33 IGC excursion No 104, August 10th, 2008

33 IGC, The Nordic Countries

Classical fossil localities in the Oslo area

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Object

This local trip will give a brief insight to the local geology with stops at a selected number of classical localities where Cambrian and Ordovician rocks are exposed. One locality of Silurian interest is included.

Introduction

Participants entering the Oslo area by land, sea or air on a fine day cannot help but note how much the surrounding landscape reflects the local geology (Fig. 1).

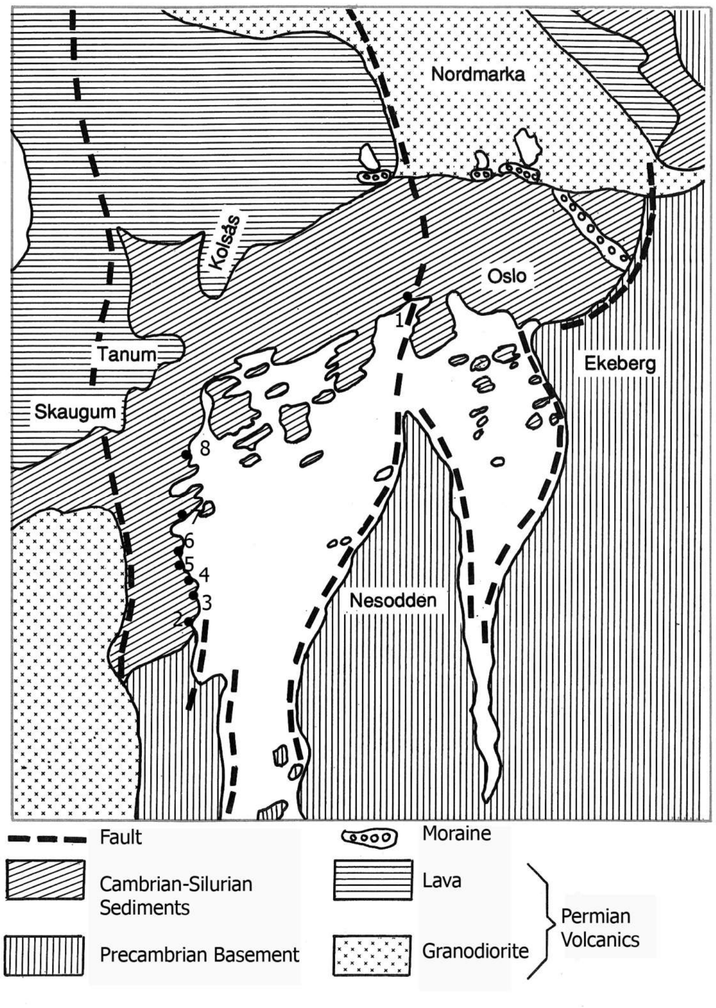


Figure 1. Simplified map of the Oslo fjord and adjacent areas with excursion stops:
1,Vækkerø; 2, Nærsnes beach;
3, Slemmestad centre;
4, Slemmestad cross roads;
5, Bjørkåsholmen peninsula;
6, Vollen bentonite;
7, Spirodden;
8, Holmen boatyard.

The city of Oslo lies innermost in the fjord which owes its origin to the activities of ice from the last ice age and to the fact that it forms the east side of the Oslo graben where periods of active faulting have existed from the Precambrian to the present. Looking south westwards from the waterfront in the city centre, the distant, flat hill tops of Kolsås, Tanum and Skaugum are eye-catching. These have their origin in association with Permian faulting with resultant outpourings of basaltic and granodiorite lavas which flooded huge areas of a Carboniferous and older landscape. To the south and east the dark, formless landscape of Nesodden and Ekeberg form a solid bastion of Precambrian gneiss dated to be more than 1000 million years old.

The Oslofjord with its Permian and Precambrian backcloth is scattered with numerous islands with beaches orientated in a characteristic Caledonian northeast-southwest direction. These islands and adjacent coastal sections make up the classical localities of the Oslo area, with its Lower Palaeozoic rocks and fossils known internationally since 1844. Between 1855 and

1878 the names Cambrian and Silurian were used for these rocks and not before 1916 was the name Ordovician introduced. Together this sedimentary succession southwest of Oslo forms the bedrock for some of the richest agricultural areas of the neighbouring communities. The characteristic alteration of dark shales, mudstones, limestones and sandstones forms the basis for the stratigraphical classification of numerous formations and members, with local and regional distribution. These lithostrigraphical units are mappable and form the framework for the detailed description of both rocks and fossils, the local and regional structure, stratigraphy, economic resources and the geological evolution through time. In the 1980's and 90's the Ordovician and Silurian rocks were subjected to intensive study resulting in new definitions of units (Owen et al. 1990, Worsley et al. 1982, 1983). Stratotypes and localities were selected and these today provide a solid foundation for future studies. In 1996 a new map (scale 1:250000) was issued (Berthelsen et al. 1996) for an area where almost 25% of the Norwegian population lives.

Many of the classical sections in the Oslo area are small in extent and have been subjected to intensive collection throughout the years. Beginning in 1985, a proposal to protect certain localities was made by the Ministry of the Environment after recommendations from geologists at the University of Oslo. These were later accepted and in June 2008 a bill confirming the full protection of sites in the inner fjord area went through parliament. We have chosen several stops where collecting and use of hammers is forbidden, but at others collecting will be possible.

Regional Geology

The local stratigraphy

The correlation charts (Figs. 2, 4, 6) reflect a preferred Baltoscandian terminology for the Cambrian and Ordovician while reference to a standard British system is applicable for the Silurian.

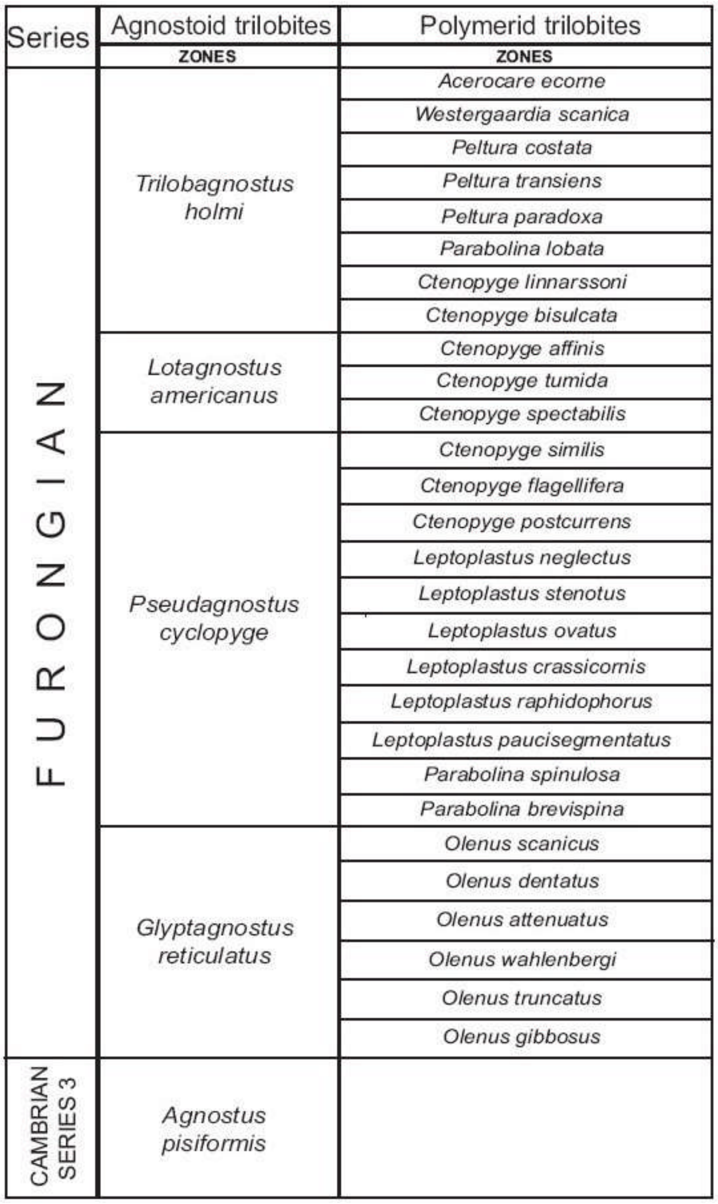
Brøgger 1878	**Strand 1929**	**Westergård 1946**		**Skjeseth 1963**	**Peng & Robison 2000 (proposed global zonation)**	**Høyberget & Bruton 2008**
					Glyptagnostus stolidotus Zone	*Agnostus pisiformis* Zone
					Linguagnostus reconditus Zone	
Stage 1d Zone with *Paradoxides Forchhammeri*	Zone of *Agnostus lævigatus* 1d•	*Paradoxides forchhammeri* stage	Zone of *Lejopyge laevigata* C3	*Lejopyge laevigata* 1d•	*Proagnostus bulbus* Zone	*Lejopyge laevigata* Zone
	Zone of *Paradoxides forchhammeri* 1d•		Zone of *Solenopleura brachymetopa* C2	*Solenopleura brachymetopa* 1d•	*Lejopyge laevigata* Zone	
Stage 1c Zone with *Paradoxides Tessini* and *Paradoxides rugulosus*	Zone of *Paradoxides davidis* and *rugulosus* 1c•		Zone of *Ptychagnostus (T.) lundgreni* and *Goniagnostus nathorsti* C1	Goniagnostus nathorsti *1c*•$_2$	*Goniagnostus nathorsti* Zone	*Goniagnostus nathorsti* Zone
		Paradoxides paradoxissimus stage	Zone of *Ptychagnostus (P.) punctuosus* B4	*Ptychagnostus punctuosus* 1c•$_1$	*Ptychagnostus punctuosus* Zone	*Ptychagnostus punctuosus* Zone
	Zone of *Paradoxides tessini* 1c•		Zone of *Hypagnostus parvifrons* B3	*Hypagnostus parvifrons* 1c•$_2$	*Ptychagnostus atavus* Zone	*Ptychagnostus atavus* Zone
			Zone of *Tomagnostus fissus* and *Ptychagnostus (P.) atavus* B2	*Tomagnostus fissus Ptychagnostus atavus* 1c•$_1$		
	Zone of *Ctenocephalus exsulans* 1c•		Zone of *Ptychagnostus (T.) gibbus* B1	*Ptychagnostus gibbus* 1c•		*Ptychagnostus gibbus* Zone
	Zone of *Paradoxides ölandicus* 1c•	*P. oelandicus* stage	Zone of *Paradoxides pinus* A2	*Paradoxides oelandicus* 1c•		**Acadoparadoxides** *oelandicus* Superzone
			Zone of *Paradoxides insularis* A1			

Figure 2. Middle Cambrian biostratigraphy of Scandinavia. From Høyberget & Bruton (2008).

Cambrian

The Cambrian rocks exposed in the Oslo area consist of dark shales with intermittent dark, bituminous limestone beds and concretions (stinkstones). These are the Alum Shale Formation (Nielsen & Skovsbo 2007), which includes the traditional Middle and Upper Cambrian and the overlying Tremadocian. In the Oslo area the alum shale is the thickest in Baltoscandia and approximately 100m was deposited in deep water. 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 and to the north of Oslo.

The 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. 2) though in the Oslo area the middle Cambrian sections are fragmented by faults.



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 ovatus
		Leptoplastus crassicornis
		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 3. Trilobite zonation of the Furongian (Upper Cambrian) in Scandinavia. From Terfelt et al. (2008).

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) in 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).

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 have led the Furongian to be divided into four agnostoid and 28 polymerid trilobite zones (Terfelt et al. 2008) (Fig. 3). 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 area 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 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) has been well documented in the Oslo-Asker area by Henningsmoen (1957) and Bruton et al. 1982, 1988).

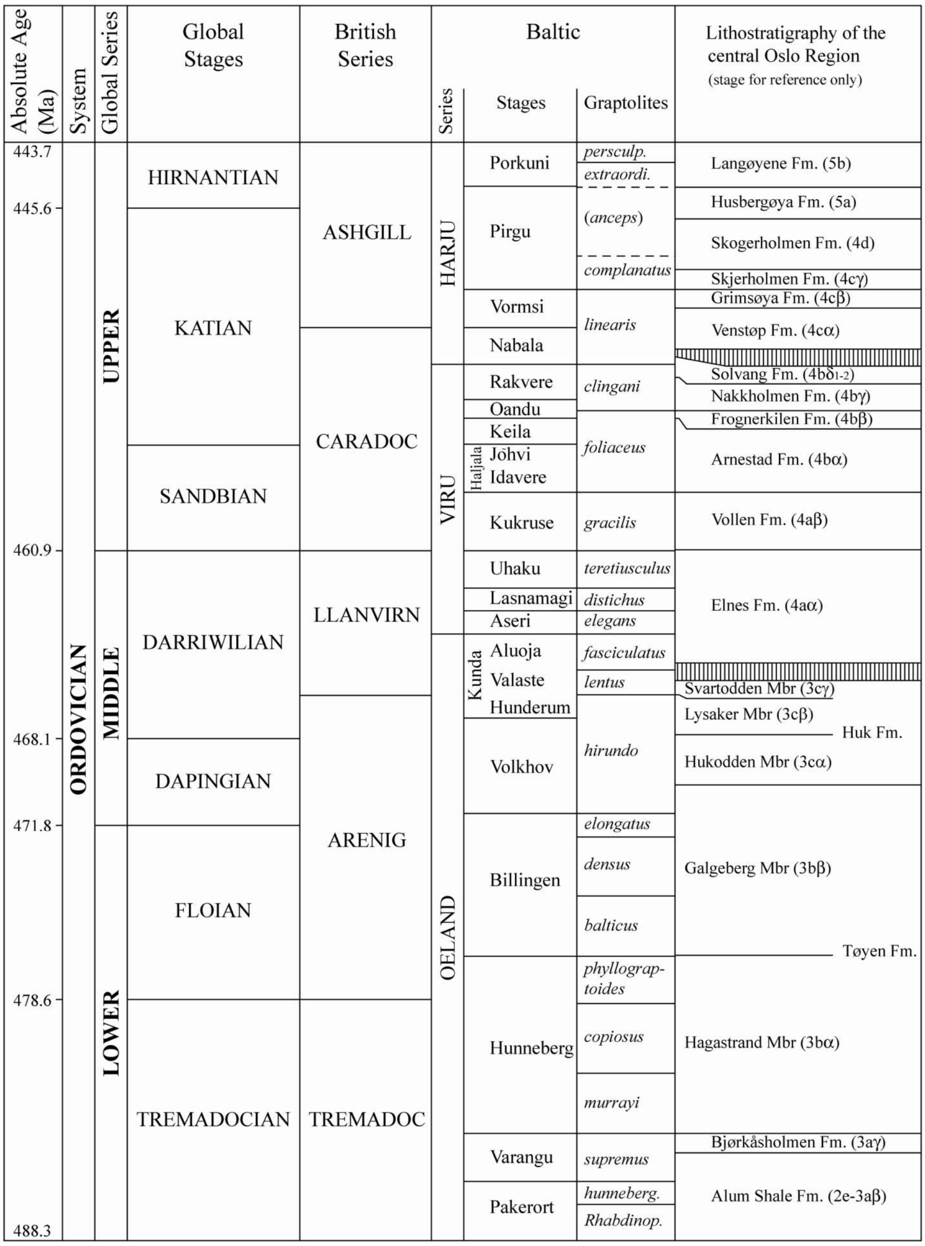


Figure 4. The correlation of the Ordovician succession of the central Oslo Region with the standard British and Baltic sequences. Note that the relative duration of the chronostratigraphical units are not equivalent to their absolute durations but are scaled to fit the detail of the Oslo region succession. From Bruton (in press).

Ordovician (Fig. 4)

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, while elsewhere the process of transgression (Jaanusson 1979, p. A138-139) may have been complex and iterative rather than gradual. 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 1896, see also Ebbestad 1999).

A sequence of pale grey and black silty shales with a thickness >20 m make 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 shorewards 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 are given 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 but for the remainder of the System, correlation becomes less precise, the reason being 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, T. Hansen 2007) 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 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, and 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 position, 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 Baltican plates.

T.Hansen (2007, p. 4, fig. 2, p. 147, fig. 41), 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 (Fig. 5) 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 regressive event is recorded by sand infilling a karst surface in limestones containing corals and stromatoporoid bioherms in Ringerike (Hanken 1974), Hadeland (Heath & Owen 1991, Braithwaite & Heath 1992, Braithwaite et al. 1995) and Skien-Langesund (Harland 1981b). In the north, the Mjøsa Limestone with constituent reefs (Harland 1981a, Opalinski & Harland 1981) 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 2007).

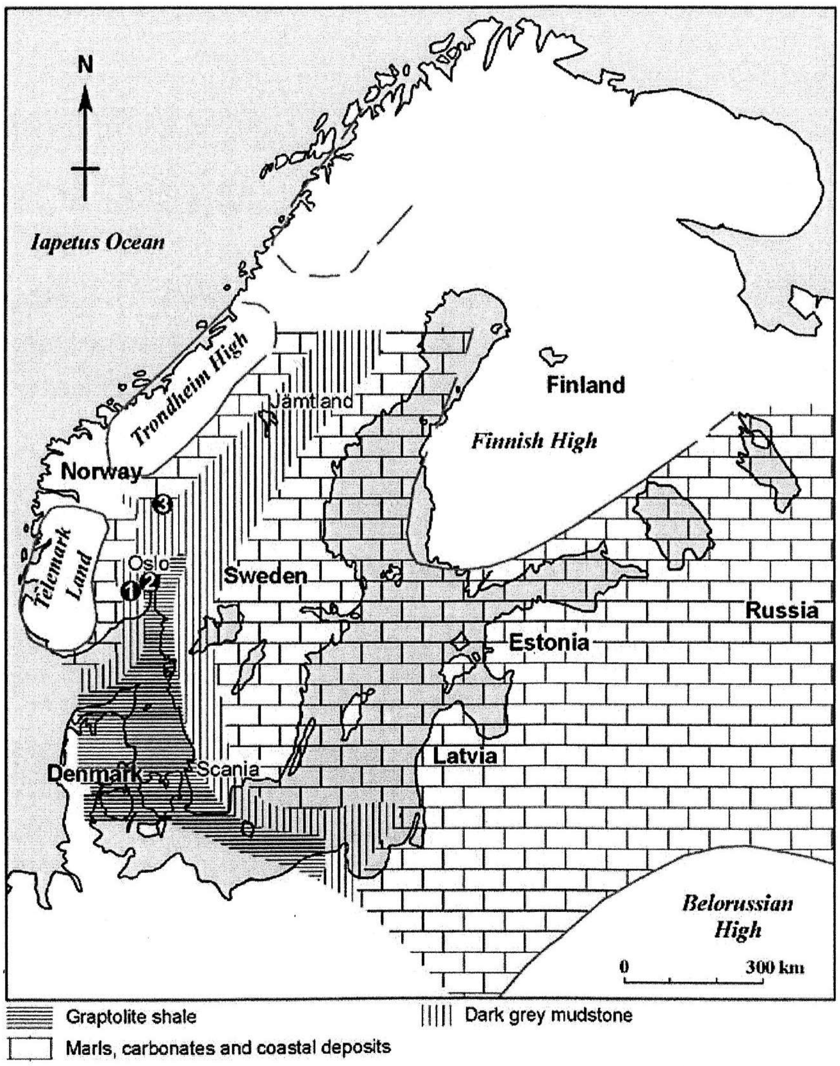


Figure 5. Lithofacies map of the mid Darriwilian deposits in Baltoscandia showin the approximate distribution of the different sedimentary environments. From T.Hansen (2008).

In a thought-provoking paper, Braithwaite et al. (1995) raised doubts on 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 clearly related to dated sequences. Likewise, Braithwaite et al. (1995) discussed various channel infills and through careful block study suggested that the channels were neither tidal-cut nor do they belong to the same time interval as their contained blocks.

Silurian (Fig. 6)

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 sediments 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 Oslo-Asker (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.

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.
	LUDLOW	Ludfordian	Kuressaare		*formosus/balticus*
			Paadla	Sundvollen Fm. (10)	*koslowskii- auriculatus*
					bohemicus/aversus
					leintwardinensis
		Gorstian			*scanicus/chimaera*
			Rootsiküla		*nilssoni/colonus*
	WENLOCK	Homerian			*ludensis*
				Steinsfjorden Fm. (9)	*nassa*
					lundgreni
			Jaagarahu		*ellesae*
					linnarssoni
		Sheinwoodian	Jaani	Malmøya Fm. (8c-d)	*rigidus*
SILURIAN				Skinnerbukta Fm. (8a-b)	*riccartonensis*
					murchisoni
					centrifugus
	LLANDOVERY	Telychian	Adavere	Vik Fm. (7c)	*crenulata*
					griestoniensis
				Rytteråker Fm. (7a-b)	*crispus*
					turriculatus
					maximus
		Aeronian			*sedgwickii*
			Raikküla	Solvik Fm. (6a-c)	*convolutus*
					argenteus
					magnus
					triangulatus
		Rhuddanian			*cyphus*
			Juuru		*acinaces*
					atavus
443					*acuminatus*

Figure 6. The correlation of the Silurian succession of the central Oslo Region with the standard British and Baltic sequences. From Bruton (in press).

Description of localities to be visited

Stop 1. Vækkerø

[Asker Sheet 1814 I (1976) NM 925 432]
History of research (J.F. Bockelie)

The shore sections at Vækerø were first observed by Leopold von Buch during his trip to Norway and appeared his publication “Reise durch Norwegen und Lappland” which was published in 1810.
When the 4th Nordiske Naturforsker Møte (Nordic Natural Researchers meeting) was held in Christiania (Oslo), where also Leopold von Buch participated, one of the excursion leaders was a young Norwegian geologist, Theodor Kjerulf who chose Vækerø as one of the localities to visit.

At this time, Vækerø was owned by Hoffsjef (Lord Chamberlain) Løvenskiold and this may have been one of the reasons for choosing the locality. One of the leading members of the excursion group was the British geologist Sir Roderick Murchison, who at that time was working on the Silurian of the Welsh Borderland. He recognized all the main aspects of the geology of the Oslo Region and was an immense inspiration for Theodor Kjerulf.

On the beach the folds, the thrusts and the inverted section were visited and discussed. Based on all the input from these discussions, Kjerulf was probably pressured to complete a systematic mapping of the Vækerø area and later (Kjerulf 1855) he published a geological map in scale 1:100.000 of the greater area around Oslo together with a description of the structural geology, including many profiles, stratigraphy of dyke complexes and a first chemical analysis of the composition of both sedimentary rocks and igneous rocks within the mapped area. He also established the first lithostratigraphy of the Oslo area with a list of the most important fossils.

In 1857 Kjerulf published a more comprehensive study: “Uber die geologie des Südlichen Norwegens” where he established the stratigraphy of the Oslo Region in much greater detail with profiles and maps. One of the profiles is from Vækerø, showing an anticline with traditional Upper Cambrian through Lower Ordovician. He described the *Dictyonema* shales from Vækerø and the presence of *Agnostus pisiformis* and a species of “*Lingula*”. A geological map in colour shows the distribution of the “Oslo Gruppe” (=Cambrian-early Middle Ordovician) and the “Oscarshall Gruppe” (=Middle Ordovician). His geological understanding is “in place”.

1865. Kjerulf published an excursion guide to the Oslo area (“Veiviser ved Geologiske Excursioner i Christiania Omegn”). Here he described several fossils from Vækerø.

1871. In his paper (“Grundfjeldet”) Kjerulf also describes Vækerø as an important locality to understand the geology of the Oslo area. He presented a sketch map of the shore areas and described the style of folding.

1882. W.C. Brøgger produced a more detailed description of the locality with a sketch map and profiles (Figure). He also described for the first time, several late Cambrian and early Ordovician fossils from this locality.

1884. Reusch (“Geologiske Notiser fra Kristiania egnen”) discussed divergent explanations to Brøgger as to the deformation style at Vækerø.

1920. Størmer described the early Ordovician shore section at Vækerø with a comprehensive Lower Ordovician shelly fauna.

1938. Størmer (“Tektoniske iagttagelser på Bygdøy”), concluded with some comments on the tectonic style at Vækerø.

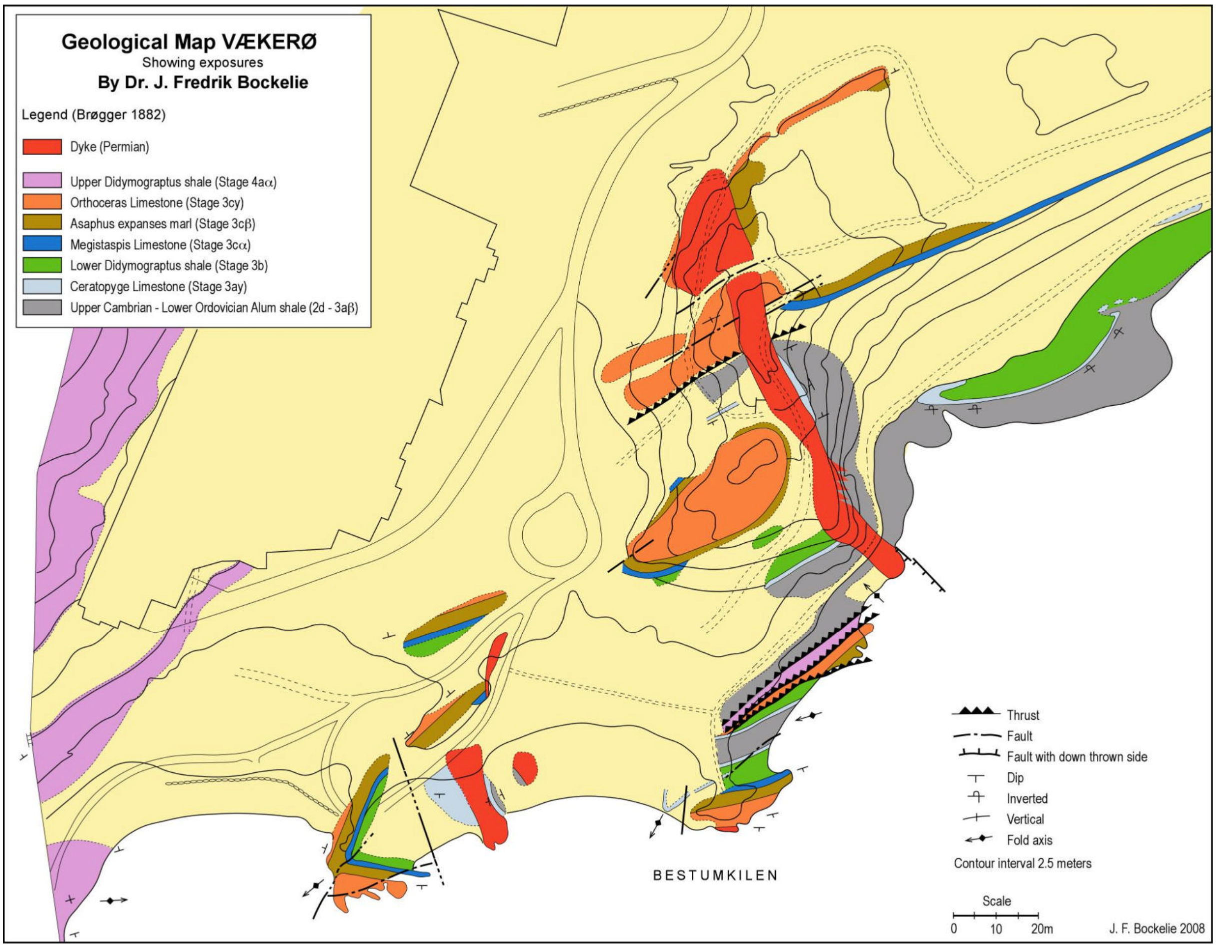


Figure 7. Geological map of Vækerø by Bockelie 2008. The legend follows that of Brøgger (1882) so that the two maps can be compared.

The outcrops are reached by passing through the office areas of Norsk Hydro and down to the public beach. Here can be seen sections from the Upper Cambrian Alum shale through the Middle Ordovician Elnes Formation. The tectonic deformation is typical for the Lower Ordovician of the Oslo Region with intensive thrusting of the section at certain stratigraphic intervals. In the eastern part of the area covered by the map (Fig. 7) the alum shale is inverted, and most likely there are several thrust zones present, but these have not yet been mapped in any detail.

The area is cut by two zones of north-south trending Permian rhomb porphyry dykes showing clear striation markings from the last glaciations (10ka).

Fossils are common at all stratigraphic levels in a more or less continuous deposition from the Furungian *Peltura scarabaeoides* Zone through the lower part of the Darriwilian *Didymograptus murchsoni* Zone. Each of the limestones is dominated by a wide variation in shelly faunas, whereas the shales are dominated by graptolites.
Svartodden is the stratotype area for the Svartodden Member of the Huk Formation (Fig. 8).

Figure 8. Limestone of the Svartodden Member, shore section, Vækerø. Note cross sections of Endoceras. Photo: J.F. Bockelie.

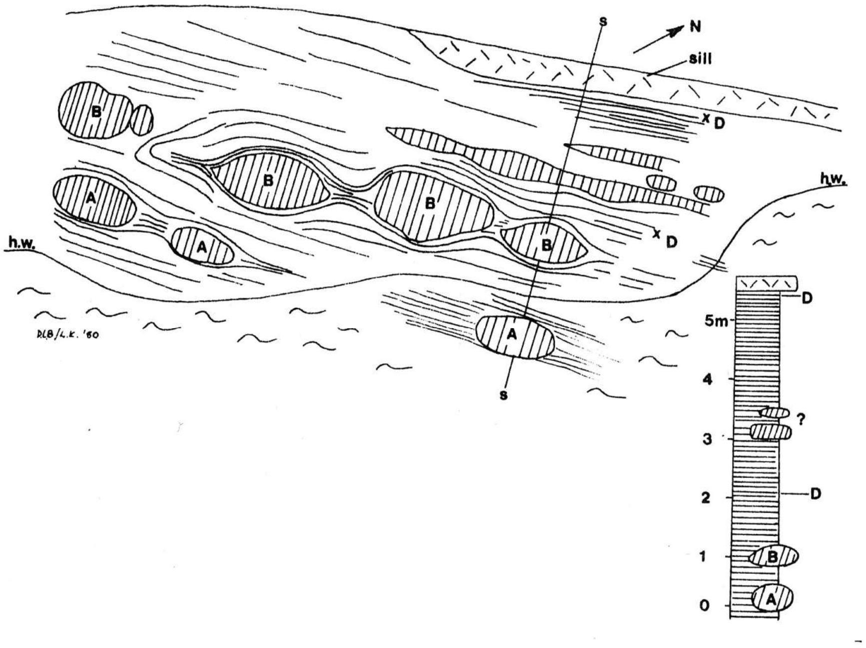


Figure 9. Sketch of Nærsnes beach section south of sill.From Bruton & Erdtmann (1980). Limestone concretions with cross-hatching contain A- Acerocare, B- Boeckaspis. D- Dictyonema (=Rhabdinopora).

Stop 2. Nærsnes beach section

[Asker Sheet 1814 I (1976) NM 844 258]

This was a paratype section used in connection with the unsuccessful attempt to define the Cambrian- Ordovician boundary in the Oslo area (Bruton et al. 1982a). Here a succession of alum shales and concretions occurs to the north and south of a metre thick Permian sill (Fig.9). A section south of the sill (Fig. 10) shows concretions containing *Acerocare ecorne* and *Parabolina acanthura* on the beach just below high water mark, succeeded by an horizon of large concretions containing the Ordovician trilobite *Boeckaspis hirsuta*. *Rhabdinopora flabelliforme parabola* occurs in the shales at three levels: 2m and 2m 10cm above the *Acerocare* layer, and at 10cm below the sill.

Following a visit to the locality in 1982, John Repetski later successfully retrieved conodonts from the westernmost concretions containing *Acerocare* and *Boeckaspis* (Bruton et al. 1988). Stratigraphically significant conodonts are (Fig. 11):
Cambrian Olenid Series (*Acerocare ecorne* subzone)
Utahconus utahensis (Miller)
Semiacontiodus cf. *S. nogaamii* (Miller)
? *Fryxellodontus* sp.
Cordylodus proavus Müller
Drepanoistodus sp.
Ordovician Tremadoc Series (*Boeckaspis hirsuta* Zone)
C. proavus
C. lindstromi Druce & Jones
C. intermedius Furnish
Iapetognathus praeengensis Landing

The section and others nearby are unique within the Acado-Baltic faunal province in that they provide abundant trilobites together with graptolites and conodonts in an apparently unbroken, uniform sedimentary succession across the Cambrian-Ordovician boundary interval.

Figure 10. The Nærsnes beach section. Note the large concretions at the base of the Ordovician. Photo: Karl Bruton.

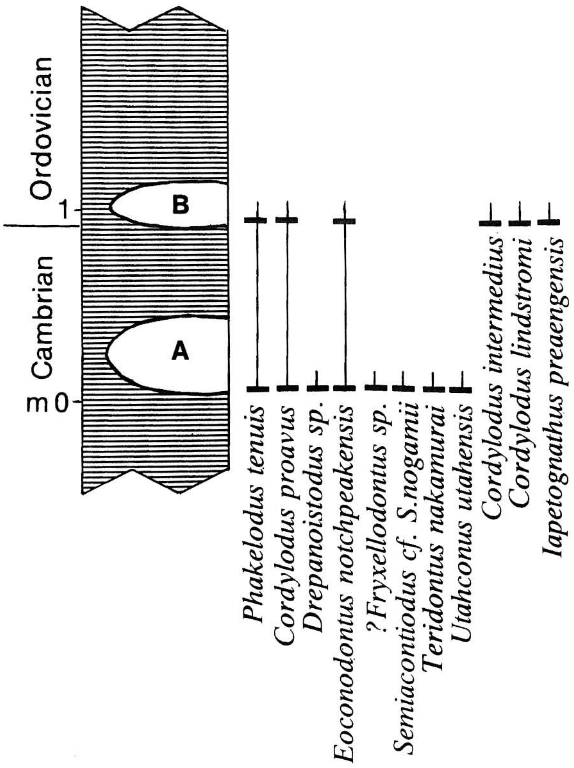


Figure 11. Stratigraphic ranges of conodonts in limestone concretions (A, B), Nærsnes beach section A- Acerocare ecorne, B- Boeckaspis hirsuta. From Repetski in Bruton et al. (1988).

Figure 12. The Cambrian unconformity at Slemmestad centre. Photo: Karl Bruton.

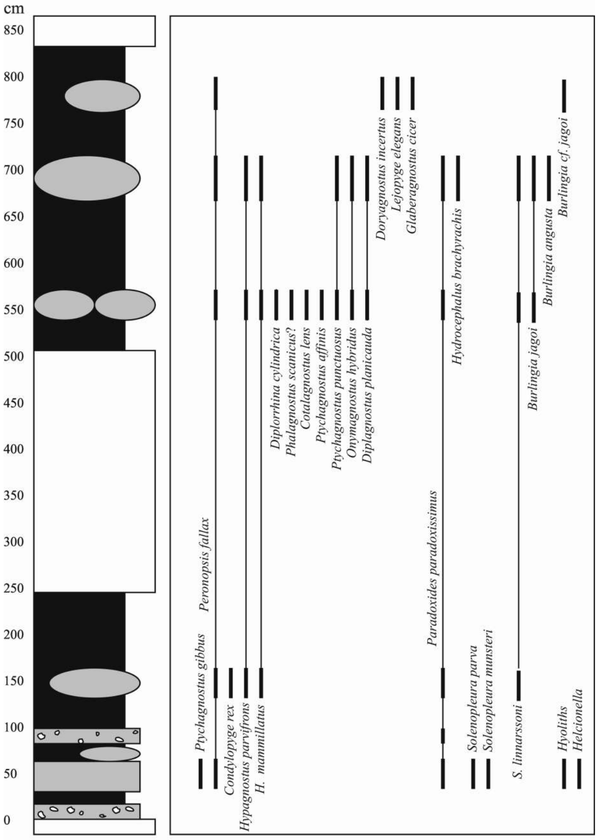


Figure 13. Cambrian stratigraphic section at Slemmestad and distribution of fossils. From Høyberget & Bruton (2008).

Stop 3. Slemmestad centre

[Asker Sheet 1841 1 (1976) NM 842 281]

At Slemmestad (Figs. 12, 13) 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 bed 20-40 cm thick, fragmental in the 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.

Stop 4. Slemmestad cross roads

[Asker Sheet 1814 1(1976) NM 836 283]

This locality has not been studied in detail as it is the approach road to a new housing estate. Away from the main road, it can be examined in detail from the Cambrian up to and including the Arenig-Llanvirn boundary. Of interest will be (Figs. 14, 15):

i) The Cambrian-Ordovician boundary with abundant *Rhabdinopora*
ii) Near the top of the Alum Shale Formation in Oslo-Asker is a unit of two or more planar limestone beds with a Late Tremadocian trilobite fauna forming a good marker horizon (Henningsmoen 1973, Owen et al. 1990) and recently defined as the *Incipiens* Limestone Bed by Nielsen & Schovsbo (2007)
iii) The Bjørkåsholmen Formation with glauconite.
iv) Abundant graptololites of the Tøyen Formation including *Didymograptus extensus*, *Tetragraptus quadribranchiatus* and *Phyllograptus angustifolius*.

This will be an ideal collecting stop where hammers are allowed.

Figure 14. Slemmestad cross roads section with Tremadoc Incipiens Limestone member. Photo: Karl Bruton.

Figure 15. Slemmestad cross roads section with tripartite Huk Formation and underlying shales of Tøyen Formation. Photo: Karl Bruton.

Stop 5. Bjørkåsholmen, Asker

[Asker Sheet 1814 I (1976) NM 844 294]
The peninsula here exhibits a sequence including the Bjørkåsholmen Formation through the overlying Tøyen Shale and limestones of the Huk Formation.

The Bjørkåsholmen Formation (Fig. 16) contains a varied shelly fauna of trilobites (see Ebbestad 1999) including *Ceratopyge forficula*, *Euloma ornatum*, *Symphysurus angustatus* and *Niobe insignis*. Note the dark concretions at the base forming a marker horizon over the entire region and containing the olenid trilobite *Bienvillia angelini* (Linnarssson). The limestone is glauconitic and contains arrow-like pseudomorphs of gypsum(?).

The Tøyen Shale is not particularly fossiliferous here but the green-grey- black transition between the Hagestrand Member and the overlying Galgeberg Member is obvious.

The tripartite division of the Huk Formation is best seen along the northern flank of the peninsula. The units are fossiliferous especially the trilobites (see Nielsen 1995) and the endoceratid cephalopod conchs can exceed 1 m in length.

This locality is the basal stratotype for the Bjørkåsholmen Formation.

Stop 6. Vollen bentonite bed

[Asker Sheet 1814 I (1976) NM 835 311]
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. Here at Vollen (Fig. 17) is one of several in the section, this being the thickest and probably the same as that at Sinsen (the Kinnekulle K-bentonite = BXX1 of Hagemann & Spjeldnæs 1955). This 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 Baltican plates.

Stop 7. Spirodden

[Asker Sheet 1814 I (1976) NM 840 339]
This is one, of few well preserved coastal sections (Fig. 18) showing superb and highly fossiliferous limestones of the Lower Silurian Solvik Formation. This section was described in detail by Kiær (1908) and later in detail by Baarli (1995) who identified 160 metres through the lower and middle parts of the formation from high 6a• to the base of 6a• in Kiær's terminology. Brachiopods (*Eoplectodonta, Dicoelosia, Leangella*) are usually small but comprise about 70% of the fauna which otherwise consists of tabulate corals such as *Halysites* and *Favosites* (Fig. 19), various rugose corals including *Grewingkia* and *Borelasma* and superb stromatoporoids . Private approach to this section through the kindness of the owners Michael and Margaret Rustad.

Stop 8. Holmen boatyard

[Asker Sheet 1814 I (1976) NM 839 365]

This locality exhibits one of the most impressive submarine channels involving blocks of the late Ordovician Langåra Formation. These blocks contain rugose and tabulate corals, the calcareous alga *Palaeoporella* and clasts of calcareous oolitic limestone all locally derived. The Langåra Formation is restricted to the western part of the Oslo-Asker area and was interpreted by Brenchley & Newall (1975) as a nodular, calcareous equivalent of the deeper water Huserbergøya in the east and massive sandstone development of the Langøyene Formation to the south. Participants will be invited to discuss their interpretation of the channel infills (Fig. 20).

Figure 16. The Bjørkesholmen Formation and the rust weathering overlying base of the Tøyen Formation, Bjørkåsholmen peninsula. Photo: Karl Bruton.

Figure 17. The pale green- weathering bentonite bed of the Caradoc Arnestad Formation (Zone of Didymograptus multidens), Vollen, Asker. Photo: Karl. Bruton.

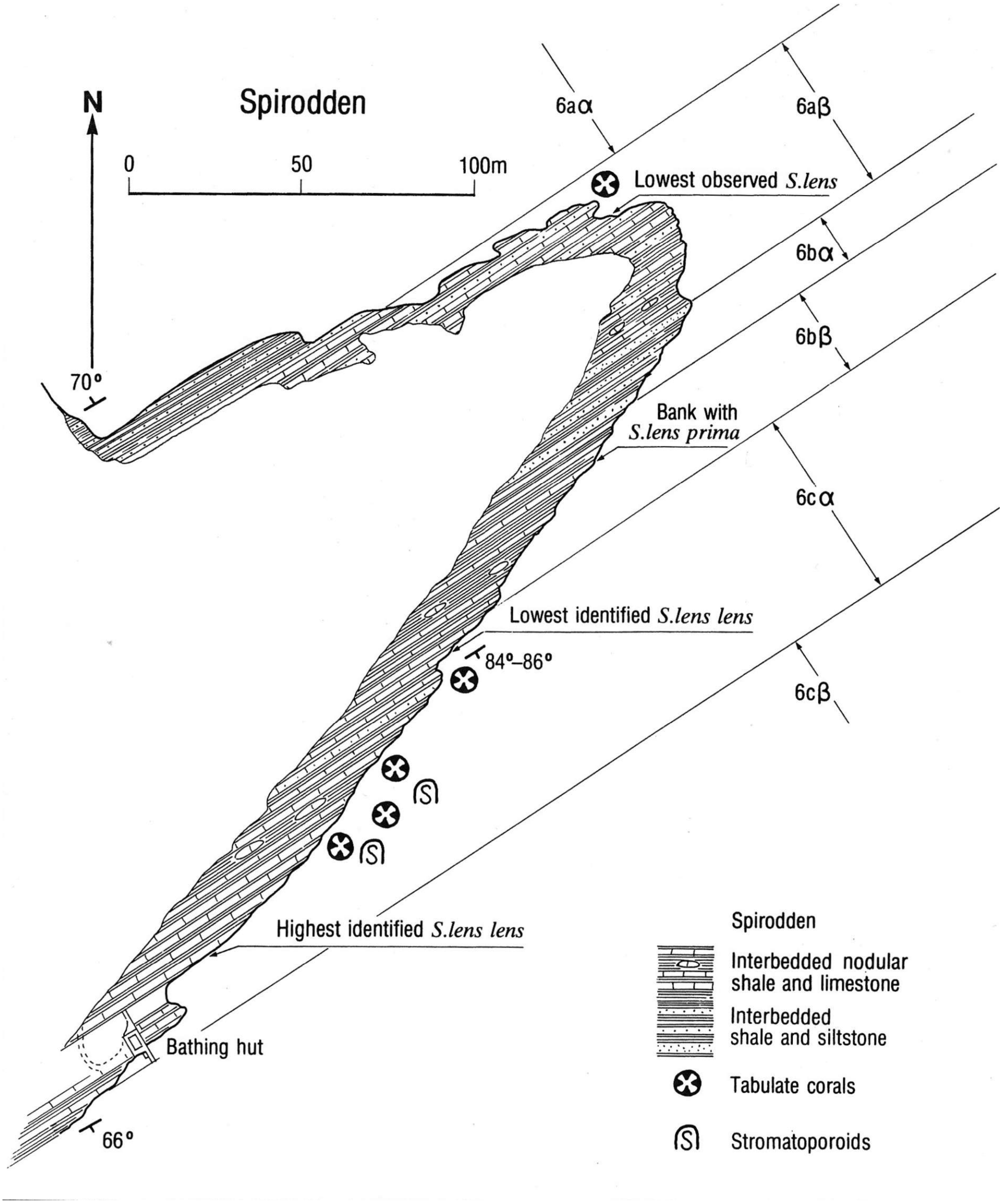


Figure 18. The Spirodden beach section showing lithology and important fossil occurrences in the Lower Silurian Solvik Formation. From Worsley et al. (1982).

Figure 19. Colonies of Favosites in beds of the Solvik Formation (see Fig.18), Spirodden, Asker. Photo: Karl Bruton.

Figure 20. Holmen boatyard, Asker. Late Ordovician channel infill. The lady stands at the top of the channel. Note the line of the base just above the wooden gangway and how it extends several metres into the underlying beds. Photo: J. F. Bockelie.

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