NGF-Oslos ekskursjon til Tyrifjorden

Søndag 11. august 2024

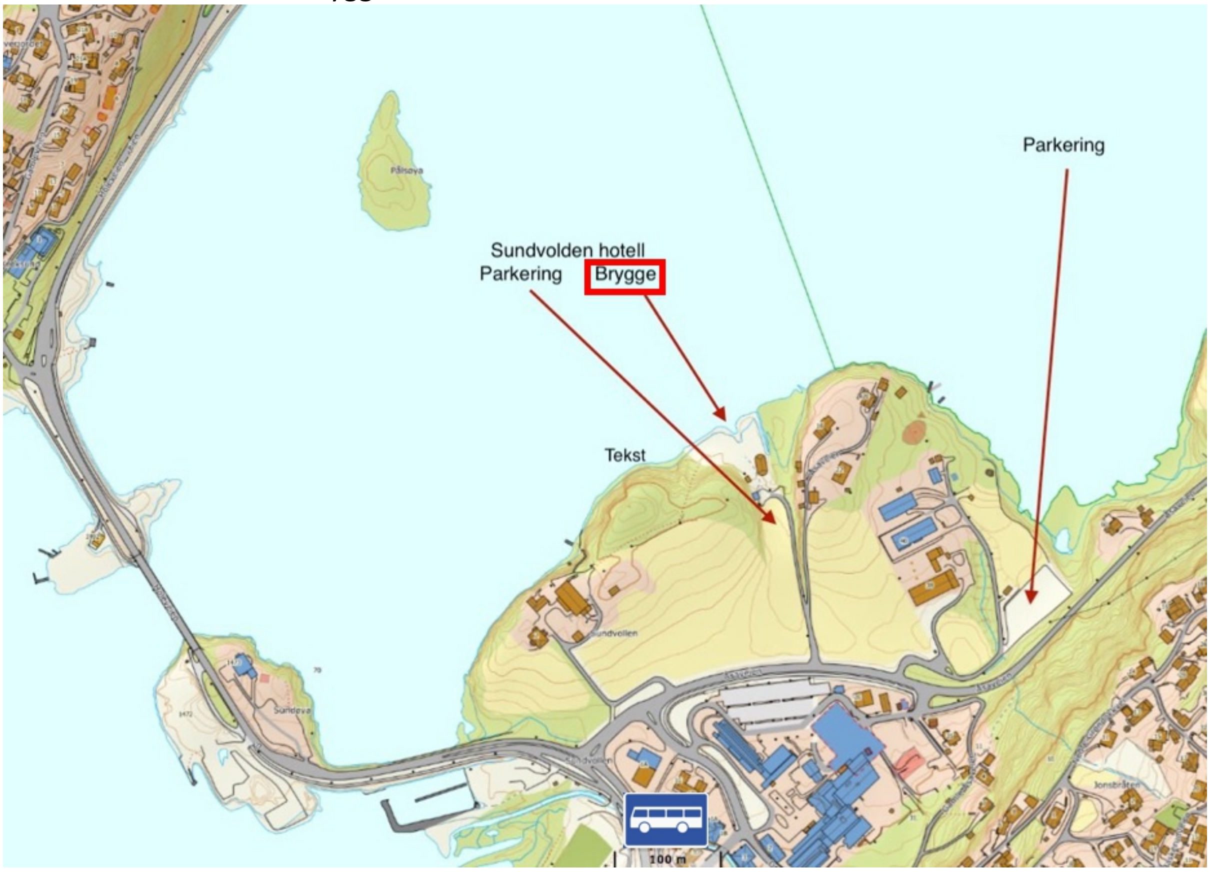
Guide på turen: Bjørn T. Larsen

(Dette heftet inneholder enkeltsider fra utvalgte artikler, noen kart og noen bilder)

NORSK GEOLOGISK FORENING

Planlagt rute / logistikk:
Familieekskursjon med båten "Dronning Tyra" på Tyrifjorden, Ringerike, ledet av Bjørn Tore Larsen. **Avreise kl 11:00** fra Sundvollen brygge (og retur til samme sted), Steinsfjorden (god parkering ved brygga, og 15 min å gå fra busstopp E16).
Buss fra Oslo bussterminal, rute 200 til Hønefoss, med avgang kl 09:40 passer med båtens avreise.
Planlagt reiserute, avhengig av vannstand og mulighteter for ilandstiging:

Avreise fra Sundvollen brygge:



Båten går til Braksøya (i Steinsfjorden) og vi ser på klippene der, med sedimentære bergarter og korallrev fra silur (Bruflatformasjonen med Braksøyaformasjonen over). Ikke ilandstigning.

Deretter under E16 inn i Holsfjorden. Neste lokalitet er Limovnstangen tilhørende Ryttarager gård. Vi går i land her, og ser på Sælabonn - og Rytteråkerformasjonen (nedre silur). Regner med at denne stoppen tar en times tid.

Vi seiler videre langs Svartøyene, ser på geologien der fra båten, og går videre til Frognøya. Der går vi i land og spiser (medbragt) lunsj, og bruker tid på å studere geologien (Solvangformasjonen med Venstøpformasjonen og Sørbakkformasjonen over, øvre ordovicium) og finne fossiler (koraller). Her er det lov å ta med seg fossilene hjem (ikke fredet).

Planen videre er å gå inn i Nordfjorden, og kanskje inn mot Storelvas utløp og se på kvartæravsetningene der. Dette avhenger litt av tidsbruken og vannføring.

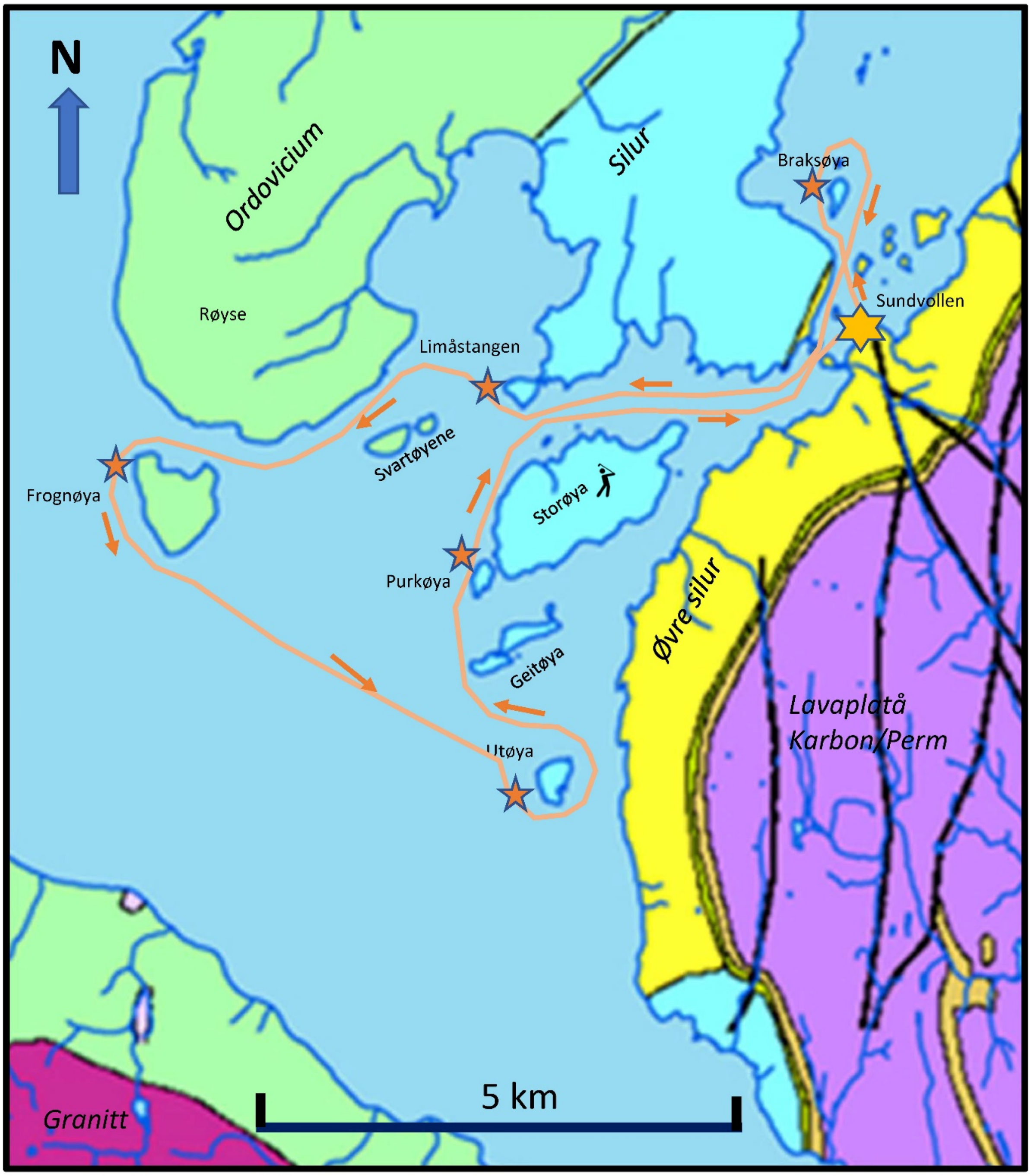
Deretter sørover mot Utøya (Steinsfjordformasjonen, folding og skyvning), og via Geitøya og Storøya tilbake til Sundvollen.

Praktisk informasjon:
Vi regner med en rundt 4-5 timers tur med ilandstigning to steder der vi kan spise egen medbragt lunsj, og finne noen fine fossiler. Det vil være mulig å kjøpe kaffe, boller, brus og pølser på båten.
Det er **begrenset antall plasser** på båten og turen krever påmelding. Meld deg/dere på så snart som mulig, så er du/dere sikret plass (send epost til h.a.nakrem@nhm.uio.no). Egenandel kr 200,- for medlemmer/partnere, 400,- for ikke-medlemmer. Barn under 16 år gratis. Påmelding er bindende, og deltakeravgift må betales via Vipps en uke før turen (det kommer vi tilbake til). Båten krever navn og mobilnummer til alle deltakerne.

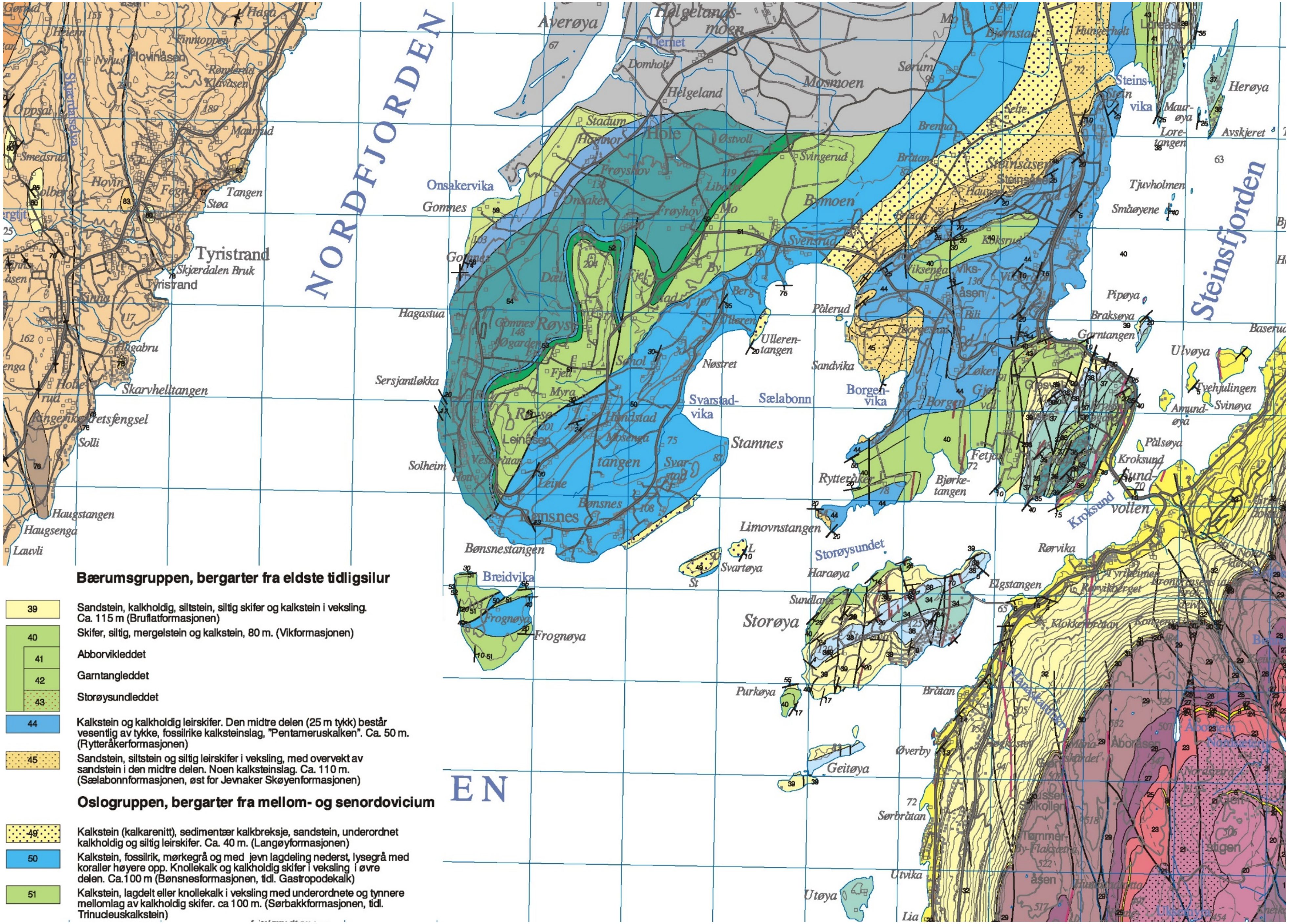
Bussinformasjon

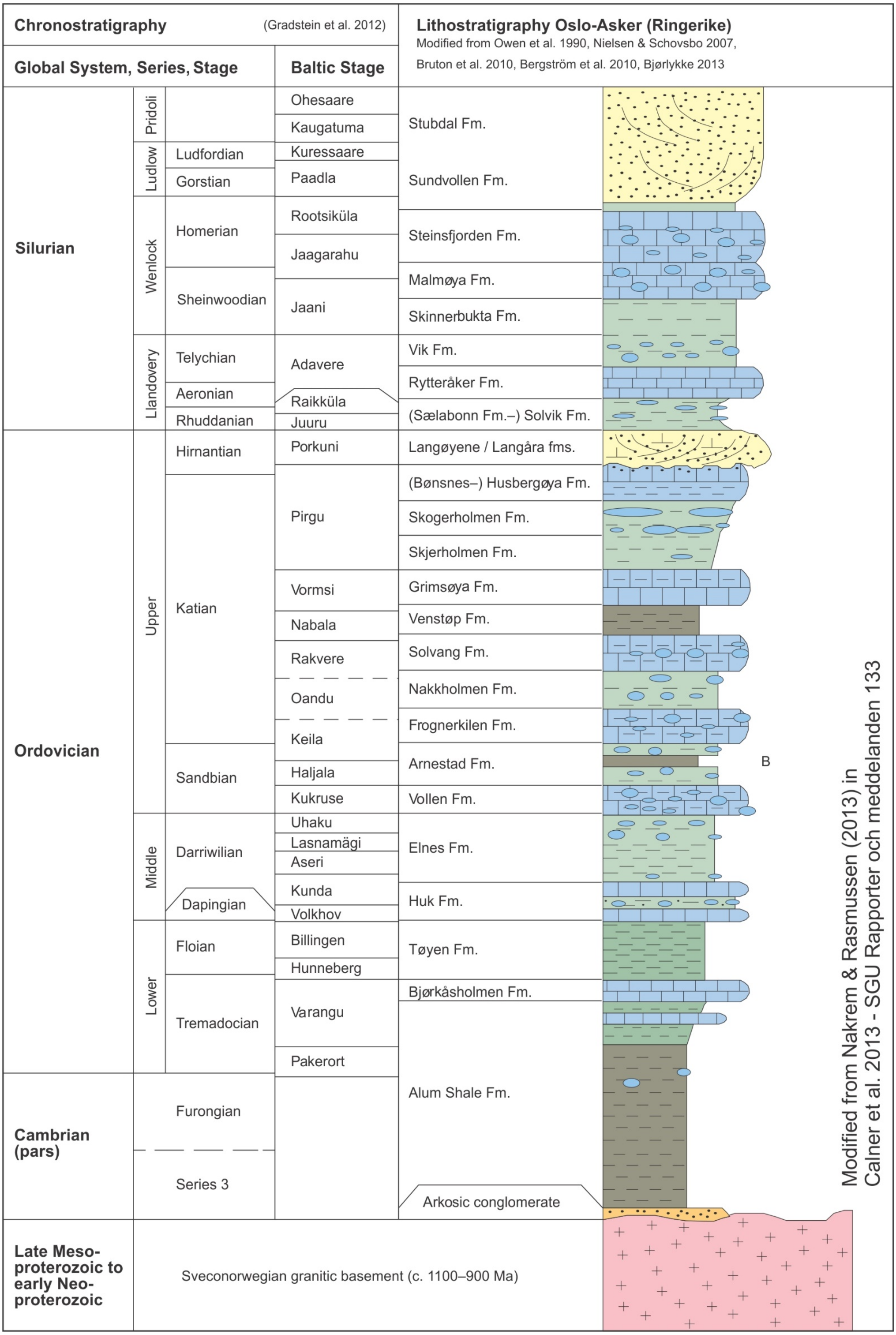
Bussrute 200, avreise fra Oslo bussterminal kl. 09:40:

Bussrute 200, retur fra Sundvollen mot Oslo bussterminal kl 16:20

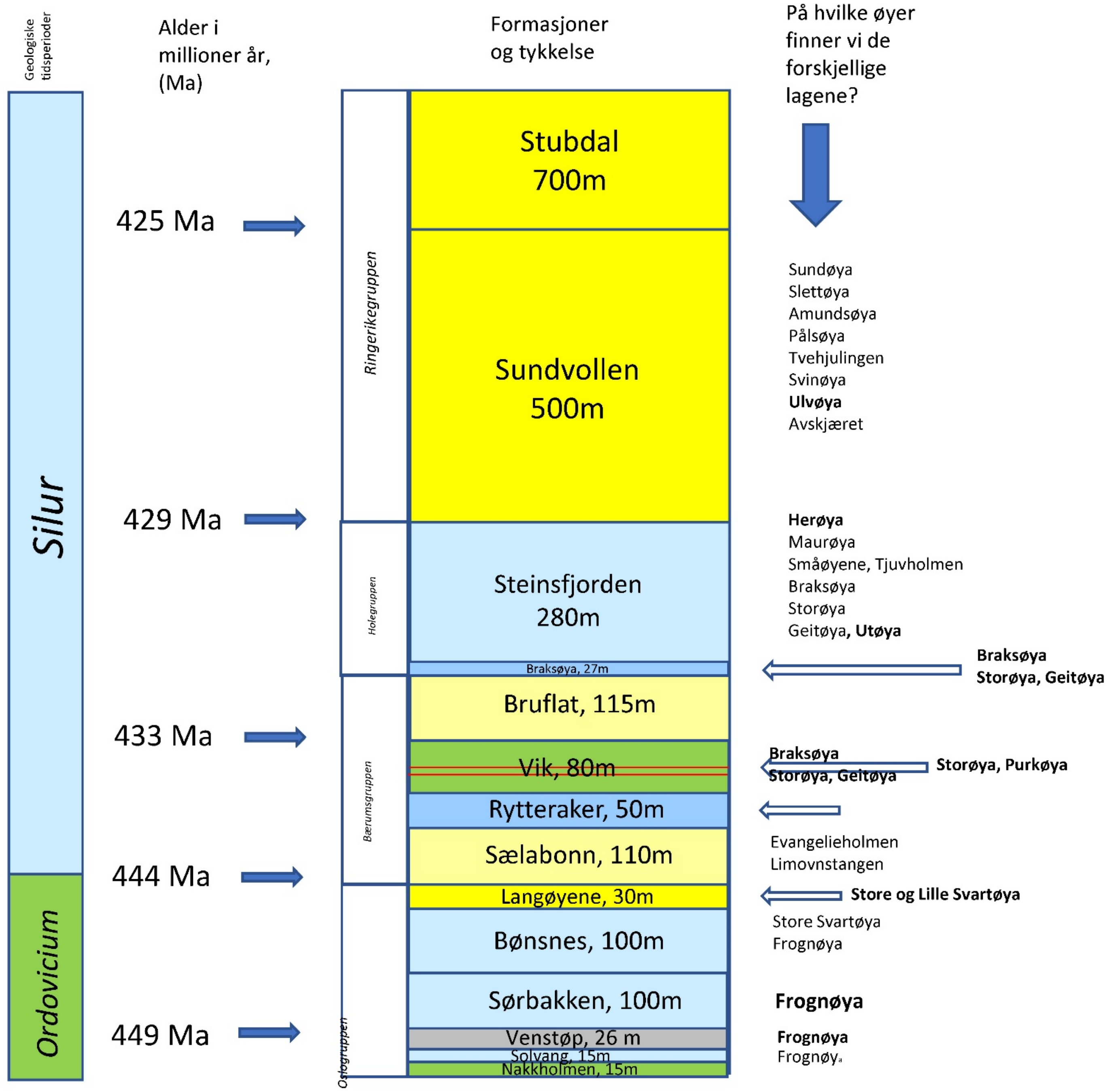


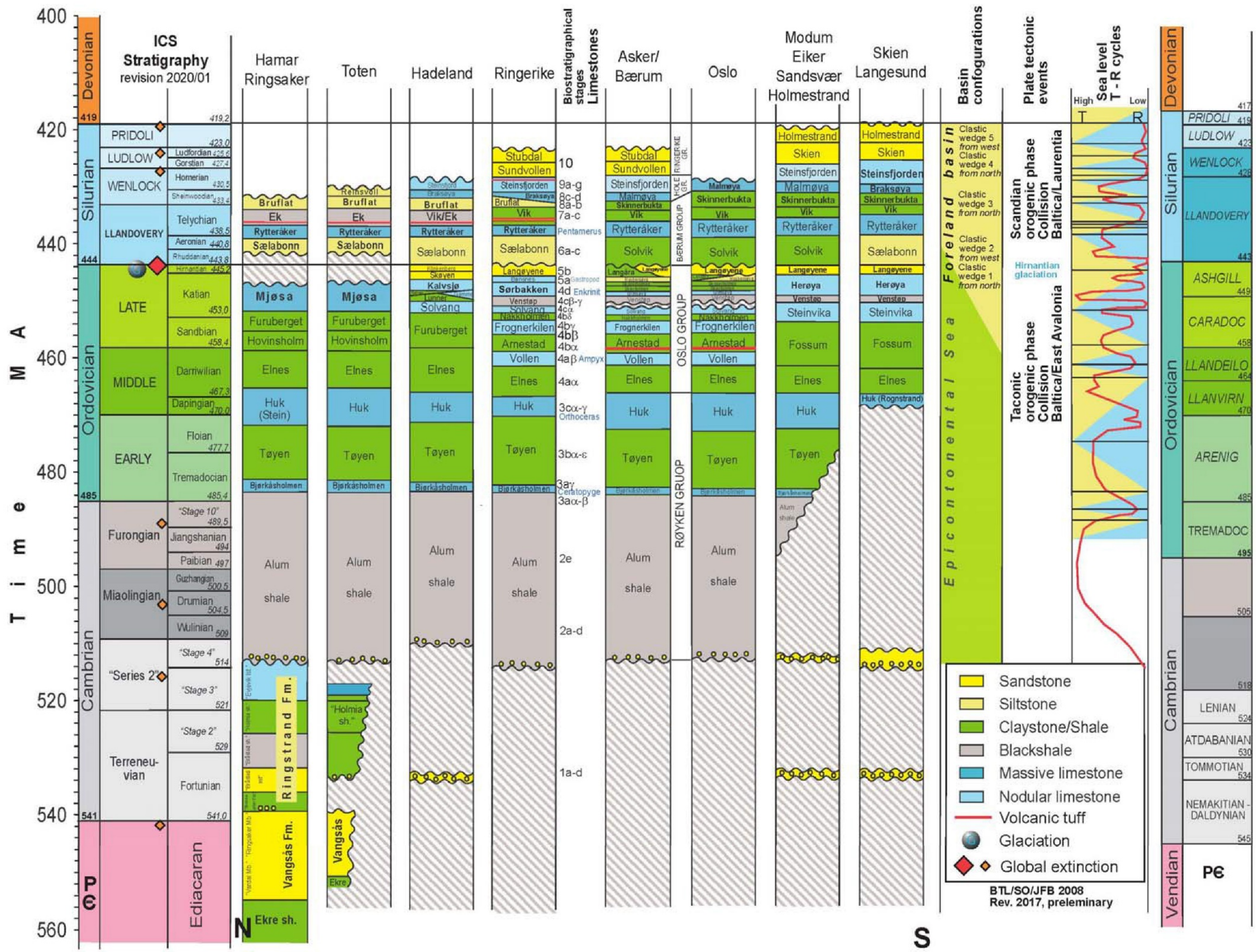
Geologisk kart med planlagt rute inntegnet


Bærumsgruppen, bergarter fra eldste tidligsilur
39 Sandstein, kalkholdig, siltstein, siltig skifer og kalkstein i veksling. Ca. 115 m (Bruflatformasjonen)
40 Skifer, siltig, mergelstein og kalkstein, 80 m. (Vikformasjonen)
41 Abborvikleddet
42 Garntangleddet
43 Storøysundleddet
44 Kalkstein og kalkholdig leirskifer. Den midtre delen (25 m tykk) består vesentlig av tykke, fossilrike kalksteinslag, "Pentameruskalken". Ca. 50 m. (Rytteråkerformasjonen)
45 Sandstein, siltstein og siltig leirskifer i veksling, med overvekt av sandstein i den midtre delen. Noen kalksteinslag. Ca. 110 m. (Sælabonnformasjonen, øst for Jevnaker Skøyenformasjonen)
Oslogruppen, bergarter fra mellom- og senordovicium
49 Kalkstein (kalkarenitt), sedimentær kalkbreksje, sandstein, underordnet kalkholdig og siltig leirskifer. Ca. 40 m. (Langøyformasjonen)
50 Kalkstein, fossilrik, mørkegrå og med jevn lagdeling nederst, lysegrå med koraller høyere opp. Knollekalk og kalkholdig skifer i veksling i øvre delen. Ca.100 m (Bønsnesformasjonen, tidl. Gastropodekalk)
51 Kalkstein, lagdelt eller knollekalk i veksling med underordnete og tynnere mellomlag av kalkholdig skifer. ca 100 m. (Sørbakkformasjonen, tidl. Trinucleuskalkstein)
NORDFJORDEN
Steinsfjorden
Tyristrand
Averøya
Helgelandsmoen
Hole
Røyse
Storøya
Stamnes
Sælabonn
Storøysundet
Frognøya
Utøya
Geitøya
Purkøya
Svartøya
Limovnstangen
Bønsnestangen
Breidvika
Onsakervika
Gomnes
Sundvollen
Kroksund
Ulvøya
Herøya
Tjuvholmen
Elgstangen
Rørvika
Skarvhelltangen
Haugstangen
Sersjantløkka
Hagastua
Solheim
EN

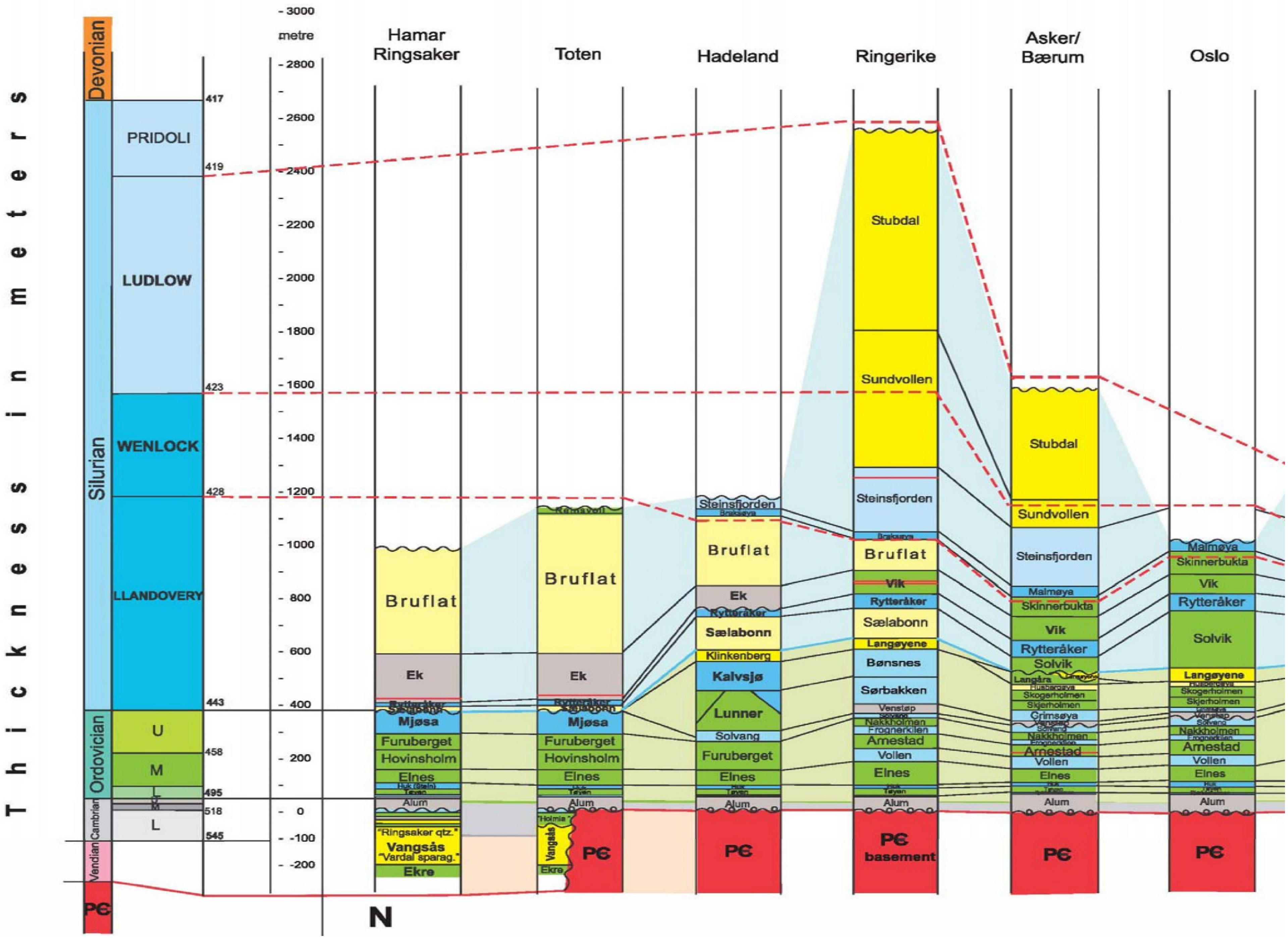


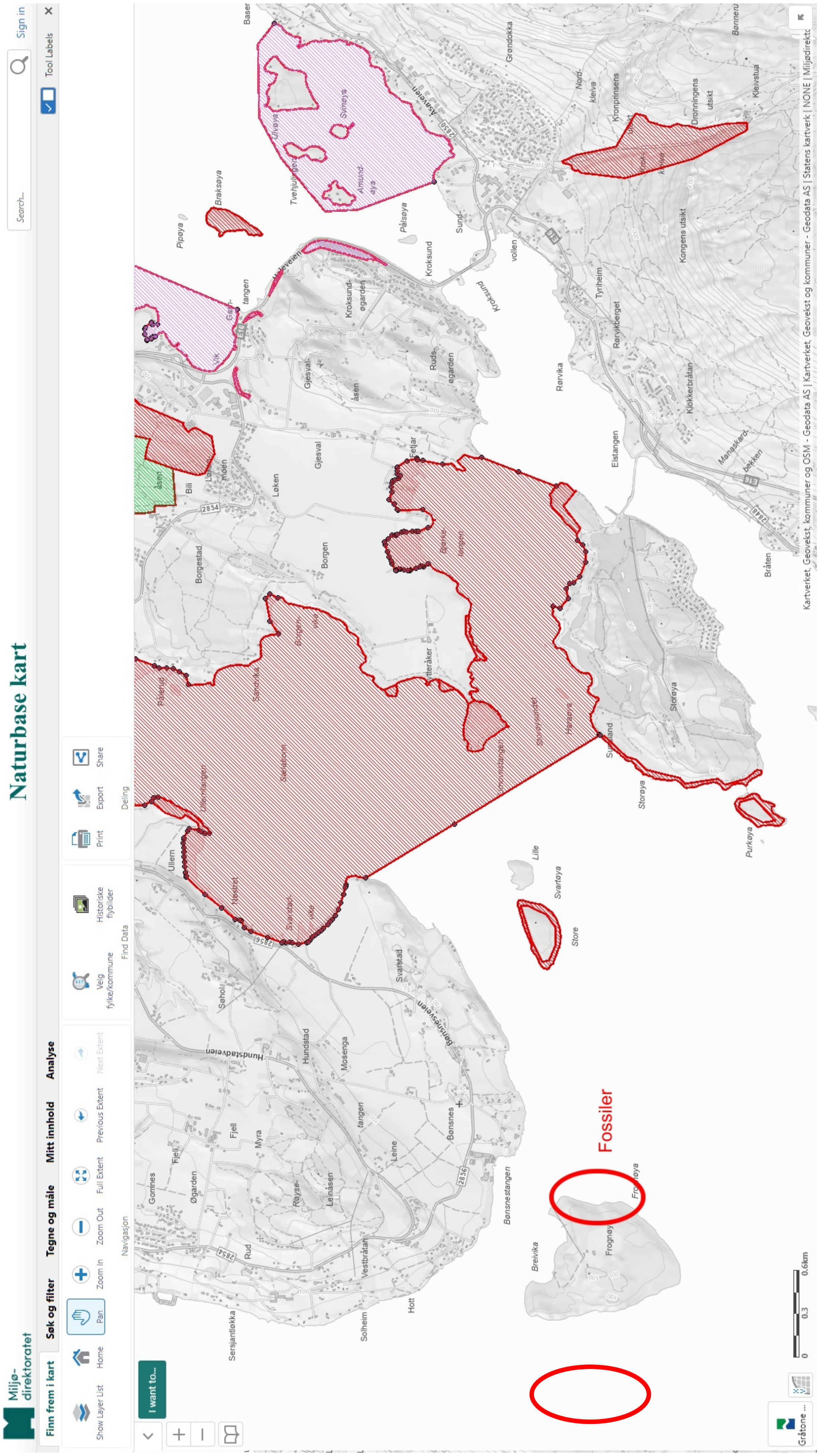
Chronostratigraphy
(Gradstein et al. 2012)
Lithostratigraphy Oslo-Asker (Ringerike)
Modified from Owen et al. 1990, Nielsen & Schovsbo 2007, Bruton et al. 2010, Bergström et al. 2010, Bjørlykke 2013
Global System, Series, Stage
Baltic Stage
Silurian
Pridoli
Ludlow
Wenlock
Llandovery
Ludfordian
Gorstian
Homerian
Sheinwoodian
Telychian
Aeronian
Rhuddanian
Ohesaare
Kaugatuma
Kuressaare
Paadla
Rootsiküla
Jaagarahu
Jaani
Adavere
Raikküla
Juuru
Stubdal Fm.
Sundvollen Fm.
Steinsfjorden Fm.
Malmøya Fm.
Skinnerbukta Fm.
Vik Fm.
Rytteråker Fm.
(Sælabonn Fm.–) Solvik Fm.
Ordovician
Upper
Middle
Lower
Hirnantian
Katian
Sandbian
Darriwilian
Dapingian
Floian
Tremadocian
Porkuni
Pirgu
Vormsi
Nabala
Rakvere
Oandu
Keila
Haljala
Kukruse
Uhaku
Lasnamägi
Aseri
Kunda
Volkhov
Billingen
Hunneberg
Varangu
Pakerort
Langøyene / Langåra fms.
(Bønsnes–) Husbergøya Fm.
Skogerholmen Fm.
Skjerholmen Fm.
Grimsøya Fm.
Venstøp Fm.
Solvang Fm.
Nakkholmen Fm.
Frognerkilen Fm.
Arnestad Fm.
Vollen Fm.
Elnes Fm.
Huk Fm.
Tøyen Fm.
Bjørkåsholmen Fm.
Alum Shale Fm.
B
Cambrian (pars)
Furongian
Series 3
Arkosic conglomerate
Late Meso-proterozoic to early Neo-proterozoic
Sveconorwegian granitic basement (c. 1100–900 Ma)
Modified from Nakrem & Rasmussen (2013) in Calner et al. 2013 - SGU Rapporter och meddelanden 133


Geologiske tidsperioder
Alder i millioner år, (Ma)
Formasjoner og tykkelse
På hvilke øyer finner vi de forskjellige lagene?
Silur
Ordovicium
425 Ma
429 Ma
433 Ma
444 Ma
449 Ma
Ringerikegruppen
Holegruppen
Bærumsgruppen
Oslogruppen
Stubdal 700m
Sundvollen 500m
Steinsfjorden 280m
Braksøya, 27m
Bruflat, 115m
Vik, 80m
Rytteraker, 50m
Sælabonn, 110m
Langøyene, 30m
Bønsnes, 100m
Sørbakken, 100m
Venstøp, 26 m
Solvang, 15m
Nakkholmen, 15m
Sundøya
Slettøya
Amundsøya
Pålsøya
Tvehjulingen
Svinøya
Ulvøya
Avskjæret
Herøya
Maurøya
Småøyene, Tjuvholmen
Braksøya
Storøya
Geitøya, Utøya
Braksøya
Storøya, Geitøya
Braksøya
Storøya, Geitøya
Storøya, Purkøya
Evangelieholmen
Limovnstangen
Store og Lille Svartøya
Store Svartøya
Frognøya
Frognøya
Frognøya
Frognøya



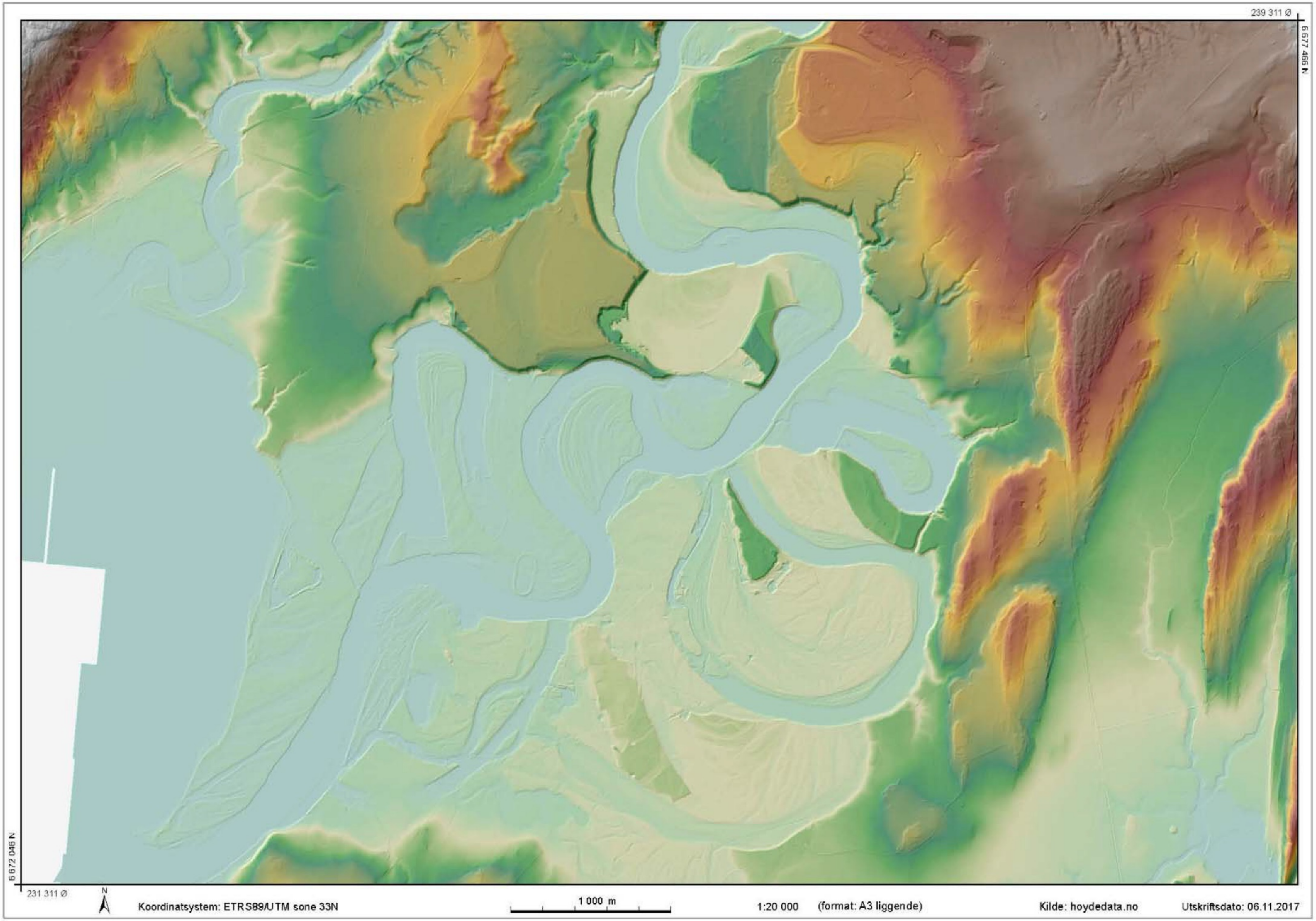
Time MA
ICS Stratigraphy revision 2020/01
Devonian
Silurian
Ordovician
Cambrian
PЄ
PRIDOLI
LUDLOW
WENLOCK
LLANDOVERY
LATE
MIDDLE
EARLY
Furongian
Miaolingian
"Series 2"
Terreneu-vian
Ediacaran
Hamar Ringsaker
Toten
Hadeland
Ringerike
Biostratigraphical stages Limestones
Asker/ Bærum
Oslo
Modum Eiker Sandsvær Holmestrand
Skien Langesund
Basin confogurations
Plate tectonic events
Sea level T - R cycles
Epicontonental Sea
Foreland basin
Scandian orogenic phase Collision Baltica/Laurentia
Hirnantian glaciation
Taconic orogenic phase Collision Baltica/East Avalonia
RØYKEN GROUP
OSLO GROUP
BÆRUM GROUP
Alum shale
Tøyen
Huk
Elnes
Ringstrand Fm.
Vangsås Fm.
Ekre sh.
Sandstone
Siltstone
Claystone/Shale
Blackshale
Massive limestone
Nodular limestone
Volcanic tuff
Glaciation
Global extinction
BTL/SO/JFB 2008
Rev. 2017, preleminary
N
S
Vendian
ASHGILL
CARADOC
LLANDEILO
LLANVIRN
ARENIG
TREMADOC
LENIAN
ATDABANIAN
TOMMOTIAN
NEMAKITIAN - DALDYNIAN


Thickness in meters
Devonian
Silurian
Ordovician
Cambrian
Vendian
PЄ
PRIDOLI
LUDLOW
WENLOCK
LLANDOVERY
U
M
L
417
419
423
428
443
458
495
518
545
metre
Hamar Ringsaker
Toten
Hadeland
Ringerike
Asker/ Bærum
Oslo
Bruflat
Ek
Mjøsa
Furuberget
Hovinsholm
Elnes
Alum
"Ringsaker qtz."
Vangsås
"Vardal sparag."
Ekre
Steinsfjorden
Sælabonn
Klinkenberg
Kalvsjø
Lunner
Solvang
Stubdal
Sundvollen
Vik
Rytteråker
Langøyene
Bønsnes
Sørbakken
Venstøp
Nakkholmen
Frognerkilen
Amestad
Vollen
basement
Malmøya
Skinnerbukta
Solvik
Grimsøya
Skogerholmen
Skjerholmen
N

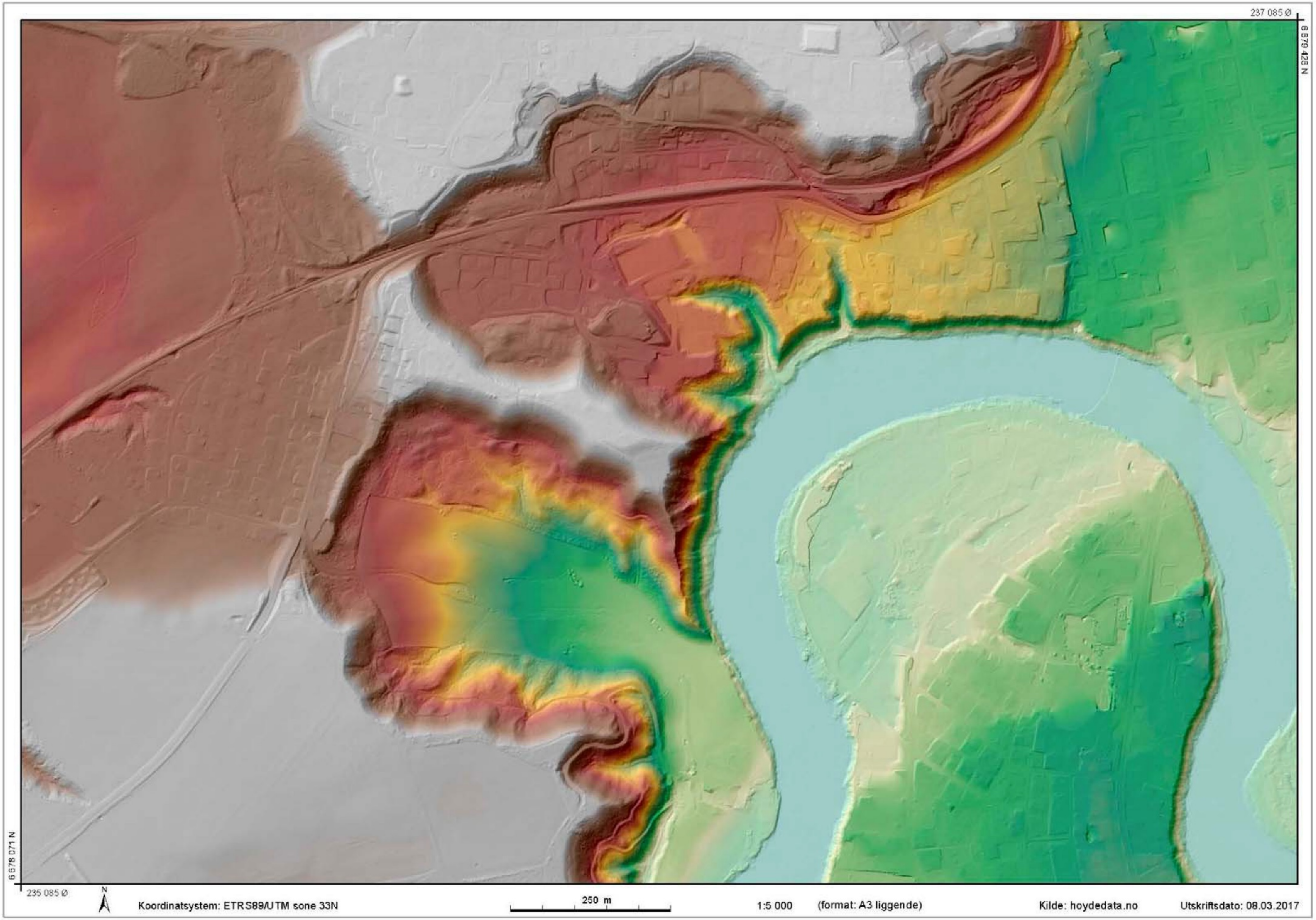


Verneområder (rødt skravert)

Meandrerende elv, Storelva nedre del og delta



Lidarkart, Eikeli Hønefoss. To store kvikkleire-skred (https://hoydedata.no/Laserinnsyn2/)

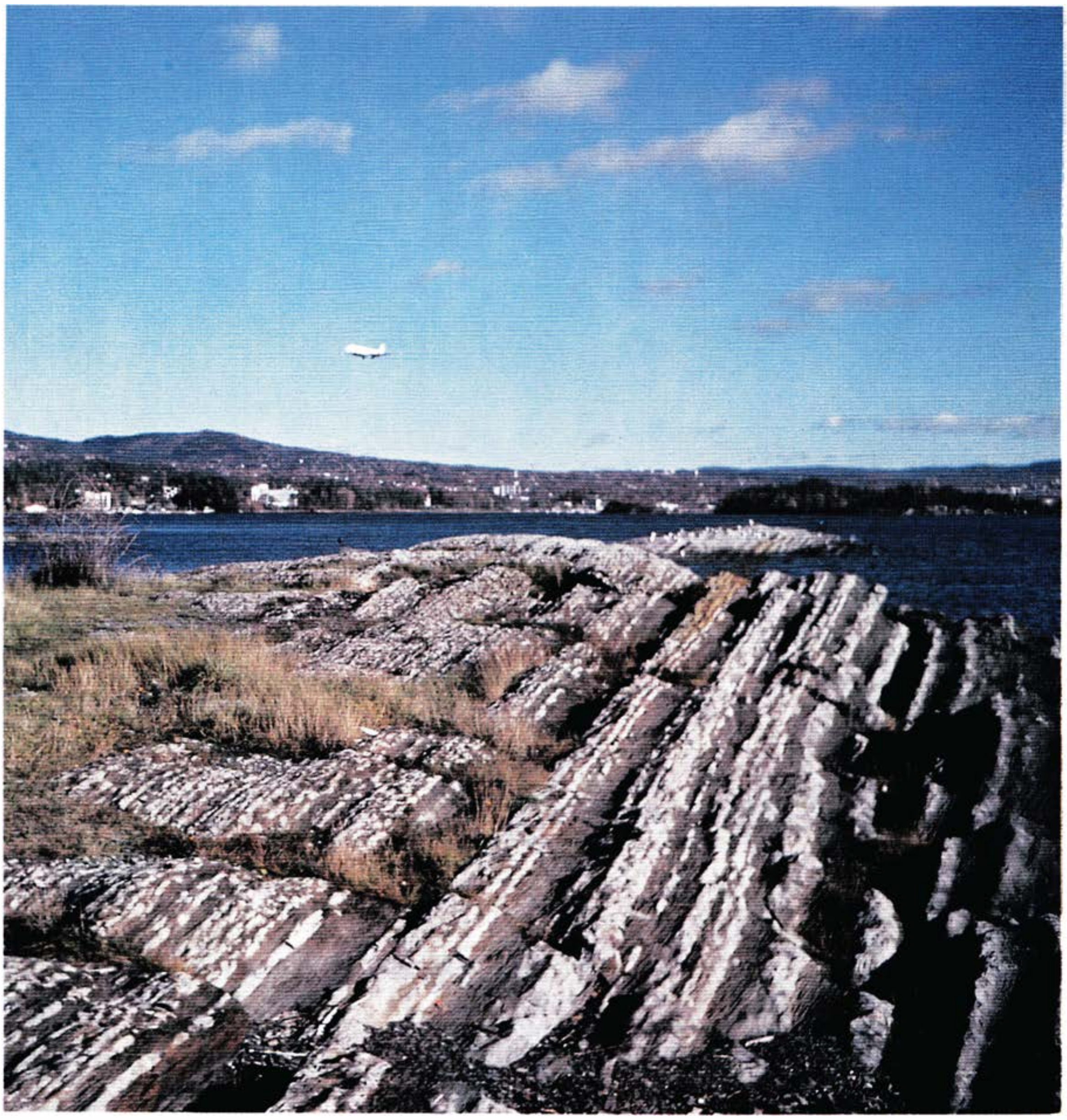


NORGES GEOLOGISKE UNDERSØKELSE

THE ORDOVICIAN SUCCESSIONS OF THE OSLO REGION, NORWAY

Alan W. Owen, David L. Bruton,
J. Fredrik Bockelie & Tove G. Bockelie

Special Publication 4



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Late Ordovician Trace Fossils from Offshore to Shallow Water Mixed Siliciclastic and Carbonate Facies in the Ringerike Area, Oslo Region, Norway

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ABSTRACT

Upper Ordovician (Rawtheyan–Hirnantian) deposits in the Ringerike area contain 21 ichnogenera of burrows and two ichnogenera of borings. These deposits consist of a lower siliciclastic part and an upper part dominated by carbonates and mixed clastic-carbonate deposits. Sedimentological and geochemical investigations combined with an ichnological analysis in the lower siliciclastic part point to a shallowing from a transitional–offshore partly dysoxic zone to an oxic delta front/upper shoreface facies. The trace fossils belong to the proximal, archetypal, and distal *Cruziana* ichnofacies. The upper part of the sequence comprises a complex pattern involving patch reefs interfingering with shallow marine deposits of sandstones and crinoidal limestones in the southern area and carbonate mud banks to the north. The carbonate mud banks were subaerially exposed with the development of local coastlines. The overlying transgressive sediments, consisting of sandstones and carbonates, contain an offshore to transitional trace fossil assemblage.

KEYWORDS
Facies; Geochemistry; Ichnology; Norway; Ordovician

Introduction

Lower Paleozoic deposits of the Oslo Region contain abundant and diverse trace fossils, some of which have been known since the 19th century. Brongniart (1828) described *Chondrites antiquus* from the Ordovician limestones of Lindøya island situated about 1.5 km south of Oslo harbour (see also Goeppert, 1861). Kiær (1924) illustrated an "euryp-terid" trackway from the Silurian at Rudstangen (see also Abel, 1935, figs. 221, 225). Seilacher and Meischner (1964) recognized several other trace fossils and used them for paleo-environmental, mainly bathymetric, analysis. Further information on the ichnology of the Ordovician and Silurian in the Oslo Region has been provided by Turner (1974), Hanken and Størmer (1975), Harland (1978), Brenchley et al. (1979), Whitaker (1979), Brenchley and Newall (1980), Opalinski and Harland (1980), Brenchley and Cocks (1982), Pollard et al. (1982), Thomsen (1982), Pollard and Walker (1984), Spjeldnæs (1989), Stanistreet (1989), Ekdale et al. (2002), Davies et al. (2006), and Hansen et al. (2009). The ichnology of the Ordovician deposits, however, has never been analyzed in detail. In this paper, we describe trace fossils and combine the ichnological analysis with sedimentological, geochemical and sequence stratigraphical investigations of the Upper Ordovician deposits in the Ringerike area (Fig. 1).

Geological setting

Baltica, located in the southern hemisphere during the Early Paleozoic (Cocks and Torsvik, 2002, 2005; Tychsen and Harper, 2004; Torsvik and Cocks, 2005), drifted rapidly northward during the Ordovician to a near-equatorial position in the Silurian (Perroud et al., 1992). The paleogeographic position indicates a warm climate, which is also supported by, e.g., the presence of Upper Ordovician oolite shoals and warm water coral-stromatoporoid-algal reefs in the Oslo Region (Hanken and Owen, 1982; Owen et al., 1990). During the Ordovician, much of Baltica constituted a broad platform covered by a shallow epicontinental sea. The Oslo Region was part of a cratonic basin or depression near the western margin of the Baltic Shield and was earlier believed to be partly sheltered from the Iapetus Ocean by the "Telemark Land" to the west (Skjeseth, 1952; Bruton and Owen, 1982; Bruton and Harper, 1988). However, Bjørlykke (1974), Brenchley et al. (1979), and Brenchley and Newall (1980) suggested that the "Telemark Land" was in

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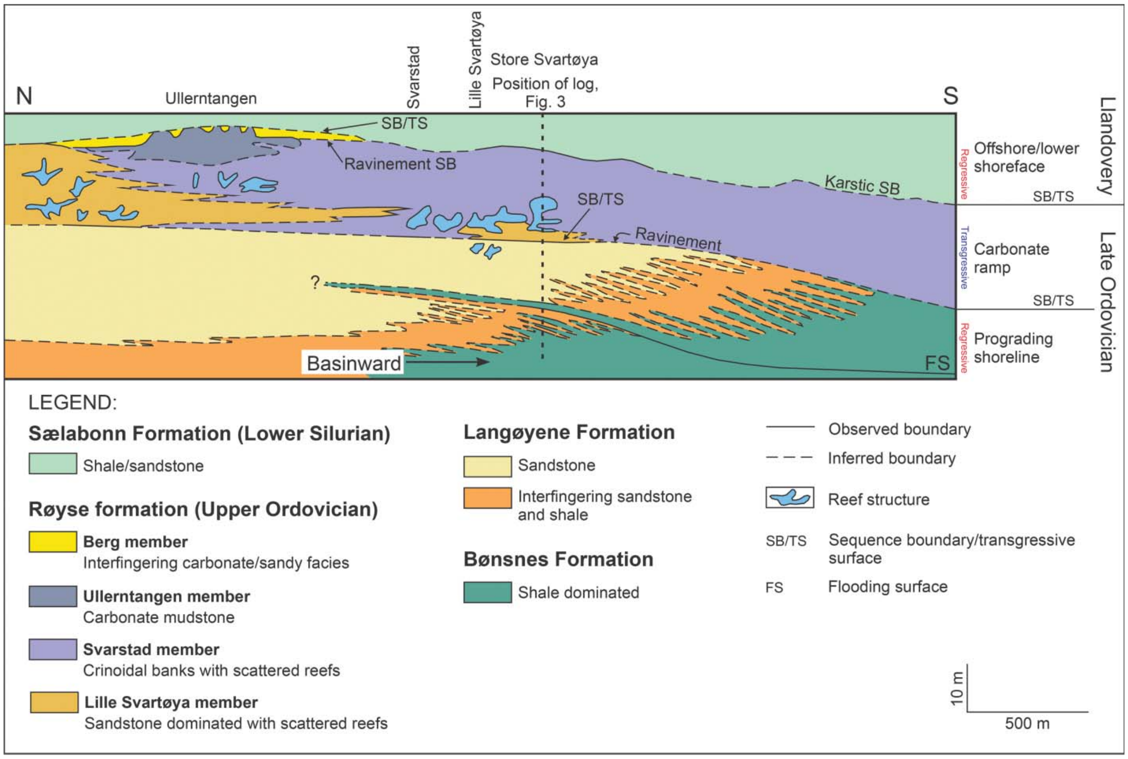


Figure 2. Conceptual geological model of the Upper Ordovician strata in the Ringerike area. The cross-section shows the lateral and vertical facies changes in a proposed sequence stratigraphic framework. The vertical scale is exaggerated. The log from Store Svartøya is shown in Fig. 3.

Store Svartøya (Fig. 1B), showing a good exposure of the uppermost 7.5 m of the Bønsnes Formation, which is 100 m thick in this area (Owen et al., 1990). At Svartøya, the shale-dominated Bønsnes Formation passes gradually into the sandstones of the 23.5 m thick Langøyene Formation. The boundary between these formations is located where the sandstone benches begin to dominate over the shales.

The boundary between the Langøyene Formation and the overlying, not yet formally defined, limestone-dominated Røyse formation, is erosional with the development of a basal sandstone conglomerate consisting of rounded pebbles derived from the underlying Langøyene Formation. A karstic surface defines the boundary between the Upper Ordovician Røyse formation and the Lower Silurian Sælabonn Formation. Only 11 m of interbedded shale, thin-bedded limestone and sandstone of the Sælabonn Formation is exposed on the northwestern side of Store Svartøya.

Depositional environment and transgressive/regressive (TR) cycles

Together with the exposed part of the Bønsnes and Sælabonn formations, the Langøyene and Røyse formations are subdivided into transgressive and regressive (TR) cycles (Figs. 2 and 3). At Store Svartøya, the upper part of the Bønsnes and the Langøyene formations coarsens upward from shale through interbedded shale and sandstone and to massive sandstone with channelized feature at the top, interpreted as a shallowing upward unit and as a prograding shoreline/wave-dominated delta. The boundary between the Langøyene Formation and the overlying limestone-dominated, 14.5 m thick Røyse formation is marked at the base with a 10–15 cm thick monomict sandstone conglomerate showing the same lithology as the underlying unit. The base of the Røyse formation is observed as an undulating and erosive surface with reworked sandstone clasts from the Langøyene Formation (Fig. 3) and is interpreted as a combined subaerial unconformity and ravinement surface, i.e., Unconformable Shoreline Ravinement (SR-U) as defined by Embry (2009). The Røyse formation is deposited as a carbonate ramp with reefs intersected by medium to fine-grained cross-stratified sandstone in the lower part, passing upward to patch reefs, and ends with a 4 m thick crinoidal grainstone. The lower and middle reef bodies in the Røyse formation are occasionally overturned (black arrows in Fig. 2), suggesting storms have broken up catch-up reefs, while the upper reefs end with a give-up stage or drowned reefs. The formation represents a transgressive cycle.

A karstic surface defines the boundary between the Røyse and the Lower Silurian Sælabonn formations. This subaerial unconformity surface coincides with a biostratigraphic hiatus (Thomsen, 1982; Worsley et al., 1983; Grahn et al., 1994). The hiatus between Ordovician and Silurian is regional correlative and is well documented (Owen et al.,

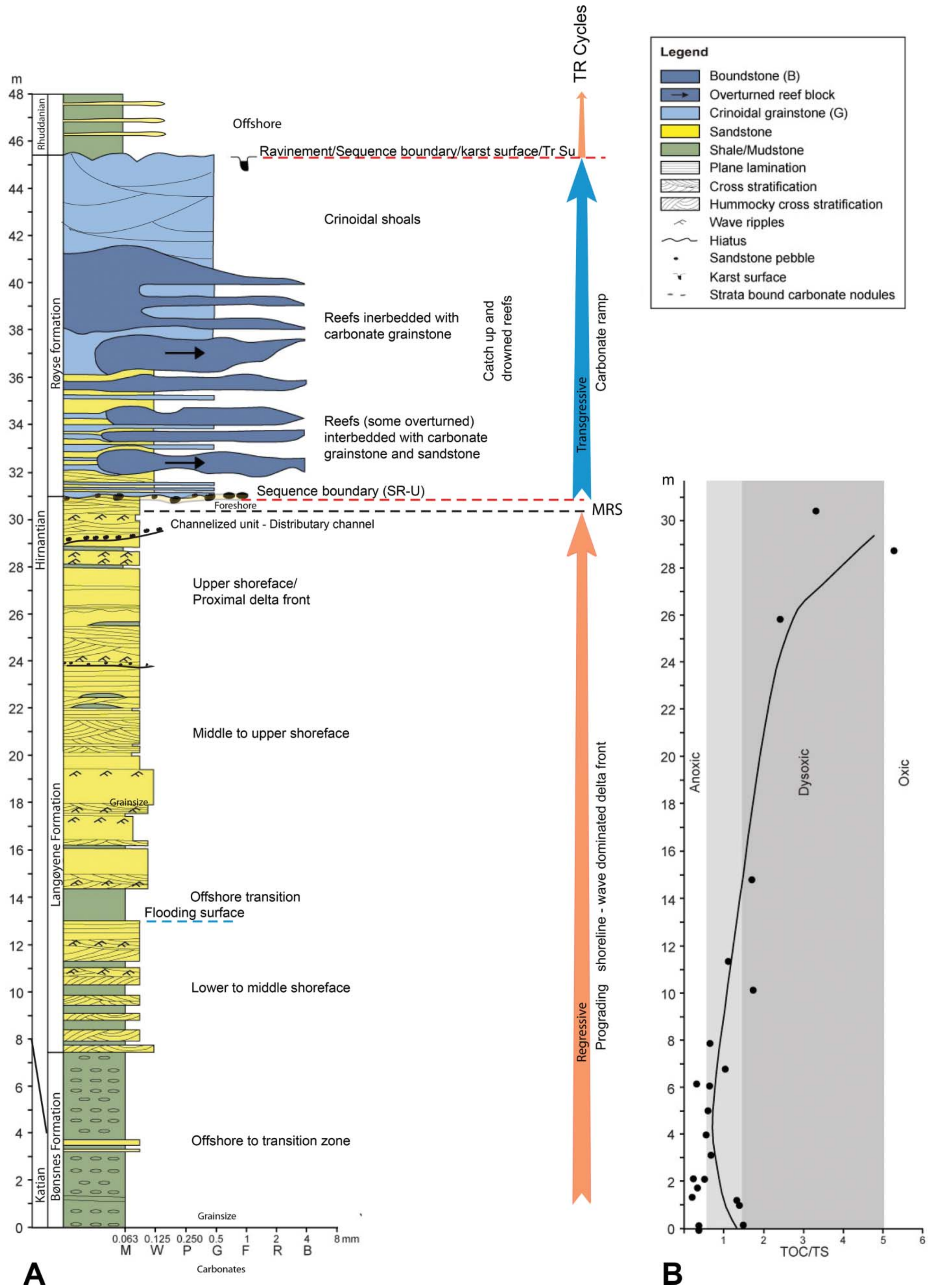


Figure 3. Sedimentary and geochemical features of the studied section. A. Sedimentological log of the exposed Upper Ordovician-Lower Silurian section on Store Svartøya island. Based on the interpreted depositional environment and fauna/flora, a sequence stratigraphic subdivision transgressive/regressive (TR) cycles is suggested. B. Graph showing the TOC/TS ratio in shales from the upper part of the Bønsnes Formation and the Langøyene Formation together with an interpretation of the general trend with increasing oxygen content of the bottom water during deposition. See the text for discussion of the limit values. SR-U: Unconformable Shoreline Ravinement, MRS: Maximum Regressive Surface. Tr Su: Transgressive surface. M: Mudstone, W: Wackestone, P: Packstone, G: Grainstone, F: Framestone, R: Rudstone, B: Boundstone, TOC: Total Organic Carbon, TS: Total Sulfur.


HA3_1360_Frognøya_Solvang-fm(lst)-Venstøp(shale)


HA3_1371_Frognøya_Solvang-fm(lst)-duplexer

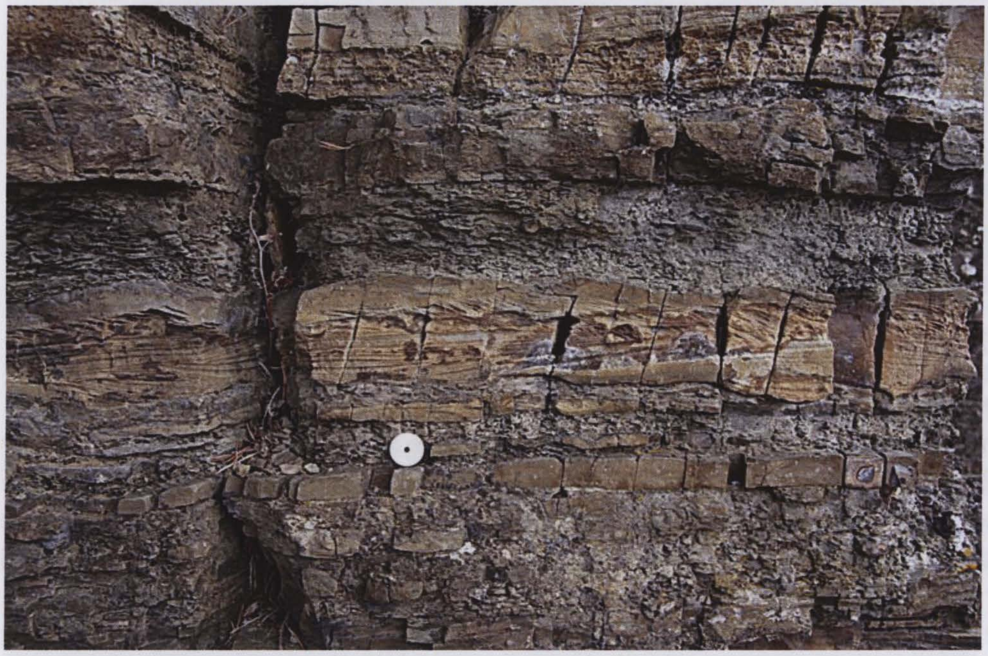

HA3_1376_Frognøya_Sørbakken-fm_w_bryozoans


HA3_1382_Frognøya_Sørbakken-fm_w_bryozoans

3 - 2: LIMOVNSTANGEN, Rytteraker, Hole

The Sælabonn Formation ; Ringerike

The age of the approximately 110 m thick Sælabonn Formation is dated to Rhuddanian and Idwian stages in Llandovery. The formation consists of mixed sandstone, siltstone and shale with subordinate limestone and is subdivided into three members. Only the upper member outcrops at the locality Rytteraker. While the middle member suggests a coastal shoreline facies, the underlying and overlying members are interpreted as offshore inner shelf environment. Calcareous mudstones in the upper member are intersected either by coarse grained fossilfereous normal graded limestone beds or sandstone beds. The sandstone beds are often well organised with a coarse grained lag (commonly brachiopods) passing upward to finer grained planar or hummocky cross stratification and are capped by either current, climbing or wave ripples. Soft sedimentary deformation structures are also common. These beds are interpreted as storm deposits, tempestites.



Sandstone beds above coin show hummocky cross strata passing up to climbing ripples and wave ripples on top, Rytteraker.

The Rytteraker Formation at Rytteraker.

The Rytteraker Formation (*Pentamerus* limestone, etage 7 a and b of Kiær (1908) from the pentamerid brachiopod *Pentamereus*) is the first major carbonate factory period within the Silurian. Siliciclastics input where shut off in the Ringerike area. The formation comprises well stratified, occasionally low angle cross strata pentameride grainstone or rudstone deposited as shallow marine shoals or banks, probably within a carbonate ramp. A shallowing upward trend is notified in the lower and middle part of the formation. At Hadeland the crest of the shoals have been exposed.

Small but genetic important reeflike structures occur in upper part of the formation at Rytteraker. Hanken, Olaussen & Worsley, (Unpublished Reef Newsletter no. 5, 1979) describe the organic build up as *"small isolated structures with observed diameters 5-6m and maximum height of 1, 5 - 2,0m. They grow on biosparitic banks composed of pentamerid and crinoid debris. Laterally they show near vertically inter-fingering contacts with well bedded crinoid biosparites. Stabilising colonizers consist of stromatoporoids, favositids and heliolitidis. Their framework is dominated by halysitids, and stromatoporoids with minor favositdis, heliolitidis and syringoporids."* In addition bryozoans and blue green alga (*Girvannella*) act as binders. "*Upper surface and overlying sediments suggest that growth stopped at diversification stage as a result of a transgressive episode*"Larger reef structures occur further north in the Ringerike area. They are probably deposited in upper part of the Formation.

Overlying unit, the Ek formation is interpreted to be deposited in deeper shelf environment and siliciclastics, although very fine grained, is now returning into the basin.

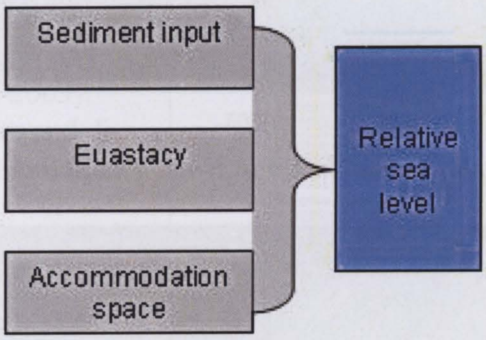
Some remarks/thoughts of the sequence stratigraphy of the Sælabonn and Rytteraker formations along the shore of Rytteraker - a challenge.

The top of Ordovician represents a 2nd order sequence boundary as we observed in Inner Oslofjord the first day as well as in Ringerike. In Ringerike areas both a karstic surface and time break (Baarli & Johnson, 1988) define this sequence boundary.

It is possible to interpret the Llandovery outcrop at Rytteraker in a third order sequence stratigraphic facies cycle.

- The upper part of Sælabonn is interpreted to be deposited in an inner shelf environment. The tempestites suggest a water depth around storm wave base.
- The overlying lower and middle part of the Rytteraker Formation comprises high energy shoals of shallow marine origin, at least shallower than the upper part of the Sælabonn Formation.
- The reef in upper part of the shoals *"was probably initiated subsequent to a relative rise in sea level which resulted in stabilisation of the shoals' highly mobile substrate"* Worsley et. al. 1983, p. 21).

This means that we have passed trough a relative sea level fall and rise. We have to put a sequence boundary somewhere along the outcrop. One candidate is within the upper part of the Sælabonn Formation (turning point). The stratified shoals in the lower part of the Rytteraker Formation are then a part of a transgressive system tract. Upper part of Rytteraker and probably a large part of the Ek Formation is interpreted as deposited during relative rise in sea level. Is this a part of retrograding transgressive system tract? But how does this fit with the on and off cycle of the siliciclastics input to the basin, e.g. the evolving foreland basin? If lack of siliciclastics is a response of drowning of hinterland, how does this fit with the cycles? If highstand suggests carbonates and lowstand siliciclastics, why do we observe the shallow or exposed surfaces in the carbonates?



A small bioherm or "patch reef" in the Rytteraker Formation at Limovnstangen, Rytteraker.

3 - 1: SVARSTAD, Røyse, Hole

We will visit the Upper Ordovician Bønsnes and Langøyene formations and see the lateral facies similarities and differences from the counterparts at Rambergøya and Hovedøya in Inner Oslofjord. As in the inner Oslofjord the formations are mixed shallow marine carbonate/siliciclastic units.

The 40 m thick Langøyene Formation at Svartøya and Svarstad can informally be subdivided into three lithostratigraphic units. **The lower unit** comprises a coarsening upward sequence from a limestone and shale of the Bønsnes Formation towards coarser grained sandstone in the upper part. This unit consists of very fine grained wave rippled and hummocky crosstratified sandstone in the lower part. Planar and trough crosstratified or parallel laminated medium to coarse grained sandstone, intersected by carbonate grain or rudstone, is seen in the upper part. This unit is interpreted as a prograding shoreline within an offshore to upper shoreface environment. A similar prograding or shallowing upward trend was also suggested in the inner Oslofjord area.

The middle limestone unit consists of reef structures and large meter scale carbonate blocks. Pockets of shales, fossil debris or crosstratified grainstone are interpreted as cavity fill within the reef structure. This few meters thick unit shows large load structures into the sandy unit below. Loading and soft deformation of the substrate will give instability and suggest that the carbonate blocks are a result of tilted or broken massive reef structures. An extensive study of the fauna; sedimentology and diagenesis of this unit is investigated by Hanken (1974, 1979a, 1979b).

The main facies difference in the Langøyene Formation between the inner Oslofjord area and Hole outcrops occur in this middle limestone unit.

The upper unit (5-8 m) consists of bedded limestone with crosstratified grainstone or crinoidal debris. A rich shelly fauna is observed. The upper part has a karst surface and is defined as a second order sequence boundary between Silurian and Ordovician, see discussion on Rambergøya and Rytteraker.

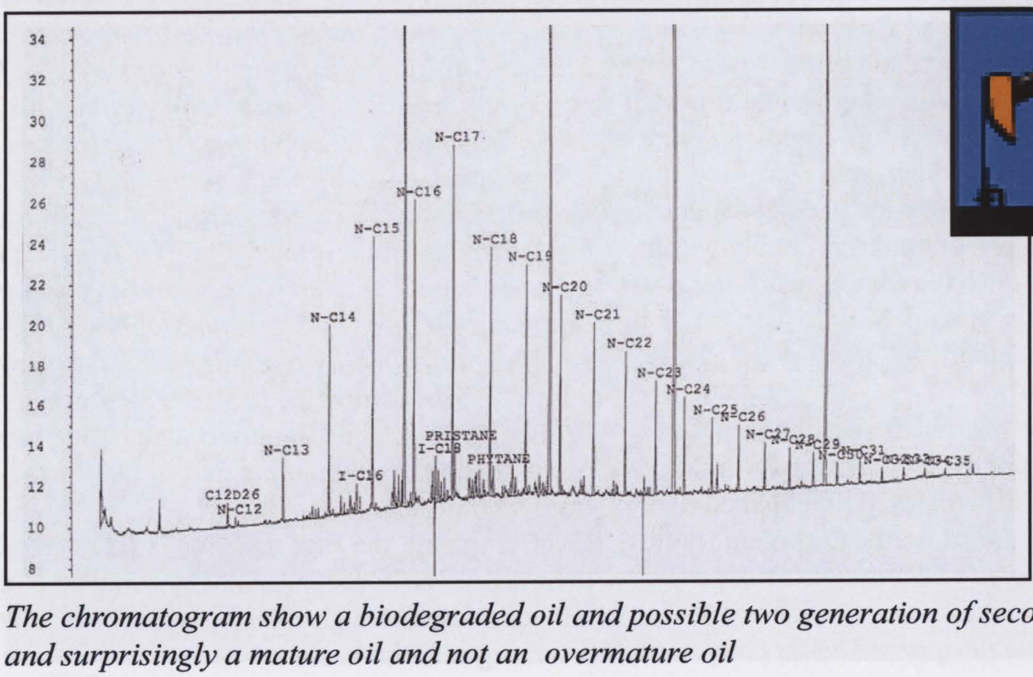
The carbonate units in the Langøyene Formation can now be seen as natural carbonate facies belts (e.g. Wilson 1975). The carbonate factories (reef development) occur in Ringerike and probably in several other non exposed or non preserved parts of the Oslo Region. Oolithic shoals were developed in the Oslo/Asker area. These facies are the provenance of the limestone breccia/debris as we see on the islands of the inner Oslofjord. The Silurian carbonate units are interpreted as carbonate ramp deposits. The recognised facies belts and the sedimentary structures of high energy origin in the Upper Ordovician Langøyene Formation could suggest a more rimmed carbonate shelf or a carbonate platform setting.

Oil-stain in fractured limestone of the Upper Ordovician Bønsnes Formation, Hole

Sandstones with carbonate units above, Store Svartøya, Hole

Exhumed oil field in Hole?

In this part of Ringerike bitumen or oil staining are common in both Upper Ordovician and Lower Silurian sandstones and limestones. Especially in the reef structures of the Langøyene Formation at Svartøy and Svarstad staining and paraffinic smell are easily recognised. This observation suggests a previous hydrocarbon accumulation. A 'fossil field' was probable a four way dip closure anticline, which was sealed by Lower Silurian shale. Reservoirs were within the reef and inter reef facies in the Langøyene Formation. Karstic processes could have acted as porosity enhancement within the reservoir unit. Further studies and a are needed to suggest source, timing and time of exhuming the field. This will be an interesting future challenge.



The chromatogram show a biodegraded oil and possible two generation of secondary migration and surprisingly a mature oil and not an overmature oil

The Silurian succession of the Oslo Region

DAVID WORSLEY, NILS AARHUS, MICHAEL G. BASSETT, MICHAEL P.A. HOWE, ATLE MØRK & SNORRE OLAUSSEN

Worsley, D., Aarhus, N., Bassett, M.G., Howe, M.P.A., Mørk, A. & Olaussen, S. 1983: The Silurian succession of the Oslo Region. *Nor. geol. unders. 384,* 1–57.

The marine Silurian succession of the Oslo Region displays a great variety of mixed clastic and carbonate lithofacies. Maximum thicknesses (<650 m) and most complete successions are seen in the central parts of the region in the Ringerike and Asker districts. Existing numerical stratigraphical units are based on a mixture of faunal and lithological criteria and are often diachronous. We herein propose the replacement of this scheme throughout the region by a series of formal lithostratigraphical units and use existing such units where possible. In these terms the entire marine succession comprises two groups and eleven formations, all of which are defined and described in this paper. Our new information on the age relationships and depositional environments of these units permits a new appraisal of the palaeogeographical evolution of the Oslo Region and adjacent sectors of the Caledonides during the Llandovery and Wenlock. Our work has restricted itself to the marine Silurian succession; the transition to the overlying red bed deposits of the Ringerike Group occurred in the late Wenlock in the Ringerike district. In order to present a complete review of Silurian deposits of the Oslo Region we also give a brief description of the red bed sequence.

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11 m above the base of the formation on Ormøya (Fig. 2a). This graptolite ranges from the ?upper *persculptus* to lower *acuminatus* Biozones elsewhere and the base of the Solvik Formation therefore approximates to the Ordovician/Silurian boundary as taken at the base of the *persculptus* Biozone. Occurrences of subspecies of *Stricklandia lens* in the Asker district indicate that the top of the formation there approximates to the Idwian/Fronian transition (Baarli 1981).

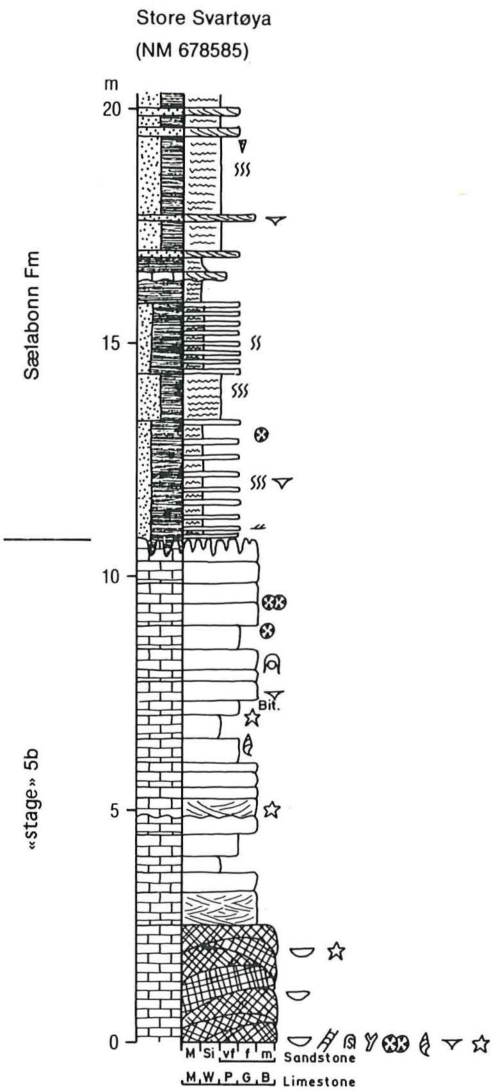

Fig. 8. A schematic section through the basal boundary stratotype of the Sælabonn Formation, Store Svartøya, Ringerike. For legend, see Fig. 9.

THE SÆLABONN FORMATION

Definition

The Sælabonn Formation is best demonstrated in the Ringerike district (Fig. 2b) in a series of small coastal exposures around Sælabonn, a small bay in the northern part of Tyrifjorden. This formation corresponds in general to stage 6 of Kiær (1908) in the Ringerike, Skien, Hadeland, Toten, Hamar and Ringsaker districts. Our proposal incorporates the Helgøya Quartzite of Skjeseth (1963), reduced to member rank, in the three latter districts. The Sælabonn Formation is approximately 110 m thick in its type area, where it is characterised by varying proportions of sandstone, siltstone and shale. Sandstones dominate the middle part of the unit and lithological variation was clearly the basis for Kiær's (1908) tripartite subdivision into 6a, b & c. Formal proposals for subdivision into three members approximately equivalent to Kiær's units will result from work in progress in the Ringerike area (Thomsen 1981).

The entire Sælabonn Formation is not exposed in any one section in the type area; the basal stratotype for the formation is defined on Store Svartøya (NM678585) where the lower 11 m of the formation are also exposed (Fig. 8). A reference section through the middle of the unit is exposed on the east coast of Sælabonn (NM696606) and its upper parts are well displayed in the basal

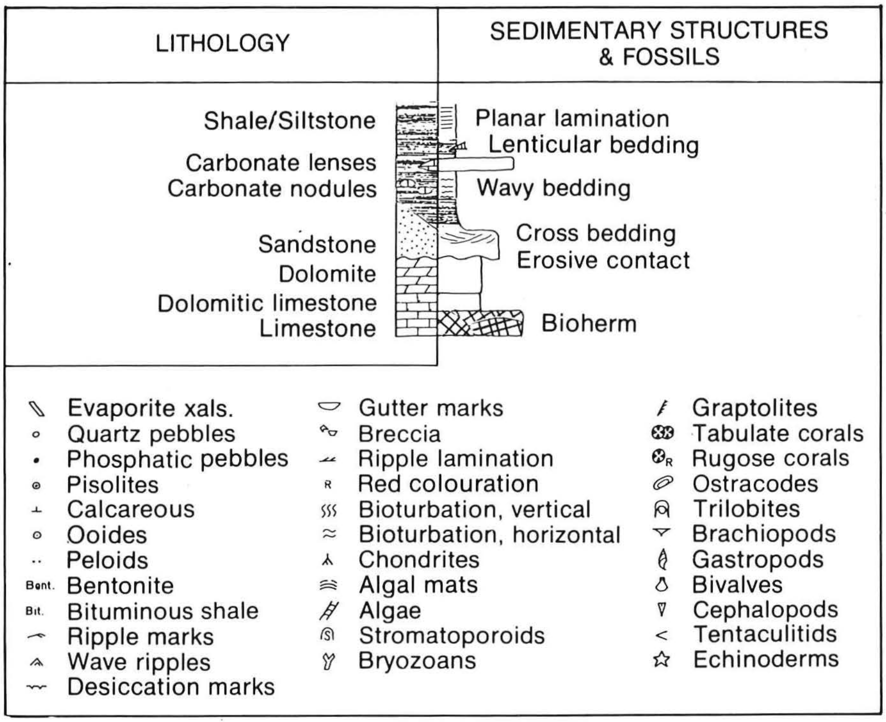

Fig. 9. Symbols used in the stratigraphic sections presented herein.

stratotype for the overlying Rytteråker Formation at Limovnstangen (p. 20). The base of the Sælabonn Formation is defined on Store Svartøya where crinoidal biosparites of 5b show a karstic upper surface and are overlain by silty shales with minor thin limestones and siltstones (Fig. 8). This 20 m-thick lower development of the formation coarsens up into medium to thickly bedded sandstones with minor siltstones and shales (6b of Kiær 1908, 50 m thick). These further fine up into thin to medium interbeds of siltstone and shale with increasing limestone intercalations towards the junction with the overlying Rytteråker Formation.

Other occurrences

Exposures elsewhere in the Ringerike and Skien districts indicate a similar tripartite development to that of the type area. The base is exposed at several localities in the southern parts of the Skien district (e.g. Skrapekleiv NL381523) where silty shales of the formation overlie a thin (0.5–1 m) very coarse sandstone which has an erosive contact with small biohermal structures and biosparites of upper 5b (Rønning 1979). Exposures north of Skien at Jønnevall in Gjerpendalen (NL321708) show an erosive contact with 5b, but the base of the formation there consists of sandstones which grade up into the silty shales assigned to 6a by Kiær (1908). Metamorphosed outcrops assigned to this formation are also seen in the Eiker district.

In Hadeland, Owen (1978) defined the Skøyen Sandstone Formation as a sandstone and shale unit with a gradational base (to his Kalvsjø Formation, 5a of earlier workers) and top (to our Rytteråker Formation). This unit is 120 m thick and correlates with Stages 5b and 6 of earlier workers. Because of poor exposure Kiær (1908) and Major (1946) were unable to define the boundary between 5b and 6 in Hadeland, and Owen's approach is eminently justifiable as present exposures do not display the precise contact between these units. However, sections examined by us suggest an important change in sedimentological development in the middle of Owen's Skøyen Sandstone and the upper 60 m of this unit show a tripartite development similar to that of the Sælabonn Formation in the adjacent Ringerike district. Pending further detailed analysis we suggest as an interim measure that Owen's Skøyen Sandstone be regarded as an informal unit, the upper part of which is clearly correlative with the Sælabonn Formation at Ringerike.

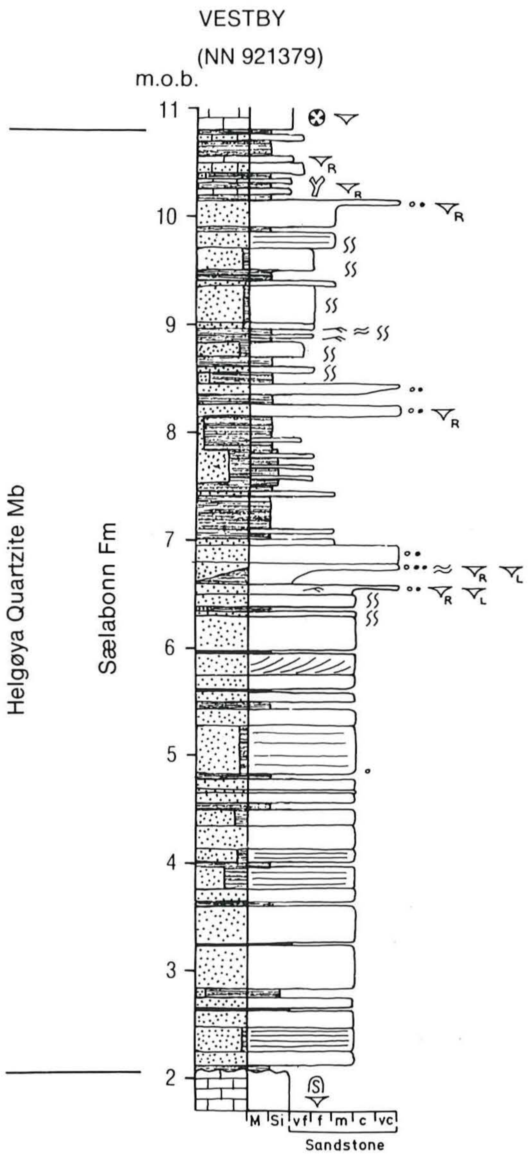

Fig. 10. Hypostratotype through the Helgøya Quartzite Member of Sælabonn Formation at Vestby (Toten district).

Further north, in the Toten, Hamar and Ringsaker districts, the Sælabonn Formation is represented *in toto* by the thin Helgøya Quartzite Member which rests on eroded surfaces of the Mjøsa Limestone. Sandstone infills of the karstic topography marking the top of this limestone are seen at several localities in Toten. The Helgøya Quartzite's original type section at Eksberget (PN087355) on Helgøya (Skjeseth 1963) is poorly exposed and a hypostratotype is proposed in a disused quarry at Vestby near Gjøvik (NN921379). The member is 9 m thick there (Fig. 10). The lower 5 m consist of medium to thickly bedded sandstones with thin shaly partings; these grade up into thinly interbedded sandstones and shales, with limestone intercalations uppermost marking the transition into the overlying Rytteråker Formation. Other exposures further north in Brumumddalen (PN076586) and on Helgøya indicate an essentially similar, but thicker development (15 to 30 m).

Depositional environments

Basal sandstones and shales in the Ringerike and Skien districts reflect the early Silurian transgression of these areas. Sandstones in the middle of the formation represent a subsequent progradational episode and deposition in coastal environments. The upper parts of the unit in both areas suggest renewed transgression, with a gradual transition from clastic to carbonate-dominated sedimentation. Exposures in Hadeland suggest a similar depositional history. The thin sandstones of the Helgøya Quartzite Member in the Toten, Hamar and Ringsaker districts reflect the transgression of an area which had been emergent throughout the late Ordovician. This development appears to correlate with the upper part of the Sælabonn Formation in its type area. In all districts the transition to the overlying Rytteråker Formation suggests a complex and irregularly diachronous cut-off of coarse clastic supply as a result of continuous transgression. The faunas of the formation are reminiscent of Benthic Assemblages 1 to 3 of Boucot (1975).

Age

A general Rhuddanian to Idwian age is suggested in the type area by brachiopods (Thomsen 1981) and conodonts (R.J. Aldridge, pers. comm. 1981). The occurrence of *Borealis borealis* around the junction with the overlying Rytteråker Formation indicates a middle Idwian age for the uppermost beds of the Sælabonn Formation in its type area (Mørk 1981). However, the base of the formation has not yet been definitively dated.

THE RYTTERÅKER FORMATION

Definition

The name of this formation is derived from Rytteråker Farm (NM699594) on the west coast of Tyrifjorden in the Ringerike district. The formation's character is well demonstrated in this type area, especially in coastal exposures around Limovnstangen, a peninsula 1 km south of Rytteråker Farm.

The Rytteråker Formation is essentially equivalent to 7a and 7b of Kiær (1908) throughout the Oslo Region. Our formational proposal replaces the term 'Pentamerus Limestone' which has been widely used subsequent to Kiær's work. Whereas many workers (e.g. Henningsmoen 1960) have applied this term in a sense which generally conforms to our Rytteråker Formation, Kiær applied it only to those restricted parts of our Rytteråker and overlying Vik Formations which contain abundant pentamerids. This varying usage prompts our rejection of the name 'Pentamerus Limestone' in spite of its priority. Pending the results of our work, Owen (1978) and Høy & Bjørlykke (1980) used the informal terms 'Engen limestone' and 'Limovnstangen formation' in the Hadeland and Hamar/

Ringsaker districts respectively. Sequences assigned to those units are here grouped within the Rytteråker Formation.

The limestone dominated sequence of the Rytteråker Formation is approximately 50 m thick in the type area; Kiær's tripartite division (7a, 7bα, 7bβ) was based both on faunal composition and on varying proportions of limestone and calcareous shale within the unit. A single complete type section is not seen, but the basal stratotype is defined on the northern tip of Limovnstangen (NM691591) and reference sections through the middle and upper parts of the formation are exposed along both coasts of this peninsula. The top is seen under the basal stratotype of the overlying Vik Formation on the limb of a small syncline whose axis defines the northern coast of Limovnstangen (NM695596).

The basal stratotype of the Rytteråker Formation shows a gradational development: interbedded thin to medium siltstones and shales of the Sælabonn Formation show intercalations of limestone beds upwards. The base of the Rytteråker Formation is defined at the quantitative dominance of limestone over siltstone (Fig. 11). Our formational base is therefore 5.5 m higher in the section than the junction between 6c and 7a defined by Kiær (1908) and corresponds to Kiær's bed XIV (Kiær 1908: Profiltafel II). Limestones with pentamerids become increasingly abundant through the basal 10 m of the formation and grade upwards into thickly bedded biosparites in the middle 25 m of the unit (7bα of Kiær 1908). These beds are composed of finely comminuted pentamerid and crinoid debris; small bioherms are found at the top of this sequence throughout the Ringerike district (Hanken, Olaussen & Worsley 1979). The uppermost 17 m of the formation (7bβ of Kiær 1908) consist of planar limestone beds and well-bedded calcareous nodules with

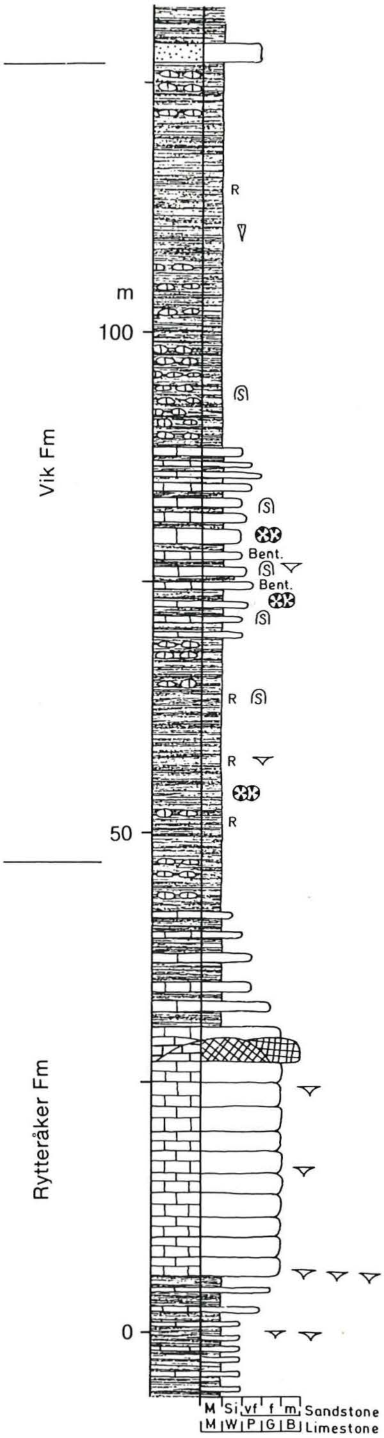

Fig. 11. A general section through the composite stratotypes of the Rytteråker and Vik formations in Ringerike.

interbedded shales; the shale content increases towards the contact with the overlying Vik Formation.

Other occurrences

Although the character and content of carbonates in the Rytteråker Formation vary from district to district, the unit can be traced throughout the Oslo Region. The formation thins markedly northwards from the type area (Fig. 4); it thickens southeastwards and southwards to 65 m in Oslo/Asker and 80 m in Skien.

Exposures in Hadeland show a gradational contact with the Sælabonn Formation, interbedded limestones and shales passing up into a thickly-bedded pentamerid biosparite unit. This is erosively overlain by interbedded limestones and shales with both bioclastic and general carbonate content decreasing upwards to the contact with the Ek Formation (see p. 25). The Rytteråker Formation thins progressively northwards through the Toten, Hamar and Ringsaker districts. Northernmost exposures at Torsæter Bridge in Brumunddalen (PN076586) show a 15 m-thick sequence of interbedded thin limestone beds, nodular horizons and shales.

Sequences assigned to the Rytteråker Formation share many common features in Asker, Oslo, Holmestrand and Skien. The base is gradational in all cases, either from the more sandy Sælabonn or more shaly Solvik Formations. Thin, fine-grained limestones and shales occur in equal proportions in the lower parts of the unit in all these areas. Limestone beds thicken and coarsen upwards and shale content decreases into the middle and upper parts of the unit. The transition to the overlying Vik Formation is often rapid, marked by the renewed development of interbedded limestones and shales.

Depositional environments

The Rytteråker Formation represents the establishment of relatively shallow carbonate depositional environments throughout the Oslo Region at a time when earlier source areas for coarse clastic material were submerged. The pentamerid biosparites of Hadeland and Ringerike represent high-energy shoals, with crests which may have been intermittently emergent (e.g. in Hadeland). Biohermal development on the upper surfaces of the shoals in Ringerike was probably initiated subsequent to a relative rise in sea-level which resulted in stabilization of the shoals' highly mobile substrates. Other districts show more distal marine carbonate sequences. However, in all these other districts a general shallowing-upwards trend throughout the lower and middle parts of the formation is indicated by an increase of better sorted and thick bedded biosparites at the expense of shale and fine-grained limestones. Abundant pentamerids, corals and stromatoporoids together with benthic algae in all districts indicate that the formation was not deposited in water of any great depth. The fauna is typical of Benthic Assemblage 3 of Boucot (1975).

Age

Occurrences of the pentamerids *Borealis* and *Pentamerus* suggest a somewhat diachronous base for the Rytteråker Formation, ranging from the middle to late Idwian in Ringerike and Hadeland to the late Idwian or early Fronian in central and southern districts (Mørk 1981). The transition to the Vik and Ek Formations is dated by the graptolite and brachiopod faunas of these overlying units (pp. 25 and 27).

THE VIK FORMATION

Definition

The development of this formation is best demonstrated in widespread but partial exposures throughout the Ringerike district. Easily accessible sections are seen in roadside cuttings immediately east of Vik (NM715609), prompting our use of this formational name. The formation generally corresponds to stage 7c of Kiær (1908) in the Ringerike, Oslo, Holmestrand and Skien districts and to Kiær's 7bβ and 7c in Asker. The Vik Formation is approximately 80 m thick in its type area and shows a tripartite development with varying proportions of both red* and greenish grey shales, marls and limestones. This tripartite development was the basis of Kiær's (1908) subdivision into 7cα, 7cβ and 7cγ; the members proposed by Aarhus (1978) generally correspond to Kiær's subdivisions. We here modify the provisional nomenclature of Aarhus and propose the establishment of the Storøysundet, Garntangen and Abborvika Members (in ascending order) in the Vik Formation in its type area. A single type section for the formation cannot be designated but a basal stratotype is defined in a coastal section northwest of Rytteråker Farm (NM695596). This section shows the gradation from thinly interbedded limestones and greenish grey shales of the underlying Rytteråker Formation into predominantly red shales. The base of the Vik Formation is defined at the sharp transition from limestone to shale dominance 4 m below the lowermost occurrence of red shales.

The base of the Storøysundet Member is, by definition, coincident with the base of the Vik Formation. The basal stratotype displays 12.5 m of the member, but a total thickness of approximately 20 m in the type area of the Vik Formation is suggested by other coastal exposures around Storøysundet (NM6958). The red shales of the Storøysundet Member contain minor bioclastic limestone lenses, small calcareous nodules and occasional greenish grey shale interbeds. A diverse but sparse fauna includes crinoids, brachiopods, stromatoporoids and tabulate corals.

The middle 13 m of the Garntangen Member are exposed in the E68 road section near Garntangen (NM720609) on the coast of Steinsfjorden. The member is also well exposed on the west coast of Storøya (NM690576 to NM694582) where its basal stratotype is defined. Its base is taken at the marked increase in limestone interbeds 3 m above the uppermost red shales of the underlying unit. The Garntangen Member is approximately 25 m thick and consists of thinly bedded limestones and calcareous nodules with minor greenish grey marls. Fresh

* Red units, referred to here and subsequently, show colours varying from pale to dark reddish brown, 10R5/4 to 10R3/4 of the Standard Rock Color Chart. Greenish grey beds correspond to 5GY 6/1 of the same chart.