The Caledonides of the Oslo Region, Norway – stratigraphy and structural elements

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In geological terms, the Oslo region is a graben structure containing downfaulted fossiliferous, Lower Palaeozoic rocks in a belt 40-70 km in width and extending 115 km north and south of the city of Oslo. Shelly, graptolitic and early vertebrate faunas together with microfaunas and -floras offer a detailed biostratigraphy and time scale for the Caledonide tectonics and associated events. The provided correlation charts reflect a preferred Baltoscandian terminology for the Cambrian and Ordovician successions and a standard British system for the Silurian. Reference to recent biostratigraphic and sedimentological studies allows speculation on changes in sedimentary rates having both global and local causes based on the fact that the Oslo Region occupied an intermediate position between the stable platform to the east and the developing orogen to the west. Sedimentary rates, were high with dominantly mudstones and limestones and local thicknesses up to 1 km in the Ordovician and nearly twice this amount in the Silurian where siliceous rocks in a red-bed facies first appear around the Wenlock-Ludlow boundary.

Caledonian tectonics in the Oslo Region activated the Osen-Røa detachment along which the major displacement was to take place. This structure underlies the entire Oslo Region, but dies out to the south in the Skien-Langesund area. In the Oslo Region, the Osen-Røa detachment lies within the late Cambrian Alum Shale and is developed as an intensely deformed thrust plane, from which numerous faults splay up-section into the Ordovician and Silurian strata, forming a duplex structure. Although the strain intensity decreases towards the south and towards the upper part of the Cambro-Silurian section, three major structural levels, in addition to the basal Osen-Røa detachment are identified. These are partly associated with flats of semi-regional significance in the nappe pile. The bulk transport is towards the south-southeast, but areas of southerly (Klekken area) and southeasterly transport (southern Ringerike) are also prominent.

The detailed timing of the deformation is not well established, but the first sedimentary response to the growing mountain chain to the northwest is believed to be the fine-grained sandstones and siltstones of the Elnes Formation of late Middle Ordovician (Darriwilian) age, whereas the first siliciclastic sediments of more significant thickness date to the latest Ordovician. Finally, it is evident that the up to 1250 m-thick, Upper Wenlock-Lower Ludlow sandstones of the Ringerike Group have been affected by the contractional deformation, defining a maximum age for the latest Caledonian (Scandian) orogenic movements.

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Introduction

During the Palaeozoic Era, Baltica, almost all of Gondwana (with adjacent plates) and Laurentia, South China and Siberia were situated in the southern hemisphere. Only North China was truly north of the palaeoequator and the Oslo Region was situated at mid-latitudes (Cocks & Torsvik 2002, 2005, see Tychsen & Harper 2004 for map). An estimated rapid northward drift of the Oslo Region during the Ordovician was presented by Perroud *et al.* (1992) and a near-equatorial position is assumed for the region during the Silurian.

In southern Norway, remnants of the Caledonides can be traced northeastwards from Stavanger to the area of Valdres and eastwards into the northern part of Mjøsa before extending into Sweden to the north and east. Remains of the Caledonian thrust front can be traced into Sweden as far as the Siljan district some 240 km from Oslo. Based on conodont Colour Alteration Index (CAI), Bergström (1980) has estimated that in the latter area a Caledonian rock sequence of at least 2.5 km has been eroded while as much as 10 km has been lost farther north in Jämtland. However, Apatite Fission Track studies suggest that these figures may have been overestimated (Hendriks & Redfield 2005). Nevertheless it seems obvious that a comprehensive and complex foreland basin system existed. South of the present Caledonian front, slivers of the Lower Allochthon (*sensu* Bryhni & Sturt 1985) were downfaulted during the Permian and crop out in a graben structure forming the Oslo Region (Dons & Larsen 1978, Sundvoll & Larsen 1994). Thus sequences here provide a unique section through the external thrust system.

The geological term Oslo Region (Fig. 1) refers to an area of approximately 10,000 km^2 extending 115 km north and south of the city of Oslo. Evidence for an offshore extension comes from a drill core in the Skagerrak which yielded rocks of a Late Ordovician-Early Silurian age (Smelror *et al.* 1997, Pedersen *et al.* 2007). The Oslo Region varies in width from 40 to 70 km and contains a well documented, fossiliferous, Lower Palaeozoic succession which has been thrust and folded and dissected by a series of Upper Palaeozoic lavas, dykes and sills causing local metamorphism with temperatures of 300ºC or more, as shown by CAI indices of 4.5-5, based on Ordovician samples (Bergström 1980).

Since the 18th century the area has been an important reference for Norwegian geology where the detailed Palaeozoic biostratigraphy has provided a time-scale for dating the Caledonian tectonic and associated events. We here draw attention firstly to the Cambrian-Ordovician evolution of an epicontinental basin and the transition to a true foreland basin accompanied by influx of clastic sediments throughout the Silurian and Early Devonian. Secondly, we document the folding and thrusting that affected the entire Palaeozoic succession and indicate that a significant part of the deformation in the Oslo Region is of Devonian age. We are indeed aware that the present contribution would have benefited from the inclusion of a sedimentary analysis of the Cambrian – Devonian. The history of the study and the resources available unfortunately precluded this.

Lower Palaeozoic stratigraphy and faunas

An attempt is made here to provide some recent thoughts on the importance of the Lower Palaeozoic rocks of the Oslo Region with reference to some of the latest literature. Despite studies spanning more than 200 years, there are still huge gaps in our knowledge of the stratigraphy. This is especially true for the upper Cambrian where type sections are still lacking, though the trilobite faunas are well documented (Henningsmoen 1957, Martinsson 1974, Terfelt *et al.* 2008) and a revision of Silurian faunas is long overdue. The Ordovician stratigraphic framework established by Størmer (1953) provided the basis for a series of palaeontological contributions (see Bruton & Williams 1982, p. 215) and a later comprehensive, modern lithostratigraphical scheme (Owen *et al.* 1990). Encouraged by demands from the IUGS Subcommission on Silurian Stratigraphy to provide type sections, Worsley *et al.* (1982, 1983) published a corresponding lithostratigraphical scheme for the Silurian. Each of these publications contains a detailed historical summary of research in the Oslo Region together with extensive reference lists, not repeated here. The correlation charts (Figs 2-6) reflect a preferred Baltoscandian terminology for the Cambrian and Ordovician, while reference to a standard British system is applicable for the Silurian. Fossiliferous Cambrian to Silurian rocks can be studied at key localities in a number of districts identified by Størmer (1953) and since modified (Fig. 1).

Cambrian

During the Cambrian, Baltica, southern Britain and east maritime Canada were parts of the marginal Gondwanan Avalonian plate and this is reflected in their similar trilobite faunas (Henningsmoen 1957).

A revised lithostratigraphic scheme for the early Cambrian in the Mjøsa area (Fig. 2) has recently been published by Nielsen & Schovsbo (2007, pp. 63, 69) and attempts have been made to incorporate the acritarch biostratigraphy of Vidal & Nystuen (1991). The Early Cambrian is either allochthonous, occurring in the Osen-Røa Nappe Complex (Bockelie & Nystuen 1985), or autochthonous-parautochthonous overlying a Precambrian peneplain with a basal conglomerate always present. In the allochthon, Cambrian rocks rest unconformably on the Vangsås Formation which is the uppermost unit of the >2000 m-thick Hedmark Group.

The Vangsås Formation contains the acritarch *Fimbriaglomerella minuta* in the marine Vardal Member (Vidal & Nystuen 1990, p. 189) which is not basal Cambrian (Moczydlowska 1991), and the overlying Ringsaker Member lacks stratigraphically diagnostic acritarchs and macrofossils. Thus, the base of the Cambrian cannot be recognised using fossils.

In older literature, several formations were included in the former Holmia Series between the Vangsås Formation and the middle Cambrian Alum Shale Formation (Skjeseth 1963) and these were later redefined by Vidal & Nystuen (1991). Following Nielsen & Schovsbo (2007), these are now regrouped into five members of the Ringstrand Formation (Fig. 2), estimated to be around 50-60 m thick in the Lower Allochthon.

The Brensætersag Member contains acritarchs of the *Heliospheridium dissimilare - Skiagia ciliosa* Zone (Vidal & Nystuen 1991) and trace fossils are abundant in the overlying Redalen Member. A specimen of the trilobite *Holmia* cf. *mobergi* reported from this unit (Bergström 1980, p. 12) may be from higher in the section at Brensætersaga (Høyberget in Nilesen & Schovsbo 2007, p. 67).

The Tømten Member can no longer be studied at its classical type locality (Kiær 1917) and the section at Brensætersaga has been chosen as the new stratotype (Nielsen & Schovsbo 2007, p. 68). This member has yielded acritarchs of the *Heliospheridium dissimilare - Skiagia ciliosa* Zone and trilobites of the *Holmia kjerulfi* Zone (Ahlberg et al. 1986; see also Ebbestad et al. 2003). In terms of the older stratigraphy, the Tømten Member is equivalent to the Bråstad Shale (Vidal & Nystuen 1991) and the overlying Holmia Shale (Kiær 1917). The Evjevik and Skyberg members occur only in the Lower Allochthon and a break (the Hawke Bay unconformity) separates the Tømten Member from the middle Cambrian alum shales of the autochthon-parautochthon. Bioclastic limestones

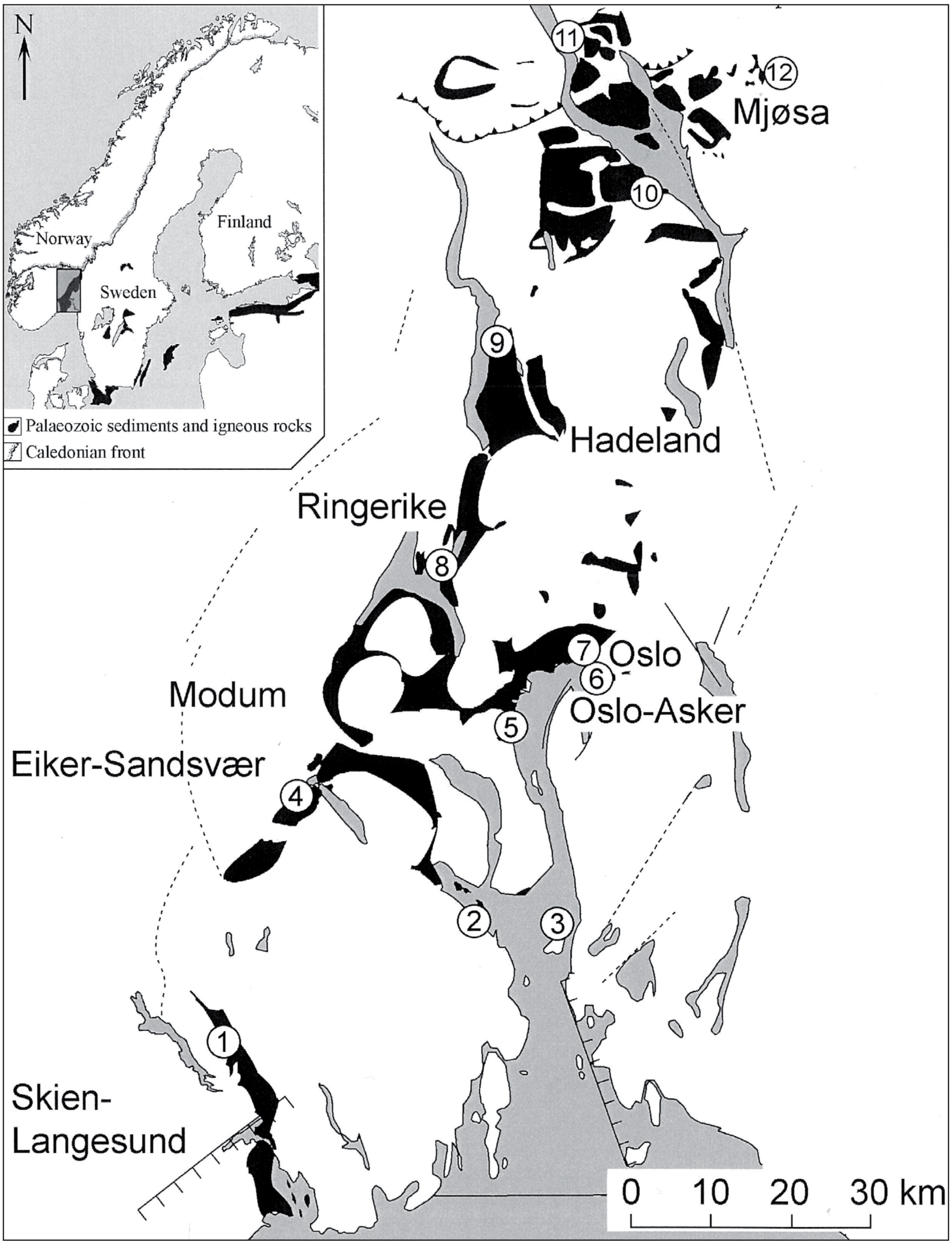

Figure 1: Map of the Oslo Region showing outcrops of Cambrian, Ordovician and Silurian rocks, in black. Important localities mentioned in the text: 1- Skien, 2- Holmestrand, 3- Jeløya, 4- Stablum, Krekling, 5- Slemmestad, 6- Malmøya, 7- Sinsen, 8- Vik, Rudstangen, 9- Røykenvika, 10- Risbakken, 11- Steinvika, Tømten, 12-Brensætersaga. Major structural elements: normal fault (barred line), fault/thrusts - (dashed line), Caledonian thrust front (barbed line). Inset map shows position of Oslo Region (box). Modified from Ebbestad (1999).

in the Evjevik Member (= *Strenuella* limestone of Kiær 1917; Evjevik limestone of Skjeseth 1963) at Tømten have yielded trilobites of the *'Ornamentaspis' linarssoni* Zone, including *Holmia kjerulfi* and *Kjerulfia lata* together with the brachiopod *Magnicanalis rotundata* and the gastropod *Latouschella* (Nikolaisen 1987). Acritarchs provide no definite age for these beds but the greenish-grey mudstones of the overlying Skyberg Member have yielded *Lophospaeridium dubium* near the base indicating that this unit is older than the *Eliasum-Cristillium* acritrach assemblage zone of Hagenfeldt (1989).

In the middle Cambrian across Baltoscandia, a succession of dark shales with intermittent, dark, bituminous limestone beds and concretions (stinkstones) makes up the Alum Shale Formation (Bergström & Gee 1985, Nielsen & Skovsbo 2007) which includes middle to upper Cambrian beds and extends into the Tremadocian. The alum shales are low in carbonate content and are enriched in a variety of trace elements including uranium, vanadium, molybdenum and nickel (Bjørlykke 1974, Andersson *et al.* 1985, Schovsbo 2000). In the Oslo Region, the middle Cambrian begins with a transgression from the northwest and there is a general diachronous overstep from north to south. The great aerial extent of Alum Shale facies over Baltoscandia indicates deposition over a stable platform in the east with thicknesses of approximately 20-30 m. Westwards in the Oslo Region, thicknesses increase to about 100 m and deepwater conditions seem to have prevailed through much

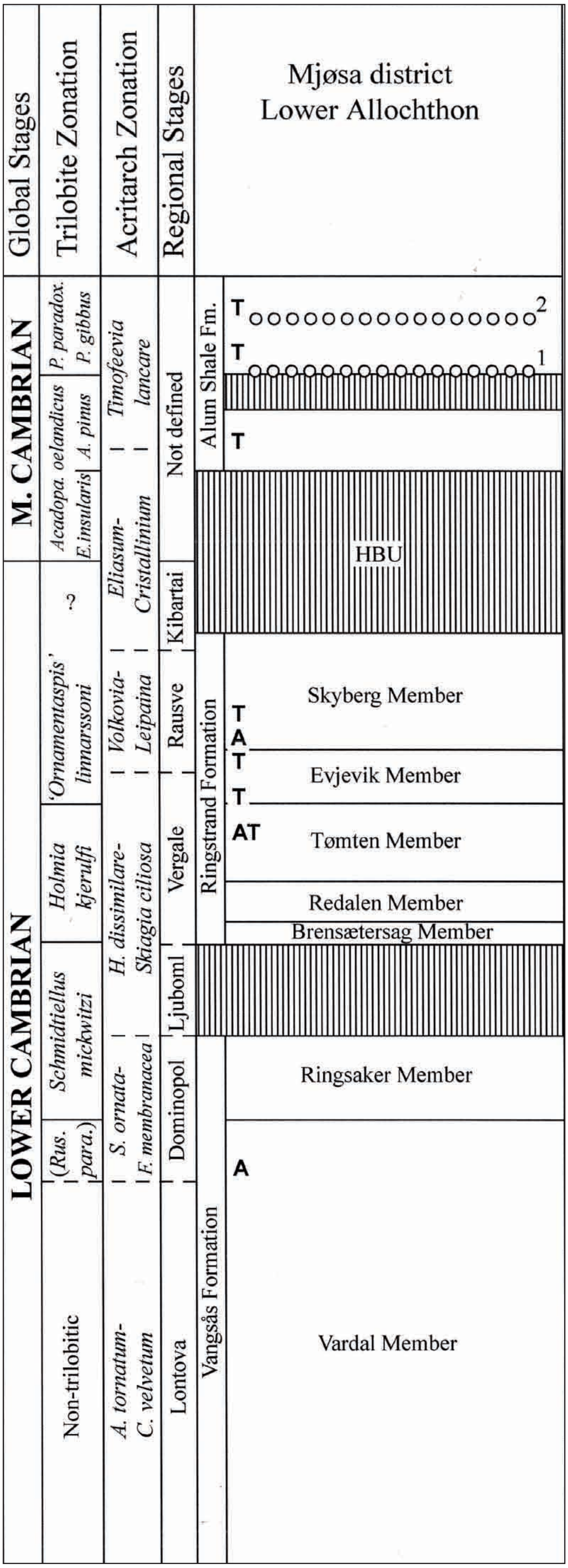

Figure 2. Stratigraphy of the Lower and Middle Cambrian in the Lower Allochthon of the Mjøsa area. Symbols: A- acritarchs, T- trilobites, open circles- Middle Cambrian conglomerates thought to be equivalent to Forsemölla Limestone[1] and Exsulsans Limestone[2] of Scania, Sweden. HBU- Hawke Bay unconformity. Modified from Nielsen & Schovsbo (2007).

of the time interval. A review of the palaeogeography for the middle Cambrian was presented by Bruton & Harper (2000, fig. 3) who identified shallow-water facies belts in Sweden and western Norway but only in the northern part of the Oslo Region.

The traditional middle Cambrian biostratigraphy of Scandinavia established by Westergård (1946) has since been modified in line with work by the International Subcommission on Cambrian Stratigraphy (ISCS) for correlations of strata worldwide (for a summary, see Axheimer & Ahlberg 2003). The high-resolution stratigraphic scheme was originally based on occurrences of certain agnostoids and one polymerid trilobite, without defining zonal boundaries. A description of the zones and defined boundaries requires well-exposed and continuous sections with determinable agnostoids and only recently have the lower boundaries of zones been defined by the stratigraphical lowest occurrences of geographically widespread index species (Peng & Robison 2000, Peng et al. 2004). The proposed global agnostoid zonation can also be applied in Sweden (Axheimer & Ahlberg 2003) and Norway (Høyberget & Bruton 2008) (Fig. 3) though in the Oslo Region the middle Cambrian sections are fragmented by faults with the exception of Krekling where Brøgger (1878) documented a well preserved succession of black shales.

The *Hypagnostus parvifrons* Zone of Westergård (1946) is based on a very long-ranging occurrence of the index species, which makes it unsuitable as an eponymous species, and this zone is now included in an extended *Ptychagnostus atavus* Zone. *H. parvifrons* appears in the middle part of the *P. atavus* Zone in Scandinavia (Brøgger 1878, Grönwall 1902, Strand 1929, Westergård 1946, Axheimer & Ahlberg 2003), becomes locally very abundant at the top of the zone (= the former *H. parvifrons* Zone of Westergård) and is still quite common high in the succeeding *P. punctuosus* Zone. Likewise, the *Solenopleura brachymetopa* Zone (named after a polymerid trilobite) is now included in the *Lejopyge laevigata* Zone since *L. laevigata* itself appears already at the base of the *S. brachymetopa* Zone (Axheimer et al. 2006).

Study of the middle Cambrian in the Oslo Region has been concentrated in the classical areas of Slemmestad (Spjeldnæs 1955, 1962) and Krekling (Brøgger 1878) west of Oslo. At Slemmestad, the Cambrian rests unconformably upon weathered Proterozoic granite and belongs to the *Ptychagnostus gibbus* Zone represented by a basal arkose followed by a thin layer of shale and a limestone

Brøgger 1878	Strand 1929	Westergård 1946		Skjeseth 1963	Peng & Robison 2000 (proposed global zonation)	Høyberget & Bruton 2008
					Glyptagnostus stolidotus Zone	*Agnostus pisiformis* Zone
					Linguagnostus reconditus Zone	
Stage 1d Zone with *Paradoxides Forchhammeri*	Zone of *Agnostus lævigatus* 1dβ	*Paradoxides forchhammeri* stage	Zone of *Lejopyge laevigata* C3	*Lejopyge laevigata* 1dβ	*Proagnostus bulbus* Zone	*Lejopyge laevigata* Zone
	Zone of *Paradoxides forchhammeri* 1dα		Zone of *Solenopleura brachymetopa* C2	*Solenopleura brachymetopa* 1dα	*Lejopyge laevigata* Zone	
Stage 1c Zone with *Paradoxides Tessini* and *Paradoxides rugulosus*	Zone of *Paradoxides davidis* and *rugulosus* 1cδ		Zone of *Ptychagnostus (T.) lundgreni* and *Goniagnostus nathorsti* C1	*Goniagnostus nathorsti* $1c\delta_2$	*Goniagnostus nathorsti* Zone	*Goniagnostus nathorsti* Zone
		Paradoxides paradoxissimus stage	Zone of *Ptychagnostus (P.) punctuosus* B4	*Ptychagnostus punctuosus* $1c\delta_1$	*Ptychagnostus punctuosus* Zone	*Ptychagnostus punctuosus* Zone
	Zone of *Paradoxides tessini* 1cγ		Zone of *Hypagnostus parvifrons* B3	*Hypagnostus parvifrons* $1c\gamma_2$	*Ptychagnostus atavus* Zone	*Ptychagnostus atavus* Zone
			Zone of *Tomagnostus fissus* and *Ptychagnostus (P.) atavus* B2	*Tomagnostus fissus Ptychagnostus atavus* $1c\gamma_1$		
	Zone of *Ctenocephalus exsulans* 1cβ		Zone of *Ptychagnostus (T.) gibbus* B1	*Ptychagnostus gibbus* 1cβ		*Ptychagnostus gibbus* Zone
	Zone of *Paradoxides ölandicus* 1cα	*P. oelandicus* stage	Zone of *Paradoxides pinus* A2	*Paradoxides oelandicus* 1cα		*Acadoparadoxides oelandicus* Superzone
			Zone of *Paradoxides insularis* A1			

Figure 3. Revised Middle Cambrian biostratigraphy of Scandinavia. From Høyberget & Bruton (2008).

bed 20-40 cm thick, fragmental in its lower part and possibly corresponding to the Forsmölla Limestone Bed in Scania, Sweden (Nielsen & Schovsbo (2007, p. 84; Fig. 2). The fragments include numerous broken shields of *Paradoxides paradoxissimus*, solenopleurids, *Ptychagnostus gibbus*, hyolithes, brachiopods and a rare helcionellid. *P. gibbus* occurs in great abundance above the fragmental layer. A thin arkosic layer is separated from the limestone by up to ten centimetres of shale. Indeterminable trilobite fragments occur in the arkose from which Spjeldnæs (1955, p. 108) reported a pygidium of *P. paradoxissimus*. Above the arkose is a shale sequence up to 1.5 m thick containing scattered limestone lenses metamorphosed by an overlying 3 m-thick Permian sill. The *Ptychagnostus atavus* Zone has not been identified, indicating a poorly developed or missing part of the middle Cambrian at Slemmestad. The metamorphosed limestone lenses contain trilobites indicative of the upper part of the *P. atavus* Zone (formerly the *Hypagnostus parvifrons* Zone). At Nærsnes south of Slemmestad, Høyberget & Bruton (2008) have discovered the first known occurrence of the *Agnostus pisiformis* Zone in the area.

In the Krekling area, a drillcore from Stablum reached sandstones of the early Cambrian between 94.28 m and 96.55 m and the overlying middle Cambrian Alum Shale extends up to the first occurrence of the genus *Olenus*, at 56.0 m. No species from the *Ptychagnostus gibbus* or the *Ptychagnostus atavus* zones have been identified in the core and the first appearance of *Agnostus pisiformis* is recorded at 68.30 m, thus leaving a total thickness of 16.63 m for the combined *G. nathorsti* and *L. laevigata* zones.

Middle Cambrian shales and limestone are exposed at low water levels at Røykenvik, Gran, along the shore of Randsfjorden. Høyberget & Bruton (2008) confirmed the allochthonous position of these beds as noted by Strand (1947). At Risbakken, Toten, a basal conglomerate of middle Cambrian age rests unconformably on the early Cambrian consisting of fine-grained sandstone, shale and conglomerates 50-200 cm thick, yielding small shelly fossils including *Torellella*, resting on a weathered gneiss. The section above the base of the middle Cambrian contains agnostoids, indicative of the upper part of the *Ptychagnostus atavus* Zone through to the lower part of the *Lejopyge laevigata* Zone and probably up to the top of the middle Cambrian.

When the water is low at Steinvika, Ringsaker, the transition between the *Acadoparadoxides oelandicus* and *Paradoxides paradoxissimus* superzones is exposed in a coarse phosphatic conglomerate at the top of a 90 cm-thick, yellow-weathering limestone bed. Below this limestone is a sequence of alternating, thin, calcareous sandstones and shale 6.50 m thick, representing the top of the *A. oelandicus* Super Zone and containing fragmentary remains of this species together with solenopleurids and inarticulate brachiopods. At approximately 8 m above the base of the section, a condensed limestone 50-110 cm thick contains a middle Cambrian fauna with species restricted to the *Ptychagnostus punctuosus* Zone in the lower level associated with a variety of hyolithids occurring in a band 10-15 cm thick (corresponding to the Hyolithes Limestone Bed of Scania and Bornholm; Nielsen & Schovsbo 2007, p. 85). In the middle of the bed, a cross-bedded conglomeratic level has yielded a mixed fauna with agnostoids characteristic of the *Goniagnostus nathorsti* and *Lejopyge laevigata* zones. The conglomerate is up to 20 cm in thickness and contains limestone pebbles surrounded by coarse crystalline calcite. The fossils are commonly fragmented and show traces of transportation. This conglomerate is probably slightly younger than that below the *Exporrecta* Conglomerate in Västergötland, Sweden, which contains fossils indicative of the *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones (Weidner et al. 2004, p .42).

The Furongian (formerly Upper Cambrian)

The Furongian alum shale facies is characterised by a low-diversity, high–abundance fauna dominated by trilobites of the family Olenidae (Henningsmoen 1957) with subordinate agnostoids. Short ranges and well preserved, easily recognisable species has led the Furongian to be divided into four agnostoid and 28 polymerid trilobite zones (Fig. 4) (Terfelt *et al.* 2008). Note that, compared with previous zonation (Henningsmoen 1957), the *Agnostus pisiformis* Zone is now assigned to the middle Cambrian (Peng *et al.* 2004). The Oslo Region has the thickest and stratigraphically most complete Furongian succession in Baltoscandia but tectonic dislocation is common throughout so the figures of 45 m in the Oslo-Asker district and the 40-57 m in drill cores from the Krekling area must be taken as approximate. Regrettably, reference sections for much of the Furongian are poorly documented but isolated sections can be identified stratigraphically, especially where the carbonate concretions (stinkstones) are present. Disarticulated trilobites abound in the concretions which are more common in the upper rather than the lower parts of the succession.

The late Furongian (*Acerocare Zone*) is missing in the Krekling cores but has been well documented in the Oslo-Asker area by Henningsmoen (1957) and Bruton *et al.* 1982, 1988). In the Skien-Langesund area, only 12 metres of Upper Cambrian strata are present, lacking parts of the *Peltura* Zone and all of the *Acerocare Zone*.

Ordovician

Throughout the world, the Ordovician is transgressive on underlying rocks but a conspicuous break occurs at the base all over Scandinavia except at Nærsnes, near Oslo, for many years a strong contender as the type reference section for the Cambrian-Ordovician boundary (Henningsmoen 1973, Bruton *et al.* 1982, 1988). Well documented dendroid graptolites (Cooper *et al.* 1998), trilobites and conodonts occur in a continuous section of alum shale (formerly Dictyonema Shale) with stinkstone concretions showing that deeper water prevailed here. Elsewhere, the process of transgression (Jaanusson 1979, p. A138-139) may have been complex and iterative rather than gradual. Near the top of the Alum Shale Formation in the Oslo-Asker area a unit of two or more planar limestone beds with a Late Tremadocian trilobite fauna forms a good marker horizon (Henningsmoen 1973, Owen *et al.* 1990). This has recently been defined as the *Incipiens* Limestone Bed by Nielsen & Schovsbo (2007). The alum shale ends abruptly with the development of the Tremadoc Bjørkåsholmen Formation, a thin (0.6-1.2 m), richly fossiliferous, micritic, limestone with trilobites of the widespread *Euloma-Niobe* fauna (Brøgger 1898, Ebbestad 1999, Egenhoff *et al.* 2010).

Series	Agnostoid trilobites ZONES	Polymerid trilobites ZONES
FURONGIAN	*Trilobagnostus holmi*	*Acerocare ecorne*
		Westergaardia scanica
		Peltura costata
		Peltura transiens
		Peltura paradoxa
		Parabolina lobata
		Ctenopyge linnarssoni
		Ctenopyge bisulcata
	Lotagnostus americanus	*Ctenopyge affinis*
		Ctenopyge tumida
		Ctenopyge spectabilis
	Pseudagnostus cyclopyge	*Ctenopyge similis*
		Ctenopyge flagellifera
		Ctenopyge postcurrens
		Leptoplastus neglectus
		Leptoplastus stenotus
		Leptoplastus angustatus
		Leptoplastus ovatus
		Leptoplastus raphidophorus
		Leptoplastus paucisegmentatus
		Parabolina spinulosa
		Parabolina brevispina
	Glyptagnostus reticulatus	*Olenus scanicus*
		Olenus dentatus
		Olenus attenuatus
		Olenus wahlenbergi
		Olenus truncatus
		Olenus gibbosus
CAMBRIAN SERIES 3	*Agnostus pisiformis*	

Figure 4: Trilobite zonation of the Furongian (Upper Cambrian) in Scandinavia. From Terfelt et al. *(2008).*

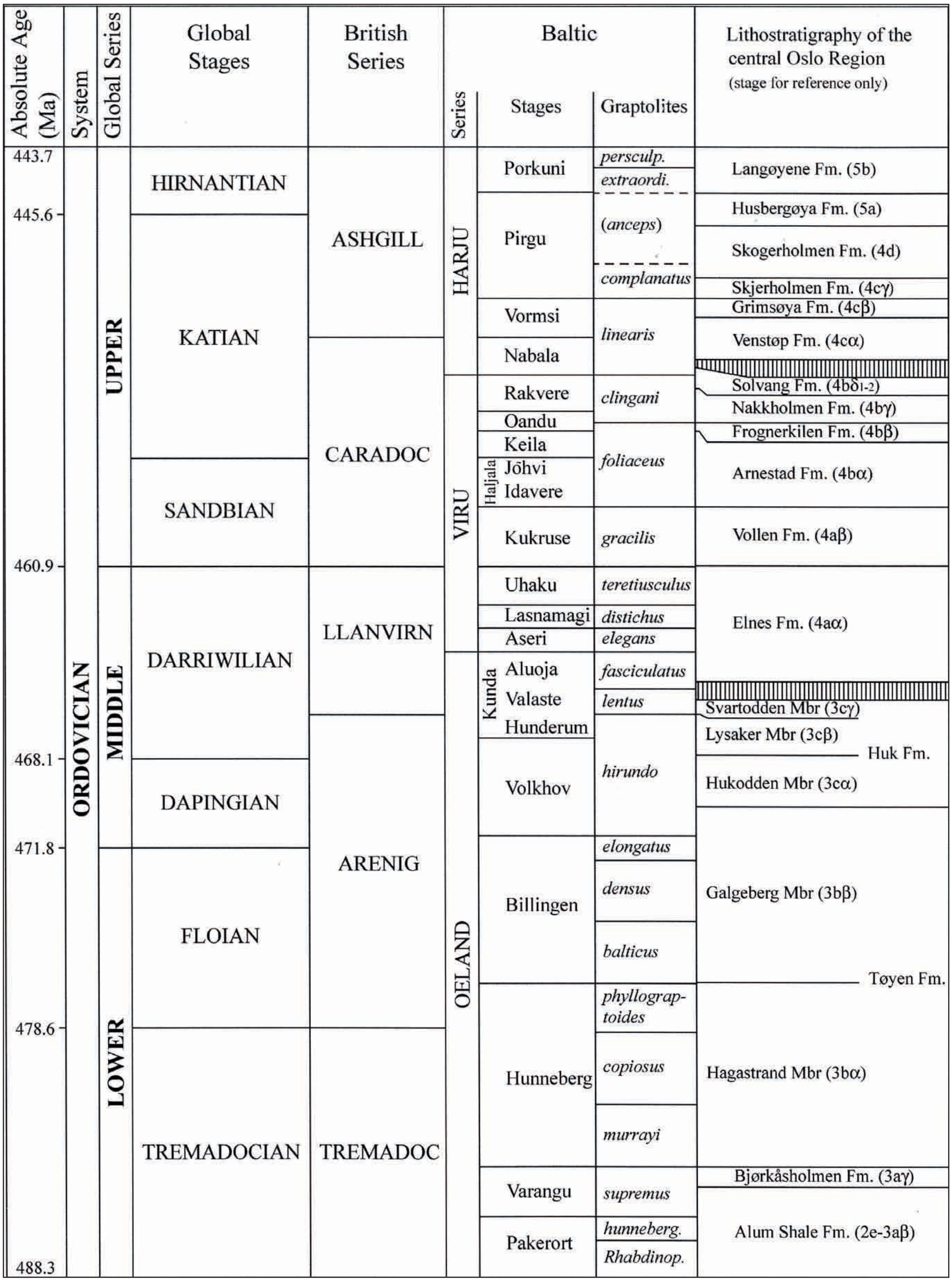

Figure 5. The correlation of the Ordovician succession of the central Oslo Region with the standard British and Baltic sequences. Note that the relative durations of the chronostratigraphical units are not equivalent to their absolute durations but are scaled to fit the detail of the Oslo Region succession. Based on Owen et al. *(1990), Nielsen (2004), Gradstein* et al. *(2004) and Dronov & Rozhnov (2007; pars).*

A sequence of pale grey and black silty shales with a thickness of >20 m makes up the Tøyen Formation of latest Tremadoc-Mid Arenig age deposited on the continental slope forming the western edge of the Baltic platform. Both the Bjørkåsholmen Formation and the Tøyen Shale can be traced westwards into the allochthonous units of the Norwegian Caledonides (Bruton & Harper 1988, Bruton *et al.* 1989, Rasmussen & Bruton 1995, Rasmussen 2001) and eastwards where they form part of the Autochthon of the Baltoscandian platform. Both here and shoreward in the Oslo Region, limestone horizons in the shale contain trilobites (Tjernvik & Johansson 1980, Hoel 1999a, b) while graptolites and acritarchs dominate in the shales (Erdtman 1965, Lindholm 1991, Tongiorgi *et al.* 2003) developed in the so-called Oslo-Scania-Lysogor confacies of Erdtman & Paalits (1994). In Norway, the Tøyen Formation is divided into two members, the pale grey, poorly fossiliferous Hagastrand Member at the base, overlain by the black, graptolitic Galgeberg Member (Owen *et al.* 1990). Discussions on the Tremadocian-Arenig boundary and the status of the Hunneberg Stage in the Oslo Region based on the contained graptolites and trilobites were presented by Lindholm (1991) and Hoel (1999a, b).

Shales of the Tøyen Formation are succeeded by another widespread limestone unit, the Huk Formation and equivalents (Owen *et al.* 1990, Nielsen 1995, Rasmussen 2001, Rasmussen & Bruton 1995). This unit covers the Volkhov and Kunda stages of the Baltic terminology and contains the Arenig-Llanvirn boundary. Biostratigraphy is based on trilobites (Nielsen 1995), conodonts (Rasmussen 2001), chitinozoa (Grahn *et al.* 1994, Grahn & Nõlvak 2007) and acritarchs (Ribecai *et al.* 2000; Tongiorgi *et al.* 2003), all indicating both transgressive and regressive events during deposition (Nielsen 2004).

So far in the Ordovician, detailed bed by bed correlation of units has been possible with equivalents in Sweden although for the remainder of the System, biostratigraphical correlation becomes less precise. However, this has recently been superseded by the application of $\delta^{13}C$ chemostratigraphy allowing a refinement of correlation within the Oslo Region and between this area and Sweden, Estonia, North America and China (Bergström *et al.* 2010; Bergstrom *et al.* in press). Complications with the biostratigraphy result from a combination of syn-depositional faulting (Bockelie 1978, Stanistreet 1983) causing changes in the topography of the sedimentary basin, and varying sedimentary regimes in the west. Thus, in the east (Sweden) the Ordovician succession is thin (commonly less than 200 m) and represents deposition rates of 2-3 mm per thousand years (Lindström 1971). These sediments, which are dominantly carbonate-rich, accumulated in distinct belts (confacies belts of Jaanusson 1973, 1976), which maintained fairly constant litho- and biofacies characteristics throughout the period. These show a deepening towards the west in the Oslo Region where mean sedimentation rates were much higher (Bjørlykke 1974a), and local successions approaching 1 km thick are known in the Oslo-Asker region (Owen *et al.* 1990). Lateral and vertical facies changes are more marked with alternating mudstones and limestones, commonly nodular, and periods of siliciclastic sedimentation occurred, especially in the Elnes Formation (Maltez 1997, Maletz *et al.* 2007, T. Hansen 2008, 2009, Candela & Hansen 2010) and later towards the end of the Ordovician (Brenchley *et al.* 1979, Brenchley & Newall 1980). To the north and south, limestones dominate in the Mjøsa and Skien areas, respectively, whereas from east to west sediments are arranged in a series of facies belts (Størmer 1967, fig. 16). Jaanusson (1973, p. 29-30) speculated that changes in sedimentation rates had both global and local causes, and since the Oslo Region occupies an intermediate position between the stable platform to the east and the developing orogen in the west, features of the successions here rather than those of the more stable Swedish platform may be linked to processes occurring within the fold and thrust belt outboard of the edge of Baltica. These phenomena are now thought to be related to early nappe movement, loading of the western margin (Hossack *et al.* 1985) and shedding of clastic material from local and exotic terranes. Thus, a progressive but gradual increase, beginning in the Early Llanvirn in the Oslo Region, in metallic elements such as manganese, iron, nickel and chromium and in detrital minerals, notably chromite, as well as higher chlorite to illite ratios in the sediments (Bjørlykke 1974a), may be related to the erosion of earlier or coeval island-arc sequences which may be *in situ*, already obducted or present within an early advancing nappe system (Bjørlykke 1974b, Schovsbo 2003, Sturesson *et al.* 2005).

Widespread volcanic ash beds, perhaps representing volcanic eruptions lasting a couple of weeks or less, have been known for many years from sections of the Caradoc Arnestad Formation (zone of *Diplograptus multidens*; Owen *et al.* 1990, J. Hansen 2007) in and around Oslo. Of these, the Sinsen section (Hagemann & Spjeldnæs 1955) has yielded four beds or complexes of beds, identified as K-bentonites by Bergström *et al.* (1995). Using conodonts, graptolites and chitinozoans (Grahn *et al.* 1994, Grahn & Nõlvak 2007) to determine their stratigraphic positions, and trace element studies and chemical fingerprinting to distinguish each ash flow, it has been possible to trace these with decreasing thicknesses from Oslo across Baltoscandia to Ingria in western Russia. The thickest bed at Sinsen (the Kinnekulle K-bentonite = BXX1 of Hagemann & Spjeldnæs 1955) occurs somewhat above the middle of the Arnestad Formation and has been directly correlated with the Millbrig K-bentonite in eastern North America (Huff *et al.* 1992). Comparative maximum thicknesses between the southern Appalachians and southern Sweden suggest that the vent responsible for producing the type of explosive pyroclastic eruption needed for such a widespread bentonite, was centred in the Iapetus Ocean somewhere between the Laurentian and Baltic plates (Huff *et al.* 2010).

T. Hansen (2008, 2009), has outlined the topography of the Oslo Region during the mid Darriwilian (zone of *Pterograptus elegans*; Maletz 1997, Maletz *et al.* 2007) and has attempted a reconstruction of the palaeogeography and depositional environments. This model can also be used for much of the Late Ordovician. Important in this interpretation is the presence of a foreland basin >200 m deep, bordered to the southeast by the main Baltoscandian carbonate platform, and a land area (Telemark Land) to the northwest. The latter not only formed a barrier to the Iapetus Ocean, but was an important source area for siliciclastic material, including the turbiditic siltstones of the Elnes Formation and a terminal Ordovician major incursion of sand bars, with well-worked, millet-seed quartz grains, deposited during a marked phase of shallowing. The latter is thought to have been glacio-eustatic in origin (Brenchley &

Newall 1980) combined with syn-sedimentary faulting (Stanistreet 1983) and resultant deep-water channelling with local block infill. Outside the Oslo-Asker area, the end Ordovician (Sandbian-Katian) regressive event is recorded by sand infilling a karst surface in limestones containing corals and stromatoporoid bioherms in Ringerike (Hanken 1974, 1979), Hadeland (Heath & Owen 1991, Braithwaite & Heath 1992, Braithwaite *et al.* 1995) and Skien-Langesund (Harland 1981b). This regression coincides with the global Guttenberg Carbon Isotope Excursion (GICE) recently identified in the Mjøsa Limestone Formation of Late Caradoc age (Bergström *et al.* 2010). This formation with its constituent reefs (Harland 1981a, Opalinski & Harland 1981) and associated sediments, has yielded a warm-water, North American, mid-continent conodont fauna (Bergström 1998) which possibly entered the area via a gulf separating Telemark Land from another land area, the Trondheim High. This gulf was also a migration route for earlier trilobite immigrants which reached the Oslo area during the early Late Ordovician (T. Hansen 2008, 2009).

In a thought-provoking paper, Braithwaite *et al.* (1995) raised doubts about the shape and depth of the Oslo Region during the Late Ordovician, the existence of a western source of sedimentation from a 'Telemarkland' and the influence of advancing nappes from this direction. Instead, they concluded that sediment was dominantly from an adjacent Precambrian source to the east and from advancing nappes shedding sediment from the north and northeast. Sediment transport, distribution, type and thickness were determined by sea-level changes on a global scale (see Nielsen & Harper 2003) or by faulting delimiting local fault basins and submarine slopes. Petrological studies showed for the first time the existence of a broad carbonate platform to the east and also the source area for the millet-seed sands. Fault-controlled sedimentary patterns were discussed and are shown to be clearly related to dated sequences. Likewise, Braithwaite *et al.* (1995) discussed various channel infills and by careful block study suggested that the channels were neither tidal-cut nor did they belong to the same time interval as their contained blocks.

Silurian

Silurian rocks amount to a roughly 1,950 m-thick sedimentary succession consisting of marine shales and limestones (Llandovery-Wenlock) and a transition to non-marine and red-bed facies at or just below the Wenlock-Ludlow boundary. Deposition of the marine rocks took place in a similar foreland basin to that described for the Ordovician with a palaeocoastline to the west but with a series of constantly shifting parallel facies towards the east.

There is a notable hiatus between the Ordovician and Silurian in the Mjøsa area (Owen *et al.* 1990) and in Ringerike (Worsley *et al.* 1983). Earlier workers (Spjeldnæs 1957, Bjørlykke 1974a) envisaged a gradual continuous transgression of the early Lower Silurian sediments in the Oslo Region but Worsley *et al.* (1983) showed that marine environments were established very early over much of the region in the Llandovery. Support for this is the diverse brachiopod fauna of the Solvik Formation in the Asker area, dominated by relict genera more typical of the Ordovician. Baarli & Harper (1986) and Baarli (1995) suggested that these were deeper water forms that survived the main extinction event of the Late Ordovician before disappearing as immigrant Silurian stocks took over higher in the sequence.

Timing of the Early Silurian transgression may be equivalent to either the persculptus or the *acuminatus* graptolite zones but this is not certain (Baarli *et al.* 2003). The trilobite *Acernaspis*, considered by Lespérance (1988) to be indicative of the *acuminatus* zone, occurs in the overlying *atavus* zone in the middle of the Solvik Formation in the Oslo-Asker area (Barnes & Bergström 1988, p. 331) and immediately above the base of the shallower water equivalent Sælabonn Formation in Hadeland (Owen & Heath 1991, p. 104; Thomsen *et al.* 2007). Owen *et al.* (2008) have assessed the shelly fauna of the lower Sælabonn Formation in Hadeland in terms of the recovery of faunas after the end Ordovician extinction event. They conclude that it comprises a mixture of environmentally very tolerant Ordovician survivor genera that continued to thrive during the Silurian together with pioneer taxa (*Acernaspis* and the brachiopod *Zygospirella*) that have no unequivocal Ordovician record but diversified rapidly and became common during the early Silurian (Rhuddanian) in many parts of the world.

Möller (1987, 1989) made a detailed study of the overlying Rytteråker Formation which is traceable over the whole region, varying in thickness from 15 m in the north to over 80 m in the south. Interbedded limestones and shales pass rapidly up into massive bioclastic limestones with coquinas of complete and isolated valves of the brachiopod *Pentamerus* overlain by small patch reefs with stromatoporoids and halysitid corals as frame builders together with favositids, rugose corals and bryozoa. These build-ups are found down slope on the seaward side of the carbonate shoals which acted as protection from an easterly terrigenous land source. This dynamic model is the reverse of the one presented by Worsley *et al.* (1983; see also Baarli 1990) and suggests a shelf lagoon to the east where terrigenous sediments were buried under the foreshore deposits of a retreating barrier belt which, in turn, was covered with patch-reef and open shelf deposits.

The remaining Llandovery units (Vik, Ek, Bruflat and Porsgrunn formations) are made up of nodular limestones and shales. Those of the Vik Formation, in its type area of Ringerike, are characteristically red in colour, whereas those of the Ek (Hamar district) and Porsgrunn (Skien area) formations are dark grey to black and con-

System	Epoch/Stage		Baltic Regional Stages	Central Oslo Region (stage for reference only)	Standard graptolite Zones
416	PŘIDOLÍ		Ohesaare	Stubdal Fm. (10)	*transgrediens-perneri*
			Kaugatoma		*bouceki*
					lochkovensis
					pridoliensis-ultimus s.l.
SILURIAN	LUDLOW	Ludfordian	Kuressaare		*formosus/balticus*
			Paadla		*koslowskii-auriculatus*
					bohemicus/aversus
					leintwardinensis
		Gorstian		Sundvollen Fm. (10)	*scanicus/chimaera*
					nilssoni/colonus
	WENLOCK	Homerian	Rootsiküla		*ludensis*
				Steinsfjorden Fm. (9)	*nassa*
					lundgreni
			Jaagarahu		*ellesae*
		Sheinwoodian			*linnarssoni*
			Jaani	Malmøya Fm. (8c-d)	*rigidus*
				Skinnerbukta Fm. (8a-b)	*riccartonensis*
					murchisoni
					centrifugus
	LLANDOVERY	Telychian	Adavere	Vik Fm. (7c)	*crenulata*
					griestoniensis
				Rytteråker Fm. (7a-b)	*crispus*
					turriculatus
					maximus
		Aeronian			*sedgwickii*
				Solvik Fm. (6a-c)	*convolutus*
			Raikküla		*argenteus*
					magnus
					triangulatus
		Rhuddanian			*cyphus*
					acinaces
					atavus
443			Juuru		*acuminatus*

Figure 6. The correlation of the Silurian succession of the central Oslo Region with the standard British and Baltic sequences. Based on Worsley et al. *(1983), Cocks & Worsley (1993), Bruton* et al. *(1997), Gradstein* et al. *(2004) and Davies* et al. *(2005b).*

tain well dated graptolites (Howe 1982, Cocks & Worsley 1993). The 80 m thick succession of the Skinnerbukta Formation now belongs entirely to the Wenlock but, as suggested by Worsley *et al.* (1983), both top and bottom are diachronous and beds farther south in the Skien area (Porsgrunn Formation) are of Llandovery age. The Bruflat Formation (Toten district) is now thought to be much thinner (Cocks & Worsley 1993, p. 41) than previously thought (Worsley *et al.* 1983, p. 27) with a strong clastic component suggestive of a shallow-water and near-shore environment. This includes a shelly fauna brachiopod and coral element indicating a Llandovery/Wenlock age and not younger as suggested by Skjeseth (1963). Both the Vik and the Ek formations contain numerous, thin, bentonite beds. Thirteen such beds from the middle member of the Vik Formation in Ringerike have been analysed and indicate two volcanic sources to the south or southwest of Oslo. Comparison with similar bentonites from the island of Gotland, Sweden, allows a tentative correlation to be made with beds belonging to the *Monograptus spiralis* Zone (Batchelor *et al.* 1995, Batchelor & Evans 2000).

The boundary between Llandovery and Wenlock is marked throughout the region by a depositional break before the establishment of open marine carbonates, represented by the Braksøya Formation, formed in an outer belt from Ringerike via Holmestrand to Skien and by a central shoaling, the Malmøya Formation, in the Oslo-Asker area. In the type area of Ringerike, the Bragsøya Formation is a biohermal unit of stromatoporoid patch reefs and beds indicative of short periods of very shallow water as indicated by the occurrence of pseudomorphs after evaporates (Olaussen 1985, fig. 2). There is a transitional unit of interbedded shales and limestones separating the Skinnerbukta Formation from the overlying Malmøya Formation which, in its type area and to the west in Bærum, consists of bioclastic limestones and stromatoporoid biostromes. In Bærum, the top of the unit bears witness to restricted marine environments of the succeeding Steinsfjorden Formation which contains seven lithofacies types deposited in supratidal, intertidal and subtidal environments (Olaussen 1985).

The base of the Steinsfjorden Formation has yielded a variety of marine invertebrates including eurypterids (Tetlie 2002, 2006). The well defined cyclicity in the upper part of the formation is attributed to either prograding events of the overlying, diachronous, Old Red Sandstone deposits of the latest Silurian Ringerike Group and/or basinal subsidence caused by local folding. The Steinsfjorden Formation, with its interbedded, red-coloured, dolomitic shales, effectively marks the beginning of the end of marine deposition in the area.

Previous stratigraphic studies of the Ringerike Group have tended to concentrate in and around the type area (Kiær 1908, 1911, 1924, Spjeldnæs 1966, Whitaker 1966, Dam & Andreasen 1990). Turner (1974) erected a stratigraphic framework which has since been elaborated on by Davies (2003) who studied the entire outcrop and later presented a revised stratigraphy (Davies *et al.* 2005b). This now includes the Sundvollen Formation, and the Stubdal Formation north of Oslo, where the group attains its maximum thickness of approximately 1000 m, and the progressively thinner Arøya and Holmestrand formations to the south. The age of the Ringerike Group is still open to debate, depending on which method is used (see Davies *et al.* 2005b, table 1), but 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 (but see Hetherington *et al.* 2004 for the age of the underlying Steinsfjorden Formation).

Much faith has been assigned to the fish microfossils (Turner & Turner 1974) found both in the underlying Steinsfjorden Formation and in the overlying sediments of the Ringerike Group, but there is a strong possibility that these are either reworked or facies fossils and are imprecise as biostratigraphic tools. The exceptional Rudstangen Fauna (for history, see Tetlie 2000, pp. 45-55) from the base of the Sundvollen Formation, contains well preserved, eurypterids, arthropods and fish (Kiær 1911, 1924, Størmer 1934, Heintz 1939, 1969) thought to be of Ludlow age, while the abundant articulated specimens of *Hemicyclaspis kiaeri* from the Holmestrand Formation at Jeløy, near Moss (Heintz 1974), provide a conclusive Přídolí age (Blieck & Janvier 1991). Thus, a north-south diachronism between the sediments at Ringerike and Holmestrand fits well with the model of the Ringerike Group being a siliciclastic sequence that advanced southwards over the underlying Steinsfjorden Formation (Davies *et al.* 2005a). The sedimentary rocks of each of the constituent formations were deposited in a complex of coastal or fluvial palaeoenvironments (Davies 2003) in which a north-south variation can be explained by tectonic activity controlling a rapid shift in sediment transport directions in a foreland basin. The basin was divided into two by the Caledonide thrust front partially separating a northern piggyback basin from the basinal area south of Oslo. A topographic barrier between the two forced the Ringerike Group fluvial systems to divert down a palaeoslope from a southward (Stubdal Formation) to an eastward (Arøya Formation) direction as they drained from a Caledonide source. Initially, the topographic high was the local source of sediment for the Holmestrand Formation until the northern basin filled and overspilled, bringing sediment from a northern source. Detailed studies by Davies *et al.* (2006) have revealed a wealth of palaeoenvironments for both invertebrates and vertebrates where some marine influence was once present. These include the eurypterid tracks in the basal Sundvollen Formation, thought to be among the earliest examples of invasion of the land in a muddy coastal plain setting (Hanken & Størmer 1975, Braddy 2004), to a plethora of various non-repichnian trace fossils specific to the varying substrates of the

Figure 7. A fresh outcrop of Cambrian alum shale with "stinkstone" concretions. Temporary excavation at Stortorget, city of Oslo. Photo. D. L. Bruton.

Figure 8. Steeply dipping Ordovician nodular limestones of the Frognerkilen Formation with dark shales and planar limestones of the Arnestad Formation below. Shore section, Fornebu, Bærum. Newspaper for scale. Photo. D. L. Bruton.

Sundvollen and Holmestrand formations. Organisms responsible for these traces were the forerunners of a major colonisation of the coastal and fluvial settings of the Early Devonian and of the later invaders of the continental interiors.

Structural history and development

Murchison (1847) and Kjerulf (1855, 1862, 1873, 1879) each recognised the extensive folding and faulting in the Oslo Region. The latter author expressed astonishment over the complex pattern of folds exposed during construction of new roads in the Oslo area in the latter part of the 19th century and observed (with reference to Kjerulf 1855) that "none of the sections, that are now uncovered, were available at that time" (Kjerulf 1879, p. 65). He went on to recognise the contractional deformation of the Oslo Region and wrote (translated) "Thus, one can here rest one's eyes on the shapes by which the sedimentary strata perform … in folds, in offsets by dislocations and thrusts" (Kjerulf 1879, p. 46). He also noted the numerous faults ("mirror planes"), associated with the folding itself, and discussed the amount of shortening involved. When studying the Ordovician rocks in the Ringerike area, Kjerulf (1862) suggested that the intense

Figure 9. Massive units of the middle Member of the Silurian Vik Formation with thin inter-layered bentonites. Road section at Garntangen, Ringerike. Photo. H. A. Nakrem.

folding seen was the result of gabbro intrusions, though later he offered no mechanism for the shortening, only noting that the dislocations might have been exploited by later magmatic intrusions (Kjerulf 1879) .

Brøgger (1882, 1890) was the first to recognise the real effect and importance of the Caledonian deformation in the Oslo Region. He presented a series of detailed structural profiles and pointed to the interrelation between folds and thrusts ('Faltungsverwerfungen'). The dominant ENE-WSW trend of the Cambro-Silurian strata and the dominant NNW dip of faults and axial surfaces were noted and he deduced that the main tectonic transport direction was from the NNW to the SSE. One should note that he also recognised SSE-dipping faults and concluded that these represented an opposite tectonic vergence to the major movement.

Working in the interior of the Caledonides, Törnebohm (1888, 1896) and K.O.Bjørlykke (1901) provided a framework for the development of the mountain belt and the position of the Oslo Region in this. Their ideas were taken further by Schiøtz (1902) who worked in the northernmost part of the Oslo Region. He attempted to calculate the displacement of the uppermost sandstones of the upper parts of the 'sparagmite' (Osen Nappe of Nystuen 1981, 1983, Bockelie & Nystuen 1985) and concluded that they had been transported 30-40 km towards the south. The general view of the allochthonous nature of these units was later supported by Zenzén (1932) and Asklund (1933) and furthermore, the involvement of the basement in the contraction was demonstrated by Törnebohm (1896), Zenzén (1932) and G. Holmsen (1935, 1937). However, the amount of displacement (Holtedahl 1915, 1930, Ramberg & Englund 1969, K. Bjørlykke 1974a, 1978, Morley 1986a) is still a matter of conjecture. It was not until the 1980s that serious attempts were made to place the Oslo Region in the context of the developing Caledonide Orogen. Thus, Ramberg & Bockelie (1981), Nystuen (1981, 1983), Harper & Owen (1983) Bockelie & Nystuen (1985), Hossack & Cooper (1986) and Morley (1986a, b, 1987a, b, 1994), together, provide excellent regional structural syntheses of the Oslo Region, based on modern concepts and the increasing knowledge of orogenic processes. Below we highlight new interpretations of the folding and thrusting affecting the entire Lower Palaeozoic sequence and identify some of the remaining unsolved problems surrounding the Caledonian contraction of the Oslo Region. We illustrate this with examples from the southern part of the region, between Klekken and Slemmestad (Fig. 10) and our aim is to systematize previous and recent structural data on the Caledonian deformation in the Oslo Region and use them as a basis for a general structural synthesis. Based on tectonic transport direction, transport length and structural style, we divide the area into four structural subareas. Furthermore, by correlating major thrust levels and structural styles we suggest that four levels can be distinguished. These are separated by major thrusts (flats) and characterised by distinct structural styles and strain intensities.

Regional setting

Closing of the Iapetus Ocean between the Laurentian and Baltican plates, and the onset of the Caledonian Orogeny in southern Norway, led to the extensive formation of thrust sheets (e.g., Gee 1975, Bryhni & Sturt 1985) associated with an E to SE transport direction (present coordinates). In detail, however, areas with significant compo-

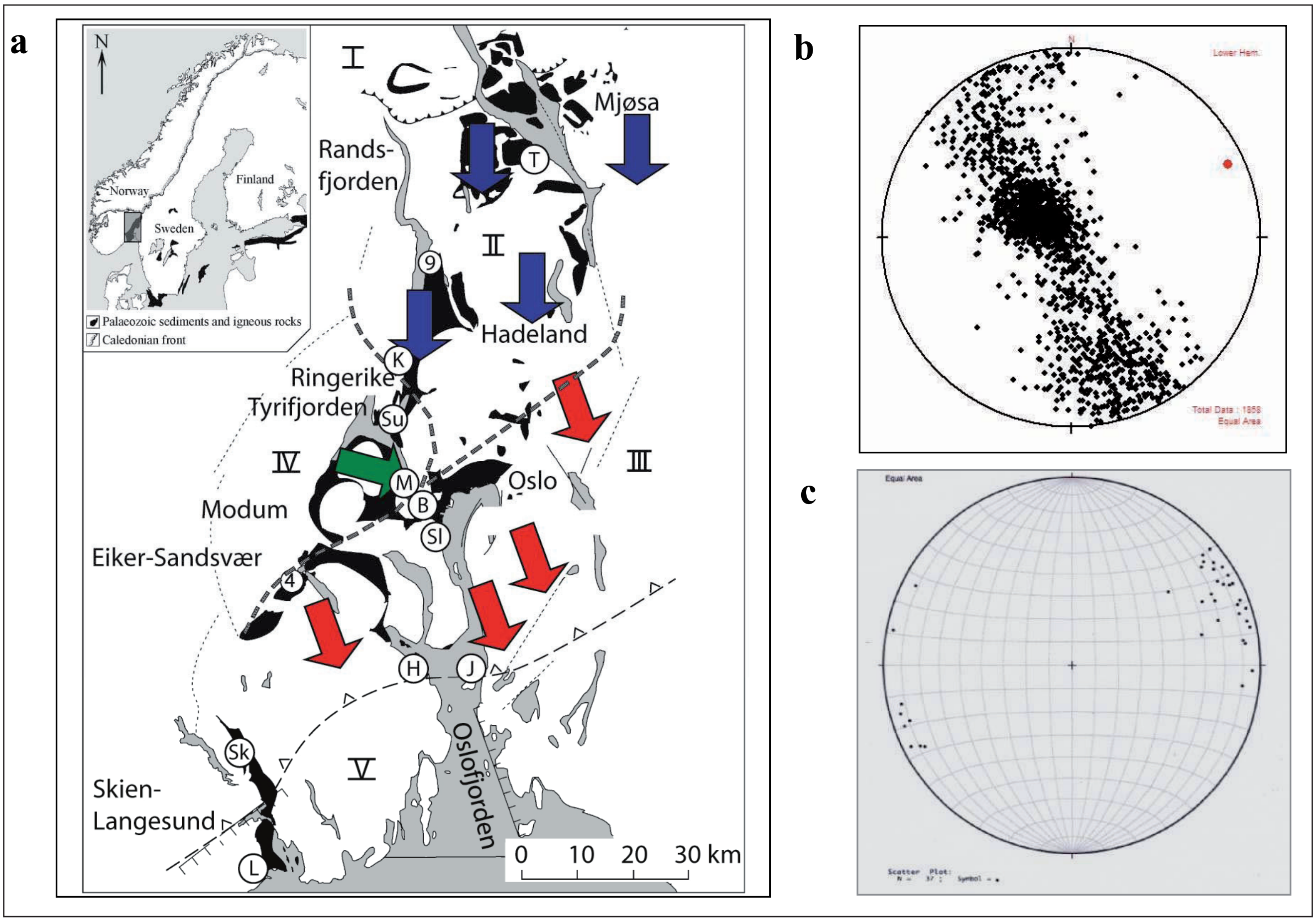

Figure 10. (a) Structural key map, Oslo Region , with main tectonic sub-areas (Roman numerals I-V), key localities (circled letters) and main tectonic transport directions (arrows). The tectonic sub-areas are characterised by decreasing transport length and strain intensity from north (sub-area I) to south (sub-area V), where transport length is zero. Locality sites: B = Bjerkås, H = Holmestrand, J =Jæløya, K = Klækken, L = Larvik, Sk = Skien, Sl = Slemmestad, Su = Sundvollen, T = Toten. Localities 4 and 9 are Eikern and Brandbu, respectively.

(b) Stereoplot, lower hemisphere, poles to bedding surfaces in the Klekken – Ringerike – Slemmestad areas (n = 1858) and statistical fold axis (β). (c) Fold axes from the Klekken – Ringerike area (n = 37).

nents of top-to-the-ENE movement, such as in western Norway (Fossen 1998) and in the Oslo Region (Størmer 1934, Morley 1987b), as well as a local NE transport (Fossen *et al.* 2006) have also been documented. Additionally, a complex Caledonide pattern of late- and post-orogenic westerly and transverse (NE-SW-trending) extension has also been observed (Andersen 1998, Fossen 1998, Braathen *et al.* 2002, Osmundsen *et al.* 2006).

The earliest collision occurred in the westernmost part of the Fennoscandian Shield during the Tremadoc at around 485 Ma (Gradstein *et al.* 2004) and the closing of the Iapetus Ocean was complete by the Ludlow (late Silurian) at around 420 Ma (Pedersen *et al.* 1988, 1992, Hossack & Cooper 1986). The first indirect effect of nappe translation along the western Baltoscandian margin of the shield recorded in the Oslo Region is in the latest Llandovery (dated to approximately 430 Ma; Gradstein *et al.* 2004). Input of coarse, clastic sediments, reflecting erosion of the growing mountain chain in the west and northwest, took place in several pulses from the late Ordovician (Katian) to the latest Silurian (?Pridolí). Earlier obduction and erosion of mafic, tholeiitic seafloor from the Iapetus Ocean is also reflected by the increased influx of elements such as iron, manganese, nickel and chromium from the early Ordovician (Llanvirn) and onwards (Bjørlykke 1978, Hossack *et al.* 1995).

Structurally and traditionally, the Oslo Region has been subdivided into a northern regime of nappes consisting of Neoproterozoic rocks (the Osen–Røa Nappe Complex of Nystuen 1981) and a southern regime of folded autochthonous/parautochthonous Cambro-Silurian sedimentary rocks. The two were considered to be separated by the 'Caledonian nappe front' (e.g. Skjeseth 1963) (Fig. 10), situated around the northern part of Lake Mjøsa. Oftedahl (1943), however, realised that the basal thrust, occurring beneath the Neoproterozoic 'sparagmite', could be followed southwards beneath the Cambro-Silurian sediments of the Oslo Region and calculated a shortening of

50% for that area. This correlation was confirmed in later studies (Høy & Bjørlykke 1980, Nystuen 1981, Ramberg & Bockelie 1981, Bockelie & Nystuen 1985 and Morley 1986a). Thus, the final position of the thrust front is now considered to have extended from the Moss-Horten area, across the Oslofjord to a point north of Langesund and beyond to east of Lista (Hossack & Cooper 1986, Morley 1986b, Abramowitz *et al.* 1998, Abramowitz & Thyboe 2000) (Fig. 1). There is some dispute as to whether or not the frontal thrust terminates in a blind imbricate north of Langesund (Ramberg & Bockelie 1981, Bockelie & Nystuen 1984, Morley 1986b). However, what is clear is that the 'Osen-Røa thrust sheet' includes the imbricate units in the Asker and Bærum districts of the Oslo Region (Morley 1986b, p. 621), and the term 'Osen-Røa thrust' can be applied for the basal thrust as far south as it is traceable. Of interest in this connection is the fact that Oftedahl (1943) proposed the term 'Oslo thrust' for the basal fault in this part of the system.

The Oslo Region is situated within the external, frontal zone of the Caledonian Nappe System and exhibits many of the typical characteristics of such systems, including a pronounced basal thrust, from which splay faults define several detachment levels. These, in turn are associated with imbricate stacks, back-thrusts, duplexes, harmonic and disharmonic folds, lateral, oblique and transverse ramps, and deformed foreland basin units (nomenclature of Dahlstrom 1970, Boyer & Elliot 1982, Nystuen 1989). The deformational style is not uniform, but changes along the strike of the thrust front, parallel to the main thrust direction, due to decreasing transport length towards the south and southeast, and vertically within the nappe pile, due to variations in lithology, thickness of the deforming unit, stress situation, basement relief and depth of burial. From north to south, the sole thrust cuts up-section and defines a ramp and a cut-off line (of the Vangsås Formation; Morley 1986a), whereas the style of an imbricate stack reappears farther north in the vicinity of Lake Mjøsa (Voigt 1953, Nystuen 1983). Here, the two thrust levels merge to define a complete duplex, the 'frontal duplex' of Hossack & Cooper (1986).

Caledonian deformation has, to a varying degree, affected the greater part of the Lower Palaeozoic sedimentary succession in the Oslo Region but shows contrasts of style (Spjeldnæs 1957, Morley 1986b, 1987a, b, 1994, Naterstad *et al.* 1990) depending on the mechanical properties of the units affected, the tectonic position within the thrust system, as well as on the regional, tectono-sedimentary, time-dependent development of the thrust sheets. Thus, the principal Caledonide structure of the greater Oslo Region is that of a frontal duplex in some areas and that of an imbricate stack in others. The style of thrusting and folding also varies from the bottom to the top of the tectonosedimentary succession (Fig. 11). Although the dominant structural grain is oriented ENE-WSW, the thrust direction and style of deformation are not entirely uniform in the Oslo Region. Thus, in Ringerike, north of a line from Klekken and across Stubdal, the fold axes have an E-W strike (Harper & Owen 1983), whereas in the Oslo-Asker area they are distinctly NE-SW to ENE-WSW. Also, locally, and particularly in Ringerike, there are areas where NE-SW-trending structures have been rotated to strike E-W. (Størmer 1934, Larsen & Olaussen 2005) (Fig. 10).

The tectonostratigraphy of the Oslo Region

The total thickness of the Lower Palaeozoic succession of the Oslo Region is around 2000 m (Bockelie & Nystuen 1985) and erosional remnants of these rocks, up to several hundred metres thick, are preserved within the Oslo Graben that formed during Carboniferous-Permian time. The structural style of the uppermost parts of the succession is strongly influenced by the >1000 m thick (Worsley *et al.* 1983), mechanically competent, continental sandstones forming the Ringerike Group.

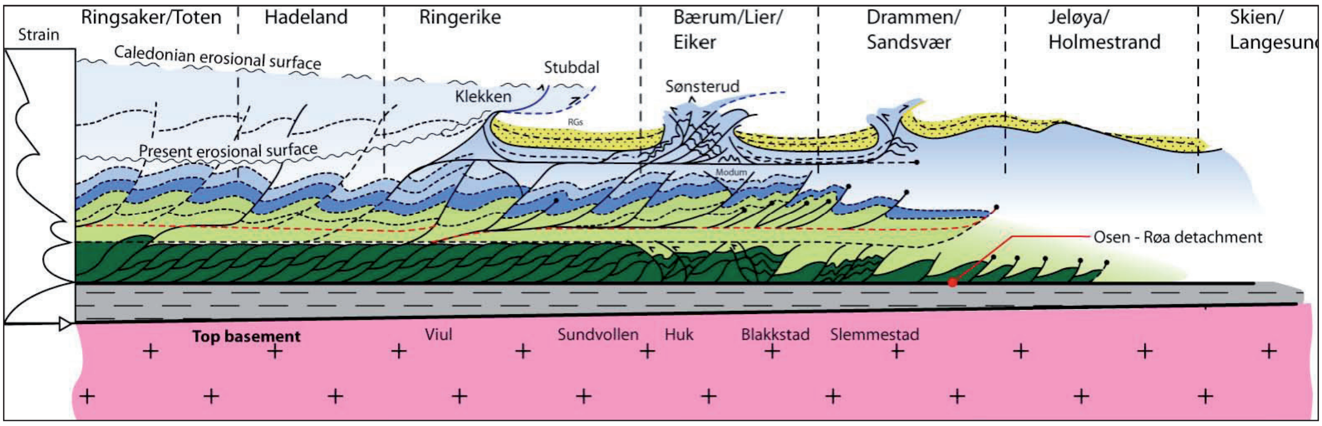

Figure 11. Schematic, tectonic, NNW-SSE (left to right) cross-section of the Oslo Region displaying the four principal structural levels (see text). The present and the Caledonian erosional surfaces are indicated to the north, where the sequences have not been protected by the Permian volcanic rocks. The curve to the left schematically indicates the strain intensity distribution associated with each structural level. The figure is not to scale.

All in all, we have recognised four principal structural levels, each characterised by a distinct (Caledonian) structural style, in the Lower Palaeozoic succession of the Oslo Region (Fig. 11). Fault ramps, duplexes and fold trains are associated with each of these levels. A similar situation is reported for the Osen–Røa Nappe Complex, containing both the Osen-Røa thrust proper and the Stubdal thrust (Morley 1986a). The latter ramps up-section (to our structural level 4) and was then eroded (Harper & Owen 1983), whereas the former is restricted to the Alum Shale Formation at levels 1 and 2.

Although the dominant Caledonian ENE-WSW structural grain in the Oslo Region has been known since the time of Brögger (1882), detailed documentation in the form of published structural data is sparse (Harper & Owen 1983, Morley 1987b). Figs. 10b and 10c show our new data from a section between Klekken and Slemmestad and illustrate the overall structural picture, of a dominating ENE-WSW trend of strata and the corresponding (statistical) fold axes.

Structural level 1. The basal thrust system

The generally flat, basal thrust in the Oslo Region (equivalent to the Osen–Røa thrust/detachment) underlies the entire allochthonous/parautochthonous pile and, as such, is the most fundamental tectonic discontinuity in the area. Field relationships of the thrust can be studied in great detail at localities such as Viul, in Ringerike (Fig.10) where it is underlain by the up to 75 m-thick, black, Middle Cambrian to Furongian Alum Shale (Strand 1960, Berthelsen *et al.* 1969, Harper & Owen 1983, Bockelie & Nystuen 1985, Naterstad *et al.* 1990; Fig. 12). This implies that autochthonous and parautochthonous shales separate the lowermost thrust and its associated imbricate stack from the undeformed Proterozoic basement. The basal thrust *sensu stricto* is consequently positioned within the Cambrian Alum Shale Formation. With one exception near Klekken (F. Bockelie *pers. comm.* 2007), the master thrust plane is nowhere seen to cut down into the basement, or to involve the basement, as it does in the western and central parts of the Norwegian Caledonides (Holtedahl *et al.* 1934, Nystuen 1983, Bockelie & Nystuen 1985, Fossen *et al.* 2006). Although lack of exposure prevents confirmation, it has been regarded likely that the basal thrust steps up and dies out as a blind fault trace in the Cambrian sequence between Jeløya-Holmestrand and Skien-Langesund (Oftedahl 1943, Nystuen 1983, Morley 1986a).

The autochthonous/parautochthonous rocks are affected by a vast number of slip surfaces and folds on all scales (Ramberg & Bockelie 1981, Morley 1986a, Hossack & Cooper 1986). The entire package is characterised by a variable style of deformation and strain intensity, from cases where the Alum Shale is completely undeformed to where all primary structures are obliterated over a distance of a few centimetres. Contractional, north-dipping faults and asymmetrical folds with overturned lower limbs and north-dipping axial planes, with wavelengths of 3-4 m and amplitudes of 4 m, occur frequently in the Alum Shale Formation. In some cases, parasitic folds are associated with larger structures (see also Morley 1986b). Three generations of cleavage can be identified. The oldest cleavage has been folded, whereas the youngest is more commonly preserved and is sub-horizontal and parallel to the master basal thrust fault (Lutro *et al.* 2000). The second cleavage generation (of intermediate age) is associated with the axial planes of the larger folds. The total thickness of the succession affected by the basal thrust typically varies between 10 to 50 m.

In Ringerike and at Slemmestad, the Alum Shale of the lowermost detachment is intensely folded with upright axial planes and very large amplitude/wavelength ratios. This fold-style is commonly associated with very steep reverse faults with displacements in the order of a few metres up to 20 m or more. Morley (1994) suggested that such reverse faults developed late in the deformational history and at a stage when the intense folding could no longer accommodate shortening. In some places, the structural picture of the Alum Shale is masked by the intrusion of maenaite (mica syenite) sills (310 – 304 Ma) such as at Kistefoss (mapsheet 1815 II; UTM 759 770) and Slemmestad (mapsheet Asker, UTM 845 283) (Spjeldnæs 1955, Sundvoll *et al.* 1992, Sundvoll & Larsen 1994, Larsen & Olaussen 2005) where the sills climb up-section and intrude along the sheared margins of the horses as at Viul (map sheet 1815 III Hønefoss UTM 737 745). In the central and northern areas, the basal thrust zone is overlain by a contractional zone that generally constitutes a hinterland-dipping duplex system or an imbricate fan. To the south, the contractional system may be developed as a leading imbricate fan. The basal thrust is associated with splays that propagate up-section mainly in the transport direction, leading to the development of imbricate fans, hinterland-dipping and foreland-dipping duplexes, and antiformal stacks at scales of tens of metres.

Examples of the deformational style in the shale immediately above the basal thrust can be seen in the eastern riverbank section along Randselva at Viul (mapsheet 1815 III Hønefoss UTM 737 745) (Fig. 12), and another in the railway section, about 20 m above the river bank. Here, a hinterland-dipping duplex system of four separate horses is exposed in a section about 100 m wide. The horses are separated by decimetre-wide thrust faults, occurring at intervals of 10-15 m and dipping approximately 30o - 40o to the NNW. Zones of Alum Shale are concentrated along the margins of the duplex, where it is strongly sheared. The interiors of the horses are structurally chaotic and lithologically inhomogeneous and encompass shear lenses of shale and limestone and disrupted, disharmonic folds in the same rocks (Fig. 12). Second-order (dm-scale) duplexes and folds are com-

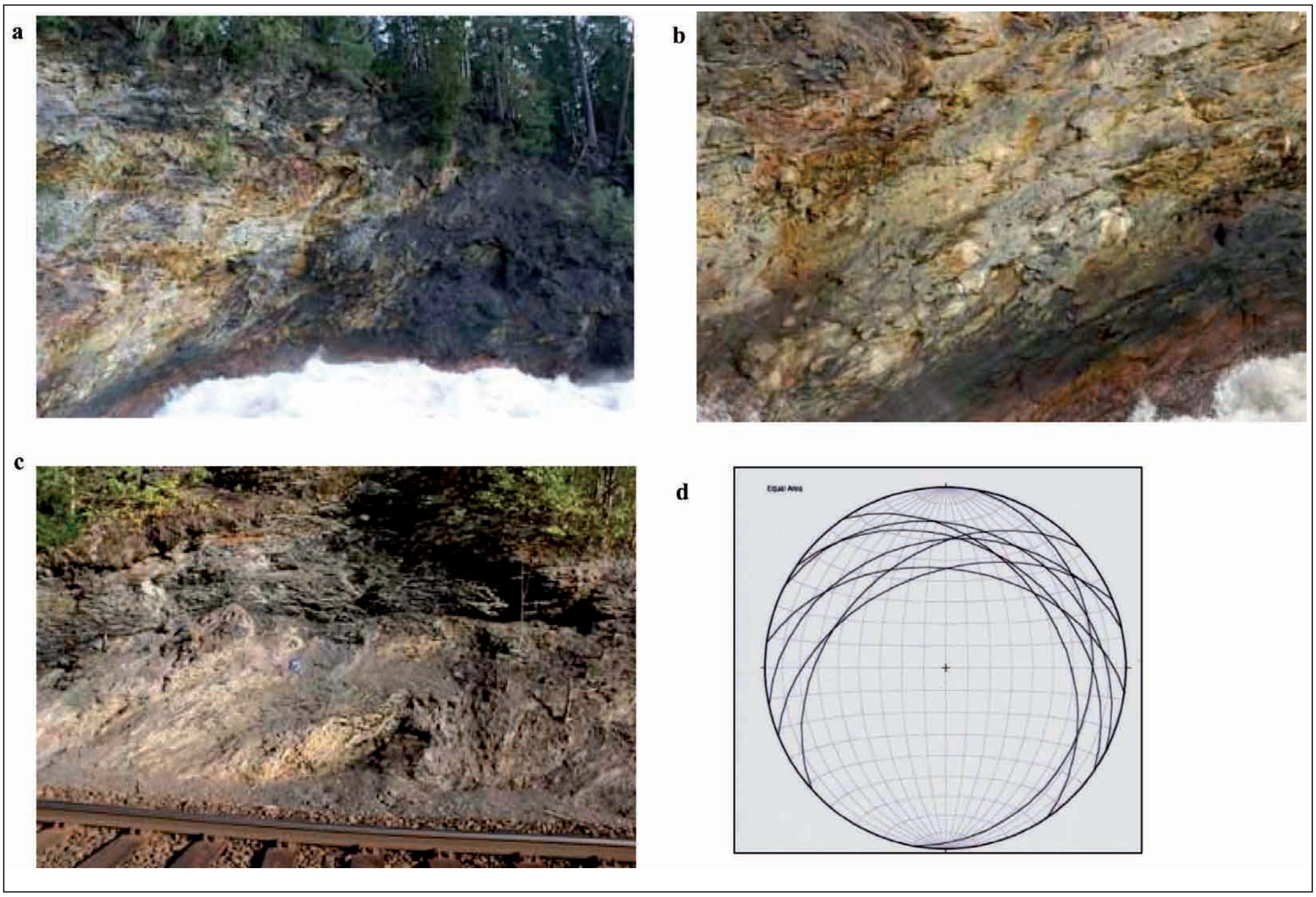

Figure 12. Basal thrust system at Viul (structural level 1). (a) Secondary splay faults associated with the basal thrust. The height of the tree in the middle right of the picture is c 1.5 m. (b) Border zone between horses in the lowermost, exposed part of the duplex shown in (a). Note the strong fragmentation of limestone beds along fault plane. (c) Upper part of the main duplex, with faults flattening and merging with the roof-fault. (d) Stereoplot, equal area, lower hemisphere, great circles to contractional faults associated with the Viul duplex system suggesting regional, southerly transport, but also transverse shortening on the local scale (n= 8).

monly associated with the master shear zones of the margins of the horses, and zones of coarse breccia and cataclasites are seen in association with these shear zones. In the Viul area, the transport direction is towards S to SSE (Fig. 12d), which is in accord with the general transport direction in the area as inferred from geological correlation and structural maps.

Another section through the basal thrust system and its shallower, branching splay faults is exposed at Slemmestad (mapsheet Asker, UTM 842 283) (Ramberg & Bockelie 1981, Naterstad *et al.* 1990, Morley 1994). Here, the basal thrust involves the Furongian shale and the overlying Ordovician Tøyen, Huk and Vollen formations (Fig. 13). In the Cambrian shale, the style of deformation is similar to that seen at Viul, viz., horses with numerous internal shear planes, disrupted lenses and disharmonic folds. Typical amplitudes and wavelengths vary from decimetres to metres. Secondary reverse faults and thrusts that splay out from the basal master thrust zone are common in the more competent beds and are characterised by much wider separation between thrust zones and folds with wavelengths varying between a few metres and 100 metres. The fold geometry is also highly variable from open upright structures to tight and even small, overturned, isoclinal folds. The latter types are mainly associated with thrust faults and are fault-propagation folds (Fig. 13; see also Morley 1986a, 1994). The dominant transport direction in the Slemmestad area is SSE, and backthrusts are locally important between Hjellum and Heggedal (Naterstad *et al.* 1990). It is striking that the thrust faults commonly cut the frontal limbs of the overturned folds, rather than the hinge lines, as would be expected for fault-propagation folds. This situation, combined with an analysis of strain distribution along fault planes, led Morley (1994) to conclude that many contractional faults at this tectonic level were nucleated within folds in the massive limestone beds of the Huk Formation, propagating both up-section and down-section from this level.

It can be concluded that the basal thrust *sensu stricto* is restricted to the Alum Shale Formation, causing folding and imbrication throughout the Cambrian strata, with

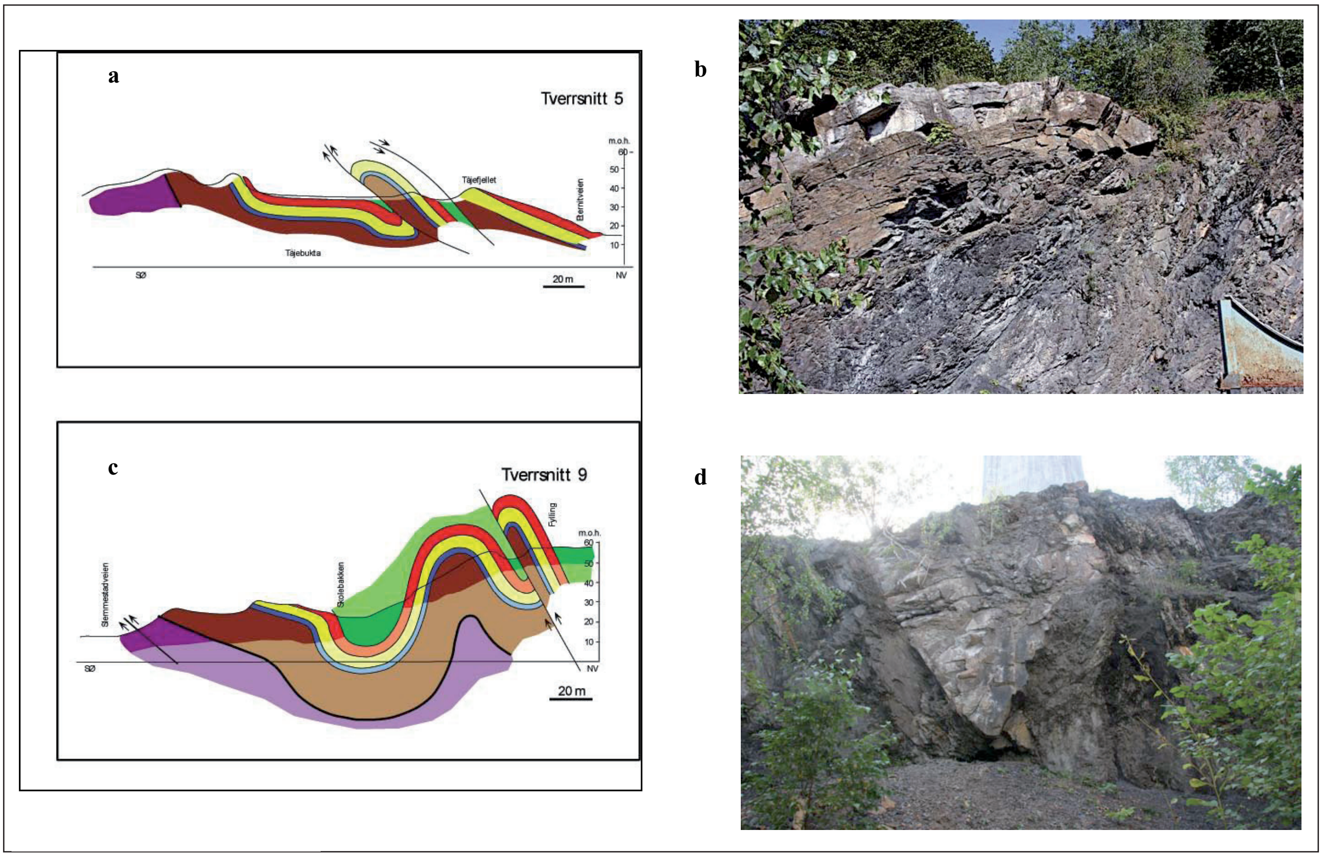

Figure 13. Folds, reverse faults and thrusts associated with structural level 1 at Slemmestad, western shore of the Oslo fjord (mapsheet Asker, UTM 845 283). (a) and (b) Top-to-the-SSE low-angle thrust and associated, disrupted folds. Note numerous reverse faults in footwall. Here, limestones of the Huk Formation are thrust above rocks of the Tøyen Formation (both Lower Ordovician). (c) High-angle, reverse fault and (d) sheared, isolated fold hinge (Huk Formation) delineated by steep reverse faults. Figures (a) and (c) kindly provided by John Korstgård, University of Aarhus.

the development of individual horses separated from each other by distances of up to tens of metres. Similar shortening in the overlying Ordovician shales and limestones developed partly by upward splaying of fault branches, but also by primary folding and the development of secondary contractional faults, caused by space problems along the fold hinges. The system is characterised by horses and associated folds with wavelengths in the order of up to 100-300 m. The total thickness of the affected units and hence the maximum wavelength of the associated folds is of the order of 50-100 m.

Structural level 2. The middle thrust system

Although the strain intensity generally decreases upward above the basal thrust (Bockelie & Nystuen 1985, Morley 1986a, 1994), zones of strong deformation are common throughout the entire Lower Palaeozoic succession of the Oslo Region. Because larger areas of basically flat-lying strata are interrupted by zones of intense deformation with single folds, trains of folds and contraction faults, it is reasonable to assume that a ramp-flat-ramp geometry prevails. However, very few flats with intensely sheared weak rocks have yet been identified above the Lower Ordovician units. Examples of distinct ramps can be studied north of Klekken, in the Horn-Pålsrud area (mapsheet 1814 IV Lier; UTM 715 486) and at localities (Holmen, Fornebu) along the western shore of the Oslo fjord. Here, the major thrust plane appears to affect mainly the Ordovician-Lower Silurian succession.

The deformation associated with structural level 2 involves reverse faults, imbricate thrust sheets and asymmetrical, overturned folds above contraction faults with listric shapes. Most exposed folds at this level are second- and third-order structures and it is common for such fault traces to terminate as blind structures within the pre-Hinantian sequences. The lower faults vary in dip between 10° and 60° with lower angles typically down-section. The deformation varies in intensity, reaching up to 20 repetitions in less than 400 m in the limestones of the Stein Formation (Skjeseth 1963). An average imbricate repetition of one thrust per 150 m is typical for the Mjøsa district (Morley 1987a) and also generally in the areas delineated to the south by the Klekken fault. The intensity of imbrication is lower in the Oslo area. The beds contained inside each horse can be strongly folded, and the presence of numerous minor reverse faults, many of which are blind, suggests horizontal shortening of the horses. This shortening is commonly accentuated by back-thrusting.

No regional detachment zone has been observed in relation to level 2, though several subhorizontal thrust branches at this level can be seen or inferred. For example, between Nordre Horn and Pålsrud in Modum (UTM 717 480; Fig. 14) an isolated zone of deformation is dominated by disharmonic upright folds with steeply dipping to vertical axial planes (Gunby *et al.* 2003). Reverse faults that cut off fold limbs are steeply dipping (mostly between 60° and 70°) and back-thrusts are common. In the dominantly thick-bedded limestones of the Ryteråker Formation, which has the highest mechanical competence of the succession, folds display a box-like geometry and are more rarely faulted. The fold axes trend ENE-WSW. All structures at this locality are affected by a late generation of top-to-the-south, shallowly dipping thrust faults, which accommodate displacements in the order of centimetres to decimetres.

Ramps thought to be related to the second structural level are common along the western shore of the Oslo fjord (Figure 15). At Holmen (UTM 838 363), a ramp involving beds of the Upper Ordovician has a strongly sheared base formed by shale of the Venstøp Formation. This shale shows a style of deformation with shale lenses, sheared-off, isolated isoclinal folds and protocataclastically deformed limestone beds, similar to structures in the Alum Shale at Viul. Beneath the shale, the nodular limestone-shale sequence forming the footwall is cut by numerous calcite-filled, lowangle, strongly striated, shear surfaces, up to ten metres below the master fault. Similar ramps associated with sheared shale and calcite mineralization are found elsewhere in the Upper Ordovician rocks at Veritasparken (UTM 875 403) and along Fornebustranda (UTM 915 417) (Fig. 15b, c). From the occurrence of distinct zones of imbrication duplexes and intense folding separated by larger areas of flat, undeformed sequences, it is natural to assume that a system of climbing ramps hard-linked to flats exists above the basal thrust level. It is not yet possible to determine which are the most important thrusts in this system, but reports that shales of the Ordovician Elnes and Arnestad formations vary considerably in thickness (Owen *et al.* 1990), make these units good candidates for such detachments. The size and geometries of structures associated with the second structural level vary considerably and structures of several orders of magnitude are involved. Hence, amplitudes and wavelengths occur from the scale of a metre and upwards. Typical first-order wavelengths are in the order of 100-500 m and amplitudes are commonly between 50 and 100 m.

Figure 14. Duplex/fold train in the Lower Silurian Solvik Formation at Horn/Pålsrud, western shore of Hornsfjorden, below structural level 3 (mapsheet 1814 IV Lier; UTM 715 486). (a) Schematic cross-section, (b) details around the major fold in a stitched photograph of a 70 m long transect of the section. (c) fold axes (equal area, lower hemisphere) measured along the entire section displayed in figure (a) (n = 15).

Figure 15. Low-angle and subhorizontal top-to-the-SSE thrusts affiliated to structural level 2. (a) Approximately 1 m-thick duplex zone in the lowermost part of the Upper Ordovician Grimsøya Formation above black shales of the Venstøp Formation at Husbergøya, Inner Oslofjord. Width of section c. 25 m. (b) Thrust contact between limestone of the Middle Ordovician Vollen Formation and black shale of the Upper Ordovician Venstøp Formation at Fornebustranda, western shore of inner Oslofjord; looking SW. Width of picture c. 3 m. (c) Ramp associated with structural level 2 in the Elnes and Vollen formations at Fornebu, western margin of inner Oslofjord; looking SW. Length of the profile is approximately 30 m.

Structural level 3

The third structural level is characterised by thrusts that are probably linked to the second level by upward-ramping fault planes. Such ramps are not commonly exposed but at Sundvollen (mapsheet 1815 III Hønefoss, UTM 725 601), the uppermost thrust flattens below the sandstones of the Ringerike Group. Normally, the interior of the sandstone basin is undeformed, but where the thrust ramps climb up-section, as at Sønsterud (mapsheet 1814 IV Lier; UTM 723 513), the sandstones become steeper very abruptly, and are in places even vertical or slightly overturned (Fig. 11). Structures within the ramps are very complex. At the levels immediately beneath the thick Ringerike Sandstone, the Rytteråker, Vik, Bruflat and Steinsfjorden formations are strongly folded, faulted and sheared (Fig. 16), in some instances with the characteristics of a tectonic mélange (Halvorsen 2003). The fold axes are oriented NE-SW with variable axial plunges. The fold geometry varies from open to (disrupted) isoclinal. The deformation in these zones is too intense to work out a precise structural chronology, but the zones have a strong imprint of back-thrusting that post-dates all other structures. Moreover, the contractional faults in the ramp zones are over-steepened and commonly display dips in the order of 70-80°. In some cases, they are even overturned. This indicates that the ramps probably nucleated in areas of previous buckle folding in the competent Ringerike Group sandstone, so that extremely steep ramps developed, perhaps associated with triangle-zones and potential pop-ups. A similar situation to that described for the Ringerike area is present in the sandstones of the Ringerike Group and the Steinsfjorden Formation of Bærum and perhaps also in the Drammen area (Fig. 11). However, farther south, the uppermost thrust dies out and fold intensity decreases. Also, the Upper Silurian sandstones in the Jeløya - Holmestrand - Skien areas are not deformed.

At Garntangen (Ringerike; mapsheet 1815 III Hønefoss, UTM 725 601) (Fig. 16), a flat in a thrust linking levels 2 and 3 can be seen exposed in a c. 400 m-long, NW-SE-oriented section involving the Llandovery Vik and Bruflat formations. Parts of a series of three separate horses of an antiformal stack are exposed. Strata to the northwest and to the southeast are flat-lying, indicating that the structure at Garntangen was developed above an extensive ramp in the master fault. Horse 1 (Fig. 16)

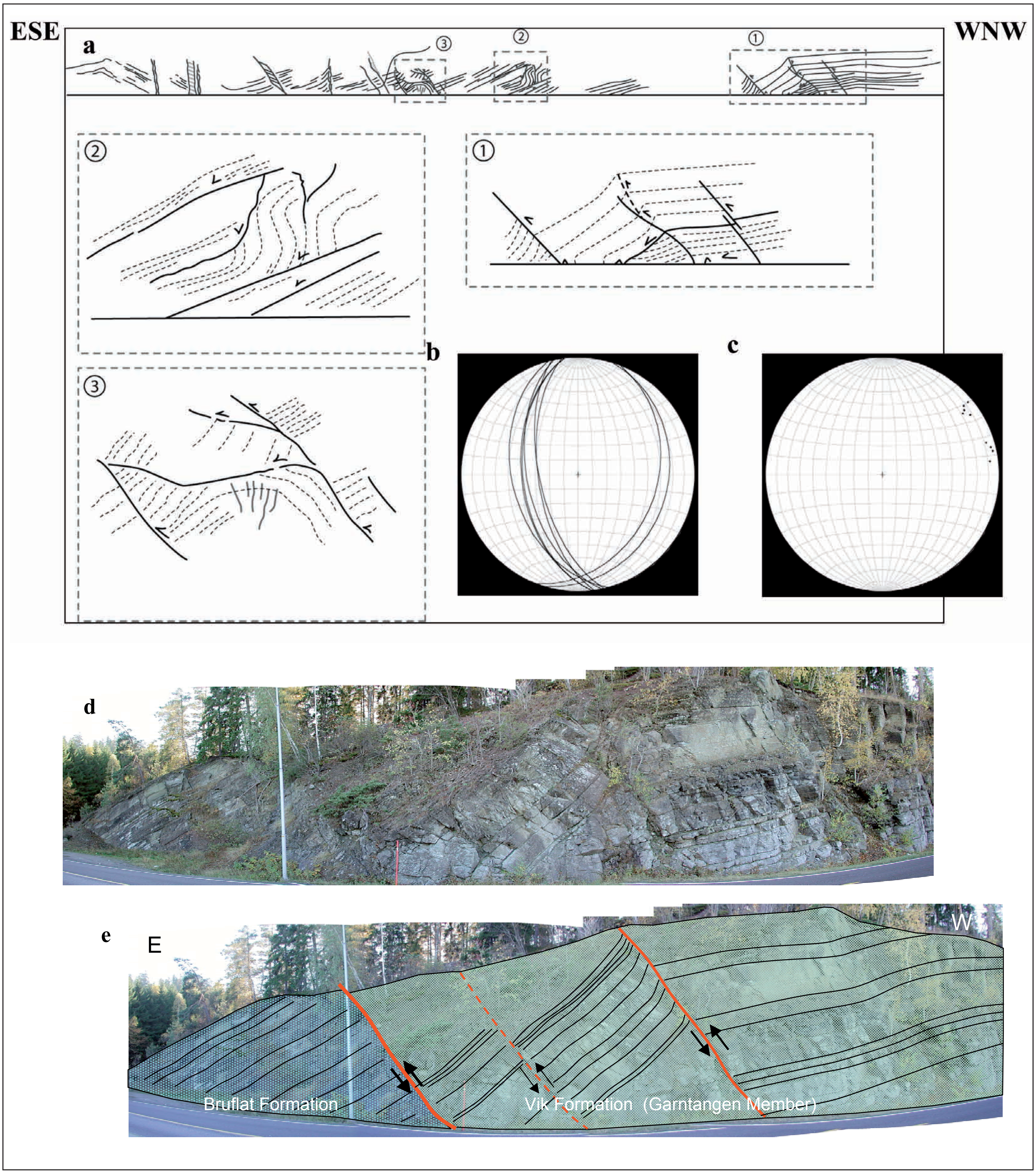

Figure 16. Part of duplex structure at Garntangen, Ringerike (mapsheet 1815 III Hønefoss, UTM 725 601). (a) Cross-section with positions of details displayed in sections 1, 2 and 3. (b) thrust-planes (equal area, lower hemisphere, great circles) and (c) fold axes (n = 9). The transport direction is top-to-the-ESE and the status of this structural level relative to the other major structural levels described in the text (Fig. 11) is uncertain.

displays the typical geometry of a frontal horse. Correlation of the Vik and Bruflat formations suggests a vertical displacement component in excess of 40 metres across the fault branches associated with this horse. Its front has been cut off in the process of developing the next horse, indicating an in-sequence, foreland-directed emplacement of horse 2. Horse 3, to the southwest has a complex configuration and seems to be broken up by later, out-of-sequence, steeper, reverse faults. The structure is finally affected by a steeply dipping, NNW-SSE-striking, strike-slip fault, of assumed Permian age, that has twisted the folds associated with the Caledonian contraction. The Garntangen duplex is associated with back-thrusts exposed along the shoreline of Sælabonn, Tyrifjorden. Here, high-angle, top-to-the-west, contractional faults at Rytteråker (mapsheet 1815 III Hønefoss, UTM 695 593) and similar low-angle faults at Borgenvika (mapsheet 1815 III Hønefoss, UTM 699 603) are associated with tight to isoclinal, overturned folds of two generations, indicating a multistage development. The orientation of the thrust planes suggests a mainly top-to-the-east structural transport at Garntangen, succeeded by west-directed back-thrusting (Fig. 16). Although the Garntangen duplex may represent one of several links between levels 2 and 3, it is evident that the thrust faults within the duplex indicate a top-to-east transport and, hence, this deviates clearly from the general tectonic transport direction of top-to-the-SSE. This may be taken as an indication that this system could represent a structural anomaly with respect to the main thrusting and, as such, is unique. It is also noticeable that the orientation of the thrust planes at Garntangen deviates considerably from that of the basal thrust plane at Viul and Slemmestad (see below). However, at Garntangen, there are indications of a complex and multi-stage structural development, suggesting that the second structural level may be more complex than hitherto assumed. A more detailed study of this structure is therefore needed before its significance can be established.

The wavelength-amplitude relations for the deformation associated with the uppermost thrust plane are markedly different from those of the lower levels. Thus, the typical wavelengths of the flat synclines seen in the sandstones of the Ringerike Group and its equivalents are as much as 15-20 km, whereas in the ramp areas they are in the order of 500 m. The amplitude is a few hundred metres in both cases.

Structural level 4

The master faults of the fourth structural level are closely linked to structural level 3. They occur in a few areas where the thrust faults have ramped through the Ringerike Group sandstones and its equivalents. The thrusts become flat locally within the Ringerike Group sandstone or ramp up-section and flatten at a structurally higher level within the bedded sandstone. Due to both decreasing-upward strain intensity and erosion, structures of this level are rarely preserved. At Klekken (mapsheet 1815 III Hønefoss, UTM 735 707), however, a good example involves the upturned margin of the Ringerike Group sandstones and an overturned limb containing the older Steinsfjorden, Brakerøya and Vik formations. This coincides with a triangle-zone at depth. Harper & Owen (1983) emphasized the contrasting deformational styles of the areas north and south of the Klekken fault and concluded that the area to the north consists of the imbricate fan of a hinterland-dipping duplex system, post-dating the folding. The triangle-zone is overrun by a thrust splay that is linked to the Osen-Røa thrust to the north at Honerød near Viul (Fig. 11). A similar situation was reported by Størmer (1934) at Stubdal, where Ordovician rocks (Harper & Owen 1983, Halvorsen 2003) have been intensely folded and displaced above the Ringerike Group sandstones (Fig. 10) and a comparable situation is seen at Sønsterud (Fig. 17). Størmer (1934) described a train of tight folds, with axial planes dipping steeply towards the north. These are separated by zones of strongly deformed ?Cambrian shale and underlain by a floor fault that ramps up-section at the contact with the sandstones and flattens out directly above the sandstones (= structural level 4). The total top-to-the-south displacement was calculated by Størmer (1934) to be more than 5 km. The larger part of the flat of the master fault of level 4 at Stubdal was eroded prior to the extrusion of the Permian volcanic rocks.

Tectonic transport and sedimentary response to Caledonian orogenic events

Morley (1987a, 1994) acknowledged that tectonic transport in a large nappe system is complex and this is particularly the case when the underlying basement, above which transport has taken place, contains older zones of weakness including transverse and lateral ramps. Although such complexities are obvious in the Oslo Region and sub-domains of anomalous transport directions may be important locally, when seen on a regional scale, the SSE-directed tectonic transport of the Osen-Røa Nappe Complex dominates. In the sub-domains where an anomalous southerly and southeasterly transport is involved, it is questionable whether these can best be explained by the existence of basement ramps, or whether time-dependent fluctuations in the far-field stress are the more likely cause.

A key to understanding the tectonic evolution of the Oslo Region is to look for structural features such as unconformities, and sedimentary signals such as the source area and direction of palaeocurrent flows, and the timing of the first appearance of clastic sediments into the basin. The timing of faulting and thrusting cannot be determined exactly unless an interaction with sedimentary processes such as growth-faulting can be documented. Generally, there are few links between the two in the Oslo Region, and it appears that the incursion of coarse clastics generally commenced before the main episodes of folding and thrusting, as even the youngest sandstones of the Ringerike Group are thrusted and folded. The earliest siliciclastic units appear in the Darriwilian (Llanvirn) when sedimentation rates increased and the epicontinental Baltic Basin, characterised by a mud and carbonate deposition, slowly became an active foreland basin with the deposition of carbonates, sand and subordinate mud well into the Silurian (Bjørlykke 1974b, Størmer 1953,

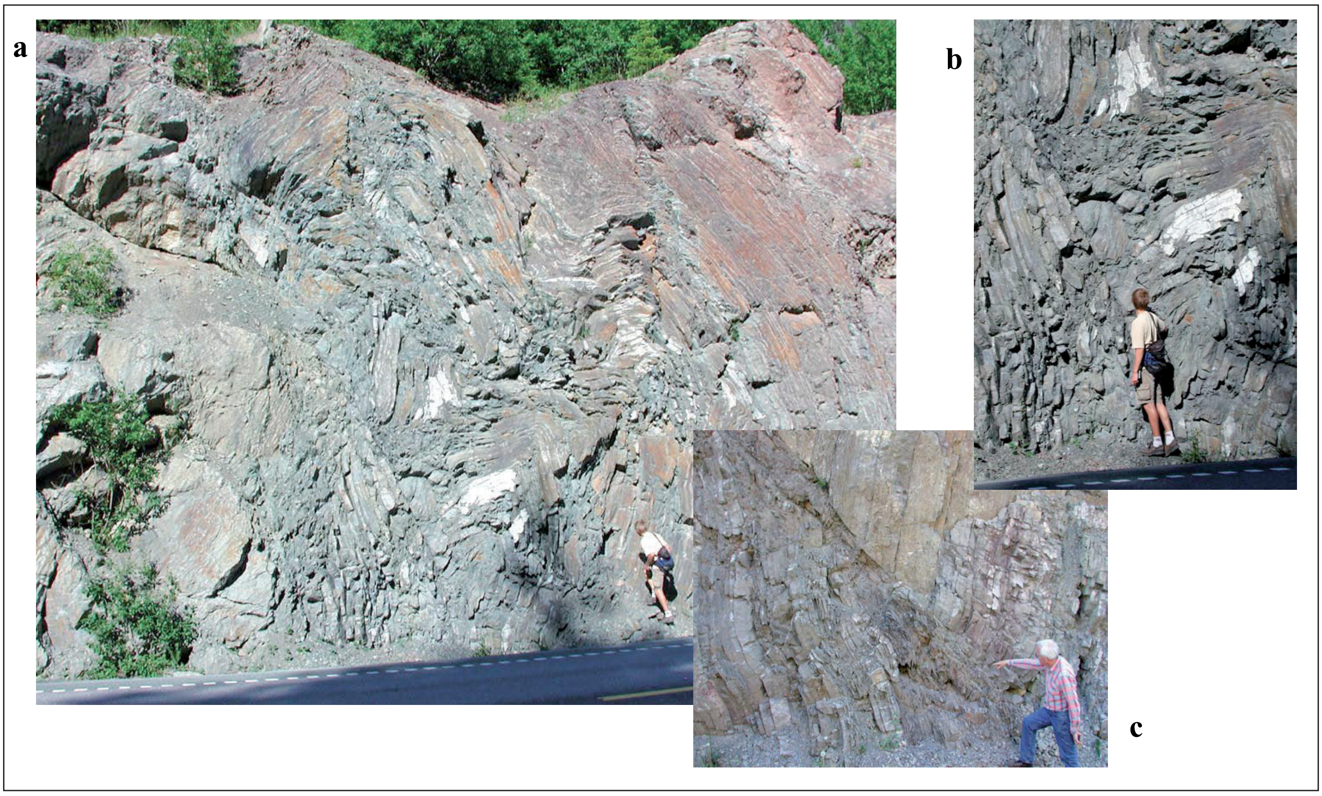

Figure 17. Style of deformation associated with ramp structures between structural levels 3 and 4 at Hole, Sønsterud (map-sheet 1814 IV Lier; UTM 723 513), looking northeast. a) and b) over-steepened beds with isolated fold hinges and shear lenses. (c) Back-thrusts are common in these zones and are, in places, associated with pop-up-structures.

Worsley *et al*. 1983). Various authors (Størmer 1953, T. Hansen 2007, Egenhoff *et al*. 2007) have discussed the thin, fine-grained, sandstones and siltstones of the Elnes Formation, whereas the first siliciclastic sediments of a more significant thickness occur towards the end of the Ordovician. This reflects an invasion of sand from source areas to the northwest (Spjeldnæs, 1957, Størmer 1967, Brenchley & Newall 1975, Bockelie & Nystuen 1985, Owen *et al*. 1990) or northeast (Braithwaite *et al*. 1995). The Upper Ordovician Langøyene Formation is up to 60 m thick in the type area and can be followed southwards to Skien. In Hadeland, Braithwaite *et al*. (1995) described the Klinkenberg Formation, a 45 m thick sandstone equivalent thinning towards the west. The sediments of the Langøyene and Klinkenberg formations are varied, consisting of bioclastic and siliciclastic sandstones, conglomerates, mudstones and biohermal limestones. Spjeldnæs (1957) pointed to the Hirnantian hiatus in the Mjøsa district and suggested that beds equivalent to the Langøyene Formation to the south were the result of a response to tectonic events in the mountain chain. Brenchley & Newall (1980), however, preferred an interpretation involving a major regressive phase with a glacio-eustatic origin.

The Lower Silurian Sælabonn Formation is up to 110 m thick in the type area of Ringerike and can be followed from the Mjøsa district in the north to the Skien area in the southwest. In the Oslo-Asker and Holmestrand areas, the equivalent is a mudstone unit (Solvik Formation, Worsley *et al*. 1983). The Sælabonn Formation is divided into three members, the middle of which contains coarse sandstone units (Thomson 1982). In Ringerike, as in the Mjøsa district, it rests on a karst surface, the upper unit being the Helgøya Quartzite to the north (Skjeseth 1963, Worsley *et al*. 1983). The Sælabonn Formation is therefore a transgressive sandy unit deposited on top of an erosional surface indicating that the source area to the northwest had existed throughout the Ordovician. Bockelie (1978) suggested that sediment transport may have been aided by N-S-trending, tectonically active, basement blocks.

The Upper Llandovery (Telychian) Bruflat Formation in the Mjøsa district (Skjeseth 1963) is said to be 400-550 m thick (Worsley *et al*. 1983) although these figures may be exaggerated due to complex folding and repetition. It consists mainly of fine-grained, calcareous sandstones, siltstones and silty shales in the north, but south of Ringerike its equivalents are the graptolitic shales of the Skinnerbukta Formation. The northerly source of the Bruflat Formation clearly indicates that an active foreland basin had already developed. The uppermost of the four sandstone units in the Oslo Region is of Wenlock-Ludlow age and reaches a thickness of 1250 m in the Ringerike area. It consists of medium- to fine-grained sandstones and interbedded siltstones which form the Sundvollen and Stubdal formations (Turner 1974a, b, Davies 2006). The depositional environment at Ringerike was that of a fluvial to coastal plain influenced by tidal marine conditions in the lower part with a braided stream environment in the upper part (Holmestrand Formation, Turner 1974). Dam & Andreasen (1990) identified a delta system with alternating ephemeral streams and sandy beach face deposits on a broad coastal floodplain with some tidal influence (see also Davies *et al.* 2005 a, b).

The syntectonic nature of the Ringerike Group sandstones is reflected in its southward younging (Wenlock to Pridoli in its southern depositional area (Davis *et al.* 2005 a, b). Halvorsen (2003) argued in favour of a 'piggy-back' setting of the basin during its later development and suggested that in the Ringerike area basin infilling occurred simultaneously with formation of the major synclines. If this is correct, it is the only firm observation that links the sedimentation with tectonics in the Oslo Region. The correlation indicates that major contraction occurred throughout Wenlock-Ludlow time and continued with significant deformation into the Early Devonian, as indicated by the large synclines in the Ringerike area.

The structural development of the Oslo Region – remaining problems

Within the Permo-Carboniferous Oslo Graben the general internal tectonic architecture is fairly well established but several important questions still remain. These include the following:

1) The nature of the frontal part of the imbricate fan is not clear. Bockelie & Ramberg (1985) reported the superposition of older strata above younger, by thrusting in the Skien-Langesund area, but this was questioned by Morley (1986b). This problem needs to be resolved.
2) The mechanism causing the switch from a SE-directed regional to a more localised SSE-directed, Caledonian tectonic transport in the Oslo Region is not well understood. New reflection seismic data may be necessary to solve this.
3) The significance of the local variation in tectonic transport within the Oslo Region also remains enigmatic. The true extent and variation of such abnormal transport is not documented in sufficient detail, nor is it known whether this deviation is restricted to certain regions or to particular (time) events.
4) Studies of the relationship between relief, provenance, erosion, sediment transport and deposition have the potential for unravelling hitherto little known aspects of the tectonic history of the Oslo Region.

It is clear that the time is ripe to initiate a new, multidisciplinary and coordinated study of the Lower Palaeozoic geology, sedimentology and structure of the Oslo Region.

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References

Abramovitz, T. & Thybo, H. 2000: Seismic images of Caledonian, lithosphere-scale collision structures in the southeastern North Sea along Mona Lisa Profile 2. *Tectonophysics, 317*, 27-54.

Abramovitz, T., Thybo, H. & MONA LISA Working Group, 1998: Seismic structure across the Caledonian Deformation Front along MONA LISA profile 1 in the southeastern North Sea. *Tectonophysics, 288*, 153-176.

Ahlberg, P., Axheimer, N., Babcock, L.E., Eriksson, M. E., Schmitz, B. & Terfelt, F. 2009: Cambrian high-resolution biostratigraphy and carbon isotope chemostratigraphy in Scania, Sweden: first record of the SPICE and DICE excursions in Scandinavia. *Lethaia 42*, 2-16.

Ahlberg, P., Bergström, J. & Johansson, J. 1986: Lower Cambrian olenellid trilobites from the Baltic Faunal Province. *Geologiska Föreningens i Stockholm Förhandlingar 108*, 39-56.

Andersen, T. B.1998: Extensional tectonics in the Caledonides of south Norway, an overview. *Tectonophysics, 285*, 333-351.

Andersson, A., Dahlman, B., Gee, D. G. & Snäll, S. 1985: The Scandinavian Alum Shales. *Sveriges Geologiska Undersökning Serie Ca 56*, 1-50.

Asklund, B. 1933: Vemdalskvartsitens ålder. *Sveriges Geologiska Undersökning, Ser.C., 377*, Årbok 27, 56pp.

Axheimer, N. & Ahlberg, P. 2003: A core drilling through Cambrian strata at Almbacken, Scania, S. Sweden: trilobites and stratigraphical assessment. *Geologiska Föreningen Stockholms Förhandlingar (GFF), 125*, 139-156.

Axheimer, N., Eriksson, M. E., Ahlberg, P. & Bengtsson, A. 2006: The Middle Cambrian key species *Lejopyge laevigata* and its biozone: new data from Sweden. *Geological Magazine 143*, 447-455.

Baarli, B. G. 1990: Peripheral bulge of a foreland basin in the Oslo Region during the early Silurian. *Palaeogeography, Palaeoclimatology, Palaeoecology 78*, 149-161.

Baarli, B. G. 1995: Orthacean and strophomenid brachiopods from the Lower Silurian of the central Oslo Region. *Fossils and Strata 39*, 1-93.

Baarli, B. G. & Harper, D. A. T. 1986: Relict Ordovician brachiopod faunas in the Lower Silurian of Asker, Oslo Region, Norway. *Norsk Geologisk Tidsskrift 66*, 87-98.

Baarli, B. G., Johnson, M. E. & Antoshkina, A. I. 2003: Silurian stratigraphy and palaeogeography of Baltica. *In* Landing, E. & Johnson, M.E. (eds.) *Silurian lands and seas - Palaeogeography outside of Laurentia*. New York State Museum Bulletin 493, 3-34.

Barnes, C. R. & Bergström, S. M. 1988: Conodont biostratigraphy of the Upper Ordovician and lowermost Silurian. *Bulletin of the British Museum Natural History (Geology) 43*, 325-343.

Batchelor, R. A., Weir, J. A. & Spjeldnæs, N. 1995: Geochemistry of Telychian metabentonites from Vik, Ringerike District, Oslo Region. *Norsk Geologisk Tidsskrift 75*, 219-228.

Batchelor, R. A. & Evans, J. 2000: Use of strontium isotope ratios and rare earth elements in apatite microphenocrysts for characterization and correlation of Silurian metabentonites: a Scandinavian case study. *Norsk Geologisk Tidsskrift 80*, 3-8.

Bergström, J. 1980: The Caledonian margin of the Fennoscandian shield during the Cambrian. *In* Wones, D.R. (ed.) *The Caledonides in the U.S.A.* (Proceedings, IGCP Project 27: Caledonide Orogen, 1979 meeting, Blacksburg, Virginia). Department of Geological Sciences, Virginia Polytechnic Institute and State University, Memoir 2, 9-13.

Bergström, J. & Gee, D. G. 1985: The Cambrian of Scandinavia. *In* Gee, D. G. & Sturt, B. A. (eds.) *The Caledonide Orogen - Scandinavia and related areas*, John Wiley & Sons, Chichester, 247-271.

Bergström, S. M. 1980: Conodonts as paleotemperature tools in Ordovician rocks of the Caledonides and adjacent areas in Scandinavia and the British Isles. *Geologiska Föreningens i Stockholm Förhandlingar 102*, 377-391.

Bergström, S. M., Hamar, G. & Spjeldnæs, N. 1998: Late Middle Ordovician conodonts with Laurentian affinities from the Mjøsa and Furuberget Formations in southeastern Norway. *Seventh International Conodont Symposium held in Europe*, Abstracts, 14-15

Bergström, S. M., Huff, W. D., Kolata, D. R. & Bauert, H. 1995: Nomenclature, stratigraphy, chemical fingerprinting, and areal distribution of some Middle Ordovician K-bentonites in Baltoscandia. *Geologiska Föreningens i Stockholm Förhandlingar 117*, 1-13.

Bergström, S. M., Schmitz, B., Young, S. A. & Bruton, D. L. 2010: The δ13 chemostratigraphy of the Upper Ordovician Mjøsa Formation at Furuberget near Hamar, southeastern Norway: Baltic, Trans-Atlantic and Chinese relations. *Norwegian Journal of Geology 90*, 65-78.

Bergström, S. M., Schmitz, B., Young, S. A. & Bruton, D. L (in press). Lower Katian (Upper Ordovician) δ^{13} chemostratigraphy, global correlation and sea-level changes in Baltoscandia. *Lethia*.

Berthelsen, A., Olerud, S. & Sigmond, E. M. O., 1996: Geologisk kart over Norge, berggrunnskart Oslo 1: 250 000. *Norges Geologiske Undersøkelse*.

Bjørlykke, K., 1974: Glacial striation and clast from the Moelv Tillite of the Late Precambrian of southern Norway. *American Journal of Science, 274*, 443-448.

Bjørlykke, K. 1974a: Depositional history and geochemical composition of Lower Palaeozoic epicontinental sediments from the Oslo Region. *Norges geologiske undersøkelse 305*, 1-81.

Bjørlykke, K. 1974b: Geochemical and mineralogical influence of Ordovician island arcs on epicontinental clastic sedimentation. A study of Lower Palaeozoic sedimentation in the Oslo Region, Norway. *Sedimentology 21*, 251-272.

Bjørlykke, K. 1978: The eastern marginal zone of the Caledonide orogen in Norway. *In:* Caledonian – Appalachian Orogen of the North Atlantic region, IGCP Project 27, *Geological Survey of Canada, Paper 78-13*, 49-55.

Bjørlykke, K. O. 1901: Overskyvninger i den norske fjeldkjæde. *Naturen*, Kristiania (Oslo), 5, 1-8.

Blieck, A. & Janvier, P. 1991: Silurian vertebrates. *In* Bassett, M. G., Lane , P. D. & Edwards, D. (eds.) *Special papers in palaeontology No. 44*. The Murchison Symposium- Proceedings of an international conference on the Silurian System, 345-390. The Palaeontological Association, London.

Bockelie, J. F. 1978: The Oslo Region during the early Palaeozoic. *In* Ramberg, I. B. & Neumann, E.-R. (eds): *Tectonics & Geophysics of Continental Rifts*, D. Reidel, Dordrecht, 195-202.

Bockelie, J. F. & Nystuen, J. P. 1985: The southeastern part of the Scandinavian Caledonides. *In* Gee, D. G. & Sturt, B. A. (eds.), *The Caledonide Orogen – Scandinavia and Related areas*. John Wiley & Sons, Chichester, 69-88.

Boyer, S. E. & Elliot, D. 1982: Thrust systems. *American Association of Petroleum Geologists Bulletin, 66* 1196-1230.

Braddy, S. J. 2004: Ichnological evidence for the arthropod invasion of land. *Fossils & Strata 51*, 136-140.

Braathen, A., Osmundsen, P.T., Nordgulen, Ø. , Roberts, D. & Meyer, G. 2002: Orogen-parallel extension of the Caledonides in northern central Norway: an overview. *Norwegian Journal of Geology 82*, 225-242.

Braithwaite, C. J. R. & Heath, R. A. 1992: Deposition and diagenesis of debris flows in Upper Ordovician limestones, Hadeland, Norway. *Sedimentology 39*, 753-767.

Braithwaite, C. J. R., Owen, A. W. & Heath R. A. 1995: Sedimentological changes across the Ordovician-Silurian boundary in Hadeland and their implications for regional patterns of deposition in the Oslo Region. *Norsk Geologisk Tidsskrift 75*, 199-218.

Brenchley, P. J. & Newall, G. 1975: The stratigraphy of the Upper Ordovician Stage 5 in the Oslo – Asker District, Norway. *Norsk Geologisk Tidsskrift 55*, 243 – 275.

Brenchley, P. J. & Newall, G. 1980: A facies analysis of Upper Ordovician regressive sequences in the Oslo Region of Norway – a record of glacio-eustatic changes. *Palaeogeography, Palaeoclimatology, Palaeoecology 31*, 1-38.

Brenchley, P. J., Newall, G. & Stanistreet, I. G. 1979: A storm surge origin for sandstone beds in an epicontinental platform sequence, Ordovician, Norway. *Sedimentary Geology 22*, 185-217.

Bruton, D. L. 1999: Notes on Brøgger's type species of agnostid trilobite genera. *Geologiska Föreningens i Stockholm Förhandlingar 121*, 337-341.

Bruton, D. L. & Harper, D. A. T. 1988: Arenig-Llandovery stratigraphy and faunas across the Scandinavian Caledonides. *In* Harris, A. L. & Fettes, D. J. (eds.), *The Caledonian-Appalachian Orogen*, Geological Society Special publication No. 38, 247-268.

Bruton, D. L. & Harper, D. A. T. 2000: A mid-Cambrian shelly fauna from Ritland, western Norway and its palaeogeographical implications. *Bulletin of the Geological Society of Denmark 47*, 29-51.

Bruton, D. L., Harper, D. A. T. & Repetski, J. E. 1989: Stratigraphy and faunas of the Parautochthon and Lower Allochthon of southern Norway. *In* Gayer, R. A. (ed.): *The Caledonian Geology of Scandinavia*, Graham & Trotman, London, 231-241.

Bruton, D. L., Erdtmann, B.-D. & Koch, L. 1982: The Nærsnes section, Oslo Region, Norway: a candidate for the Cambrian-Ordovician boundary stratotype at the base of the Tremadoc Series. *In* Bassett, M. G. & Dean, W. T. (eds.), *The Cambrian-Ordovician boundary: sections, fossil distributions and correlations*. National Museum of Wales Geological Series 3, 61-69.

Bruton, D. L., Hoel, O. A., Beyene, L. T. & Ivantsov, A. Yu. 1997: Catalogue of the trilobites figured in Fredrich Schmidt's "Revision der ostbaltischen silurischen Trilobiten" (1881-1907). *Contributions from the Palaeontological Museum, University of Oslo, No. 403*, 1-117.

Bruton, D. L., Koch, L. & Repetski, J. E. 1988: The Nærsnes Section, Oslo Region, Norway: trilobite, graptolite and conodont fossils reviewed. *Geological Magazine 125*, 451-455.

Bruton, D. L., Lindström, M. & Owen, A. W. 1985: The Ordovician of Scandinavia. *In* Gee, D. G. & Sturt, B. A. (eds.), *The Caledonide Orogen – Scandinavia and Related areas*, John Wiley & Sons, Chichester, 273-282.

Bruton, D. L. & Williams, S. H. (eds.) 1982: IV International Symposium on the Ordovician System. Field excursion guide. *Paleontological Contributions from the University of Oslo No. 279*, i-iv, 1-217.

Bryhni, I. & Sturt, B. A. 1985: Caledonides in southwestern Norway. *In* Gee, D. G. & Sturt, B. A. (eds.), *The Caledonide Orogen – Scandinavia and Related areas*, John Wiley & Sons, Chichester, 89-107.

Brøgger, W. C. 1878: Om Paradoxidesskifrene ved Krekling. *Nyt Magazin for Naturvidenskaberne 24*, 18-88.

Brögger, W. C. 1882: Die silurischen Etagen 2 und 3 im Kristianiagebiet und auf Eiker, ihre Gliederung, Fossilien, Schichtenstörungen and Contactmetamorphosen. Universitätsprogramm für 2. Semester 1892, Kristiania, A. W. Brögger 1882, 375pp.

Brøgger, W. C. 1896: Über die Verbreitung der Euloma-Niobe Fauna (der Ceratopygenkalk Fauna) in Europa. *Nyt Magazin for Naturvidenskaberne 36*, 164-240.

Candela, Y. & Hansen, T. 2010. Brachiopod associations from the Middle Ordovician of the Oslo Region, Norway. *Palaeontology 53*, 833-867.

Cocks, L. R. M. & Torsvik, T. H. 2002: Earth geography from 500 to 400 million years ago: a faunal and palaeomagnetic review. *Journal of the Geological Society, London, 159*, 631-644.

Cocks, L. R. M. & Torsvik, T. H. 2005: Baltica from the late Precambrian to mid-Palaeozoic times: The gain and loss of a terrane's identity. *Earth-Science Reviews 72*, 39-66.

Cocks, L. R. M. & Worsley, D. 1993: Late Llandovery and early Wenlock stratigraphy and ecology in the Oslo Region, Norway. *Bulletin of the Natural History Museum (Geology) 49*, 31-46.

Cooper, R. A., Maletz, J., Haifeng, W. & Erdtmann, B.-D. 1998: Taxonomy and evolution of earliest Ordovician graptoloids. *Norsk Geologisk Tidsskrift 78*, 3-32.

Dahlstrom, C. D. A. 1970: Structural geology in the eastern margin of the Canadian Rocky Mountains. *Bulletin Canadian Petroleum Geology 18*, 332-406.

Dam, G. & Andreasen, F. 1990: High-energy ephemeral stream deltas: An example from the upper Silurian Holmestrand Formation of the Oslo Region, Norway. *Sedimentary Geology 66*, 197-225.

Davies, N. S. 2003: *The Ringerike Group (Late Silurian, Oslo Region): Palaeoenvironmental analysis of an Old Red Sandstone sequence in the foreland basin of the Norwegian Caledonides*. Unpublished Ph.D. thesis, Birmingham University, England, 271pp.

Davies, N. S., Turner, P. & Sansom, I. J. 2005a: Caledonide influences on the Old Red Sandstone Fluvial Systems of the Oslo Region, Norway. *Geological Journal 40*, 83-101.

Davies, N. S., Turner, P. & Sansom, I. J. 2005b: A revised stratigraphy for the Ringerike Group (Upper Silurian, Oslo Region). *Norwegian Journal of Geology 85*, 193-201.

Davies, N. S., Sansom, I. J. & Turner, P. 2006: Trace fossils and palaeoenvironments of a late Silurian marginal-marine/alluvial system: the Ringerike Group (Lower Old Red Sandstone), Oslo Region, Norway. *Palaios 21*, 46-62.

Dons, J. A. & Larsen, B. T. (eds.) 1978: The Oslo Palaeorift. A review and guide to excursions. *Norges geologiske undersøkelse 337*, 1-199.

Dronov, A. & Rozhnov, S. 2007: Climatic changes in the Baltoscandian Basin during the Ordovician: sedimentological and palaeontological aspects. *Acta Palaeontologica Sinica 46* (Suppl.), 108-113.

Ebbestad, J. O. R. 1999: Trilobites of the Tremadoc Bjørkåsholmen Formation in the Oslo Region, Norway. *Fossils and Strata 47*, 1-118.

Egenhoff, S., Cassle, C., Maletz, J., Frisk, A. M., Ebbestad, J. O. R. and Stüner, K. 2010: Sedimentology and sequence stratigraphy of a pronounced Early Ordovician sea-level fall on Baltica – The Bjørkåsholmen Formation in Norway and Sweden. *Sedimentary Geology 224*, 1-14.

Erdtmann, B.- D. 1965: Outline stratigraphy of graptolite-bearing 3b (Lower Ordovician) strata in the Oslo Region, Norway. *Norsk Geologisk Tidsskrift 45*, 481-547.

Erdtmann, B.-D. & Paalits, I. 1995: The early Ordovician "Ceratopyge Regressive Event" (CRE): its correlation and biotic dynamics across the East European Platform. *Lithuanian Geological Society "Geologija" 117*, 36-57.

Fossen, H. 1998: Advances in understanding the post-Caledonian structural evolution of the Bergen area, West Norway. *Norsk Geologisk Tidsskrift 78*, 33-46.

Fossen, H., Pedersen, R. B., Bergh, S. & Andresen, A. 2006: En fjellkjede blir til. Oppbygningen av Kaledonidene; ca 500 – 405 millioner år. *In:* Ramberg, I. B., Bryhni, I. & Nøttvedt, A. (eds.): *Landet blir til. Norges geologi*. Norsk geologisk forening, 2006, 178-229.

Gradstein, F. M., Ogg, J. G. & Smith, A. G. (eds.) 2004: *A Geologic Timescale 2004*, 1-589. Cambridge University Press, 589 pp.

Grahn, Y., Idil, S. & Østvedt, A. M. 1994: Caradocian and Ashgillian chitinozoan biostratigraphy of the Oslo-Asker and Ringerike districts, Oslo Region, Norway. *Geologiska Föreningens i Stockholm Förhandlinger 116*, 147-160.

Grahn, Y. & Nõlvak, J. 2007: Remarks on older Ordovician Chitinozoa and biostratigraphy of the Oslo Region, southern Norway. *Geologiska Föreningens i Stockholm Förhandlinger 129*, 101-106.

Grönwall, K. A. 1902: Bornholms Paradoxideslag og deres Fauna. *Danmarks geologiske undersøkelse serie 2* (13), 1-230.

Gunby, I. J., Siedlecka, A., Tveten, E. & Larsen, B.T. 2003: Berggrunnskart Lier 1814 IV, M 1: 50 000. *Norges Geologiske Undersøkelse*.

Hagenfeldt, S. E. 1989: Lower Cambrian acritarchs from the Baltic Depression and south- central Sweden, taxonomy and biostratigraphy. *Stockholm Contributions in Geology 41*, 1-176.

Hagemann, F. & Spjeldnæs, N. 1955: The Middle Ordovician of the Oslo region, Norway. 6. Notes on bentonites (K-bentonites) from the Oslo-Asker district. *Norsk Geologisk Tidsskrift 35*, 29-52.

Halvorsen, T. 2003: *Sediment infill dynamics of a foreland basin: the Silurian Ringerike Group, Oslo Region, Norway*. Unpublished Cand. scient thesis, University of Oslo, 166pp + 3 appendices.

Hanken, N.-M. 1974: *En undersøkelse av 5b sedimentene på Ullerntangen, Ringerike*. Unpubl. cand. real thesis, University of Oslo.

Hanken, N.-M. & Størmer. L. 1975: The trail of a large Silurian eurypterid. *Fossils and Strata No. 4*, 255-270.

Hansen, J. 2007: *Brachiopods and faunal dynamics in an Upper Ordovician shelf environment; an investigation of the fossil fauna in the Arnestad and Frognerkilen formations, Southern Norway*. Unpubl. Ph.D thesis, Tromsø University Museum, Department of Geology and Faculty of Science, University of Tromsø, Norway, 232 pp.

Hansen, J., Nielsen, J. K. & Hanken, N-M. 2009. The relationships between Late Ordovician sea-level changes and faunal turnover in western Baltica: Geochemical evidence of oxic and dysoxic bottom-water conditions. *Palaeogeography, Palaeoclimatology, Palaeoecology 271*, 268-278.

Hansen, T. 2008: Mid to late Ordovician trilobite palaeoecology in a mud dominated epicontinental sea, southern Norway. *In*: Rábano, I., Gozalo, R. & Garcia-Belliodo, D. (eds). Advances in trilobite research, 157-165. *Cuadernos del Museo Geomiero, No. 9. Instituto Geólogico de Espana, Madrid*.

Hansen, T. 2009: Trilobites of the Middle Ordovician Elnes Formation of the Oslo Region, Norway. *Fossils and Strata 56*, 1- 215.

Harland, T. L. 1981a: Lithofacies and depositional environments of the Steinvika Limestone (upper Middle Ordovician) and related sediments of the Langesund-Skien district, southern Norway. *Norges geologiske undersøkelse 367*, 1-37.

Harland, T. L. 1981b: Middle Ordovician reefs of Norway. *Lethaia 14*, 169-188.

Harper, D. A. T. & Owen, A. W. 1983: The structure of the Ordovician rocks of the Ringerike district: evidence of a thrust system within the Oslo region. *Norsk Geologisk Tidsskrift, 63*, 11-115.

Heath, R. A. & Owen, A. W. 1991: Stratigraphy and biota across the Ordovician-Silurian boundary in Hadeland, Norway. *Norsk Geologisk Tidsskrift 71*, 91-106.

Heintz, A. 1939: Cephalaspida from Downtonian of Norway. *Skrifter utgitt av Det Norske Videnskaps-Akademi I Oslo 1. Mat. Naturv. Klasse 1939, nr. 5*, 1-119, pls. 1-30.

Heintz, A. 1974: Additional remarks about Hemicyclaspis from Jeløya, southern Norway. *Norsk Geologisk Tidsskrift 54*, 375-384.

Heintz, A. 1969: New Agnaths from Ringerike Sandstone. *Skrifter utgitt av Det Norske Videnskaps-Akademi i Oslo 1. Mat. Naturv. Klasse. Nye Serie . No. 26*, 1-28, pls. 1-7.

Hendriks, B.W.H. & Redfield, T.F., 2005: Apatite fission track and (U-Th)/He data from Fennoscandia: An example of underestimation of fission track annealing in apatite. *Earth and Planetary Science Letters, 236*, 443-458.

Hetherington, C. J., Nakrem, H. A. & Batchelor, R. A. 2004: The Bjørntvet metabentonite: A new correlation tool for the Silurian of the southwest Oslo Region. *Norwegian Journal of Geology 84*, 239-250.

Henningsmoen, G. 1957: The trilobite family Olenidae with descriptions of Norwegian material and remarks on the Olenid and Tremadocian Series. *Skrifter utgitt av Det Norske Videnskaps-Akademi i Oslo 1. Mat. Naturv. Klasse 1957. Nr. 1*, 1-303, plates 1-31.

Henningsmoen, G. 1958: The Upper Cambrian Faunas of Norway with descriptions of non-olenid invertebrate fossils. *Norsk Geologisk Tidsskrift 38*, 179-196.

Henningsmoen, G. 1973: The Cambro-Ordovician boundary. *Lethaia* 6, 423-439.

Hoel, O. A. 1999a: Trilobites of the Hagastrand Member (Tøyen Formation, lowermost Arenig) from the Oslo Region, Norway. Part I: Asaphidae. *Norsk Geologisk Tidsskrift 79*, 179-204.

Hoel, O. A. 1999b: Trilobites of the Hagastrand Member (Tøyen Formation, lowermost Arenig) from the Oslo Region, Norway. Part II: Remaining non-asaphid groups. *Norsk Geologisk Tidsskrift 79*, 259-280.

Holmsen, G. 1935: Nordre Femund. Beskrivelse til det geologiske rektangelkart. *Norges Geologiske Undersøkelse 144*, 55pp.

Holmsen, G. 1937: Søndre Femund. Beskrivelse til det geologiske rektangelkart. *Norges Geologiske Undersøkelse 148*, 42pp.

Holtedahl, O. 1915: Iakttagelser over fjeldbygningen omkring Randsfjordens nordende. N*orges Geologiske Undersøkelse 75*, 1-32.

Holtedahl, O. 1930: Nogen sammenliknende betraktniger fra et nordnorsk og et sydnorsk område. *Geologiska Föreningens i Stockholm Förhandlingar 52*, 538-542.

Holtedahl, O., Schetleig, J., Rosendahl, H. & Størmer, L.1934: The geology of parts of Southern Norway: The Oslo region and adjacent sparagmite district. *The Geologists Association, London*, 70 pp, 12 enclosures.

Hossack, J. R. 1983: A cross-section through the Scandinavian Caledonides constructed with the aid of branch-line maps. *Journal of Structural Geology 5*(2), 103-111.

Hossack, J. R., Garton, M. R. & Nickelsen, R. P. 1985: The geological section from the foreland up to the Jotun thrust sheet in the Valdres area, south Norway. *In* Gee, D. G. & Sturt, B. A. (eds.): *The Caledonide Orogen - Scandinavia and Related areas*. John Wiley & Sons, Chichester, 443-456.

Howe, M. P. A. 1982: The Lower Silurian graptolites of the Oslo Region. *In* Worsley, D. (ed.). *International Union of Geological Sciences, Subcommission on Silurian Stratigraphy. Field Meeting Oslo Region 1982*. Paleontological Contributions from the University of Oslo No. 278, 21-32.

Høy, T. & Bjørlykke, K. 1980: Hamar, berggrunnsgeologisk kart 1916 IV, M 1: 50 000. *Norges geologiske undersøkelse*.

Høyberget, M. & Bruton, D. L. 2008: Middle Cambrian trilobites of the Suborder Agnostina and Eodiscina from the Oslo Region, Norway. *Palaeontographica Abt. A*, 286, 1-87.

Huff, W. D., Bergström, S. M. & Kolata, D. R. 1992: Gigantic Ordovician volcanic ash fall in North America and Europe: Biological, tectonomagmatic, and event-stratigraphic significance. *Geology 20*, 875-878.

Huff, W. D., Bergström, S. M. & Kolata, D. R. 2010: Ordovician explosive volcanism, *In:* Finney, S. C. & Berry, W. B. N. (eds.), The Ordovician Earth System: *Geological Society of America Special Paper 466*, 13-28.

Jaanusson, V. 1973: Aspects of carbonate sedimentation in the Ordovician of Baltoscandia. *Lethaia 6*, 11-34.

Jaanusson, V. 1976: Faunal dynamics in the Middle Ordovician (Viruan) of Balto-Scandia. *In* Bassett, M. G. (ed.): *The Ordovician System: Proceedings of a Palaeontological Association symposium, Birmingham, September 1974*. University of Wales Press and National Museum of Wales, Cardiff, 301-326.

Jaanusson, V. 1979: Ordovician. *In* Robison, R. & Teichert, C. (eds.): *Treatise on Invertebrate Palaeontology Part A, Introduction, Fossilisation (Taphonomy), Biogeography and Biostratigraphy*. The Geological Society of America Inc. and University of Kansas, Boulder Colorado and Lawrence, Kansas, A136-166.

Kiær, J. 1908: Das Obersilur im Kristianiagebiete. *Videnskapsselskapets Skrifter I Matematisk-Naturvidenskapelig Klasse I (for 1906) 2*, 1-596.

Kiær, J. 1911: A new Downtonian fauna in the sandstone series of the Kristiania area. A preliminary report. *Videnskapsselskapets Skrifter I Matematisk-Naturvitenskapelig Klasse 7*, 1-22.

Kiær, J. 1917: The Lower Cambrian Holmia fauna at Tømten in Norway. *Videnskapsselskapets Skrifter I. Matematisk.–Naturvitenskapelig. Klasse 10*: 1-140.

Kiær, J. 1924: The Downtonian fauna of Norway: I Anaspida, with a geological introduction. *Videnskapsselskapets Skrifter I Matematisk-Naturvitenskapelig Klasse 6*, 1-27.

Kjerulf, T.1855: Das Christiania-Silurbecken chemisch–geognostisch untersucht. Universitetsprogram for andet Halvaar, Christiania (Oslo)

Kjerulf, T. 1862: Jordbunden i Ringeriget. *Polyteknisk Tidsskrift 1862*, 1-15.

Kjerulf, T. 1873: II. Sparagmittfjeldet. Universitetsprogram for andet Halvaar, Christiania (Oslo), 85pp.

Kjerulf, T. 1879: *Udsikt over det sydlige Norges geologi*. W.C.Fabritius, Christiania, 262pp.

Larsen, B. T. & Olaussen, S., 2005: *The Oslo region. A study in classical Palaeozoic geology. Field Guide to NGF's Centennial Field Trip 26. - 28. May 2005. Norsk Geologisk Forening*, 88pp.

Lindholm, K. 1991: Ordovician graptolites from the early Hunneberg of southern Scandinavia. *Palaeontology 34*, 283-327.

Lindström, M. 1971: Vom Anfang, Hochstand und Ende eienes Epikontinentalmeeres. *Geologische Rundschau 60*, 419-438.

Lespérance, P. J. 1988: Trilobites. *Bulletin of the British Museum Natural History (Geology) 43*, 359-376.

Maletz, J. 1997: Graptolites from the *Nicholsonograptus fasciculatus* and *Pterograptus elegens* zones (Abereiddian, Ordovician) of the Oslo region, Norway. *Greifswalder Geowissenschaftliche Beiträge 4*, 5-98.

Maletz, J., Egenhoff, S., Böhme, M., Asch, R., Borowski, K., Höntzsch, S. & Kirsch, M. 2007: The Elnes Formation of Southern Norway: A key to Late Middle Ordovician Biostratigraphy and biogeography. *Acta Palaeontologica Sinica 46* (Suppl.), 298-304.

Martinsson, A. 1974: The Cambrian of Norden. *In* Holland, C. H. (ed.), *Cambrian of the British Isles, Norden, and Spitsbergen*, 185-283. John Wiley & Sons, London.

Moczydłowska, M. 1991: Acritarch Biostratigraphy of the Lower Cambrian and the Precambrian-Cambrian boundary in southeastern Poland. *Fossils and Strata 29*, 1-127.

Morley, C. K. 1986a: The Caledonian thrust front and palinspastic restorations in the Southern Norwegian Caledonides. *Journal of Structural Geology 8* (7), 753-765.

Morley, C. K. 1986b: Vertical strain variations in the Osen-Røa thrust sheet. North-western Oslo Fjord, Norway. *Journal of Structural Geology 8* (6), 621-632.

Morley, C. K. 1987a: Lateral and vertical changes of deformation style in the Osen-Røa thrust sheet, Oslo Region. *Journal of Structural Geology 9*, 331-343.

Morley, C. K.1987b: The structural geology of north Hadeland. Norsk *Geologisk Tidsskrift, 67* 39-49.

Morley, C.K. 1994: Fold-generated imbricates: examples from the Caledonides of Southern Norway. *Journal of structural Geology 16*, 619-631.

Möller, N. K. 1987: A Lower Silurian transgressive carbonate succession in Ringerike (Oslo Region, Norway). *Sedimentary Geology 51*, 215-247.

Möller, N. K. 1989: Facies analaysis and palaeogeography of the Rytteråker Formation (Lower Silurian; Oslo Region, Norway). *Palaeogeography, Palaeoclimatology, Palaeoecology 69*, 167-192.

Murchison, R.I. 1847: *Anskuelser over Classifikationen av de geologiske Lag i Overgangsformationen ved Christiania. Forhandl. Skandinaviske Naturf. 4de Møte, Christiania 1844*.

Naterstad, J., Bockelie, J. F., Bockelie, T., Graversen, O., Hjelmeland, H., Larsen, B.T. & Nilsen, O. 1990: Asker 1814 I, bergrunnskart M 1:50 000. *Norges Geologiske Undersøkelse*.

Nielsen, A. T. 1995: Trilobite systematics, biostratigraphy and palaeoecology of the Lower Ordovician Komstad Limestone and Huk Formations, southern Scandinavia. *Fossils and Strata 38*, 1-374.

Nielsen, A. T. 2004: Ordovician Sea Level Changes: A Baltoscandian Perspective. *In* Webby, B. G., Paris, F., Droser, M. L. & Percival I. G. (eds.). *The Great Ordovician Biodiversification Event*, Columbia University Press, New York, 84-93.

Nielsen, A. T. & Harper, D. A. T. 2003: A Late Ordovician sea-level curve for the Central Oslo Region: implications for Ashgill correlation. *In* Albanesi, G. L., Beresi, M. S. & Peralta, S. H (eds.) *Ordovician from the Andes*. INSUGEO, Serie Correlacion Geologica 17, 451-459.

Nielsen A. T. & Schovsbo, N. H. 2007: Cambrian to basal Ordovician lithostratigraphy in southern Scandinavia. *Bulletin of the Geological Society of Denmark 53*, 47-92.

Nikolaisen, F. 1987: Olenellid trilobites from the uppermost Lower Cambrian Evjevik Limestone at Tømten in Ringsaker, Norway. *Norsk Geologisk Tidsskrift 66* (for 1986), 305-309.

Nystuen, J. P.1981: The Late Precambrian sparagmites of southern Norway: a major Caledonian allochthon – the Osen-Røa Nappe Complex. *American Journal of Science 281*, 69-94.

Nystuen, J. P.1983: Nappe and thrust structures in the Sparagmite Region, southern Norway. *Norges geologiske undersøkelse 380*, 67-83

Nystuen, J.P., (ed.), 1989: Rules and recommendations for naming of geological units in Norway. *Norsk Geologisk Tidsskrift 69*, Suppl. 2, 111 pp.

Oftedahl, C., 1943: Overskyvninger i den norske fjeldkjede. *Naturen 47*, 143-150.

Olaussen, S. 1985: Sedimentology and lithostratigraphy of the tidal flat deposits of the Steinsfjorden Formation (Wenlock) of Ringerike, Southern Norway. *Norges geologiske undersøkelse Bulletin 399*, 1-25.

Opalinski, P. R. & Harland, T. L. 1981: Stratigraphy of the Mjøsa Limestone in the Toten and Nes-Hamar areas. *Norsk Geologisk Tidsskrift 61*, 59-78.

Osmundsen, P. T., Eide, E. A., Haabesland, N. E., Roberts, D., Andersen, T. B., Kendrick, M., Bingen, B., Braathen, A. & Redfield, T. F. 2006: Kinematics of the Høybakken detachment zone and the Møre-Trøndelag Fault Complex, Central Norway. *Journal of the Geological Society, London 163*, 302-318.

Owen, A. W., Bruton, D. L., Bockelie, J. F. & Bockelie, T. G. 1990: The Ordovician successions of the Oslo Region, Norway. *Norges geologiske undersøkelse, Special Publication 4*, 1-54.

Owen, A. W., Harper, D. A. T. & Heath, R. A. 2008: A route to recovery: the early Silurian shallow water shelly fauna in the northern Oslo basin. *Lethaia 41*, 173-184.

Pedersen, J. H., Karlsen, D. A., Spjeldnæs, N., Backer-Owe, K., Lie, J. E. & Brunstad, H. 2007: Lower Paleozoic petroleum from southern Scandinavia: Implications for a Paleozoic petroleum system offshore southern Norway. *The American Association of Petroleum Geologists (AAPG) Bulletin 91* (8), 1189-1212.

Pedersen, R. B., Bruton, D. L & Furnes, H. 1992: Ordovician faunas, island arcs and ophiolites in the Scandinavian Caledonides. *Terra Nova 11*, 217-222.

Pedersen, R. B., Furnes, H. & Dunning, G. R.1988: Some Norwegian ophiolite complexes reconsidered. *Norwegian Geological Survey Special Publication 11*, 80-85.

Peng, S., Babcock, L. E., Robison, R. A., Lin, H., Rees, M. N. & Saltzman, M. R. 2004: Global Standard and Stratotype-section and Point (GSSP) of the Furongian Series and Paibian Stage (Cambrian). *Lethaia 37*, 365-379.

Peng, S. & Robison, R. A. 2000: Agnostid biostratigraphy across the middle-upper Cambrian boundary in Hunan, China. *Paleontological Society Memoir 53 (Journal of Paleontology 74. (suppl. to no.4)*, 1-104.

Perroud, H., Robardet, M. & Bruton, D. L. 1992: Palaeomagnetic constraints upon the palaeogeographic position of the Baltic Shield in the Ordovician. *Tectonophysics 201*, 97-120.

Ramberg, I. B. & Bockelie, J. F., 1981: Geology and tectonics around Oslo. *In:* Larsen, B. T. (ed.): Guide to excursions B-4, 4th International Conference on Basement Tectonics, Oslo August 1981. *Nytt fra Oslofeltgruppen 7*, 81-100.

Ramberg, I. B. & Englund, J.-O., 1969: The source rock of the Biskopås Conglomerate at Fåvang, and the western margin of the sedimentation basin of the Brøttum Formation at Fåvang – Vinstra, southern Norway. *Norges geologiske undersøkelse 258*, 302 –324.

Rasmussen, J. A. 2001: Conodont stratigraphy and taxonomy of the Ordovician shelf margin deposits in the Scandinavian Caledonides. *Fossils and Strata 48*, 1-145.

Rasmussen, J. A. & Bruton, D. L. 1995: Stratigraphy of Ordovician limestones, lower Allochthon, Scandinavian Caledonides. *Norsk Geologisk Tidsskrift 74*, 199-212 (part 4 for 1994).

Ribecai, C., Bruton, D. L. & Tongiorgi, M. 1999: Acritarchs from the Ordovician of the Oslo Region, Norway. *Norsk Geologisk Tidsskrift 80*, 251-258.

Rich, J. L. 1934: Mechanics of low-angled overthrust faulting as illustrated by Cumberland thrust block Virginia, Kentucky and Tennessee. *American Association of Petroleum Geologists Bulletin 18*, 1584-1596.

Schiøtz, O. E.1902: Den sydøstlige del af Sparagmit-Kvarts-Fjeldet i Norge. *Norges Geologiske Undersøkelse 35*, 1-131.

Schovsbo, N. H. 2000: Environemental fluctuations in the Olenus Zone (Upper Cambrian), southern Scandinavia: A geochemical approach. *Bulletin of the Geological Society of Denmark 47*, 53-61.

Schovsbo, N. H. 2003: The geochemistry of Lower Palaeozoic sediments deposited on the margins of Baltica. *Bulletin of the Geological Society of Denmark 50*, 11-27.

Skjeseth, S. 1963: Contributions to the geology of the Mjøsa districts and the classical sparagmite area in southern Norway. - *Norges geologiske undersøkelse 220*, 1-126.

Smelror, M., Cocks, L. R. M., Mørk, A., Neuman, B. E. E. & Nakrem, H. A. 1997: Upper Ordovician-Lower Silurian strata and biota from offshore South Norway. *Norsk Geologisk Tidsskrift 77*, 251-268.

Spjeldnæs, N. 1955: Middle Cambrian stratigraphy in the Røyken area, Oslo Region. *Norsk Geologisk Tidsskrift 34*, 105-121

Spjeldnæs, N. 1957: The Silurian/Ordovician border in the Oslo district. *Norsk Geologisk Tidsskrift 37*, 355-371.

Spjeldnæs, N. 1962: The Middle Cambrian section at Slemmestad, Oslo Region. *Norsk Geologisk Tidsskrift 42*, 196-197.

Spjeldnæs, N. 1966: Silurian tidal sediments from the base of the Ringerike Formation, Oslo region, Norway. *Norsk Geologisk Tidsskrift 46*, 497-509.

Stanistreet, I. G. 1983: Contemporaneous faulting in the Upper Ordovician of the Oslo-Asker District, Norway and its significance in the development of the Oslo Basin. *Sedimentary Geology 37*, 133-150.

Strand, T. 1929: The Cambrian beds of the Mjøsen district in Norway. - *Norsk Geologisk Tidsskrift 10*, 307-365.

Strand, T. 1947: On the Middle Cambrian of Hadeland (Oslo Region, southern Norway). *Norsk Geologisk Tidsskrift 27*: 89-96.

Strand, T. 1960: The Pre-Devonian rocks and structures in the region of Caledonian deformation. *In:* Holtedahl, O. (ed.): Geology of Norway. *Norges Geologiske Undersøkelse 208*, 170-284.

Størmer, L. 1934: Merostomata from the Downtonian sandstone of Ringerike, Norway. *Skrifter utgitt av Det Norske Videnskaps-Akademi I Oslo 1. Mat. Naturv. Klasse 1933*, No. 10, 1-125, 12 pls.

Størmer,L., 1934: Spor av kaledonisk overskyvning i Nordmarka. *Norsk Geologisk Tidsskrift 13* (1-4), 116-128.

Størmer, L. 1953: The Middle Ordovician of the Oslo Region, Norway. 1. Introduction to stratigraphy. *Norsk Geologisk Tidsskrift 31*, 37-141.

Størmer, L. 1967: Some aspects of the Caledonian geosyncline and foreland west of the Baltic Shield. *Quarterly Journal of the Geological Society of London 123*, 183-214.

Sturesson, U., Popov, L. E., Holmer, L. E. Bassett, M. G., Felitsyn, S. & Belyatsky, B. 2005: Neodymium isotopic composition of Cambrian-Ordovician biogenic apatite in the Baltoscandian Basin: implications for palaeogeographical evolution and patterns of biodiversity. *Geological Magazine 142*, 419-439.

Sundvoll, B. & Larsen, B. T. 1994: Architecture and early evolution of the Oslo Rift. *Tectonophysics 240*, 173-189.

Sundvoll, B., Larsen, B. T. & Wandås, B., 1992: Early magmatic phase in the Oslo Rift and its related stress regime. *Tectonophysics 208*, 51-65.

Terfelt, F., Ahlberg, P., Eriksson, M. E. & Clarkson, E. N. K. 2005. Furongian (upper Cambrian) biostratigraphy and trilobites of the Håslöv-1 drill core, Scania, S. Sweden. *Geologiska Föreningens i Stockholm Förhandlingar 127*, 195-203.

Terfelt, F., Eriksson, M. E., Ahlberg, P. & Babcock, L. E. 2008: Furongian Series (Cambrian) biostratigraphy of Scandinavia – a revision. *Norwegian Journal of Geology 88*, 73-87.

Tetlie, O. E. 2000: *Eurypterids from the Silurian of Norway*. Unpubl. cand. scient thesis, Palaeontological Museum, University of Oslo, 1-152+ appendix.

Tetlie, O. E. 2002: A new *Baltoeurypterus* (Eurypterida: Chelicerata) from the Wenlock of Norway. *Norwegian Journal of Geology 82*, 37-44.

Tetlie, O. E. 2006: Two new Silurian species of Eurypterus (Chelicerta: Eurypterida) from Norway and Canada and the phylogeny of the genus. *Journal of Systematic Palaeontology 4*, 397-412.

Thomsen, E. 1982: Sælabonn Formation (nedre Silur)i Ringerike, Norge. *Dansk Geologisk Forening Årsskrift for 1981*, 1-11.

Thomsen, E., Jin, J. & Harper D.A.T. 2007: Early Silurian brachiopods (Rhynchonellata) from the Sælabonn Formation of the Ringerike district, Norway. *Bulletin of the Geological Society of Denmark 53 (for 2006)*, 111-120.

Tjernvik, T. & Johansson, J. U. 1980: Description of the upper portion of the drill core from Finngrundet in the South Bothnian Bay. *Bulletin of the Geological Institute, University of Uppsala 36*, 107-284.

Tongiorgi, M., Bruton, D. L. & Di Milia, A. 2003: Taxonomic composition and palaeobiogeographic significance of the acritarch assemblages from the Tremadoc-Arenig (Hunneberg, Billingen and lower Volkhov Stages) of the Oslo Region. *Bollettino della Societa Paleontologica Italiana 42*, 205-224.

Turner, P. 1974: Lithostratigraphy and facies analysis of the Ringerike Group of the Oslo Region. *Norges geologiske undersøkelse 314*, 101-132.

Turner, P. 1974b: Marine calcarenites from the Ringerike Group ('stage 10') of Southern Norway. *Sedimentary Geology, 12*, 215-235.

Turner, P. & Turner, S. 1974: Thelodonts from the Upper Silurian of Ringerike, Norway. *Norsk Geologisk Tidsskrift 54*, 183-192.

Turner, P & Whitaker, J. H. MacD. 1976: Petrology and provenance of late Silurian fluviatile sandstones from the Ringerike Group of Norway. *Sedimentary Geology 6*, 45-68.

Tychsen, A. & Harper, D. A. T. 2004: Ordovician-Silurian distribution of Orthida (Palaeozoic Brachiopoda) in the Greater Iapetus Ocean Region. PalaeontologiaElectronica7,http://palaeo-electronica.org/2004_1/toc.htm.

Törnebohm, A. E. 1888: Om fjällproblemet. *Geologiska Föreningen i Stockholms Förhandlingar 134*, 328-336.

Törnebohm, A. E. 1896: Grunddragen af den centrala Skandinaviens bergbygnad. *Kungliga Svenska Vetenskapsakademi Handl., 28*, 210pp.

Vidal, G. & Nystuen, J. P. 1990: Micropalaeontology, depositional environment and biostratigraphy of the Upper Proterozoic Hedmark Group, southern Norway. *American Journal of Science 290*, 170-211.

Vidal, G. & Nystuen, J. P. 1991: Lower Cambrian acritarchs and the Proterozoic-Cambrian boundary in southern Norway. *Norsk Geologisk Tidsskrift 70* (for 1990), 191-222.

Vogt, T. 1953: Biridekket og Moelv-vinduet ved Mjøsa. *Det Kongelige Norske Videnskabers Selskabs Forhandlinger 25*, 131-138.

Weidner, T. R., Ahlberg, P., Axheimer, N. & Clarkson, E. N. K. 2004: The Middle Cambrian Ptychagnostus punctuosus and Goniagnostus nathorsti zones in Västergötland, Sweden. *Bulletin of the Geological Society of Denmark 50*, 39-45.

Westergård, A. H. 1946: Agnostidea of the Middle Cambrian of Sweden. *Sveriges geologisk undersøkning serie C 477*, 1-141.

Whitaker, J. H. McD. 1966: *The Silurian and Lower Devonian Geology of Ringerike, Norway*. Unpubl. Ph.D. Thesis, Leicester University, England,

Worsley, D. (ed.) 1982: International Union of Geological Sciences, Subcommission on Silurian Stratigraphy. Field Meeting Oslo Region 1982. *Paleontological Contributions from the University of Oslo No. 278*, 1-175.

Worsley, D., Aarhus, N., Bassett, M. G., Howe, M. P. A., Mørk, A. & Olaussen, S. 1983: The Silurian succession of the Oslo Region. *Norges geologiske undersøkelse 384*, 1-57.

Zenzén, N. 1932: Nya geologiska notiser från Idre. *Geologiska Föreningens i Stockholm Förhandlingar 54*, 533-534.