A revised stratigraphy for the Ringerike Group (Upper Silurian, Oslo Region)

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The Ringerike Group is a terrigenous succession of Upper Silurian sediments that outcrops in a number of areas within the Oslo Region of southern Norway. Despite being the focus of a number of studies in the past, the stratigraphic relationships between different outcrop areas are still poorly understood. This paper compiles sedimentological and stratigraphic evidence from all the outcrop areas and a revised stratigraphy for the Ringerike Group is presented. The revised stratigraphy comprises four formations – the Sundvollen Formation, the Stubdal Formation, the Store Arøya Formation (new), and the Holmestrand Formation. These formations vary according to whether they lie north or south of Oslo. The base of the Ringerike Group is diachronous, being younger to the south, reflecting the fact that its siliciclastic depositional systems were advancing southwards from the Caledonides to the north of the Oslo Region.

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Introduction

The Ringerike Group is a succession of Upper Silurian terrigenous sediments (lower Old Red Sandstone) that crops out discontinuously throughout the Oslo Region of southern Norway (Fig. 1). The base of the group lies conformably on top of the limestones and marls of the Wenlock Steinsfjorden Formation, and thus marks the cessation of marine carbonate deposition in the Silurian of the Oslo Region. The type area of the succession is located 25 km northwest of Oslo, around the shores of Steinsfjorden and Holsfjorden, Buskerud county, where the Group occupies a broad syncline and reaches its maximum thickness of approximately 1000 m. "Other, progressively thinner, outcrops can be witnessed further south from the type area: the first occurs, after a 15 km N-S break in exposure, at Sylling. South of the Sylling exposures, there is a similar break in exposure before outcrop at Drammen and scattered outcrops at Smørstein, Holmestrand, Løvøya and Jeløya. There is then a major 54 km NE-SW absence of Ringerike Group strata, before further outcrop can be seen at Skien and Porsgrunn. The southernmost outcrop of the Ringerike Group crops out at Store Arøya, 30 km south of Porsgrunn.

There have been a number of studies that have, to some extent, considered the stratigraphy of the Ringerike Group (e.g., Kiær 1908, 1911, 1924; Whitaker 1966; Spjeldnæs 1966; Turner 1973, 1974; Dam & Andreasen 1990), but these have tended to be limited to only one or two of the outcrop areas, and have resulted in the persistence of uncertainties regarding the stratigraphic

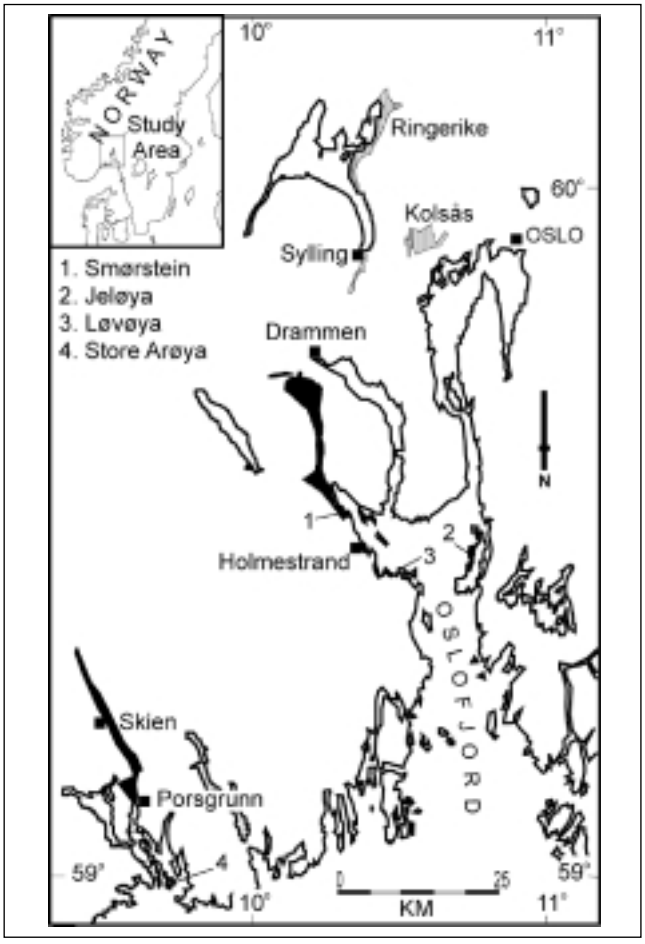

Fig. 1: Map of the Oslo Region showing areas of outcrop of the Ringerike Group. Dashed outcrop areas indicate that the succession consists of the Sundvollen and Stubdal formations, black outcrop areas indicate Store Arøya and Holmestrand formations.

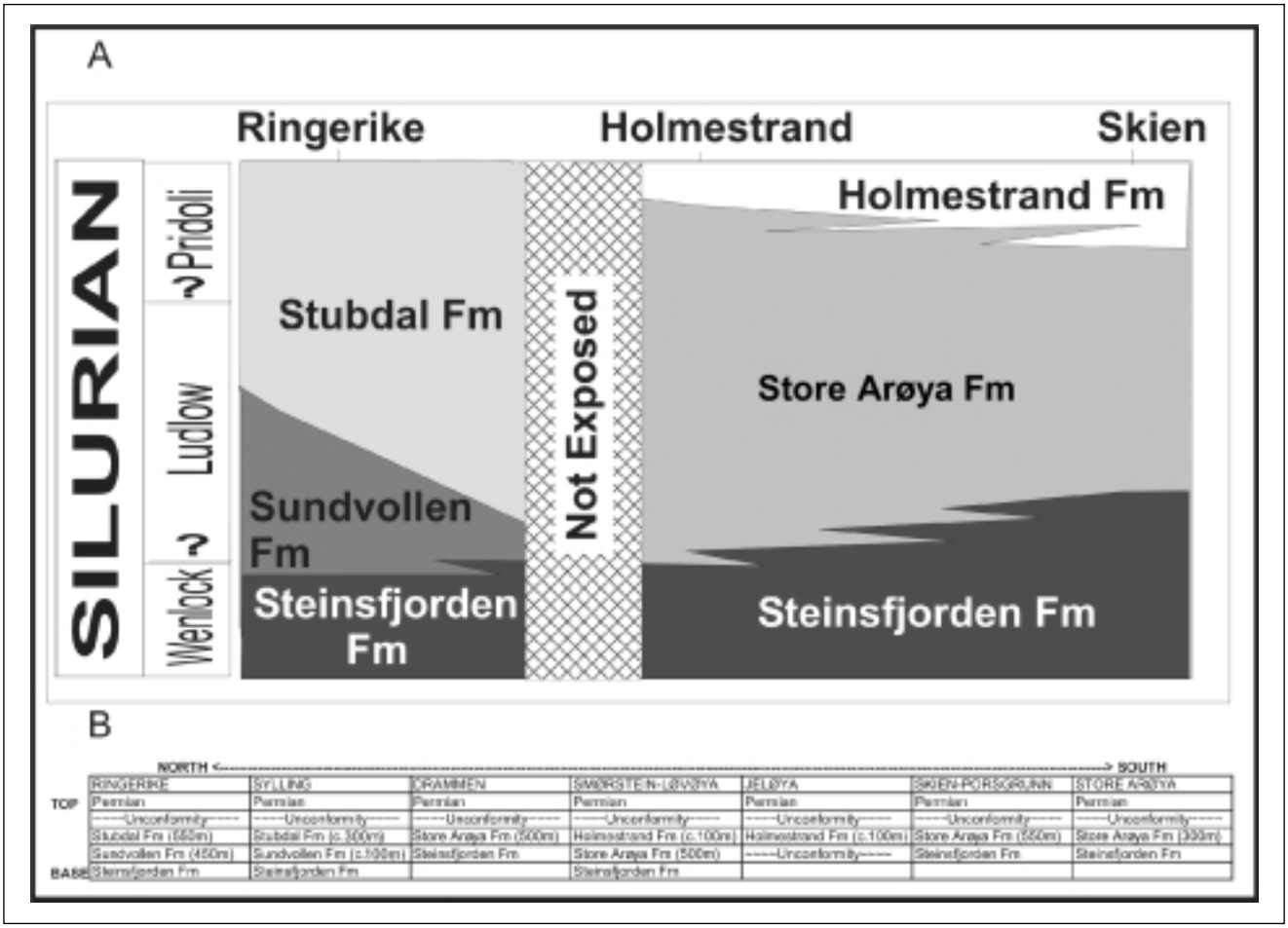

Fig. 2: A: Idealised stratigraphic relationships of the constituent formations of the Ringerike Group, and the underlying carbonates of the Steinsfjorden Formation, based on available outcrop. B: Thicknesses of constituent formations throughout the Oslo Region.

relationships between outcrop areas and the general lithostratigraphy of the entire succession. The group has previously been divided into the Sundvollen, Stubdal, and Holmestrand formations (Turner 1973, 1974), but correlation between these formations has been hindered by the lack of exposure between outcrop areas and the absence of a conclusive age.

This paper provides a revised interpretation of the stratigraphy of the Ringerike Group and introduces a new formation name – the Store Arøya Formation. The revised stratigraphy is shown in Fig. 2, and forms the basis for discussion throughout this paper.

The age of the Ringerike Group

The age of the Ringerike Group is somewhat contentious as the possibility of discovering reliable material for dating is limited and a wide variety of ages using different dating methods have been published (Table 1).

Biostratigraphy

In the type area, fossils available for biostratigraphy are limited to those recorded belonging to the Rudstangen Fauna (Kiær 1911, 1924) and to microfossils found in isolated lenses of calcarenite sediment (Spjeldnæs 1966; Turner & Turner 1974). Turner & Turner (1974) used the agnathan fish scales from these calcarenites to infer a Ludlow age for the lower part of the Ringerike Group, but the reliability of this age is hindered by the fact that the calcarenites contain material that was transported from offshore carbonates (Davies 2003) and, thus, it cannot be ascertained whether the fossils are contemporaneous with sediment deposition or not. In addition, unresolved inaccuracies in the global Silurian vertebrate biozonal scheme (Märss et al. 1995), mean that 'depositionally *in situ*' fish microfossils from the underlying Steinsfjorden Formation show a wide variety of ages (Figs. 3 & 4). This suggests that a large number of the agnathan scales found in the Ringerike Group and associated sediments are 'facies fossils' rather than having a reliable biostratigraphic signature, and, as such, only those articulated specimens with a definite biostratigraphic range should be considered as reliable

Table 1.

Given Age	Author(s)	Methodology
TOP OF STEINSFJORDEN/BASE OF SUNDVOLLEN FORMATION		
Thelodus sculptilus agnathan biozone (Late Ludlow-Early Pridoli)	Vergoossen (2002)	Agnathan biostratigraphy
Late Wenlock	Bockelie (1973)	Dating of cystoids
Late Wenlock	Olaussen (1985)	Dating of bulk fauna
Lower Wenlock (Sheinwoodian)	Smelror (1987)	Dating of miospores
SUNDVOLLEN AND STUBDAL FORMATIONS		
Wenlock-Emsian	Dewey et al. (1993)	Unspecified
Early Devonian	Kiær (1908)	Assumed to be end of sequential order of rocks in the Oslo Region
Early Devonian	Whitaker (1964, 1965, 1979)	Unspecified
Ludlow-Lower Devonian	Douglass (1988)	Palaeomagnetic data
"Downtonian"	Kiær (1911, 1924)	Comparison of Rudstangen fauna with late Silurian palaeocommunities in Scotland
Ludlow (upper part possibly "Downtonian")	Turner (1973), Turner & Turner (1974)	Agnathan fauna
Middle/Late Ludlow	Størmer (1954), Spjeldnæs (1966)	Dating of eurypterids and ostracodes
Ludlow (Gorsterian) for Sundvollen Formation	Larsen & Nakrem (2001)	Age currently used by the Norwegian Geological Survey
Early Ludlow	Heintz (1969)	Agnathan fauna
Late Wenlock - Ludlow	Worsley (1982), Worsley et al.(1983)	Review of the entire Silurian lithostratigraphy of the Oslo Region for the IUGS Subcommission on Silurian Stratigraphy
HOLMESTRAND FORMATION		
Wenlock-Early Ludlow	Baarli et al. (1999)	Dating of Rudstangen fauna
Late Wenlock	Plotnick (1999)	Eurypterid fauna
Wenlock	Turner (1999)	Biostratigraphy of *Loganellia* sp. cf. *taiti*
Pridoli	Dam & Andreasen (1990)	Suggested to be western coastal section of a shallow water basin in Scandinavia that could be correlated with the Pridolian Öved Sandstone Formation in Skåne
"Early Downtonian"	Heintz (1974)	Biostratigraphy of *Hemicyclaspis murchisoni* and *H. kiaeri*
Ludlow	Henningsmoen (pers. comm. In Worsley et al. (1983)	Single specimens of a brachiopod and a chitinozoan
Late Wenlock - Ludlow	Worsley (1982), Worsley et al. (1983)	Review of the entire Silurian lithostratigraphy of the Oslo Region for the IUGS Subcommission on Silurian Stratigraphy

Table showing the variety of ages attributed to the Ringerike Group in previous published studies.

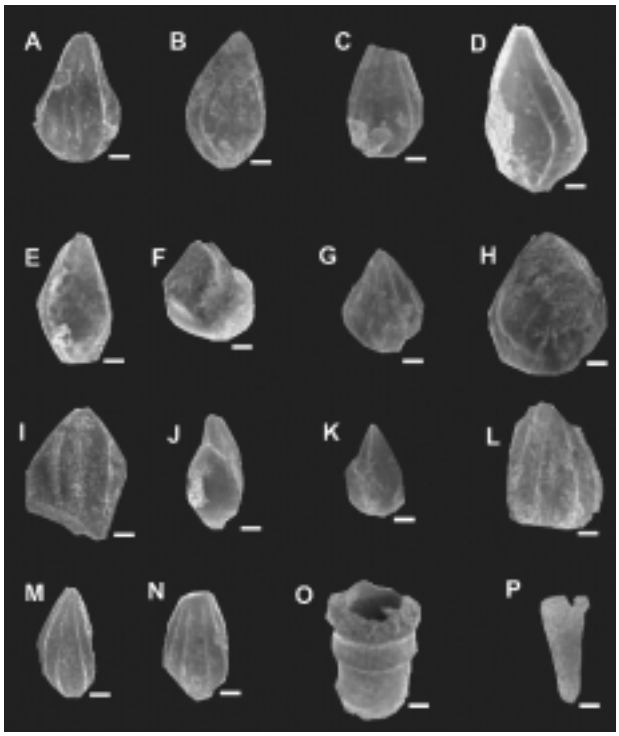

Fig. 3: Photographs of fossils from calcarenite horizons of the Sundvollen Formation taken using a Scanning Electron Microscope (all scale bars are 100 μm across). A-N: Agnathan fish scales. A: Goniporus alatus (Gross 1947), (Pridoli - Lochkovian); B: Loganellia sp. Turner 1991; C: Loganellia cuneata (Gross 1947), (Ludlow - Lochkovian); D: Loganellia scotica (Traquair 1898), (Llandovery - Wenlock); E,F: Loganellia tuvaensis (Karatajute-Talimaa 1978), (Pridoli - Lochkovian); G,H: Radioporacanthodes biblicus Lehman 1937, (Ludlow - Pridoli); I, J: Thelodus parvidens Agassiz 1839, (Wenlock - Pridoli); K, L: Thelodus sculptilus Gross 1967, (Ludlow - Pridoli); M, N: Thelodus traquairi Gross 1967, (Pridoli). Other Fossils: O: Tentaculite; P: Unidentified conodont. All the fossils are highly abraded and show a wide variety of ages (shown fully in Fig. 4), which suggests they were reworked and are not suitable for biostratigraphy.

biostratigraphic tools. For example the recovery of *Hemicyclaspis* (see Blieck & Janvier 1991) within the Holmestrand Formation (Heintz 1974) give a conclusive Přídolí age for part of the succession. Unfortunately, the only other microfossils discovered in the Ringerike Group calcarenites are rare tentaculites and specimens of the conodont *Panderodus*, and neither of these help to resolve the question of the age of the group. Despite this, and given the wide variety of dating methods used for dating in the Ringerike type area (Table 1), and the Wenlock age of the uppermost Steinsfjorden Formation (Olaussen 1985), there is a substantial amount of evidence to suggest that the base of the Sundvollen Formation is, at the earliest Late Wenlock and at the latest Early Ludlow in age. This is especially the case when proposed ages relying on agnathan biostratigraphy or even unspecified sources are omitted.

Outside of the type area, the presence of a limited fauna of "a general Ludlow aspect" from Smørstein, near Holmestrand, was reported by Henningsmoen (pers. comm. in Worsley et al. 1983) and the abundant articulated specimens of the agnathan *Hemicyclaspsis murchisoni* in the Holmestrand Formation at Jeløya have been used by Heintz (1974) to infer a younger (Přídolí) age for the sediments of the Holmestrand area. Such north-south diachronism was also suggested by Turner (1974) and Bassett (1985), although the stratigraphic table presented by Worsley et al. (1983, Fig. 5, p.12) suggested there was no diachronism between the sediments at Ringerike and Holmestrand and that the base of the Holmestrand Formation was directly correlative with the base of the Sundvollen Formation.

No biostratigraphic dates have previously been available for the metasediments that comprise the Ringerike Group in the Skien-Porsgrunn area. Samples of small carbonate mounds interbedded with siliciclastic siltstone at Bjørntvet in Porsgrunn yielded a number of fragmentary fossil shells, but most were unidentifiable fragments unsuitable for dating purposes.

Revised lithostratigraphy

Apart from the nomenclature for the constituent formations of the Ringerike Group proposed by Turner (1974) (i.e. Sundvollen, Stubdal, and Holmestrand formations), the only stratigraphic work on the Ringerike Group is that shown in the comparative table for the entire Silurian of the Oslo Region, illustrated and discussed by Worsley (1982; Fig. 3, p.18) and Worsley et al. (1983; Fig. 5, p.12). The following section of the present paper provides a new and more elaborated lithostratigraphic model and nomenclature, consisting of the existing three formations, plus the new Store Arøya Formation.

The Sundvollen Formation

The Sundvollen Formation is the oldest unit of the Ringerike Group. Turner (1973, 1974) defined the base of the formation at the appearance of the first red beds in the type section along the E16 road section between Kroksund and Vik in Ringerike (Norwegian National Grid Reference - WGS84 UTM grid: NM723595,). This lithostratigraphic base is retained in this study, but it is further defined as the top of the last carbonate bed formed *in situ* in the Steinsfjorden Formation.

The Sundvollen Formation is best exposed in a syncline that comprises the Ringerike type area, where it reaches a thickness of 490 m (notably on the lower slopes of the Krokskogen plateau between Sønsterud

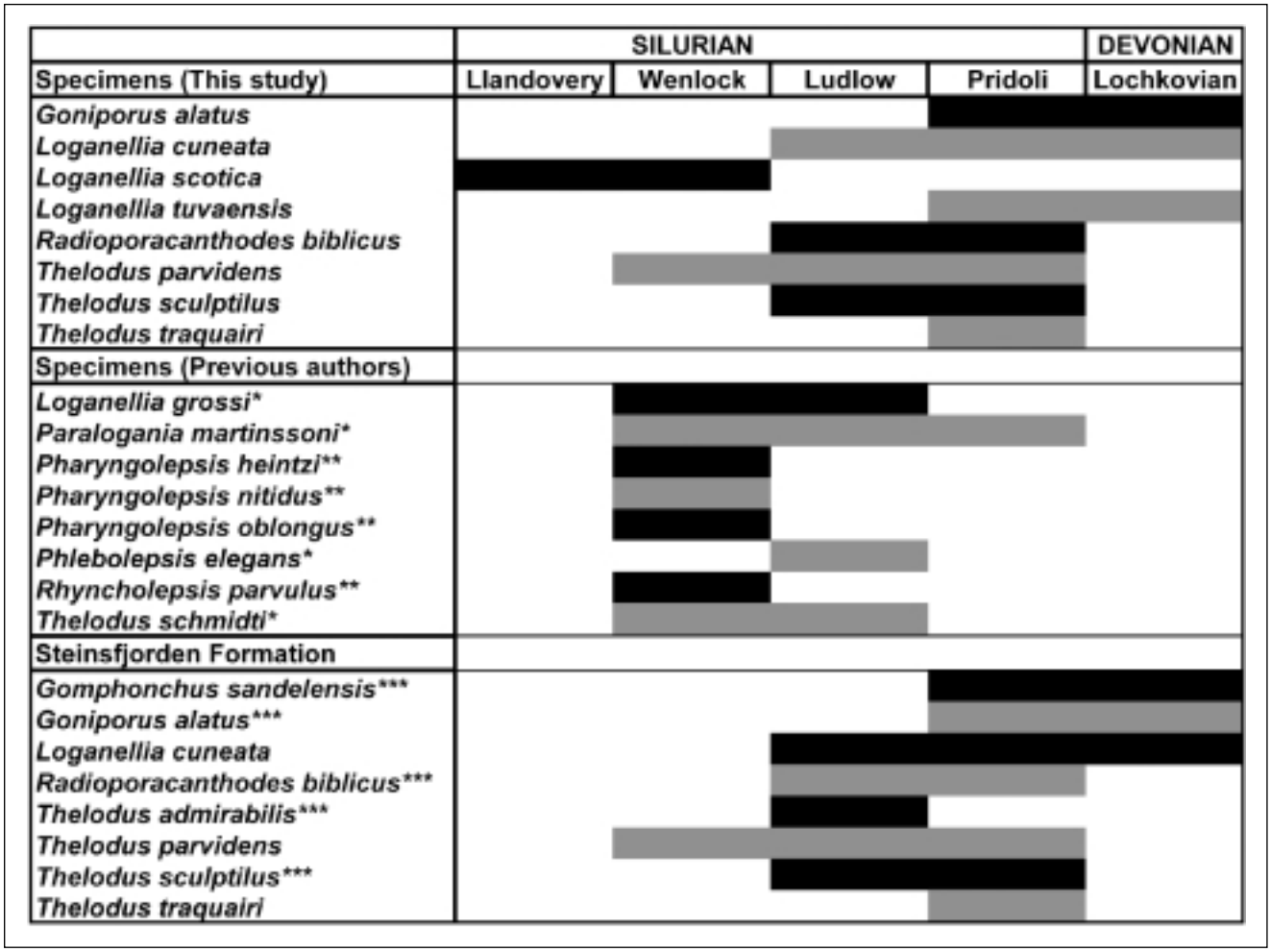

*Fig. 4: Biostratigraphic ranges of the agnathan fish fossils that are found within the calcarenite horizons of the Sundvollen Formation. Asterisked specimens indicate they have been described by other authors (*Talimaa, 2000 [after Turner & Turner, 1974]; **Blom, 2000; ***Vergoossen, 2002 [and pers. comm., 2002]. These references were also used to determine the stratigraphic ranges of all specimens.*

[NM722510] and Åsa [NM751664], and on Pålsøya [NM726596] and neighbouring islands in Steinsfjorden). Outside of the type area, exposures have been recorded in the Kolsås area, and at Asdøla, near Sylling (NM728383). Here the Sundvollen Formation is less thick than at Ringerike and although this thickness varies it is never more than 100 m. In all areas, exposures of the Sundvollen Formation are patchy, due to the vegetation cover, and are disturbed by joints related to faulting of the Permian Oslo Rift.

In its type area, the Sundvollen Formation consists of red and occasionally drab-coloured blocky siltstones and mudstones and very fine-grained drab-coloured sandstones (mature quartz arenites with c. 5% mica). Within the lower Sundvollen Formation there are also some grey, medium-grained, cross-bedded calcarenite horizons. The calcarenites are usually limited in extent and lens-shaped, while the true siliciclastic sedimentary units show a wide variety of geometries, from sheet- to wedge-shaped with some channelised forms. A wide variety of cross-stratifications and ripple forms are present throughout the formation, and desiccation cracks and intraformational mudflake conglomerates are common. In the upper part of the formation many of the siltstones show palaeosol horizons, and channelised sandstones become more common. The rocks of the Sundvollen Formation were deposited in a broad, muddy coastal plain environment, a distal realm of the Caledonide-sourced siliciclastic sedimentary systems responsible for the Ringerike Group (Davies 2003).

The only fossils known from the siliciclastic rocks of the Sundvollen Formation come from the lower part of the succession. The exceptional Rudstangen Fauna of arthropods and vertebrate fish has been described by Kiær (1911, 1924), but fragmentary bryozoans (*Monticulipora* sp.) and specimens of the green alga *Chaetocladus* are more common (Davies 2003).

The Dronningveien Siltstone Member

At around 470 m from the base of the Sundvollen Formation in Ringerike there is a 10-15 m thick siltstone

member, which extends from north to south throughout the whole Ringerike area. This horizon is named the Dronningveien Siltstone Member after its type locality on the Dronningveien road near Sundvollen (NM742598). The lateral extent of the member is hard to determine, due to outcrop constraints, but patchy outcrops may be seen from north to south throughout the type area, and it is likely that it is more extensive than was recorded by Turner (1974). The Dronningveien Siltstone Member consists entirely of massive blocky or fissile red siltstone with some small calcrete nodules. The top of the member is sometimes overlain by a thin 2-5 cm thick pisolitic limestone horizon.

The Dronningveien Siltstone Member has not been recorded from any locality outside of Ringerike.

The Stubdal Formation

Turner (1974) defined the base of the Stubdal Formation to correlate to the top of the last major siltstone cyclothem of the Sundvollen Formation, and that definition is retained here. The Stubdal Formation is restricted to the northern part of the Oslo Region and is always seen to lie conformably on top of the Sundvollen Formation in the type area (on the slopes of the Krokskogen plateau – from near Stubdal in the north [NM779660] to near Sønsterud in the south [NM722510]). Outside of the type area there are scattered exposures of the formation at Kolsås, and along an extensive road cutting on the 285 highway, south of Kopperud, near Sylling (NM728384). The Stubdal Formation represents the stratigraphically youngest part of the Ringerike Group to the north of Oslo and has an unconformable upper boundary either with the fluvial sandstones of the Carboniferous Asker Group or with Permian igneous rocks. At Ringerike the Stubdal Formation reaches a maximum thickness of 550 m, but at Kolsås and Sylling the thickness is only 300 m.

The Stubdal Formation is a purely siliciclastic and unfossiliferous braided fluvial succession dominated by very fine and fine-grained sandstones with red or drab colouring. All the sandstones are mature quartz arenites and have around 5% mica contents as is the case for Sundvollen Formation siliciclastics. These sandstones have a number of features typical of braided fluvial successions. Their sandbody geometry varies, although channel-form and sheet-form units are common (Davies et al. 2005). There are some minor siltstone horizons within the formation, but much of the silt content is actually in the form of intraformational conglomerates that exhibit a wide variety of morphologies. Near Dronningveien (NM742599) in Ringerike there is a notable siltstone unit of 1.5 m thickness that exhibits evidence of intense soft sediment deformation and occurs in the same stratigraphic horizon as many other soft sediment deformation structures (Davies et al. in press). Other common sedimentary structures within the sandstones include cross-stratification of various types, as well as massive sandstones, abundant parting lineation and flat-bedding.

The Store Arøya Formation

Outside the Ringerike type area, all sandstone strata that directly succeed the Steinsfjorden Formation have previously been referred to as the 'Holmestrand Formation'. This terminological usage has arisen from the incomplete description of the Ringerike Group outside of either Ringerike or Holmestrand-Jeløya and from the assertion that "the Holmestrand Formation can roughly be correlated with the Stubdal Formation" (Turner 1974; p. 111). However, many of the sandstones that succeed the Steinsfjorden Formation in the Drammen and Skien districts neither resemble those of the Stubdal Formation or those more characteristic of the Holmestrand Formation.

Given that the current usage of the stratigraphic term, 'Holmestrand Formation', covers two distinct sandstone lithologies and that the previous understanding of the Holmestrand Formation has led to uncertainties regarding its relationship to the type area succession, this present study has come to the conclusion that there are in fact two sandstone formations comprising the upper Ringerike Group outside of its type area. These formations are: (a) a newly erected and stratigraphically lower Store Arøya Formation, which consists of often massive fine- to coarse-grained sandstones (sheet-form geometry) with some thin silt or mudstone horizons, and (b) an upper, true Holmestrand Formation consisting of medium to coarse-grained calcareous-cemented sandstones (with minor extraformational quartzite conglomerates) and a variety of beach cross-stratification types.

The authors of this paper originally contacted the Norsk Stratigrafisk Komité (NSK) to propose the name 'Skien Formation' for the new formation. The NSK's response - that the name 'Skien Formation' was unavailable (Ramberg, 1976) - was severely delayed. As a result of this serious delay, two publications appeared in press in the intervening years referring to the new formation as the 'Skien Formation' (Davies, 2003; Davies et al. 2005). To clarify: the 'Skien Formation' referred to in these publications is actually the Store Arøya Formation (as defined herein).

The type locality for the new Store Arøya Formation is the extensive exposure across the southern part of the island of Store Arøya, located at the mouth of Langesundsfjorden (NL460397). Although not an ideal stratotype (no known exposures of the Store Arøya Formation exhibit both a lower and an upper contact), this

Fig. 5: Photomontage taken looking eastwards from Gjerpen church, Skien; showing the influence of the tabular geometry of the Store Arøya Formation on the geomorphology of the hillside east of Skien. The absence of any significant change in thickness from north to south in the Skien area has resulted in the box-shaped geometry of the Store Arøya Formation giving a stepped topography to the hills, which are capped by a plateau of Permian igneous rocks. The contacts with the underlying carbonates occur at the foot of the hill.

section shows a basal contact with the Steinsfjorden Formation, contains all of the lithologies of the Store Arøya Formation and is also one of the best examples of the typical sheet-like geometry of the units which comprise the formation.

The sheet geometry in the Skien district is so pronounced that the formation can be seen to produce a distinct step-shaped topography to the hills that lie to the east of Skien (Fig. 4). This geometry is a result of the Store Arøya Formation having been deposited by a braided fluvial system that had more lateral mobility than that responsible for the Stubdal Formation (Davies et al. 2005). There is little variation in the thickness of the Store Arøya Formation, although it is thinnest (300 m) at its type area. Elsewhere, it maintains a thickness of 550 m in the Skien area (for a lateral distance of 27 km, from Åfallås [NL308760] in the northwest to Herregårdsstranda [NL405525] in the southeast), and also has major outcrops at Drammen (c. 500 m) and along the revised course of the E18 motorway between Sande and Holmestrand (c. 500 m).

For mapping purposes, the base of the Store Arøya Formation is defined by the first terrigenous sedimentary strata that can be seen above the carbonates of the Steinsfjorden Formation in the areas south of Sylling. In the first of these, the type area on Store Arøya (NL460397), alternating beds of Store Arøya Formation sandstones and siltstones are interbedded with carbonates resembling the Steinsfjorden Formation. In the second locality, on the road which runs north-south through Konnerud (south of Drammen, grid reference: NM655197), the first sandstone beds of the Store Arøya Formation lie conformably on top of the Steinsfjorden Formation. The base is also exposed in Porsgrunn, where fluvial sandstones and distal siltstones of the Store Arøya Formation can be seen to drape carbonate mounds or tidal flats of the Steinsfjorden Formation. These exposures indicate that the southernmost Ringerike Group interfingers with the underlying carbonates.

The top of the Store Arøya Formation is either succeeded by the Holmestrand Formation (as in the exposures of Ringerike Group between Holmestrand and Horten), or, more usually, is the last unit of the Ringerike Group to have escaped erosion by the Carboniferous Asker Group or Permian igneous rocks (as is the case at Store Arøya, Skien, Porsgrunn, and all the outcrops north of Sande).

In effect, the stratigraphic position of the formation means that it is a southern lateral equivalent to the Stubdal Formation. The northernmost outcrop of the Store Arøya Formation is at Drammen, while the southernmost outcrop of the Stubdal Formation is approximately 15 km further north than this at Sylling. No physical contact is ever seen between the two formations.

In all of the exposures of the Store Arøya Formation the rocks are more accurately described as metasediments due to their proximity to Permian igneous plutons, but where grain-size is visible it can be seen to be dominantly constituted of fine to medium (mostly in the medium grain-size range) mature quartz arenite. The sandstones are usually white or pale grey, though some beds near the boundary with the Permian igneous complex in the Sande-Holmestrand area contain abundant epidote and are particularly green in colour. The formation contains more mud- or silt-grade sediment than the Stubdal Formation and this is usually black in colour. Often the siltstone units are no more than a few centimetres thick but they may be up to a metre in thickness and are laterally pervasive sheets. Another distinction from the Stubdal Formation is that the Store Arøya Formation sediments appear (from palaeocurrent analysis) to have a WNW source area (Davies et al. 2005).

The Holmestrand Formation

The new usage of this stratigraphic term refers to the uppermost 100 m of the Ringerike Group. Where its base is visible it can be seen to succeed conformably the Store Arøya Formation, and to lie beneath the Carboniferous Asker Group or Permian igneous material. As such it represents the youngest formation of the Ringerike Group.

The Holmestrand Formation is only exposed in scattered coastal exposures on either side of Oslofjorden – between Smørstein and Løvøya in the Holmestrand area, and on the north-west coast of Jeløya.

The base of the Holmestrand Formation is defined as the first extensive bed of calcareous cemented sandstone to succeed the Store Arøya Formation. The proposed type section for the base of the Holmestrand Formation is at Smørstein (north of Holmestrand, grid reference: NL725999), and here sediments of the Store Arøya Formation can be seen to gradually give way to immature medium- or coarse-grained quartz arenites with a calcareous matrix and abundant fragmentary vertebrate fossils. The abundance of both body and trace fossils indicates a more marine-influenced depositional environment than the Stubdal or Store Arøya formations, and the coarser grain-size and shallow dipping cross-bedded strata indicate that it was likely to have been deposited in a beach depositional system (Davies 2003). Most sections of non-marine strata, previously recorded as part of the Holmestrand Formation such as those discussed by Baarli et al. (2003, Fig. 3), are now a part of the Store Arøya Formation. The Smørstein exposure is the only one to show the base of the formation, but the most extensive outcrops of the Holmestrand Formation are found at Nesbukta on Jeløya (NL923950), and at Frebergsvik (NL784897), Falkenstensbukta (NL795910), and Løvøya (NL817913).

The finer grained sandstones of the formation do not often have a calcareous matrix and are relatively mature, but are distinguishable from the Store Arøya Formation by their laterally-restricted channelised geometries and upper and lower boundaries with the calcite-cemented sandstones. The Holmestrand Formation is the only formation of the Ringerike Group to contain extraformational derived conglomerate clasts (pebble- to cobble-sized metamorphosed quartzite).

The proposed definition of the Holmestrand Formation roughly equates to the upper "Medial Unit" and "Upper Unit" described by Dam & Andreasen (1990).

Conclusions

The Ringerike Group consists of four formations. These are the Sundvollen, Stubdal, and Holmestrand formations, and the presently erected Store Arøya Formation. To the north of Oslo – at Ringerike, Kolsås, and Sylling – it is the first two of these formations that comprise the group. To the south of Oslo – at Drammen, Sande, Holmestrand, Jeløya, Skien/Porsgrunn, and Store Arøya – it is the latter two. The Store Arøya Formation is the southernmost equivalent of the Stubdal Formation.

Lithostratigraphic relationships indicate that the Sundvollen Formation is the oldest, and the Holmestrand Formation the youngest formation of the Ringerike Group. The base of the Sundvollen Formation at Ringerike appears to be of Ludlow age, and the Holmestrand Formation at Jeløya is Přídolí in age. However, the precise age of the Ringerike Group outside of these areas is still unknown.

The stratigraphic relationships between the formations, presented in Fig. 2, can be explained by viewing the Ringerike Group as a siliciclastic sequence that advanced diachronously southwards, from a Caledonide source, on to the underlying Steinsfjorden Formation.

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