (Figs. 5 & 7). A few beds show inverse grading, but upward-fining trends are more common in the sedimentary packages, which are normally 1–10 m thick. Conglomerate 1 generally contains well-rounded clasts in grain-supported, non-graded appearances of fairly well-sorted textures. More than 95% of the conglomerate clasts are quartzite. In addition, some angular grains of quartz and feldspar, along with granite, gabbro, volcanic and shale clasts are observed.

Conglomerate 2 is a generally matrix-supported conglomerate with rounded to semi-angular clasts dominated by quartzite, like Conglomerate 1, but the layers are thinner, less than 20 cm thick. Other clast lithologies are granites, gabbros, volcanic and shales, but these are observed in only very small proportions. The matrix is dominated by medium-grained sand.

The thin, uppermost, poorly sorted conglomerate/breccia (Conglomerate 3) (Figs. 5 & 7) carries angular to subrounded clasts in an overall matrix-supported configuration and is only about 10 cm in thickness in the field. It is dominated by quartz and feldspar clasts, between 1 and 8 cm in diameter, but granitic and gabbroic clasts are present too. The clast composition varies along the bedding plane. This conglomerate bed has sharp boundaries to units above and below and was only found as a minor exposure in section 4a. It can be classified as a diamictite (Nordeng, 2018; Stokkebekk, 2018).

In the Grønsennknippa sections, more facies shifts are observed in the stratigraphically higher FA2 (Fig. 5) than in FA1. This may indicate shifting depositional conditions in FA2 with small-scale cyclic variations in the successions.

The two Grønsennknippa sections (#2a and #4a) are dominated by medium- to coarse-grained, well-sorted sandstones, often with dispersed clasts of rounded quartz and feldspar (see appendix). The bed thicknesses range from 1 to 4 m, with fairly homogeneous as well as fining-upwards and coarsening-upwards sequences observed. In the clast-bearing sandstones, as in Conglomerate 1, imbrication is present. The imbrication is different in the two sections studied: in section #2a transport towards the ENE is indicated, while in section #4a directions towards the ESE are indicated (Fig. 6). Crossbedding is also present within the sandstones. Palaeocurrent direction measurements such as sole marks and channel cuts were observed in an erosive structured sandstone facies and demonstrated both due north and south transport (Fig. 6).

The Grønsennknippa sandstones (FA1 and FA2) are poor in original clayey material, but in thin sections the sandstone from Grønsennknippa, as well as those from Rundemellen and Skarvemellen sections display sericite in varying amounts. The sericite is likely to be replacements of original mica and clay minerals (Småkasin, 2017; Sørhus, 2017; Stokkebekk, 2018; Nordeng, 2018) (see appendix).

The dominant Grønsennknippa sandstones are mainly structureless, but a few laminated and cross-bedded units are present. The sandstones are generally quartz- and feldspar-rich, often with erosive base and fining-upwards developments of 1 to 8 m thickness. Coarsening-upwards developments are also present, often from 1 to 10 m thick, with rounded to subrounded clasts up to 10 cm in diameter. Some of the 2 to 3 m thick coarser-grained sandstone units display erosive bases with sole marks. Sorting is poor to moderate, often in fining-upwards developments. Signs of compaction are expressed in pressure solution textures. Discrete beds of dark grey shales are present, from a few centimetres to about one metre in thickness. Probable organic fragments were observed under the microscope, but possible species identification has not been possible in the Grønsennknippa sections. The acritharchs were found in a sample from 37.5 m above the base in the Rundemellen section (see log in Fig. 4).

It should be noted that a few fine-grained, structureless, non-graded sandstone and shale beds are present, in thin pinching-out layers less than 30 cm thick. They contain a few dispersed clasts up to 2 cm in diameter.

Discussion

Basin development

The present discussion focuses on the sedimentological and stratigraphical development of the Rundemellen unit at the Skarvemellen and Rundemellen sites and possible correlatable formations at the Grønsennknippa section, as well as stratigraphic comparison to the Hedmark Group of the Hedmark Basin to the east. The tectonostratigraphic framework of the Grønsennknippa and Mellane sections (i.e., the Skarvemellen and Rundemellen sections of this study) is discussed in several unpublished theses (Småkasin, 2017; Sørhus, 2017; Stokkebekk, 2018; Nordeng, 2018) and is not a theme in this paper.

The sedimentary successions of the Valdres and Hedmark groups represent the infill of two different rift basins, the Valdres and the Hedmark basins respectively (Fig. 1). Deepwater successions have only been found in the western part of the Hedmark Basin and are missing in the Valdres Basin, demonstrating the lack of a direct basinal connection between the two (Loeschke & Nickelsen, 1968; Nystuen, 1982; Nystuen & Lamminen, 2011). The general sediment composition is somewhat different in the Valdres and Hedmark basins, but both main successions display petrographical compositions consistent with an overall Sveconorwegian clastic source (see appendix).

The Valdres Group

Depositional conditions

The sediments of the Rundemellen unit at Mellane outcrop section are commonly stained red by finely distributed hematite, reflecting generally oxidising conditions and possible subaerial deposition. The relatively low plagioclase content compared with K-feldspar, and the moderate quartz enrichments (Figs. 8 & 9) (details in appendix), illustrate a moderately mature sediment composition, which is also reflected in the often well-rounded particles.

The distance between the exposures at Grønsennknippa (sections #2a and #4a) and Mellane (Skarvemellen, Rundemellen) sections is today about 25 km, along a SW–NE-oriented profile (Fig. 3). The four field sections are lithologically comparable and are internally correlated, as representing the uppermost part of the Valdres Group (Rundemellen unit). More detailed stratigraphical comparison is, however, still difficult based on the available information alone, because the Mellane sections contain relatively few conglomeratic beds and consequently may represent more distal alluvial/fluvial facies compared with the Grønsennknippa profiles. The local correlation is mainly based on conglomerate/diamictite correlation, while a detailed lithostratigraphical correlation is challenging due to several possible erosional lacunae in such an original rift terrain.

The Grønsennknippa, Rundemellen and Skarvemellen sections are dominated by fining-upwards sandstone sequences (Figs. 4 & 5), most likely of braided stream origin, presumably analogous to time-equivalent sequences of the Rendalen Formation in the very eastern part of the Hedmark Basin (Nystuen, 1982). The varying sandstone facies associations show fluctuating, but overall high energy levels and channelled deposits dominated by traction current transport. This agrees well with an overall braided stream setting with longitudinal and transverse bars (Hein & Walker, 1977; Maizels, 1989; Miall, 1996, 2010; Collinson, 1996; Hjelbakk, 1997; Mulder & Alexander, 2001). The coarse, fining-upwards packages likely represent longitudinal bar sedimentation (Miall, 2010), while the more fine-grained successions are typical for transverse bars. The fine-grained sandstones that occur in between the coarser sandstones and conglomerates reflect significant changes in flow conditions, perhaps the result of low-energy overbank deposition after a channel changed course. Some of the finer-grained beds could be the final, upper parts of different longitudinal or transverse bars (Miall, 1996, 2010).

The braided stream deposits at Mellane represent more distal facies of possible alluvial systems compared with the coarser-grained, rapidly changing lithologies at Grønsennknippa, which mark a more proximal position (Figs. 4 & 5). The higher content of finer sandstones and shales at Mellane supports this interpretation. In both areas, the general sediment transport direction was towards the east (Fig. 6). Figure 10 depicts a possible depositional model for the Grønsennknippa and Mellane sites, with main transverse sediment sourcing from the basin axis/border faults in the west.

The matrices of the conglomerates and the sandstones at the Grønsennknippa and Mellane sites are comparable in terms of their petrographical composition (Figs. 8 & 9) (see appendix). The conglomerates and sandstones are generally arkosic in composition, rich in quartz and potassium feldspar along with a minor plagioclase component. The Grønsennknippa sections are somewhat richer in feldspar compared with the Mellane sections. The amount of plagioclase at Mellane is generally between 0 and 10%, whereas the Grønsennknippa samples typically have 20 to 40% (Figs. 8, 9 & 11; Table 1) (see appendix for details). This can be interpreted either as a reflection of source area maturity and transport paths, with Mellane samples containing the most mature sediments, or more likely a reflection of higher degrees of post-depositional metamorphism at Grønsennknippa, with associated plagioclase growth. The thin-section analysis, however, reveals overall very similar lithologies, with grains floating in sericite-rich matrices (see appendix).

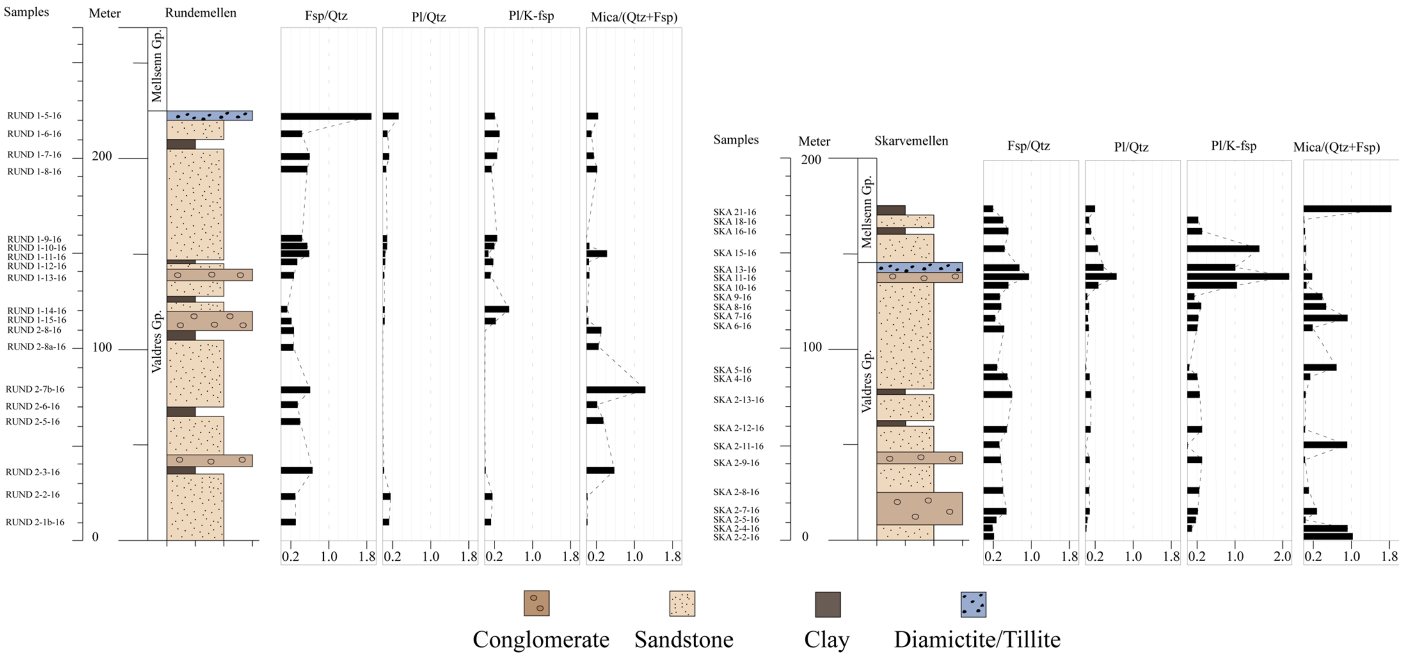

Figure 8. XRD mineral ratios from the analysed sections. Mineral distributions based on bulk XRD analysis of Rundemellen unit samples from Skarvemellen (right plot) and Rundemellen (left plot) sections (Småkasin, 2017; Sørhus, 2017). The values and ratios are based on semiquantitative XRD % values. Total feldspar/ quartz (Fsp/ Qtz), plagioclase/quartz (Pl/Qtz), plagioclase/K-feldspar (Pl/K-fsp) and the ratios of mica content/ (quartz + total feldspar) are plotted along the general stratigraphical columns of the two sections. See Fig. 4 for FA information.

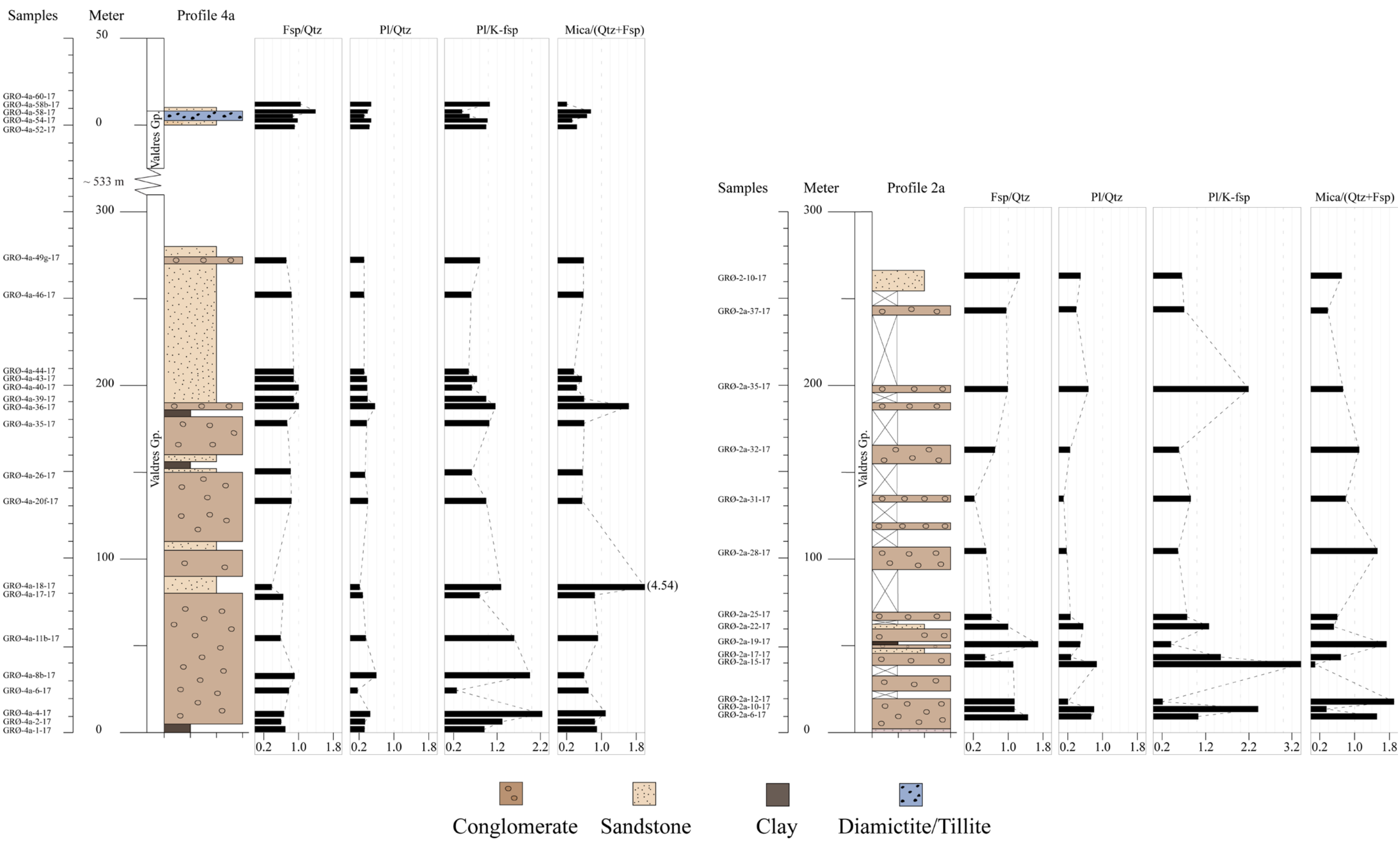

Figure 9. Mineral distributions based on bulk XRD analysis of the Rundemellen unit, sections 2a and 4a at Grønsennknippa (Nordeng, 2018; Stokkebekk, 2018). The values and ratios are based on semiquantitative XRD % values. Total feldspar/ quartz (Fsp/ Qtz), plagioclase /quartz (Pl/Qtz), plagioclase/K-feldspar (Pl/K-fsp) and the ratios of mica content/ (quartz + total feldspar) are plotted along the general stratigraphical column of the two sections, section 4a to the left and 2a to the right. See Fig. 5 for FA information.

Tangential and long grain-contacts are common at all sites, while the relative enrichment of sericite at Grønsennknippa illustrates a higher degree of metamorphism of a possibly more clay-rich original sediment (see appendix). The Skarvemellen samples generally contain more plagioclase and less quartz than the Rundemellen samples, weakly indicating a less mature composition, but the samples from the two neighbour sites are very similar lithologically. Clasts in the Skarvemellen samples appear better rounded, which indicates that they may have experienced longer, or possibly higher-energy transport compared with the clasts in the Rundemellen samples. The higher plagioclase and lower quartz content of Skarvemellen samples may, based on the statement above, suggest that the Rundemellen samples represent a slightly different source rock composition than those from Skarvemellen. The differences are, however, minimal and both sections display various types of braided stream deposits (local/regional channel avulsion) and comparable transport directions (resulting in regional changes in sediment sources) (Figs. 8, 9, 10 & 11).

The two Grønsennknippa sections (#4a and #2a) are only about 1 km apart (# 4a south of #2, (Figs. 3 & 5), and consequently similar compositional variations are to be expected in an overall alluvial environment. Section 4a contains the coarser sediments of the two sections. General eastward sediment transport directions were found in both sections, but the quartz/feldspar ratio is generally lower and less varying in 4a compared to 2a, reflecting two marginally different braided stream systems draining the same palaeoterrain with 4a representing the less altered of the two (Figs. 6 & 9).

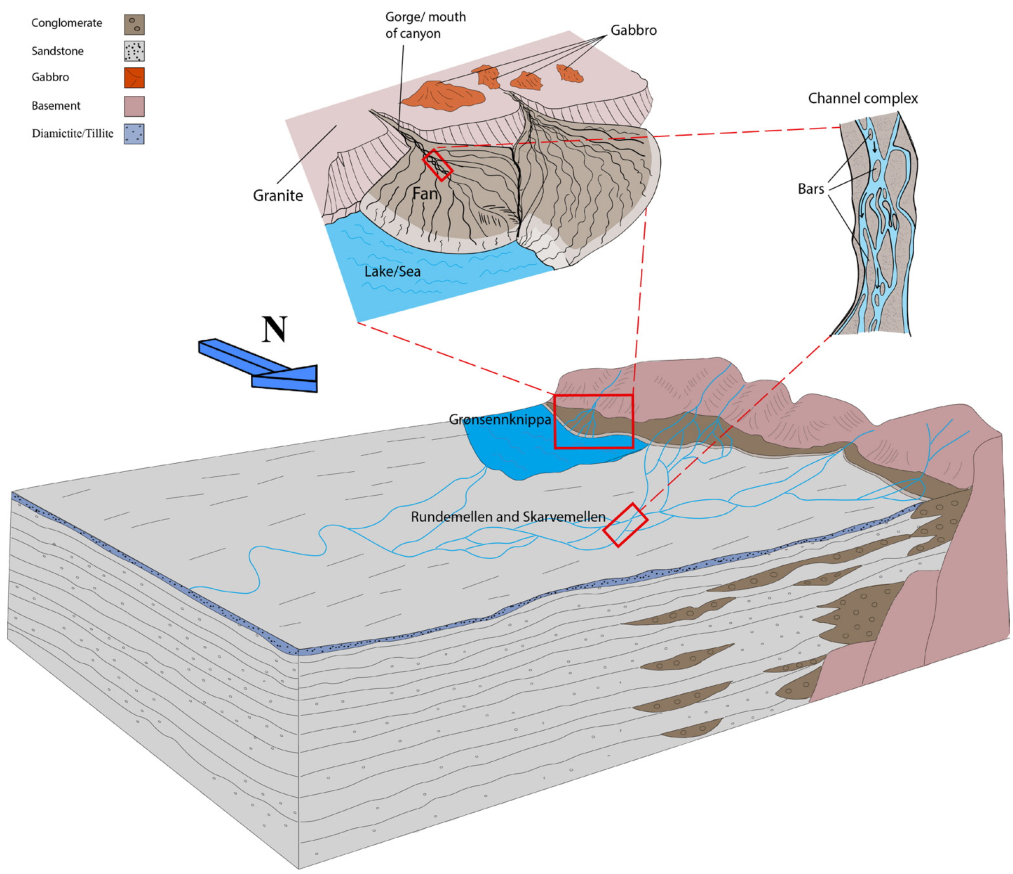

Figure 10. Tectonic and sedimentary conceptual model of the Valdres Basin and the Valdres Group, modified from Nystuen (1981). An idealized, conceptual geomorphic model and depositional expression of the Grønsennknippa, Rundemellen and Skarvemellen sections. The model also illustrates the granite and gabbro distribution in the surrounding basement at Grønsennknippa. The highlighted red squares illustrate channel complexes with associated bar development. The models are modified from Galloway & Hobday (1996), and are not to scale with the studied sections.

Generally, FA1 and FA2 in the Grønsennknippa sections are interpreted as proximal channelled streamflow deposits combined with possible unconfined mass-flood/sheet-flood deposits (Figs. 4, 5, 6, 7, 10 & 11). More shifting depositional conditions are present in FA2 (Fig. 5), with small-scale cyclic variations in the dominantly fluvial and alluvial successions, compared to FA1. These successions were periodically disrupted by possible mass- and sheet-flood events. Imbrication with an easterly transport direction, as in FA1, is present but rare in FA2. The selected FA3 and FA4 units, commonly matrix-supported with fewer clasts and locally recognised by a higher component of angular clasts, could potentially represent mass-flow deposits.

FA 5 (Conglomerate 3) is found on top of both the studied Grønsennknippa and Mellane sections and have comparable sedimentological appearance. This is further discussed in sections 5.2.2. and 5.2.3.

The highest plagioclase contents were detected in the lower parts of both Grønsennknippa sections (#2a and #4a) and both display an upward increase in the K-feldspar/plagioclase ratios (Figs. 8, 9 & 11) (see appendix). Plagioclase is less stable compared with K-feldspar and quartz (Goldich, 1938) and is therefore the first mineral of the three to disappear during longer transportation. The upwards decrease in K-feldspar/plagioclase ratios may consequently be a result of increased fluvial reworking and related mineralogical alteration through time, mirroring the input of constantly more mature and weathered clasts. The Grønsennknippa sections could represent more proximal depositional environments compared to the possible source regions (Figs. 8, 9 & 10) than the less feldspar-rich Mellane sections (Skarvemellen and Rundemellen), and may also reflect that the Grønsennknippa succession is positioned directly on the crystalline basement.

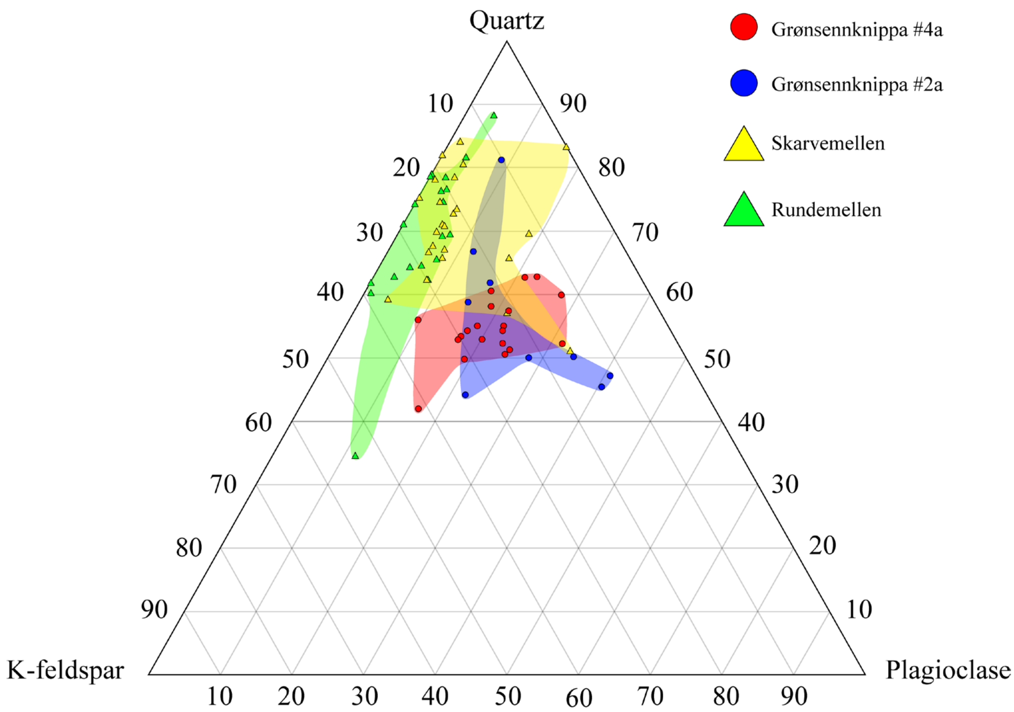

Figure 11. A ternary plot of the quartz, plagioclase and K-feldspar distribution based on XRD and thin section analysis; samples from Skarvemellen (Småkasin, 2017), Rundemellen (Sørhus, 2017) and Grønsennknippa (subsections 2a and 4a) (Nordeng, 2018; Stokkebekk, 2018). The Grønsennknippa samples show a higher content of plagioclase (between 20 and 40%) compared to the samples at Rundemellen and Skarvemellen (dominantly below 10%), while the Skarvemellen and Rundemellen samples generally contain more quartz. This reflects a more mature Mellane composition, possibly the result of somewhat longer transport distance.

Stratigraphical correlation between Grønsennknippa and Mellane areas

A tentative stratigraphical correlative level between Mellane and Grønsennknippa is provided by the Conglomerate 3 unit at the top of the studied sections in the Valdres Group (Figs. 2, 4 & 5). At Mellane this layer represents the top of the logged section, but at the tectonised Grønsennknippa sections this layer is estimated to lie 533 m stratigraphically above the major part of the logged section (Figs. 4, 5 & 7). The sandstone-dominated lithologies observed at Grønsennknippa have a composition that seems to be comparable to both the Rabalsmellen and Rognslifjell units, but no conglomerates are described from these units, except at the top of the Rognslifjell unit. The Rundemellen unit, on the other hand, is positioned in between two conglomerate units, which is comparable to the situation at Grønsennknippa (Figs. 2, 4 & 5).

The Grønsennknippa section may stratigraphically represent parts of Rundemellen and possibly Rognslifjell units. The Rognslifjell unit generally has a high feldspar content, similar to the petrography of the Grønsennknippa samples, and the Rundemellen unit overall has a quartz higher content (see also Loeschke, 1967; Loeschke and Nickelsen, 1968) (Fig. 11). Consequently, we prefer to correlate the analysed sections # 4a and # 2a from Grønsennknippa to the Rundemellen unit. It should be acknowledged that correlation across such distances (about 25 km) in heavily tectonised terrain of coarse-grained units is a challenge, especially when taking into account the possibilities for several severe erosional breaks during the various tectonic phases.

Conglomerates 1 and 2 at Grønsennknippa are more tightly packed and individually thicker compared with the possible correlatable conglomerates at Mellane, but they all display broadly similar lithofacies and clast composition. In detail, samples of the Mellane conglomerates 1 and 2 are more mature with a quartz-rich mineralogy compared with the respective conglomerates at Grønsennknippa. The Conglomerate 3 shows a greater variation in clast density, clast sorting and composition of clasts compared with the other conglomerate units (Figs. 8 & 9) (see appendix).

Conglomerate 2 of the Grønsennknippa and the Mellane sections (Figs 4 and 5) is partly matrix-supported with several angular clasts, and consequently a mass-flow/debris-flow origin is possible (Maizels, 1989; Zielinski & van Loon, 2000; Mulder & Alexander, 2001). A mass-flow origin could also explain the lack of imbrication, the paucity or absence of any unambiguous non-erosive structures to the underlying bed, the large variations in roundness, and the overall matrix-supported texture (Miall, 1996). Parts of the conglomerates in the Valdres Group may have been glaciofluvial in origin, as the massive conglomerate units show some similarities to modern outwash fans (Kjær et al., 2004). Miall (1977) described such proximal-fan braided streams as Scott Type, a shallow, gravel bar river which proximal braided stream deposits on alluvial fans. Generally consisting of > 90% gravel, which is comparable to the depositional style of Grønsennknippa.

In the Grønsennknippa sections, more facies shifts are observed in the stratigraphically higher FA2 (Fig. 5) than in FA1. This may indicate shifting depositional conditions in FA2 with small-scale cyclic variations in dominantly fluvial and alluvial successions, periodically disrupted by mass- and sheet-flood events. Imbrication with an easterly transport direction, as in FA1, is present but rarer in FA2. Generally, FA1 and FA2 are interpreted as proximal, unconfined mass-flood/sheet-flood and channelled streamflow deposits (Fig. 5). The FA4 units, recognised by the high component of angular clasts, could potentially also represent mass-flow deposits.

The more fine-grained FA3 likely reflects a lower energy, more distal depositional site on the alluvial fan, with individual units ranging from 1 to 5.5 m in thickness. Palaeoflow indicators imply a general sediment transport in a north–south direction (Figs. 5, 6 & 7). The sequence could represent distal, channelled streamflow/sheet-flood deposits, proximal-fan deposits, or possibly even overbank deposition.

The northerly/southerly sediment transport is approximately perpendicular to the orientation of the conglomerate geometries, and consequently these sandstone successions could represent sediment transport along rift basin axis/along bounding faults. The channel-fill deposits with thick beds along eroded bases in fining-upwards successions (typical for channel-fill successions, Reineck and Singh, 1975), are overlain by cross-bedded sandstones or transverse bars (Smith, 1971; Lunt et al., 2004). A transverse-bar explanation is partly supported by a non-erosional base to the underlying conglomerate, and a gradual upper transition to the homogeneous and parallel-laminated sandstones.

There are a variety of conglomerate signatures (Fig. 5) preserved in both Conglomerate 1 and Conglomerate 2 at Grønsennknippa. One signature is seen in the massive beds with tightly packed clasts. This massive conglomerate architecture may possibly be a result of tectonically influenced braided stream sedimentation in an uplift/subsiding rift-setting with resultant channel shift and/or stream capacity (Holbrook & Schumm, 1999). High fault activity may have created large accommodation space and led to high aggradation rates of the Grønsennknippa conglomerates (Fig. 5). The analysed conglomerates of the Valdres Group overall represent more proximal depositional environments compared with the sandstones and are likely associated with variations in slope angles.

The other signatures of the Grønsennknippa Conglomerates 1 and 2 involve varying sedimentary facies relations, which may indicate minor tectonic influence and more small-scale cyclic deposition variations within fluvial systems. Imbrication is, however, observed in both conglomerates 1 and 2, with the same transport direction towards east, demonstrating that depositional energy was sufficiently strong to move bed-load pebbles downstream (Fig. 6). This combination of fluvial/alluvial and mass-flow transport and deposition can occur in e.g., rift settings, especially near the basin-bounding faults separating the footwall from the hanging wall and in glaciofluvial regimes.

Conglomerate 3 (FA 5)

The diamictites of Rundemellen and Skarvemellen sections — Conglomerate 3 — are comparable where stratigraphical position and composition are concerned (Figs. 4 & 7). There is a stratigraphical shift in the quartz/feldspar ratios from underlying fluvial sandstones to the diamictites, with a sudden increase in the feldspar content (Fig. 8). This likely reflects renewed (glacial?) erosion supplying less-weathered rock fragments compared to formations below. Both diamictites (Skarvemellen and Rundemellen) are rich in small angular to subangular rock clasts in a pink to grey matrix. At the Ormtjernkampen location 30 km SE of our study area (Figs. 2 & 3), a comparable diamictite is found capping fluviatile beds (Nystuen & Lamminen, 2011), which most likely had a Sveconorwegian sediment source (Loeschke, 1967; Lamminen et al., 2015), as in the Mellane unit sandstones.

The stratigraphic position of the diamictite (Conglomerate 3) at Grønsennknippa, in the vicinity of the basement-sediment contact, indicates a probable proximal basin-margin position, rather than basin-central position. This is supported by the reduced diamictite thickness of only about 10 cm. The very thin deposit can be interpreted as reflecting marginal sedimentation of a thinned ice sheet, in contrast to an assumed thicker glacial accumulation in more basin-central positions. The thin diamictite could also be the result of glacial/post-glacial erosion, but no direct erosional traces have so far been found.

It should be noted that the diamictites could represent possible mudflow deposits. The sedimentary appearance of a tillite and mudflow deposit could be comparable in the studied sections, but the extensive distribution of diamictites (Conglomerate 3), its confined and well defined stratigraphical position, along with the possible regional correlation to the Hedmark Basin, makes a tillite interpretation most likely. This interpretation is also supported by the somewhat different petrographic composition (e.g., quartz/feldspar ratios) of the diamictite compared to the stratigraphical units below (see appendix), along with the comparable lithological composition of Conglomerate 3 (diamictites) at both Grønsennknippa and Mellane sections (Figs. 7, 8 & 9).

Correlation between Valdres Group and Hedmark Group

Conglomerate 3 (diamictite) has been correlated to the Moelv Tillite in the Hedmark Basin (Hossack et al., 1985; Kumpulainen & Nystuen, 1985; Lamminen et al., 2011; Lamminen et al., 2015). The tillites are likely attributable to the Marinoan glaciation (Bockelie & Nystuen, 1985), and thereby indirectly dated to about 660–630 Ma (Loeschke, 1967; Pringle, 1972; Hambrey & Harland, 1985; Nickelsen et al., 1985) (Figs. 1 & 2). Bingen et al. (2005a) dated the matrix of the Moelv Tillite to younger than 620 ± 14 Ma. These tillites may also correlate with similar successions in Sweden (e.g., Risbäck Basin) (Kumpulainen, 1982). In addition to the tillites, the new discovery of poorly preserved *Acantomorphic* acritarch (*Trachyhystrichosphaera*) in the Valdres Group aid the correlation (Stokkebekk et al., 2019). The occurrence suggests a late Riphean age, not younger than Cryogenian, for the lower part of the Rundemellen succession. Riedman & Sadler's (2018) recent compilation indicated an age of 738 Ma (late Tonian?), based on LAD (Last Appearance Date) of radiometrically dated late Proterozoic successions (Stokkebekk et al., 2019). In the Valdres succession the acritarch location (sample RUND 2-3-16) is 185 m below the tillite strata in the Rundemellen section (Figs. 2 & 4) (Sørhus, 2017; Stokkebekk et al., 2019).

According to the much debated "Snowball Earth" theory, these late Neoproterozoic glaciations were of global extent and can be dated to approximately 650 Ma (Hoffman & Schrag, 2002; Hoffman et al., 2017). Kumpulainen et al. (2021) gives a pre-596 Ma date for the glaciation based on the age of the Ottfjäll dyke swarm. The tillites of the Hedmark Group, as at several other "Snowball Earth" sites, are associated with interglacial or post-glacial carbonate deposits. No carbonate beds have so far been observed in the studied Grønsennknippa sections, and only few have been found in the in Mellane sections (Loesche, 1967), whereas carbonates are present in the likely comparable Heklefjell Formation in Jotunheimen (Hossack, 1976).

Based on the facies distribution, the mainly alluvial sections of the Valdres Group may generally be compared with the Rendalen Formation and Litlesjøberget Conglomerate in the easternmost part of the Hedmark Basin. Those formations represent deposits which accumulated in alluvial fan settings associated with high-relief terrain (Nystuen, 1981, 1987), displaying comparable facies to the Valdres Basin successions. The coarser-grained units of the Rendalen Formation, however, have a distinct petrographical composition, showing very different source areas, e.g., with additional Trans-Scandinavian Igneous Belt contributions.

The Ring Formation and Biskopåsen Conglomerate in the western parts of the Hedmark Basin are likely time-equivalents to parts of the Valdres Group (see introduction for more details). Most of the Ring Formation may represent deep-sea fan deposits (Bjørlykke et al., 1976; Kunz, 2002). As discussed above, the studied sections of the Valdres Group mainly represent subaerial deposits possibly in alluvial fan setting. However, some lithological similarities (see appendix) exist despite the highly divergent depositional environments, which may offer some support for a stratigraphical correlation of the

Valdres Conglomerate 3 (diamictite) to the Moelv Tillite. It should be noted that the Ring Formation of the Hedmark Group is rich in chlorite and sericite, probably due to an originally higher mud content reflecting the very different depositional conditions, and different degrees of later metamorphism.

Sediment source area and regional correlation

The sediments of the western parts of the Hedmark Basin had several source areas to the NNW, in addition to the Trans-Scandinavian Igneous Belt (Fig. 1) provenances towards the NE (Lamminen et al., 2015). The petrographical composition of the Valdres Group siliciclastics generally also reflect westerly Sveconorwegian provenances of the supercontinent Rodinia, including Mesoproterozoic rocks of the so-called Telemark Terrane /Telemarkian and Jotun Nappe rocks (see Loeschke, 1967; Loeschke & Nickelsen, 1968; Bingen et al., 2005a, b; Lamminen et al., 2015). Jotun Nappe perthites (K-feldspar with albite lamellae) have been observed in thin sections from the Mellane and the Grønsennknippa samples, showing the importance of Jotun Nappe rocks as a sedimentary source (Loeschke, 1967; Turner & Whitaker, 1976; Bingen et al., 2005a, b) (see appendix). The commonly observed metarhyolite clasts match the Telemarkian lithologies (Loeschke, 1967; Bingen et al., 2005b; Lamminen & Köykkä, 2010) and their origin is supported by an overall sedimentary transportation from the west (e.g., Gabrielsen & Sigmond, 2004).

The Rundemellen and Skarvemellen sections show comparable stratigraphical facies and display only minor petrographical differences e.g., in the quartz/feldspar ratios (Fig. 8) (see appendix). The often well-rounded clasts, moderate degree of sediment sorting and relatively high quartz content indicate moderate transport distances and a distal position in an alluvial fan system. This is also supported by somewhat better feldspar preservation in the coarser-grained feldspars. The complex tectonics related to the later Caledonian Orogeny makes detailed geological reconstruction difficult and encumbered with uncertainty. Bingen et al. (2011) dated clastic zircons from the Valdres Group to 1280 Ma, indicating a "Telemarkian" affinity. Large successions of metarhyolite exposed to the SW of the study area (Gabrielsen & Sigmond, 2004) support the hypothesis that these or comparable rocks possibly provided a composite source area. Furthermore, mesoperthites of typical Jotun Nappe affinity (Loeschke & Nickelsen, 1968) are found, illustrating the composite nature of the source area.

The sericite enrichment in the Valdres Group (see appendix) may reflect an original clay-rich matrix and an additional clay contribution from altered feldspars. Chlorite, albite and epidote are partly products of the greenschist-facies metamorphism related to later Caledonian events (Turner & Verhoogen, 1960). The large amount of sericite indicates extensive retrograde metamorphism of a possible original clay-fraction. Undulatory quartz dominates, which also illustrates tectono-metamorphic influence, as do the partial pressure-solution controlled grain boundaries (long, concave-convex and sutured). The metamorphic grade of the so-called Middle Allochthon varies from greenschist to granulite facies (likely Sveconorwegian basement origin) (Bryhni & Andreasson, 1985). The sediments at the Mellane display low-grade metamorphism characterised by sericite, in contrast to the Grønsennknippa section which has suffered higher greenschist-facies metamorphism, as reflected in the composition of chlorite, epidote and garnet in addition to sericite (see appendix).

It is uncertain whether the observed variations in heavy mineral distributions (Table 2) reflect shifts in source area. The heavy-mineral assemblages from Skarvemellen and Rundemellen sections are dominated by apatite and zircon. This suggests that the provenance area was dominated by felsic lithologies, which is supported by the lack of garnet, rutile and monazite. Heavy minerals in the Grønsennknippa section are markedly different, but the most likely reason is that the assemblages may reflect post-depositional metamorphic growth rather than original provenance character. Secondary mineral overgrowth is also evident in samples from the Skarvemellen and Rundemellen sections, where xenotime overgrowths on zircons reflect diagenesis followed by metamorphism or hydrothermal alteration (Vallini et al., 2005). Likewise, apatite overgrowths also formed during diagenesis (Morton & Hallsworth, 2007) (Table 2). Sveconorwegian basement has been identified as the main provenance of the Hedmark Group (Lamminen et al., 2015), while the Valdres Group in addition had important contributions from Telemarkian and Jotun basement (e.g., Loeschke & Nickelsen, 1968).

In the Neoproterozoic, active tectonics resulted in repeated exposure of weakly weathered basement lithologies, which later were eroded, transported, and regionally deposited by mass flows, alluvial, fluvial and possible glacial-related processes. The studied sections, representing a minor part of the Valdres area, mainly record alluvial successions dominated by braided stream deposition, with possible minor association of mass-flow sedimentation in proximal areas. Active faulting (Nickelsen et al., 1985; Heim et al., 1977) promoted the accumulations of several alluvial fans along the fault zones, as partly displayed in the often reddish successions reflecting possible subaerial deposition, dominated by fining-upwards fluvial sequences reflecting mainly overall wet fan depositional environments (Miall, 2010).

In addition to the Mellane and Grønsennknippa sites, the Valdres Group has previously been extensively mapped at Bitihorn, in the Vinstravatn area and Ormtjernkampen (Nickelsen et al., 1985) in the vicinity of the studied sections. An outlier of the Valdres Nappe has also been described at Feforkampen (Englund, 1973; Nystuen & Lamminen, 2011), where a 20–50 cm conglomerate unit with well-rounded quartz and quartzite clasts up to 5 cm is succeeded by a 5 to 8 m thick diamictite dominated by quartzite boulders up to c. 1.5 m. The thin conglomerate below the diamictite overlies the gabbroic basement directly by sedimentary contact (Englund, 1973; Nystuen & Lamminen, 2011) and has been interpreted to represent fluviatile or nearshore deposition. The diamictite on top at the Feforkampen site has been interpreted as ice-dropped debris, an equivalent to the Moelv Tillite (Englund, 1973).

Although the basement/sediment cover relation at Grønsennknippa is likely tectonically overprinted, the section has been correlated with basement/sediment contacts at Bitihorn, Vinstravatn-area and Ormtjernkampen (Nickelsen et al., 1985). The basement/cover contacts of the Beito Window (including the Bitihorn and Vinstra sections) are most likely depositional (Hossack, 1976), while unconformable contacts have not been found at Ormtjernkampen (Nickelsen, 1974).

The approximately 2 m thick diamictite at the two Ormtjernkampen sections, one eastern and one western (Fig. 2), was deposited on the crystalline basement and on top of an alluvial fan system, respectively. The westerly section is dominated by gabbroic clasts. The two depositional Ormtjen-kampen sites were probably separated by faulting (Nystuen & Lamminen, 2011). The Conglomerate 3 of Valdres Group is of wide extent and appears both with marginal and more distal diamictite affinity, comparable to the Moelv Tillite in the Hedmark Basin (cf., Siedlecka et al., 2004).

The sedimentary contact with the underlying basement was not recognised during fieldwork at Grønsennknippa, but both unfaulted contacts (Goldschmidt, 1916) and unconformable slightly deformed and mechanically altered contacts (Holtedahl, 1959; Hossack, 1972) have previously been observed in the area. The contacts with the underlying phyllite at Grønsennknippa, however, are unconformable and undisputedly tectonic. Consequently, the conglomerates, sandstones, and Jotun Nappe rocks at Grønsennknippa may represent a separate thrust sheet (Holtedahl, 1959, 1961; Hossack, 1972). This is tentatively supported by the fairly immature mineralogical composition of the Grønsennknippa sections in contrast to the Mellane sections (Figs. 8, 9 & 11). The Grønsennknippa succession may represent one of several minor nappe sheets (Heim, 1979) with different transport distance compared to e.g., the Feforkampen Valdres Nappe outlier (Englund, 1973).

We therefore suggest that the Grønsennknippa – Mellane sections may be a part of a contractional duplex with both in-sequence and out-of-sequence elements. In this picture the Mellane area represents a more frontal part that displaced above a basal thrust in an in-sequence fashion, whereas the Grønsennknippa area is a low-relief (out-of-sequence?) antiformal stack. We therefore speculate that the Mellane area experienced shorter transport distance than the Grønsennknippa area.

Thin-section analysis from Grønsennknippa samples (see appendix) show an abundance of perthites in the K-feldspars. In addition, mesoperthites and antiperthites were also observed (Nordeng, 2018; Stokkebekk, 2018). Mesoperthite, is according to Loeschke & Nickelsen (1968), common in Jotun Nappe rocks. The fact that mesoperthite is found in small amounts at Grønsennknippa and Mellane could argue for minor contributions of material from a Jotun Nappe rock source area (Loeschke & Nickelsen, 1968).

To our knowledge, the sedimentary Valdres Group described from the Mellane, Grønsennknippa, and Ormtjernkampen localities lacks radiometric dating. Bingen et al. (2011) ran 52 analyses on detrital zircons from a meta-arkosic sample collected from the Valdres Group in the western Beitostølen area. The zircon data revealed a prominent population, peaking at 1280 Ma, probably corresponding to known bimodal magmatism in the western part of the Sveconorwegian belt and the Telemarkia Terrane. The data also revealed age populations related to two other known magmatic events in the Jotun Nappe at 1650 and 1490 Ma. This indicates that the Valdres Group deposits were sourced from the Telemarkia Terrane, the Jotun Nappe and from a basement cover region exposed between the Jotun Nappe and the Valdres Group (Bingen & Solli, 2010; Bingen et al., 2001, 2008, 2011; Corfu & Heim, 2014, 2020; Roffeis & Corfu, 2014).

Conclusions

The Neoproterozoic successions of the Valdres Group are distributed among several nappe sheets in central Norway. In this study, the focus was on selected sections at Grønsennknippa (Vestre Slidre), and Rundmellen and Skarvemellen mountains at Mellane (Øystre Slidre). The upper part of the sequence, the Rundemellen unit, was analysed and the localities stratigraphically correlated in detail. The sedimentological synthesis indicates deposition by high-energy processes, most probably stream flows/mass flows in braided river systems in alluvial/fluvial/glacial settings, possibly associated with overall wet fan geometries. The studied sections contain several erosional breaks. Furthermore, these are localised in different nappe units, making even local correlation challenging.

A rift setting, as suggested here, is consistent with that suggested for comparable Neoproterozoic rifts of the region, but in the studied successions, overall alluvial deposition was dominant and capped by diamictites. This facilitates a correlation to the Moelv Tillite of the Hedmark Basin to the east. The regional and comparable appearance of the diamictite at similar stratigraphical levels in the studied sections, along with its different petrographical composition compared to prediamictite beds, makes a tillite interpretation preferrable rather than a mass-flow depositional alternative. Accordingly, the diamicton (conglomerate 3), turns out to be a key correlation unit between the Valdres and the Hedmark Basin, supporting a correlation to the widely recognised global Marinoan glaciation. In addition, the recent discovery of poorly preserved possible *Acantomorphic* acritarch (*Trachyhystrichosphaera*) in Mellane aids the correlation.

The petrographical composition and heavy-mineral distribution within the studied sections of the Valdres Group display an originally siliciclastic mineralogy, which was subsequently affected by recrystallization during variable prograde to retrograde lower to upper (middle?) greenschist-facies events. In some cases, these mineralogical variations may suggest original subaerial weathering/alteration before erosion and final deposition, or post-depositional local metamorphic effects related to nappe tectonics. The Grønsennknippa succession is more coarse-grained and feldspar-rich, reflecting an originally more immature mineralogical and textural signature than the Mellane sections. The siliciclastic sediments were mainly derived from marginal parts of the (pre-thrusting) Baltic Shield to the SW and NW of the present study area and are mainly of Sveconorwegian origin, with some additional dispersed exotic clasts from e.g., the Telemarkia terrain and Jotun Nappes.

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