DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/82

Basin analysis of the uppermost Triassic to Lower Cretaceous, Danish Basin

Biostratigraphy and log correlation

Sofie Lindström & Mikael Erlström

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

G E U S

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Biostratigraphy and log correlation

Research report on behalf of the Geological Survey of Sweden (SGU)
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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

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Abstract

The need to understand the structure and development of the subsurface sedimentary succession both on land and at sea has increased during recent years, primarily due to an increased demand of geothermal energy and possibilities for deposition and storage of CO_2 and energy in subsurface aquifers. For all these objectives high quality aquifers and cap rocks are needed. Knowledge of the location of faults or other boreholes are also essential, as CO_2 can otherwise reach the surface or freshwater aquifers closer to the surface.

The Mesozoic succession of southwestern Scania and the southern Baltic Sea contains several sandstone units that may act as potential aquifers. During the drilling of the geothermal well FFC-1 in Malmö in 2001, a 10m thick interval of medium-coarse grained sand with high permeability was encountered at a depth of 1670m. This project includes material and data from a series of Swedish wells in the southern Baltic Sea and Scania, primarily Höllviksnäs-1/Höllviken-2, Kungstorp-1, Håslöv-1, Eskilstorp-1, Barsebäck-1, Mossheddinge-1, Svedala-1, FFC-1, BH94, Fårarp-1, Köpingsberg-3. In order to obtain a better understanding of the complex subsurface geology across the Höllviken Graben and Barsebäck Platform, material and data from some important Danish wells, Karlebo-1/1A and Margreteholm-1/1A, are also included in this study. New biostratigraphic data based on terrestrial and marine palynology has been retrieved from the majority of the selected wells. Palynological events; i.e. first and last occurrences of key taxa, acmes as well as reworking, have been registered, and are used for biostratigraphic dating and correlation between the wells. Together with available geophysical logs, and sedimentological borehole descriptions provided by the SGU and GEUS databases this enables careful borehole to borehole correlation, as well as lateral and vertical mapping of potential aquifers and seals.

The data and interpretations of the Uppermost Triassic to Lower Cretaceous succession are presented along two transects: one south to north trending transect from the Höllviken Graben in the south across the Öresund straight to northern Sjælland, and the other one running west to southeast from northern Copenhagen via northern Malmö, across the

Svedala Platform to the the southern part of the Vomb Trough. The two transects clearly illustrate the complexity of the Upper Triassic to Lower Cretaceous succession in this area. The Uppermost Triassic (Rhaetian) strata are fairly uniformly developed across the part of the Danish Basin, and contain a medium-fine grained sandstone unit with a thickness between 15-20m in the Höllviken Graben. Equivalent sandstone units are primary aquifers in the Stenlille area on Sjælland, where the overlying thick succession of Lower Jurassic mudstones and shales of the Fjerritslev Formation act as primary seal.

The north-south transect clearly shows that the alternating succession of sandstone, siltstone and claystone/shale units that characterize the Lower Jurassic is more difficult to correlate and reflect a more dynamic coastline with deltas and shoreface sands. In contrast to the more distal facies known from Stenlille, the Lower Jurassic in the Höllviken Graben and on the Barsebäck Platform is more sand dominated. However, in the northern part of the transect uppermost Lower Jurassic (Toarcian) marine shales are confirmed from the two Danish wells Karlebo-1/1A and Margreteholm-1/1A. Rudimentary Toarcian deposits are indicated by the biostratigraphy in FFC-1 and may possibly also be present in Barsebäck-1.

The biostratigraphic analysis show that the 10m thick medium-coarse grained sand unit known from FFC-1 is Early Cretaceous (Berriasian–Valanginian) in age. A similar sand unit has been identified in all the wells on the north–south transect. In Karlebo-1/1A this Lower Cretaceous sand rests upon a 5m thick unit of Middle Jurassic (Aalenian) sand. Middle Jurassic (Aalenian) sedimentary rocks are also indicated below the equivalent Lower Cretaceous sand unit in Höllviksnäs/Höllviken-2.

The Lower Jurassic, post-Lower Sinemurian, succession of the Höllviken Graben contains large amounts of reworked palynomorphs of primarily Rhaetian–Lower Jurassic age that complicates the biostratigraphic interpretations. This indicates major reworking of equivalent strata during the time of deposition. In Svedala-1 on the Skurup Platform Lower Cretaceous sands (Berriasian–Valanginian) appear to rest directly upon Rhaetian strata, thus suggesting that the Skurup Platform was subject to major erosion in the Early Jurassic. In the Vomb Trough to the east the Arnager Greensand Fm rests directly upon Berrisian to Valanginian strata, providing evidence of a regional unconformity that is also known from Bornholm further to the east (Lindström and Erlström, 2011).

The results of this project help to clarify the tectonic development and depositional history of SW Scania during the latest Triassic to Early Cretaceous and the lateral and vertical extent of possible aquifers within the succession.

Introduction and background

In recent years the need to understand and characterize the structure and composition of the subsurface sedimentary succession both on land and at sea has increased. This is primarily related to an increased demand of knowledge regarding the possibilities for storage of CO_2 and energy in subsurface aquifers. For all these objectives high quality aquifers are needed. As an example, an aquifer suitable for CO_2-storage should have a thickness of at least 10m, a porosity of at least 15% and a permeability that preferably exceeds 100mD. In order to keep CO_2 in its liquid state (>31ºC, 73,6 bar) within the aquifer a burial depth of at least 800m is required. The storage aquifer must also be overlain by an impermeable rock unit, a cap rock or seal, which keeps the CO_2 in place. Good knowledge about the geological setting, including the location of faults, lateral and vertical variations in thickness and lithology, as well as distribution of different rock units is essential in the assessment of the geothermal and CO_2 storage potential.

The Mesozoic succession of southwestern Scania and the southern Baltic Sea contains several sandstone units that may act as potential aquifers. For example, during the drilling of the geothermal well FFC-1 (Malmö) in 2002 (Fig. 1 and 9), a 10m thick interval of medium- and coarse-grained sand with high permeability was encountered at a depth of 1664m. A correlation study carried out in 2005-2006 indicated the presence of similar and possibly equivalent sand units in other deep wells in SW Scania (Lindström and Erlström, 2007b). These potential aquifers were of varying known lateral and vertical extent and further work was needed in order to assess their distribution.

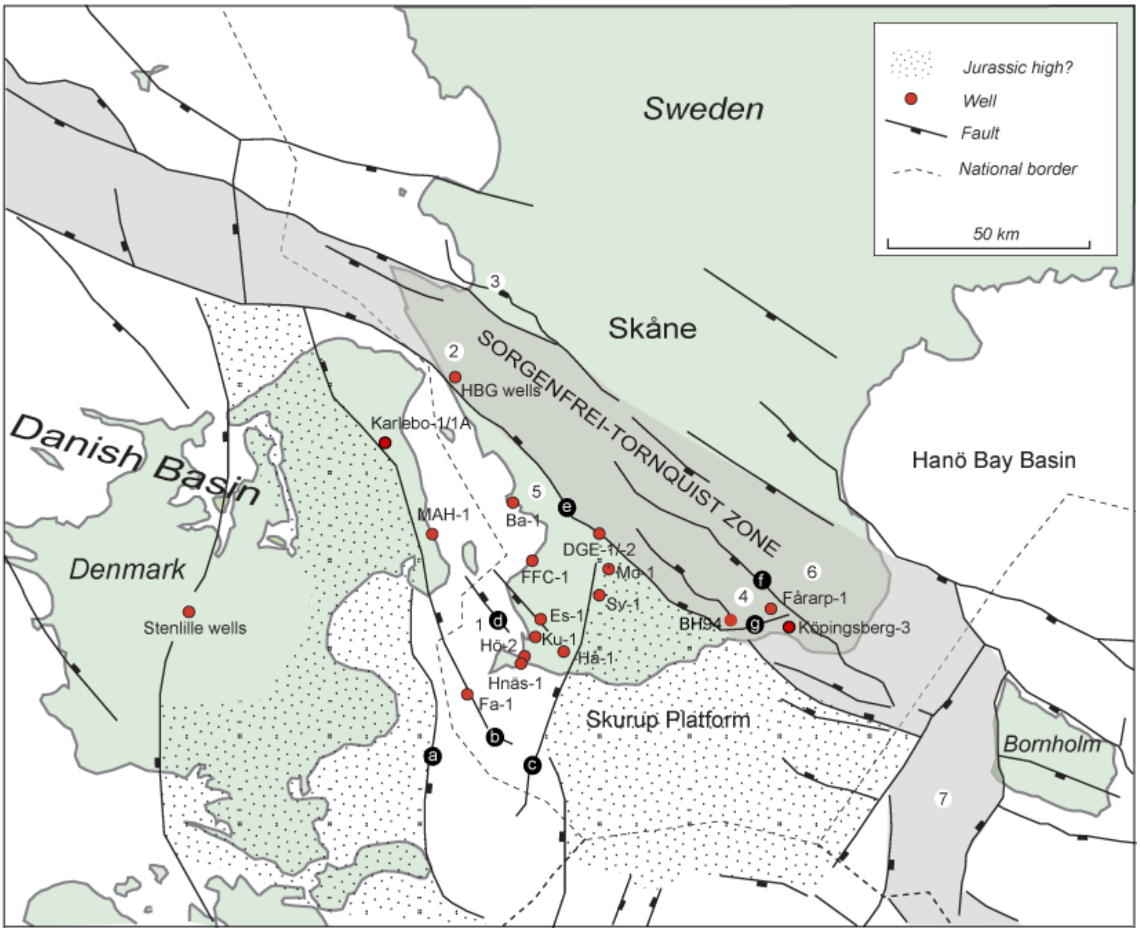
This report deals with material and data from a series of Swedish wells in the southern Baltic Sea and Scania, primarily Höllviksnäs-1/Höllviken-2, Kungstorp-1, Håslöv-1, Eskilstorp-1, Barsebäck-1, Mossheddinge-1, Svedala-1, FFC-1, BH94, Fårarp-1, Köpingsberg-3 (Fig. 1). In order to obtain a better understanding of the complex subsurface geology across the Höllviken Halfgraben and Barsebäck Platform, material and data from some important Danish wells, Karlebo-1/1A and Margreteholm-1/1A, are also included in this study (Fig. 1). New biostratigraphic data based on terrestrial and marine palynology has been retrieved from the majority of the selected wells. Together with available geophysical logs and sedimentological borehole descriptions, provided by the SGU and GEUS databases, careful borehole to borehole correlation and lateral and vertical mapping of potential aquifers and seals have been carried out.

Geological and tectonic setting

The investigated area covers a part of Scania and Denmark located in the transition zone between the Danish Basin to the west and southwest and the Baltic Shield to the northeast. The intracratonic Permian–Cenozoic Danish Basin was formed by Late Carboniferous-Early Permian crustal extension followed by subsidence governed primarily by thermal cooling and local faulting (Vejbaek, 1997, Nielsen, 2003). The basin is bordered towards the southwest by the Ringkøbing-Fyn High while its northeastern margin follows the NW–SE oriented Sorgenfrei-Tornquist Zone (STZ), a fundamental tectonic lineament characterised by extensive block-faulting along the southwestern margins of the Baltic Shield and transtension during the Triassic and Jurassic (Liboriussen et al., 1987; Erlström et al., 1997; Mogensen and Korstgård, 2003).

The block-faulting along the STZ was influenced by major plate tectonic events in the region, e.g. the break-up of Pangea, the closing of the Tethys, and the opening of the North Atlantic (Norling and Bergström, 1987; Liboriussen et al., 1987; Michelsen and Nielsen, 1993; Erlström et al., 1997). The tectonic movements actively controlled deposition and erosion, resulting in a heterogeneous representation of strata (Norling et al., 1993). The STZ has been repeatedly active since Late Palaeozoic times with the main events occurring during the Mesozoic Era. Several Triassic–Jurassic extensional episodes are recognised (Norling and Bergström, 1987), but these and older Palaeozoic events are often obscured by the Late Cretaceous-Palaeogene inversion tectonics (Norling and Bergström, 1987; Michelsen and Nielsen, 1991; Mogensen, 1994; Erlström et al., 1997).

The Late Permian–Early Jurassic was a period characterised by regional subsidence, rifting and block faulting. During the Mid to Late Permian the Sorgenfrei–Tornquist Zone and the Skagerrak–Kattegat Platform began to act as a marginal zone to the subsiding Norwegian–Danish Basin that was evolving to the southwest.



1: Höllviken Halfgraben 2: Höganäs Basin 3: Ängelholm Trough 4: Vomb Trough 5: Barsebäck Platform 6: Colonus Shale Trough 7: Rønne Graben
a: Stevns Fault b: Öresund Fault c: Svedala Fault d: Amager Fault e: Romeleåsen Fault Zone f: Fyledalen Fault Zone g: Herrestad Fault

Fig. 1. Map of southern Sweden and the Danish island Sjælland showing the location of wells and structural elements mentioned in this paper.

The Triassic tectonic realm in north Germany, Denmark and STZ was characterised by rifting in N–S striking zones. In Scania E–W tension resulted in NE–SW extensional faults, e.g. the Svedala Fault and Öresund Fault (Erlström et al., 1997; Sivhed et al., 1999).

Much of the Late Triassic deposition in Scania took place in releasing bends (pull-apart basins) in the Sorgenfrei–Tornquist Zone, and the phase of dextral transtensional stresses continued intermittently into the Jurassic (Mogensen, 1996). The Jurassic stress field was associated with the break-up of Pangea and led to dextral strike-slip fault reactivation, resulting in differential subsidence in the Late Jurassic, often referred as the Kimmerian tectonic phase (Norling et al., 1993). This Kimmerian rifting phase resulted in the formation of transtensional faults as well as reactivation of Permian fault systems in e.g. the Sorgenfrei–Tornquist Zone (Vejbæk, 1990; Mogensen, 1994).

During the uppermost Triassic to Lower Cretaceous the Danish Basin was part of an epicontinental sea that covered large parts of NW Europe. The Norian–Lower Aalenian succession was formed under tectonically tranquil conditions and a shallow marine depositional setting (Nielsen, 2003). Due to thermally controlled post-rift subsidence the basin received large amounts of sediment (Liboriussen et al., 1987; Vejbæk, 1989; Erlström et al., 1997; Nielsen, 2003).

The Mid-Jurassic featured localised tectonic uplift coupled with magmatic intrusions, which led to intensive volcanism in central Scania and removal of pre-existing strata. The stepwise decrease in the thickness of the Lower Jurassic sequence east of the STZ is an indication of Early to Mid-Jurassic tectonic activity (mid-Kimmerian tectonics), coupled with tectonic uplift and erosion of the area north of the fault zone (Norling and Bergström, 1987; Ziegler, 1990; Mogensen, 1996). There are also indications that the volcanic activity was mainly located in junctions between NE–SW and NW–SE directed fault systems (Erlström et al., 1999).

Middle Jurassic tectonic uplift of large parts of the basin culminated with the formation of the regional intra-Aalenian unconformity, and deposition became restricted to the STZ where subsidence still occurred (Nielsen, 2003). Hence, in contrast the primarily eustatically controlled Lower Jurassic succession, deposition during the Middle to Upper Jurassic was initially primarily tectonically controlled, but later gave way to more wide-spread and sea-level controlled sedimentation.

The differential subsidence continued into the Early Cretaceous, with restricted fault activity (Mogensen, 1996). Fully marine conditions prevailed across the Danish Basin, with more marginal marine to terrestrial deposition taking place near the margin of the Baltic Shield, i.e. in Scania and on Bornholm (Poulsen and Riding, 2003; Lindström and Erlström, 2011). In the Late Cretaceous, the fault-controlled subsidence within the Sorgenfrei–Tornquist Zone came to an end and the Jurassic–Lower Cretaceous depocentre became inverted during the Late Cretaceous and Early Paleogene. This resulted from a change in the regional stress orientations to a predominantly compressive regime, associated with Alpine deformation in northern Europe and the opening of the North Atlantic.

Structural setting of SW Scania and the Öresund area

SW Scania and the Öresund region, comprise a number of structural elements that have been of great importance for the distribution and stratigraphic representation of the Mesozoic succession.

The Höllviken Halfgraben (Fig. 1 and 2) was initiated during the Permian–Carboniferous Variscan rift phase resulting in a downfaulted tilted and slightly rotated rock block. It is to the west outlined by a series of normal faults, i.e. the Öresund and Arnager faults, with increasing fault throw to the SSE. The Arnager Fault joins up with a normal fault trending northwards over Sjælland. The character and definition of this fault north of the Margreteholm-1/1A (Mah-1) boring is unclear due to poor seismic information. The northern delimitations and characteristics of the Höllviken Halfgraben as wells as the Barsebäck Platform are due to the poor seismic database not yet properly defined. A general structural model of the Höllviken Halfgraben is described by Sivhed et al. (1999) and Erlström and Sivhed (2011).

Up to c. 700 m of Lower Palaeozoic strata are preserved in the deeper parts of the halfgraben. The SW-ward dipping sequence is truncated and unconformably overlain by a presumably upper Permian quartzite reflecting a period of erosion and peneplanization of the landscape prior to the Early Triassic reactivation of the rift system and resumed subsidence of the Höllviken Halfgraben. North of the Malmö faults there are no or only few scattered occurrences of preserved Palaeozoic rocks on the basement due to this major phase of erosion.

Subsidence resumed in the Höllviken Halfgraben during the early Triassic resulted in the preservation of a 500–600 m thick Lower and Middle Triassic succession in the deepest parts, adjacent to the bounding normal faults to the SW, i.e. the Amager and Öresund faults. To the east the halfgraben was now delimited by the Svedala Fault, which formed as a Triassic extension fault associated to strike slip movements in the Sorgenfrei–Tornquist Zone (STZ).

Deposition continued in the Höllviken Halfgraben during most of the Triassic and Early Jurassic. Following the Early Jurassic there is a major hiatus identified in the sequence, covering most of the Middle and Upper Jurassic interval. Resumed and more or less continuous deposition occurred again in the halfgraben, as well as on the Skurup Platform and the Barsebäck Platform from the Early Cretaceous to the Paleogene. The Rhaetian, Jurassic and Lower Cretaceous sequence in the Höllviken Halfgraben is in the range of ca 250 m thick and relatively uniform in composition and distribution.

The Öresund Fault was slightly reactivated during the Late Cretaceous inversion of the Sorgenfrei–Tornquist Zone. During the same time subsidence and Upper Cretaceous sedimentation was significant adjacent to the Romelåsen Fault Zone (Erlström, 1994). This led to a northeastward tilting of the whole area, as illustrated in Fig. 3.

Margreteholm-1/1A (Mah-1), Eskilstorp-1 (Es-1), Kungstorp-1 (Ku-1), Höllviken-2 (Hö-1), Höllviksnäs-1 (Hnäs-1) and Håslöv-1 borings in the Höllviken Halfgraben have been investigated in this study.

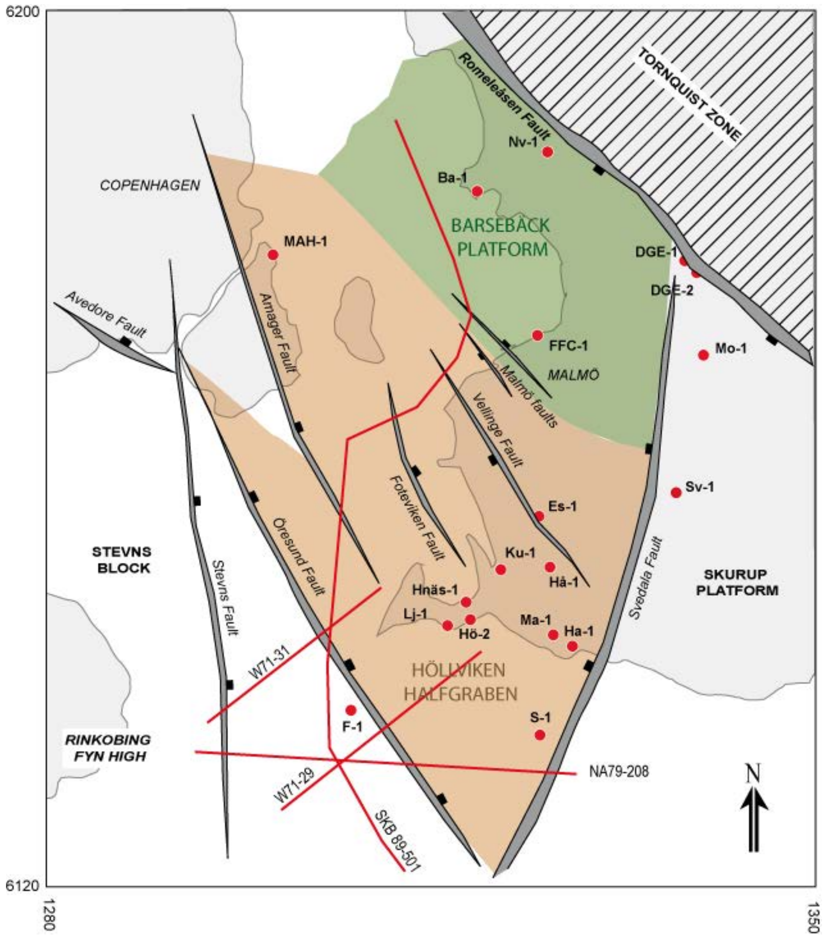


Fig. 2. Outline of the Höllviken Halfgraben and Barsebäck Platfom and locations of deep borings and cross-sections in figs. 1 and 3.

The Barsebäck Platform (Fig. 1 and 2) constitutes a relay ramp to the Höllviken Halfgraben and its SW boundary coincides with a swarm of minor faults and fracture zones south of Malmö, i.e. the Malmö Faults, as can be seen on the seismics in Fig. 3. The Platform is characterized by a relatively homogeneous rock block, gently dipping to the NE towards the Romeleåsen Fault. The Mesozoic sequence is more or less similar to the one in the Höllviken Halfgraben, however, the Lower Triassic is missing and the Middle Triassic rudimentary. Palaeozoic strata are interpreted to be largely missing, thus the Upper Triassic is directly overlying the Precambrian basement. The described and studied strata in FFC-1 and Barsebäck-1 (Ba-1) are representatives of the subsurface geology found on the Barsebäck Platform.

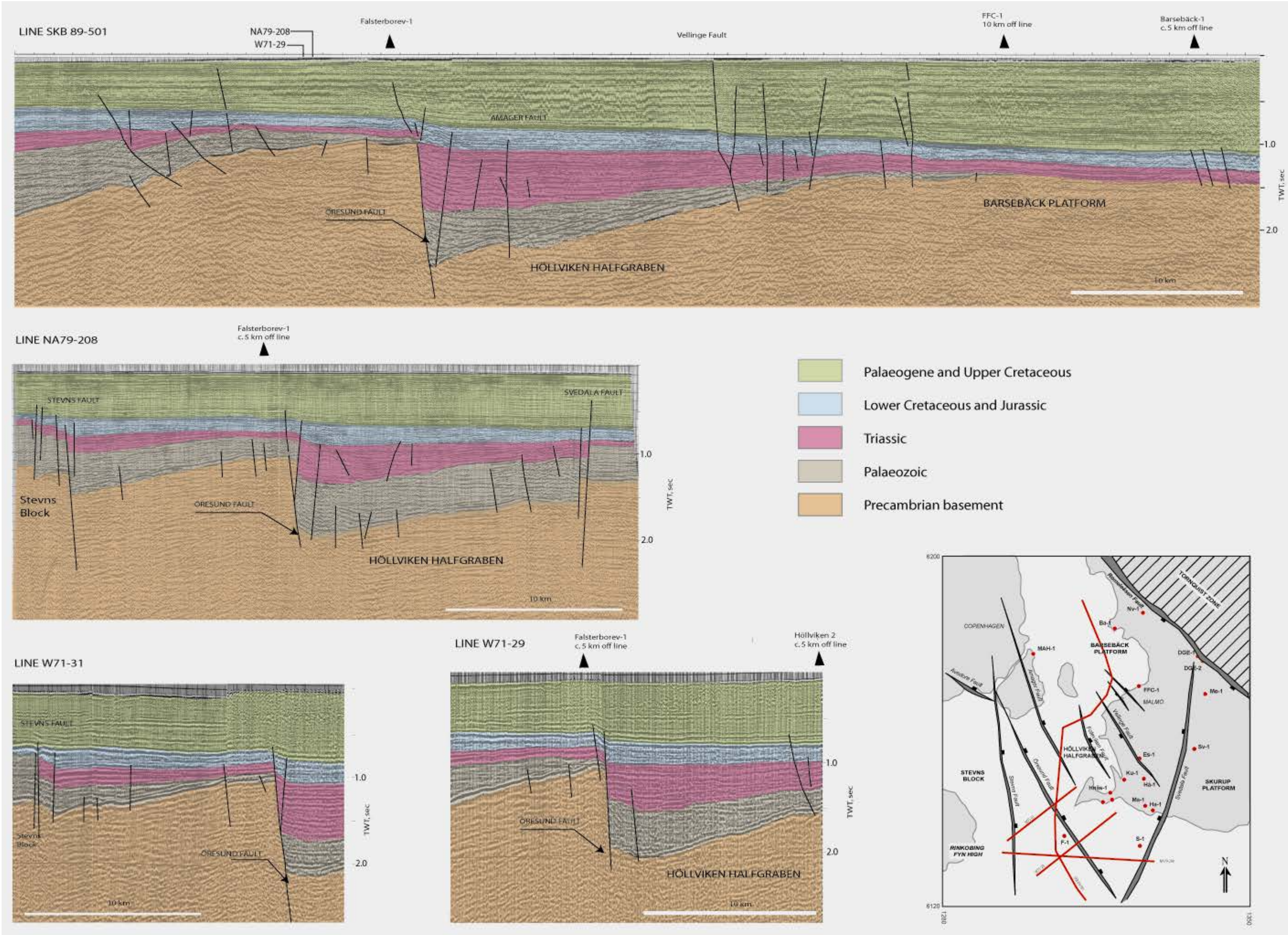


Fig. 3. Seismic profiles across the Höllviken Halfgraben (from Erlström and Sivhed, 2011).

The Skurup platform (Figs. 1 and 4) is characterised as a relatively uniform rock block without any major faulting. The structure is outlined by the Svedala Fault to the west and the Rönne Graben to the east. To the NNE it is bordered by the Romelåsen Fault Zone (RFZ). The south border coincides with a series of minor west-east oriented faults included in the Caledonian deformation front which delimits strongly tilted and deformed Lower Palaeozoic strata south of this front.

Knowledge about the sedimentary succession on the platform is restricted to a few borings in the northwestern part, i.e. Svedala-1 (Sv-1), Mossheddinge-1 (Mo-1) and Bh94. The strata on the platform is in Sv-1 dominated by c 1500 m thick sequence of Upper Cretaceous strata overlying a ca 150 m thick sequence of Lower Cretaceous and Upper Triassic deposits. In contrast to the Höllviken Halfgraben, Rhaetian–Lower Jurassic strata are incomplete or missing on the Skurup Platform.

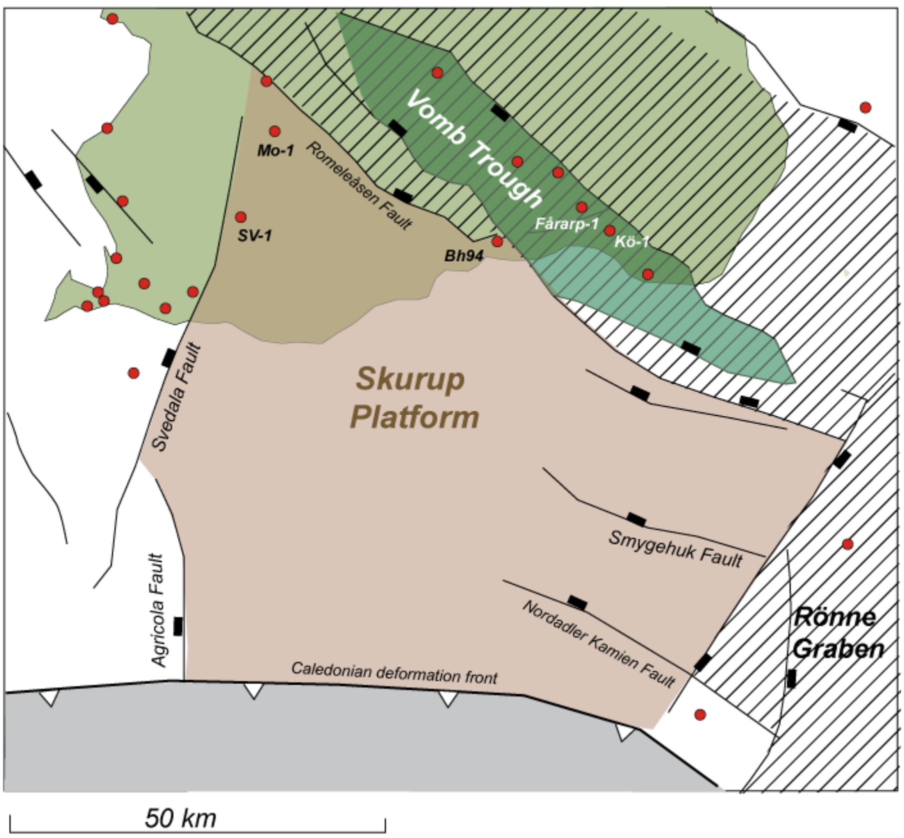


Fig. 4. Outline of the Skurup Platform and Vomb Trough.

The Mesozoic succession is from seismostratigraphic investigations (Thomas et al., 1993; Erlström et al., 1997) interpreted to cover Precambrian crystalline basement rocks or unconformably overlying gently dipping localised down-faulted sequences of Lower Palaeozoic strata, especially in the southern part of the platform. The Mesozoic succession dips gently towards the Romeleåsen Fault due to Late Cretaceous subsidence along the Sorgenfrei–Tornquist Zone. Up to 2000 m thick deposits are indicated in the seismic data adjacent to the northeastern margins of the platform.

The scattered distribution of Palaeozoic strata on the southern part of the platform constitutes erosion remnants primarily found in wedge shaped down-faulted structures formed during late Carboniferous–early Permian extension coupled to extensive erosion and peneplanization during the late Permian and Triassic. Thereafter the Skurup Platform seems to have been predominantly constituting an area with only periodic deposition of sediments until the Early Cretaceous.

Structural setting of the Vomb Trough, the Herrestad Uplift and the Fyledalen Fault Zone (FFZ)

The Vomb Trough is located within the Sorgenfrei-Tornquist Zone (STZ), and achieved its present outline during the Late Cretaceous as a result of localised subsidence and NE tilting towards the Fyledalen Fault Zone (FFZ) (Fig. 1). The FFZ, that is composed of multiple faults and contains strongly tilted and in parts thrusted Jurassic–Lower Cretaceous strata, delimits the Vomb Trough to the northeast against the Lower Palaeozoic Colonus Shale Trough (Erlström et al., 2004). The northwestern part of the Vomb Trough is outlined to the southwest by the Romeleåsen Ridge, a crystalline high separating the northeastern part of the trough from the marginal parts of the Danish Basin, i.e. the Skurup Platform (Fig 1). The trough is filled with a 400–700 m thick succession of mixed clastic Upper Cretaceous strata of the Vomb Formation, overlying a 100–300 m thick poorly defined succession of Lower

Cretaceous and Jurassic strata resting on the crystalline basement (Chatziemannouil, 1982; Erlström et al., 2004). Pre-Jurassic deposits are not known to occur in the Vomb Trough.

The Fårarp-1 coring, included in the study, is located on the Herrestad uplift, a subsurface structural high that divides the Vomb Trough into two parts (see Fig. 1 in Lindström and Erlström, 2011). The sedimentary succession is thicker in the southeastern part of the Vomb Trough, i.e. 800 to 1500 m in comparison to 400 to 600 m in the northwest part. Except for parts of the uplifted Herrestad block, the bedrock surface in the Vomb Trough is composed of Santonian, Campanian and Maastrichtian strata (Chatziemannouil, 1982).

The Herrestad Fault borders the uplift to the south and is developed as a steep fault zone with a normal extensional character. Small hanging blocks along the main fault are indicated. There are, however, also some reverse components in the fault, which indicate fault activation during at least two events. The vertical displacement over the Herrestad Fault is in the range of 1000 to 1500 m. The basement in Köpingsberg-3, drilled c. 5 km to the south-east of Fårarp-1, lies at 1160 m (Erlström et al., 2004) while on the Herrestad Uplift at c. 200–300 m depth. In Assmåsa-1, and Snaven-1 c. 10–15 km to the northwest of Fårarp-1, the basement lies at 528 m and 755 m below ground level respectively.

Material and methods

This project includes material and data from a number of Swedish wells in the southern Baltic Sea and Scania, primarily Höllviken-2/Höllviksnäs-1, Kungstorp-1, Håslöv-1, Eskilstorp-1, Barsebäck-1, Mossheddinge-1, Svedala-1, FFC-1, BH94, Fårarp-1, Köpingsberg-3 (Fig. 1). In order to obtain a better understanding of the complex subsurface geology across the Höllviken Graben and Barsebäck Platform, material and data from some important Danish wells, Karlebo-1/1A and Margreteholm-1/1A, are also included in this study. New biostratigraphic data based on terrestrial and marine palynology has been retrieved from the majority of the selected wells. The palynological samples were processed according to standard palynological methods (e.g. Poulsen et al., 1990). Palynological events; i.e. first and last occurrences of key taxa, acmes (maximum abundances) as well as reworking, have been registered, and are used for biostratigraphic dating and correlation between the wells. Together with available geophysical logs, and sedimentological descriptions of cuttings and cores provided by the SGU and GEUS databases this enables careful borehole to borehole correlation, as well as lateral and vertical mapping of interesting aquifer and seal units.

The data and interpretations of the Uppermost Triassic to Lower Cretaceous succession are presented along two transects: one north-south trending transect from the northeastern Sjælland across the Öresund straight and down to southwestern Scania, encompassing the wells Karlebo-1/1A, Margreteholm-1/1A, Barsebäck-1, FFC-1, Eskilstorp-1, Håslöv-1, Kungstorp-1, and Höllviken-2/Höllviksnäs-1, and one west-east trending transect across the Höllviken Halfgraben and the Svedala Platform into the southern part of the Vomb Trough. Integrated with a previously published basin model for the Danish area by Nielsen (2003) the two transects constitute the base for a basin analysis that enables further refinements and definition of the uppermost Triassic to Lower Cretaceous succession in the Swedish part of the Danish Basin.

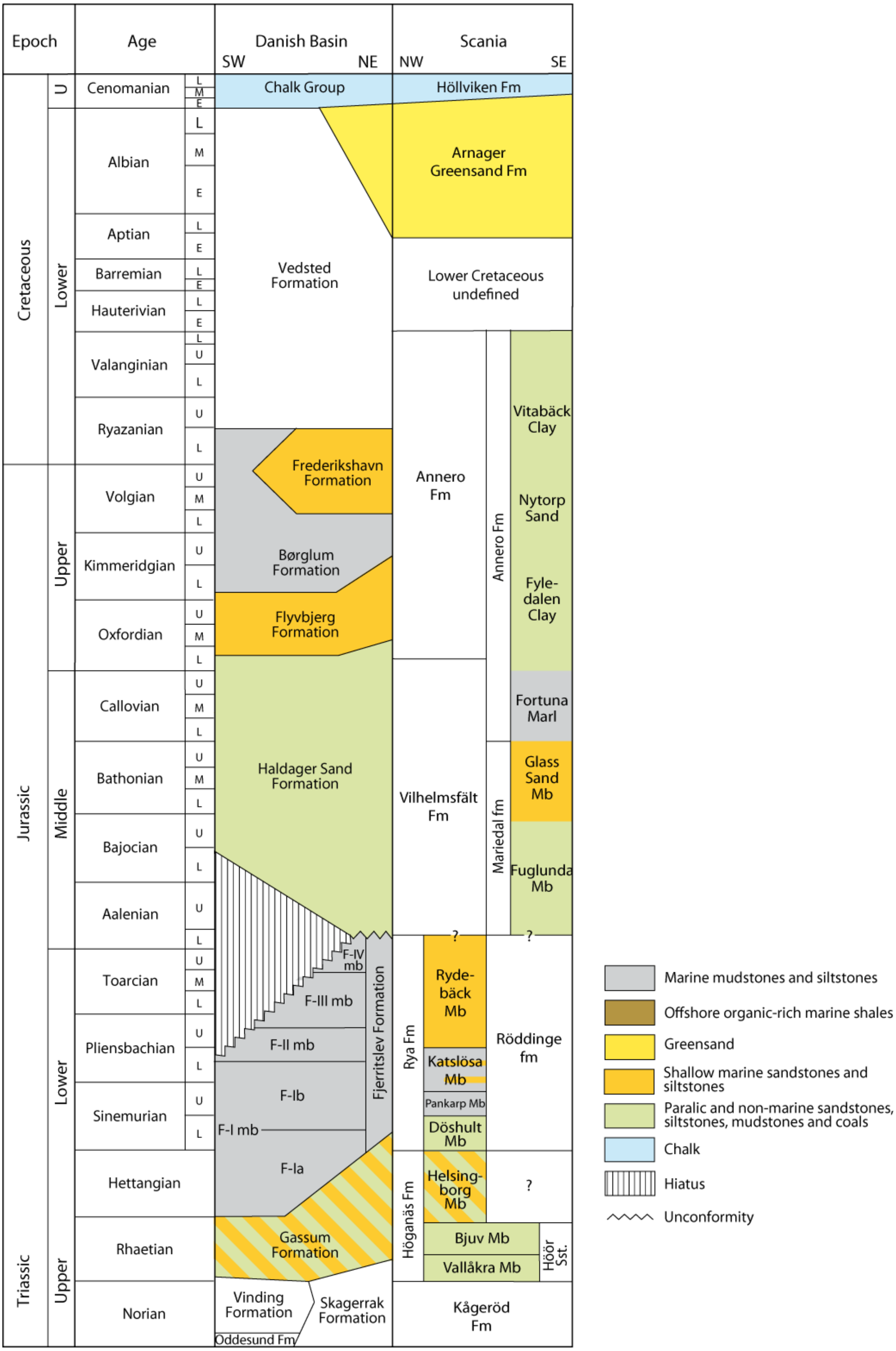


Fig. 5. Lithostratigraphic framework of the Upper Triassic to mid-Cretaceous succession in Denmark and Scania.

Stratigraphic framework

Geochronologic framework

The geochronological framework used in this study generally follows the recommendations of the International Commission of Stratigraphy (ICS). However, there is still an on-going debate regarding the position of the Jurassic–Cretaceous boundary. In our scheme the Jurassic–Cretaceous boundary is placed at the base of the *Berriasella jacobi* Tethyan ammonite Zone, equivalent to a level within the *Subcraspedites preplicomphalus* Boreal ammonite Zone (Hunt, 2004), as recommended by the ICS. As this study deals with strata deposited in the subboreal realm, we have also retained the subdivision of the uppermost Jurassic–Lower Cretaceous into the Volgian and Ryazanian in our scheme, as this subdivision is still widely used within the Boreal realm. Correlation between the two different chronostratigraphies is shown in Figs. 6 and 7.

Lithostratigraphic framework

In this study the Swedish lithostratigraphic subdivision of the uppermost Triassic–Lower Cretaceous succession have been used for wells located in the Swedish part of the Danish Basin (e.g. Ahlberg et al., 2003), but for the wells located in Denmark the Danish lithostratigraphy (e.g. Michelsen et al., 2003) has been applied (Fig. 5). During the course of this investigation it has become increasingly clear that the lithostratigraphic subdivision for the Lower Jurassic of the area needs to be revised. There is also a need for a lithostratigraphic definition that can be applied to the lowermost Cretaceous succession in SW Scania, as it is to date not entirely clear if, and to what extent, the lowermost Cretaceous succession in SW Scania can be assigned to the Annero Formation (see Fig. 5).

Palynostratigraphic framework

The biostratigraphic results of this study are compared and correlated with established palynostratigraphic schemes for the uppermost Triassic to Lower Cretaceous of western Europe. The terrestrial palynostratigraphy is primarily based on the works of Lund (1977), Batten and Koppelhus (1996), Dybkjær (1991), Koppelhus (1991), Koppelhus and Nielsen (1994), Herngreen *et al.* (2000), Abbink (1998), and Lindström and Erlström (2006, 2007a, 2011). The dinoflagellate cyst stratigraphy used herein is based on Davey (1979), Heilmann-Clausen (1987), Riding and Thomas (1992), Costa and Davey (1992), Herngreen *et al.* (2000), Woollam and Riding (1983) and Poulsen and Riding (2003). The Rhaetian dinocyst stratigraphy was further revised by Lindström (2002) and Lindström and Erlström (2006, 2007a). Important biostratigraphic events used in this study are shown in Figs. 6-8.

Assessment of palynological information from cuttings samples

Many of the assemblages investigated in this study are from ditch cuttings samples. Contamination of ditch cuttings samples due to caving from higher stratigraphical levels is usually a common and well-known minor complication for biostratigraphers working on ditch cuttings samples. However, it needs to be pointed out that in some stratigraphic intervals caving can be extra problematic. One example of this that relates to this report is caving of Jurassic strata within a Jurassic interval. Because many Jurassic spore-pollen taxa are long-ranging, the existing biostratigraphic schemes of NW Europe are largely based on quantitative data (Lund, 1977; Dybkjær, 1991; Koppelhus, 1991). Medium-large amounts of caving (or reworking, for that matter) will distort the quantitative signals rendering accurate assignment to biozones difficult or even impossible.

Hence, for ditch cuttings samples the last occurrence (LO) of a taxon in a section (unless reworked) is considered a more reliable datum than its first occurrence (FO). However, the LO of a taxon within a succession does not always correspond to its known last appearance datum (LAD), e.g. due to lack of samples, or there may be a hiatus within the succession, or the taxon may be extremily rare or absent due to palaeoenvironmental factors.

Reworking as a tool for environmental and tectonic development

The presence of reworked palynomorphs can provide interesting information about the local geology of an area, and its environmental and tectonic development. Increased reworking is usually connected to tectonic uplift or periods of increased erosion. If the reworked material is similar in age to the material deposited in situ, interpretations of the true age of an assemblage can be made very difficult. Further, if the reworked palynomorphs dominate an assemblage, the true age of that sample will be much harder to assess and is easily missed.

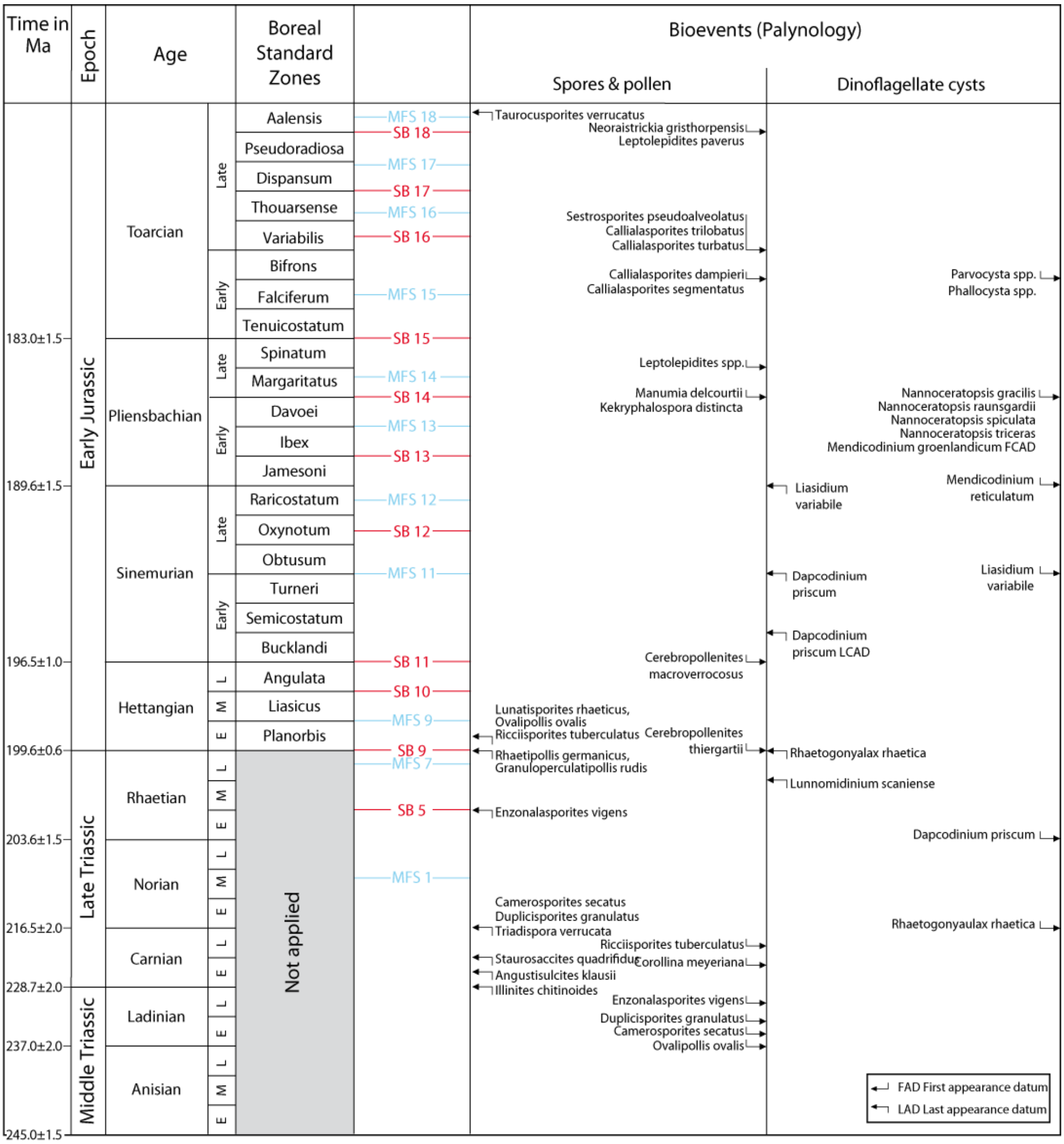


Fig. 6. Palynostratigraphic and sequence stratigraphic events for the Middle Triassic to Lower Jurassic.

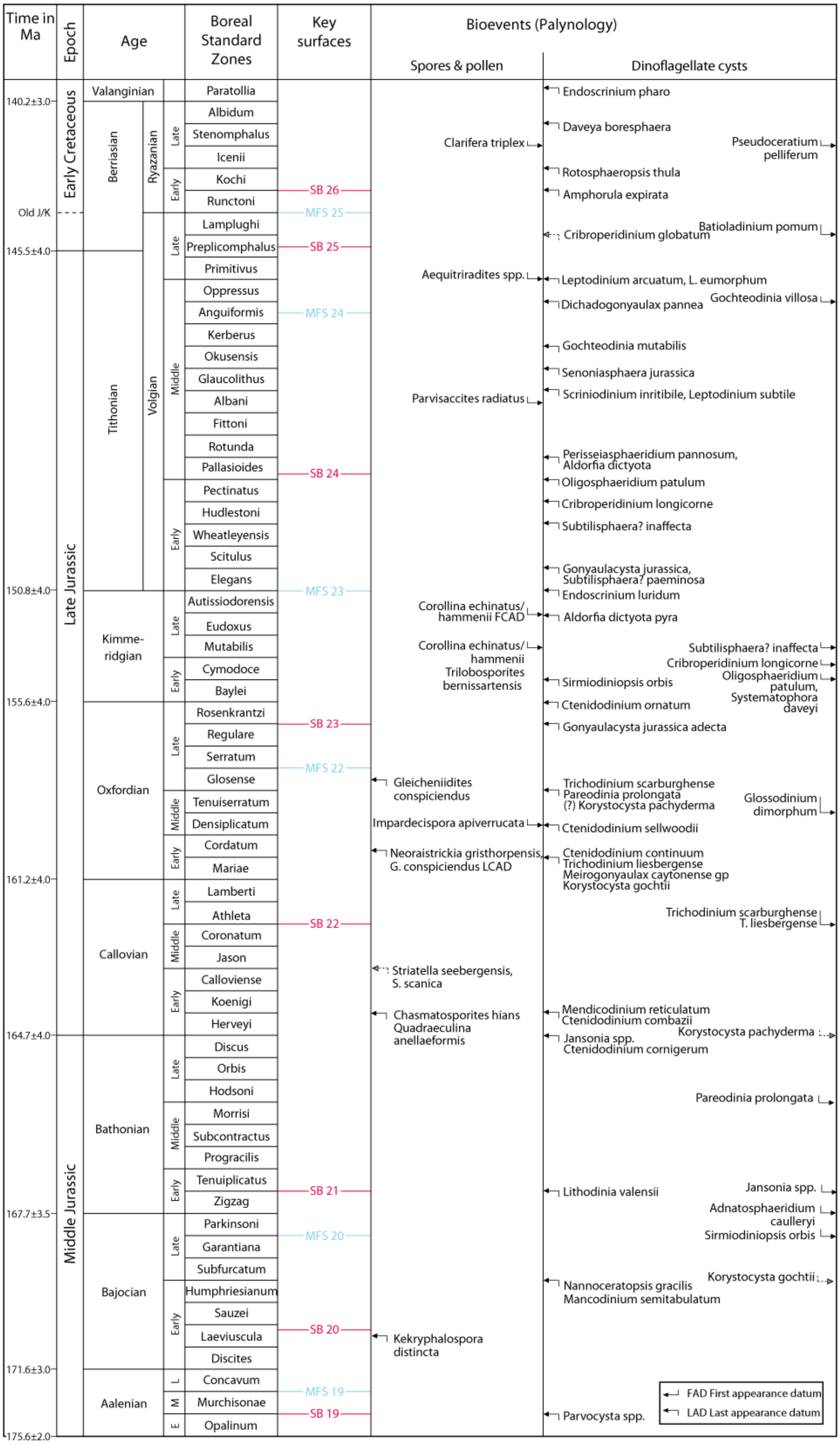


Fig. 7. Palynostratigraphic and sequence stratigraphic events for the Middle Jurassic to Lower Cretaceous.

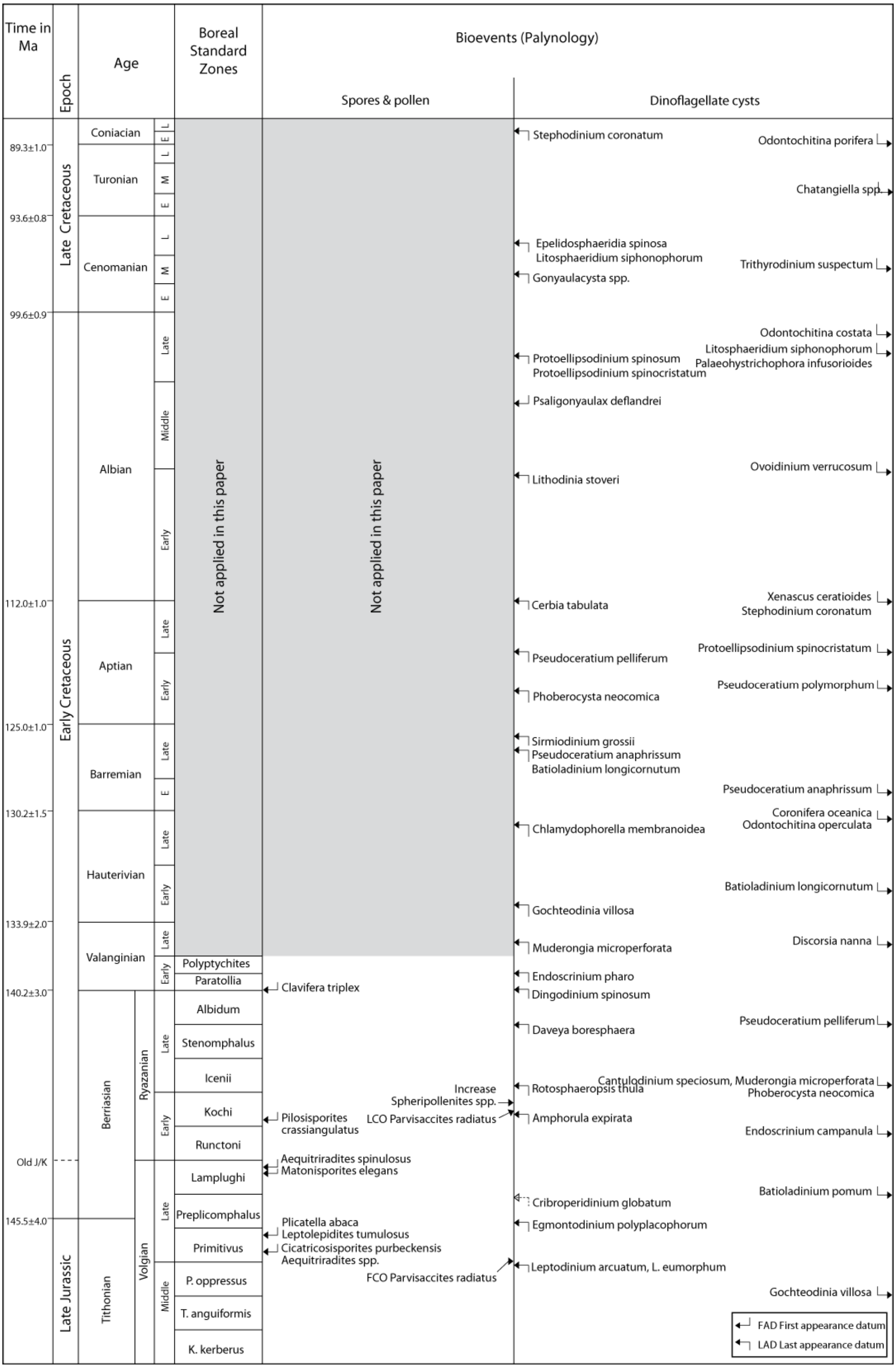


Fig. 8. Palynostratigraphic events for the Upper Jurassic to mid-Cretaceous.

Potential deep saline aquifers and seals

The Mesozoic succession includes a number of sandstone units which have a potential for being utilized for primarily geothermal purposes but also for CO_2-storage. As an example, a high quality aquifer suitable for Carbon Capture and Storage (CCS) should have a thickness of at least 10m, a porosity of at least 15% and a permeability that preferably exceeds 100mD. In order to keep CO_2 in its liquid state (>31ºC, 73,6 bar) within the aquifer a burial depth of at least 800m is needed. Further the aquifer must be overlain by an impermeable rock unit, a cap rock or seal, which prevents the CO_2 from reaching the surface. Knowledge of the location of faults or other boreholes are also essential, as CO_2 can otherwise reach the surface or freshwater aquifers closer to the surface.

On geological grounds the Mesozoic succession of southwestern Scania and the southern Baltic Sea contains several sandstone units that may act as potential aquifers suitable for CO_2-storage. Based on the Mesozoic succession in the geothermal well FFC-1 several potential aquifers and seals have been identified (Fig. 9), presented in ascending stratigraphical order below. The definition and characterization of these aquifer and seal units in FFC-1 constitute the basis for the conceptual model of the subsurface Mesozoic succession of the area.

Alternative reservoir: Rhaetian sandstones. Equivalent sand units of the Gassum Formation are currently used as reservoirs in Denmark, e.g. as natural gas storage in the in the Stenlille structure. However, the Rhaetian succession is generally much thinner in the Öresund area than in the more distal parts of the Danish Basin.

Multilayered sequence with reservoirs and seals: In Denmark the marine claystones of the overlying Fjerritslev Formation normally act as primary seal to reservoirs of the Gassum Formation. In FFC-1 it is evident that the corresponding part of the succession is much more heterogeneous, consisting of alternating silty claystone and predominantly fine-grained sandstone.

Primary reservoir: The best aquifer in FFC-1 is a 10m thick interval of medium- and coarse-grained sand with high permeability encountered at a depth of 1664m, herein referred to as the A-sand or Lower Cretaceous sand.

Intermediate seal: This interval consists predominantly of calcareous mudstones and clay-stones interbedded with fine-granied sandstone.

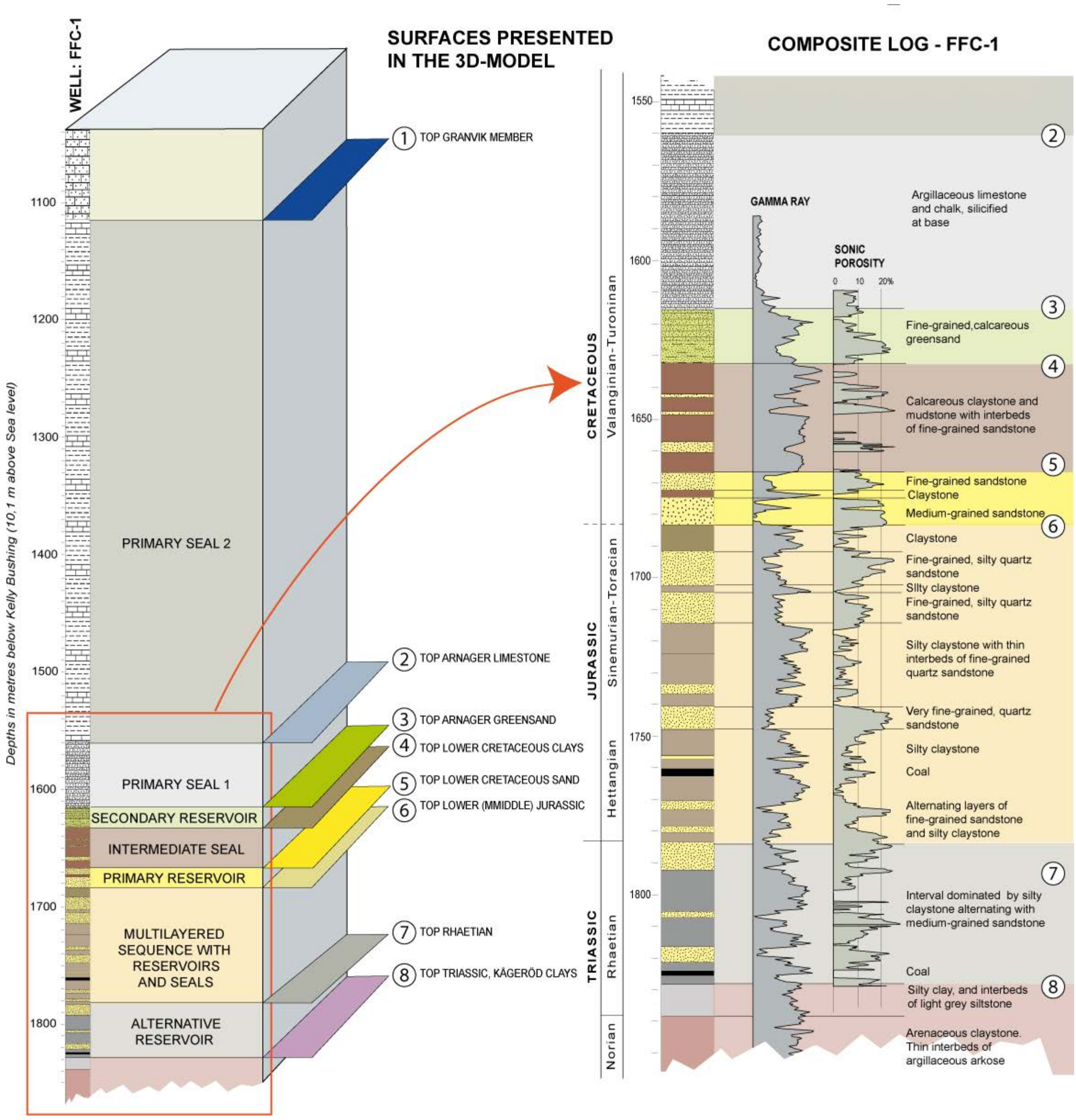


Fig. 9. Identified seals and aquifers in the FFC-1 well (from Erlström, 2011).

Secondary reservoir: The Lower Cretaceous Arnager Greensand Formation, consisting of fine-grained greensand, may act as a secondary reservoir.

Primary seal units: The primary seal consists of two units, namely the argillaceous limestone and chalk of the Arnager Limestone and a several hundred metres thick seal unit composed of argillaceous limestone, e.g. the Granvik Member.

Results

Biostratigraphic summary

This study encompasses biostratigraphic analyses of the Upper Triassic–Lower Cretaceous succession in eleven wells from the Swedish and two wells from the Danish part of the Danish Basin in the Öresund area. The location of the herein studied wells are shown in Fig. 1. The results of the biostratigraphic analysis are summarised below and presented as stratigraphic transects in Figs. 10–13. Stratigraphic event charts and palynostratigraphic range charts for the individual wells are presented in Figs. 14–31.

Explanation to range charts and event charts

Range charts: the recorded palynomorphs have been divided into groups primarily reflecting their affinity; namely spores and pollen, dinoflagellate cysts, acritarchs, and various types of other microalgae. The groups are further subdivided into *in situ*, reworked and caved elements. The palynostratigraphic range charts are constructed in two different ways. For those wells where the samples have been studied quantitatively, the percentages of individual taxa are shown. In wells where only a biostratigraphic presence/absence evaluation have been carried out only their stratigraphic ranges within the investigated interval are presented.

Event charts: From the individual range charts important palynostratigraphic events have been selected for each well and these are shown on the event charts for each well. The age implications of the palynostratigraphic events are also shown on Figs. 6-8. Spores and pollen together with freshwater algae represent the terrestrial realm, while dinoflagellate cysts and many acritarchs are marine representatives. For those wells where samples have been analysed quantitatively a “Marine vs. Terrestrial/freshwater” column is featured on the event charts. This enables the reader to assess the amount of marine influence at different levels within each well. Similarly, the amount of reworked palynomorphs is displayed in a separate column on the event charts.

Uppermost Triassic

During the Late Triassic the climate in NW Europe began to change from arid/semi-arid to more humid conditions. During the early Norian a transgression from the south resulted in deposition of oolitic limestones, marlstones and fossiliferous claystones of the Vinding Formation (Nielsen, 2003). By late Norian times the shallow sea covered most of the Danish Basin, while fluvial arkosic sands and lacustrine mudstones of the Skagerrak and Kågeröd Formations were deposited along the northern margin of the basin, in the Sorgenfrei–Tornquist Zone and in Scania.

After a phased regression which culminated in the early Rhaetian, the sea-level rose in a stepwise pattern, with deposition of shoreface sands of the Gassum Formation and marine mudstones of the Fjerritslev Formation (Nielsen, 2003). A transgression that reached its maximum in the latest Rhaetian is referred to maximum flooding surface 7, or MFS7, of Nielsen (2003). This late Rhaetian maximum flooding can be traced all over the basin, also in NW Scania where dark marine shales rich in dinoflagellate cysts are present between the two main Rhaetian coal seams, B and A (Lindström and Erlström, 2006).

The top of the Kågeröd Formation has been identified in the wells based on lithological descriptions of cores and cuttings, and is herein used as a tentative marker for the Norian–Rhaetian boundary. However, it should be stressed that further biostratigraphic datings are needed to determine the exact location of the Norian–Rhaetian boundary within each well.

Rhaetian strata have been identified in Höllviken-1, Eskilstorp-1, Håslöv-1, Svedala-1, FFC-1, Margreteholm-1/1A and Karlebo-1/1A, and additionally in the Stenlille wells and cores from the Helsingborg area (Lindström et al. on-going research). They are further well known from several localities in NW Scania (including the Lunnom and N Albert quarries, N

Vallåkra, the Fleninge 266 core and wall sections from the Helsingborg railway tunnel; Lindström and Erlström, 2006).

The Triassic–Jurassic boundary

The ratification of the Global boundary Stratotype Section and Point, GSSP, of the Triassic–Jurassic (T/J) boundary at Kuhjoch in the Northern Calcareous Alps in Austria took place in 2010. The biostratigraphic marker for the T/J boundary is the ammonite *Psiloceras spelae tirolicum*, and the accessory marker is the pollen *Cerebropollenites thiergartii*. Generally Triassic–Jurassic (T/J) boundary strata of the Danish Basin exhibit a very characteristic geophysical wire-line log-pattern (Nielsen, 2003), and based on the first occurrence (FO) of *C. thiergartii* it is placed approximately at the same level as SB9 of Nielsen (2003). The boundary is identified by palynostratigraphic events and log-pattern in Höllviken-1, FFC-1, Margreteholm-1/1A and Karlebo-1/1A, and indicated by palynology and log-patterns in several other wells. It is further well documented in the well Helsingborg 1.1008 and Stenlille-1 (Lindström et al., on-going research). In the Danish Basin the T/J-boundary strata belong to the Gassum Formation or lowermost Fjerritslev Formation.

The T/J-boundary succession in southern Scandinavia is overlain by younger strata in the North Sea, Denmark and the Baltic area between Sweden and Germany, and key outcrops occur only in Scania in southern Sweden.

In the Danish part of the basin the Rhaetian–Hettangian succession belongs to the Gassum and Fjerritslev Formations (Pedersen, 1985; Michelsen, 1975, 1989; Michelsen et al., 2003; Nielsen, 2003). The Gassum Formation (uppermost Norian–Lower Sinemurian) varies in thickness from 50–150m in the central parts of the basin to as much as 300m locally within the STZ. Formed in shallow marine to paralic environments the Gassum Formation consists of interbedded fine- to medium-grained, occasionally coarse-grained and pebbly sandstones, heteroliths, mudstones and few thin coaly beds (Bertelsen 1978; Hamberg and Nielsen, 2000; Nielsen, 2003). The overlying Lower Jurassic (Hettangian–lowermost

Aalenian) Fjerritlev Formation is dominated by marine claystones and mudstones. The transition from the Gassum to the Fjerritslev Formation occurred in several steps ranging from the latest Rhaetian in the central part of the basin to the Early Sinemurian along its northeastern margin, reflecting the overall Early Jurassic eustatic sea-level rise.

Lower to Middle Jurassic

During the Early Jurassic the climatic conditions were subtropical to warm-temperate and humid. Weathering of the granitic basement and Palaeozoic strata of the Baltic Shield supplied the Danish Basin with large quantities of clastic sediments (Nielsen, 2003). The combined effects of eustatic sea-level rise, regional subsidence and tectonic movements due to transtensional strike-slip movements in the STZ lead to an expansion of the basin towards the northeast (Nielsen, 2003).

In the Öresund area Lower Jurassic sedimentary rocks comprise predominantly fine- and medium-grained sandstones, alternating with siltstones and claystones. The sandstone units are comparatively thicker and more dominant in the southern part of the Höllviken Halfgraben (in the Höllviken-2, Kungstorp-1, Håslöv-1, and Eskilstorp-1) while on the Barsebäck Platform to the north and on Själland the individual sandstone beds are thinner, and siltstone and claystone more common (i.e. FFC-1, Barsebäck-1, Margreteholm-1/1A and Karlebo-1/1A wells).

During the late Early Jurassic to early Middle Jurassic the Ringkøbing-Fyn High (RFH) and most of the Danish Basin were uplifted with subsequent deep erosion taking place on the highest parts of RFH (Nielsen, 2003). While the Lower Jurassic was deeply eroded north of the RFH the areas closer to the STZ were less affected, and inside the STZ subsidence, albeit at a lower rate, still occurred resulting in depositing of shallow marine sands (Nielsen, 2003), e.g. in the Rønne Graben on Bornholm where Lower Aalenian shoreface sandstones are unconformably overlain by Aalenian to Bajocian fluvial conglomerates (Koppelhus and Nielsen, 1994).

Lowermost Aalenian strata have so far only been identified in Höllviken-2 in the Höllviken Halfgraben and in Karlebo-1/1A on Sjælland. In both wells the interval consists of variably sandy sediments (Fig. 11).

Upper Jurassic

Within this study Upper Jurassic strata have only been encountered in the Fårarp-1 and Köpingsberg-3 borings in the Vomb Trough. In the Fårarp-1 core the uppermost Jurassic (Tithonian) strata belong to the Fyledal Clay Member of the Annero Formation (Lindström and Erlström, 2011). Strata of equivalent age (and older) are probably present below 1060 m depth in Köpingsberg-3 where lowermost Cretaceous sediments are indicated palynostratigraphically (Figs. 13, 21, 31). The remaining ca 100 m down to basement in Köpingsberg-3 are poorly defined, but the palynology indicate a late to mid-Jurassic age for this part of the succession.

The Jurassic–Cretaceous boundary

The Jurassic–Cretaceous (J/K) boundary is currently placed at the base of the *Jacobi* Tethyan ammonite Zone, which corresponds to a level within the lower part of the *Subcraspedites preplicomphalus* Boreal ammonite Zone (Hunt, 2004).

The Fårarp-1 core penetrate almost 117 m of strata on the Herrestad Uplift in the southern part of the Vomb Trough (Lindström and Erlström, 2011). Through high-resolution palynology the Jurassic–Cretaceous (J/K) boundary was constrained by marine and terrestrial palynological events to be located within the lower part (between 106.78 m and 100.27 m depth) of the Vitabäck Clay Member of the Annero Formation.

Lower Cretaceous

Lower Cretaceous strata in southern Sweden are found in deep boreholes in SW Scania, in connection to fault zones such as the Romeleåsen and the Fyledalen fault zones, and in two boreholes in the Hanö Bay Basin (Norling, 1981)(Fig. 1). The Lower Cretaceous succession varies in thickness between 50 and 300 metres. The thickest parts are found in DGE-1, -2 on the NNW parts of the Skurup Platform and in the southeastern part of the Vomb Trough (Erlström et al., 2004).

In the Fårarp-1 core on the Herrestad Uplift Berriasian to Valanginian strata consist of a ca 70 m thick succession of alternating sand, silt and clay deposited in a marine to marginal marine environment (Lindström and Erlström, 2011). The uppermost part of the interval consists of ca 13 m of unconsolidated sand, most of which were lost during the core drilling. In Fårarp-1 this sand is unconformably overlain by Albian–Cenomanian greensand (Lindström and Erlström, 2011). It is possible that the 13 m sand interval in the Fårarp-1 core corresponds to the Lower Cretaceous A-sand unit in FFC-1.

Pre-Barremian Cretaceous succession in Scania and on Bornholm is dominated by fine-grained clastic sediments. Varicoloured clays, mudstones, siltstones and organic-rich clays are common lithologies, reflecting marginal depositional environments fluctuating between terrestrial and marine conditions.

The Valanginian–Hauterivian deposits in Scania are dominated by variably argillaceous sandstone intervals, rich in glauconite, phosphate and in parts calcareous, and these have been interpreted to represent an interval with increasing marine influence (Norling, 1981). The interval has yet to be lithostratigraphically defined.

On Bornholm Valanginian strata belong to the Jydegård Formation, above which there is a hiatus that accounts for the Hauterivian, Barremian and Aptian stages. During the Albian–Cenomanian fully marine deposition resumed during a number of transgressions resulting in the Arnager Greensand and Arnager Limestone formations. Similar conditions likely prevailed in the Vomb Trough as Aptian–Hauterivian deposits are not verified. Albian–Cenomanian deposits are, however, widely represented, e.g. in Köpingsberg-3, Snaven-1 (Norling, 1981) and in a number of shallow wells (Lindström et al., 2003). In Scania Barremian–Aptian deposits are known from wells in the Hanö Bay Basin and in SW Scania (Sivhed et al., 1999).

Basin analysis

The north–south transect

The north–south transect (Figs. 10 and 11) clearly illustrates the complexity of the Upper Triassic to Lower Cretaceous succession in the Öresund area. The Uppermost Triassic (Rhaetian) succession is fairly uniformly developed across this part of the Danish Basin, and contain a medium-grained sandstone unit with a thickness between 15–20m in the Höllviken Halfgraben. Equivalent sandstone units are primary aquifers in the Stenlille area on Sjælland, where the overlying thick succession of Lower Jurassic mudstones and shales of the Fjerritslev Formation act as a primary seal.

The north–south transect (Fig. 11) also shows that the alternating succession of sandstone, siltstone and claystone/shale units that characterise the Lower Jurassic is more difficult to correlate and reflect a more dynamic coastline with deltas and shoreface sands (Fig. 11). In contrast to the more distal facies known from Stenlille, the Lower Jurassic in the Höllviken Halfgraben and on the Barsebäck Platform is more sand dominated. However, in the northern part of the transect uppermost Lower Jurassic (Toarcian) marine shales are confirmed from the two Danish wells Karlebo-1/1A and Margreteholm-1/1A. Rudimentary Toarcian deposits are biostratigraphically indicated in FFC-1 and may possibly also be present in Barsebäck-1 (Fig. 11).

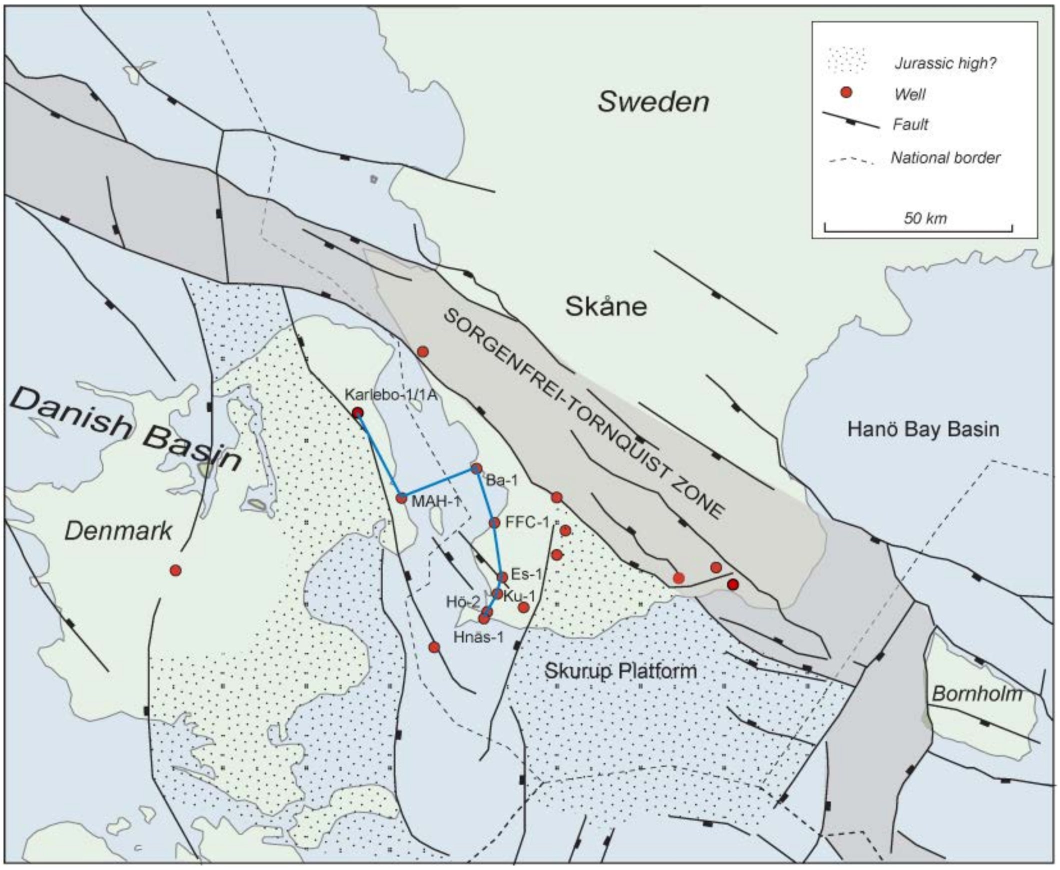
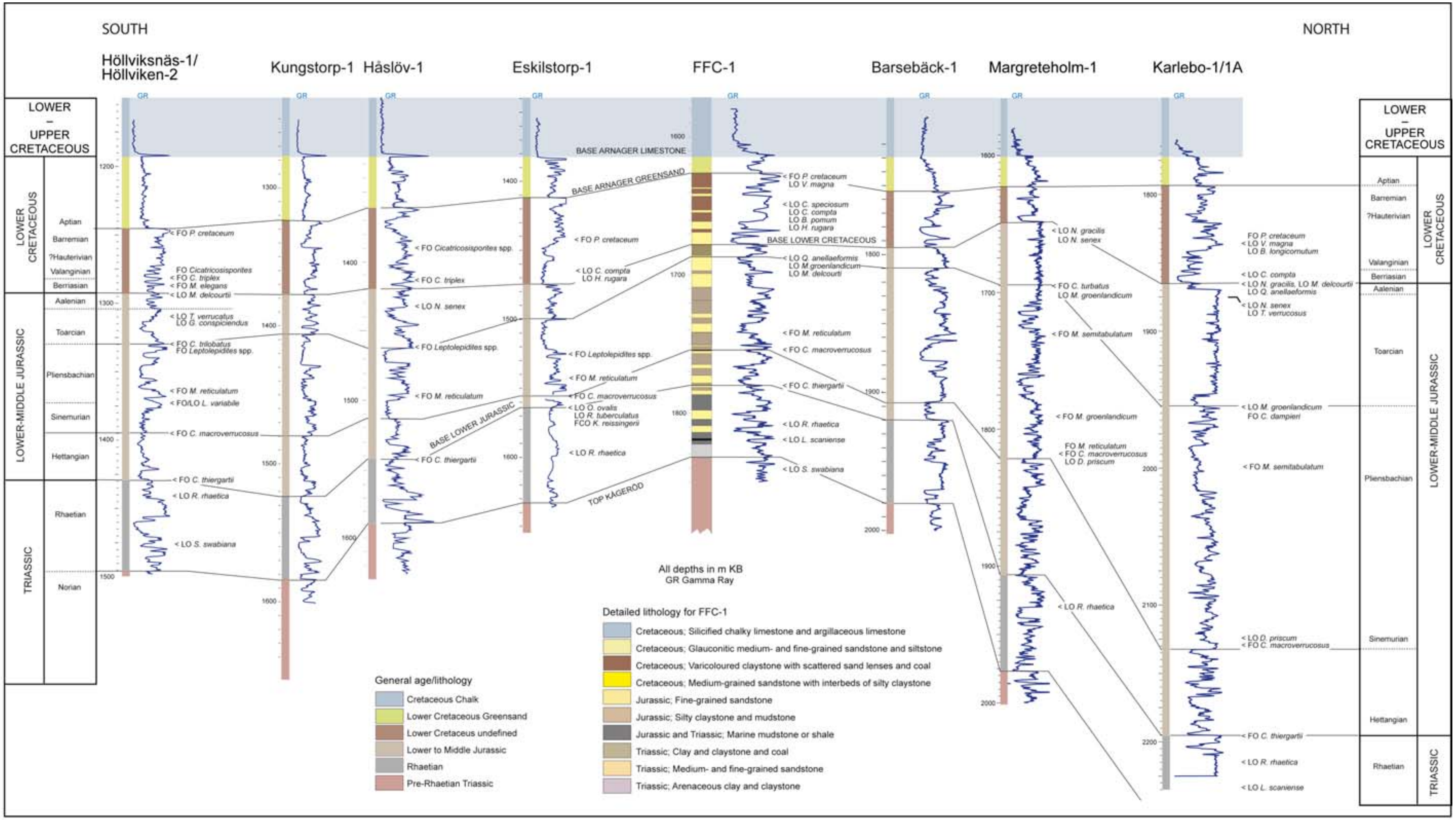


Fig. 10. The south to north transect (in blue) from Höllviken-2 to Karlebo-1/1A.

There is a considerable difference in thickness of the Lower–Middle Jurassic succession along the transect. In Höllviken-2 the interval attains a thickness of ca 140 m, but only ca 100 m in FFC-1, while in Margreteholm-1/1A (Mah-1) and Karlebo-1/1A the thickness is ca 200 m and 325 m respectively (Fig. 11).

The biostratigraphic analysis shows that the 10 m thick medium- and coarse-grained sand unit known from FFC-1 is Early Cretaceous (Berriasian–Valanginian) in age. A similar sand unit has been identified in all the wells on the north–south transect (Fig. 11). In Karlebo-1/1A this Lower Cretaceous sand rests upon a 5m thick unit of Middle Jurassic (Aalenian) sand. Middle Jurassic (Aalenian) sedimentary rocks are also indicated below the equivalent Lower Cretaceous sand unit in Höllviksnäs-1/Höllviken-2 (Fig. 11).



SOUTH
NORTH
Höllviksnäs-1/ Höllviken-2
Kungstorp-1
Håslöv-1
Eskilstorp-1
FFC-1
Barsebäck-1
Margreteholm-1
Karlebo-1/1A
GR
LOWER – UPPER CRETACEOUS
LOWER CRETACEOUS
LOWER-MIDDLE JURASSIC
TRIASSIC
Aptian
Barremian
?Hauterivian
Valanginian
Berriasian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
BASE ARNAGER LIMESTONE
BASE ARNAGER GREENSAND
BASE LOWER CRETACEOUS
BASE LOWER JURASSIC
TOP KÅGERÖD
All depths in m KB
GR Gamma Ray
General age/lithology
Cretaceous Chalk
Lower Cretaceous Greensand
Lower Cretaceous undefined
Lower to Middle Jurassic
Rhaetian
Pre-Rhaetian Triassic
Detailed lithology for FFC-1
Cretaceous; Silicified chalky limestone and argillaceous limestone
Cretaceous; Glauconitic medium- and fine-grained sandstone and siltstone
Cretaceous; Varicoloured claystone with scattered sand lenses and coal
Cretaceous; Medium-grained sandstone with interbeds of silty claystone
Jurassic; Fine-grained sandstone
Jurassic; Silty claystone and mudstone
Jurassic and Triassic; Marine mudstone or shale
Triassic; Clay and claystone and coal
Triassic; Medium- and fine-grained sandstone
Triassic; Arenaceous clay and claystone

The Lower Jurassic, post-Lower Sinemurian, succession of the Höllviken Graben contains large amounts of reworked palynomorphs of primarily Rhaetian–Lower Jurassic age that complicates the biostratigraphic interpretations. This indicates major reworking of equivalent strata during the time of deposition. In Svedala-1 on the Skurup Platform Lower Cretaceous sands (Berriasian–Valanginian) appear to rest directly upon Rhaetian strata, thus suggesting that the Skurup Platform was subject to major erosion in the Early Jurassic. In the Vomb Trough to the east the Arnager Greensand Fm rests directly upon Berriasian to Valanginian strata, providing evidence of a regional unconformity that is also known from Bornholm further to the east (Lindström and Erlström, 2011).

The west–east transect

The west–east transect (Figs. 12 and 13) shows the major differences in the Upper Triassic to Lower Cretaceous succession going from the Öresund area across the Svedala Platform and in to the Vomb Trough. It reveals major differences in the depositional history between these different structural elements. Whereas the Öresund area holds a relatively thick Rhaetian–Lower Jurassic succession (ca 140–360 m in thickness), no Lower Jurassic but only Rhaetian strata have been identified on the Svedala Platform in the Svedala-1 core. Cuttings samples from the shallow water well BH94 located just south of the Romeleåsen Ridge indicate a succession similar to that in Svedala-1, with Lower Cretaceous strata unconformably overlying Rhaetian sediments, while in Mossheddinge-1 the Lower Cretaceous rests directly on the basement (Fig. 13). On the Herrestad Uplift the Fårarp-1 core never reached the basement but confirmed the presence of an Upper Jurassic–Lower Cretaceous succession (Lindström and Erlström, 2011), similar to that described from Eriksdal in the Fyledalen Fault Zone.

Fig. 11. (p. 40) The south to north transect of Rhaetian to Lower Cretaceous strata across the Öresund area. The geographical locations of the wells on the transect are shown in Fig. 10. A larger version of this figure is included in the enclosures.

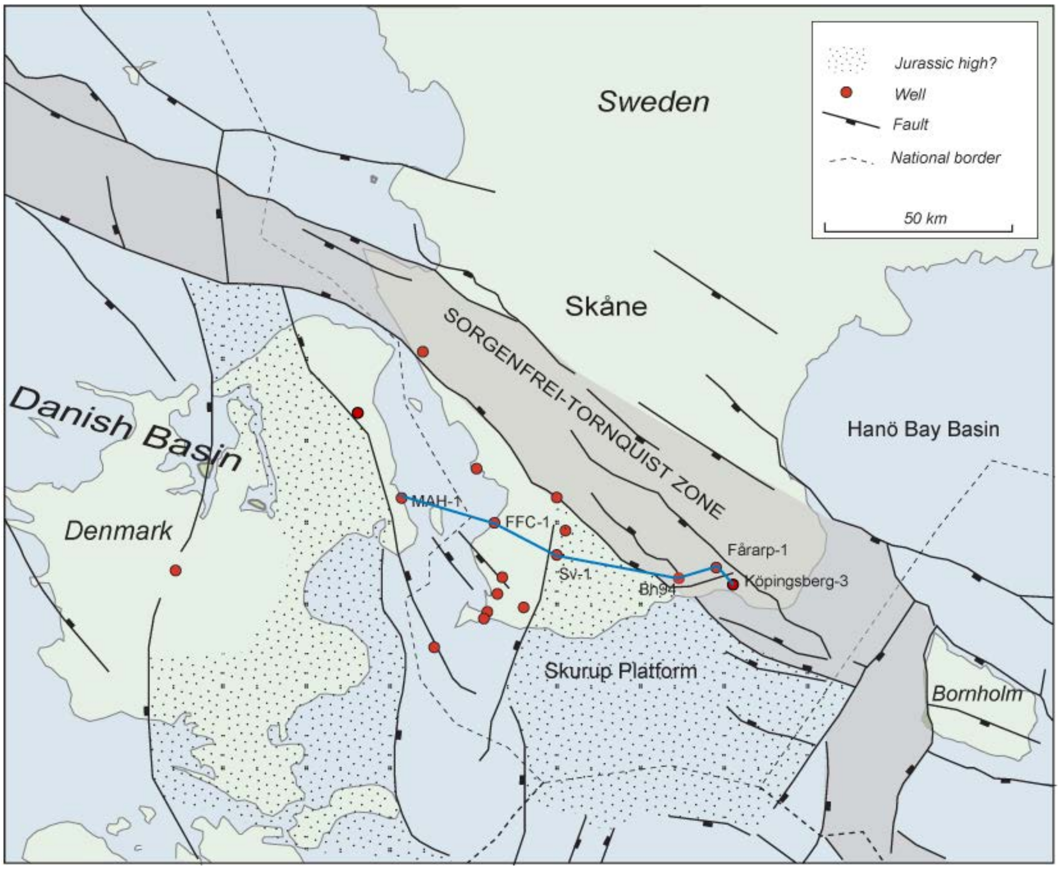
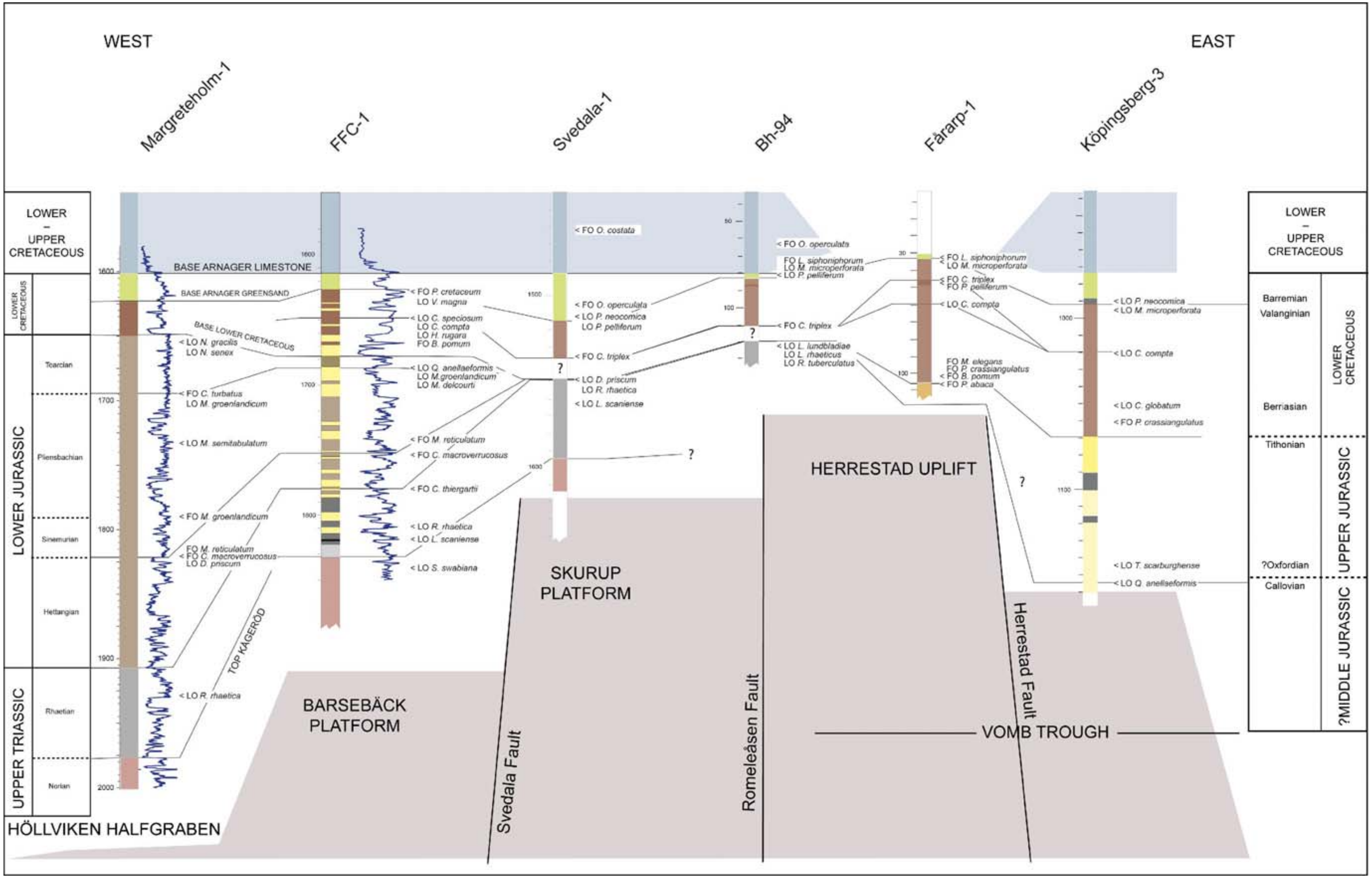


Fig. 12. The west to east transect (in blue) from Margreteholm-1/1A to Köpingsberg-3.

The main phase of faulting took place during the Early Cretaceous compressional Alpine deformation phase, which released vertical forces as well as local subsidence around the STZ. A lateral stress component in the tectonic regime resulted in transtensional as well as transpressional faulting along bends of the regional fault zones included in the STZ (Erlström and Sivhed, 2001; Erlström et al., 1997; Bergerat et al., 2007).

Fig. 13. (p. 43) The west to east transect across the Höllviken Graben to the Vomb Trough. The geographic locations of the wells on the transect are shown in Fig. 12. A larger version of this figure is included in the enclosures.



WEST
EAST
Margreteholm-1
FFC-1
Svedala-1
Bh-94
Fårarp-1
Köpingsberg-3
LOWER – UPPER CRETACEOUS
LOWER CRETACEOUS
LOWER JURASSIC
UPPER TRIASSIC
Toarcian
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
BASE ARNAGER LIMESTONE
BASE ARNAGER GREENSAND
BASE LOWER CRETACEOUS
TOP KÅGERÖD
< LO N. gracilis
LO N. senex
< FO C. turbatus
LO M. groenlandicum
< LO M. semitabulatum
< FO M. groenlandicum
FO M. reticulatum
< FO C. macroverrucosus
LO D. priscum
< LO R. rhaetica
< FO P. cretaceum
LO V. magna
< LO C. speciosum
LO C. compta
LO H. rugara
FO B. pomum
< LO Q. anellaeformis
LO M. groenlandicum
LO M. delcourti
< FO M. reticulatum
< FO C. macroverrucosus
< FO C. thiergartii
< LO R. rhaetica
< LO L. scaniense
< LO S. swabiana
< FO O. costata
< FO O. operculata
< LO P. neocomica
LO P. pelliferum
< FO C. triplex
< LO D. priscum
LO R. rhaetica
< LO L. scaniense
< FO O. operculata
FO L. siphoniphorum
LO M. microperforata
< LO P. pelliferum
< FO C. triplex
< LO L. lundbladiae
LO L. rhaeticus
LO R. tuberculatus
< FO L. siphoniphorum
< LO M. microperforata
< FO C. triplex
FO P. pelliferum
< LO C. compta
FO M. elegans
FO P. crassiangulatus
< FO B. pomum
< FO P. abaca
< LO P. neocomica
< LO M. microperforata
< LO C. compta
< LO C. globatum
< FO P. crassiangulatus
< LO T. scarburghense
< LO Q. anellaeformis
Barremian
Valanginian
Berriasian
Tithonian
?Oxfordian
Callovian
LOWER CRETACEOUS
UPPER JURASSIC
?MIDDLE JURASSIC
1600
1700
1800
1900
2000
1500
100
30
1000
1100
HÖLLVIKEN HALFGRABEN
BARSEBÄCK PLATFORM
SKURUP PLATFORM
HERRESTAD UPLIFT
VOMB TROUGH
Svedala Fault
Romeleåsen Fault
Herrestad Fault

Discussion

Significant results

The results of this project helps to clarify the tectonic development and depositional history of SW Scania during the latest Triassic to Early Cretaceous and the lateral and vertical extent of different deep aquifers within the succession.

The Rhaetian succession: The uppermost Triassic, Rhaetian strata, have great lateral extent and consist of a fairly uniform succession of Rhaetian sandstones succeeded by claystones and shales deposited during the maximum flooding (MFS7 of Nielsen, 2003). Some of the Rhaetian sandstone units are 10–15 m thick. In this interval Lower Palaeozoic, Carboniferous and Middle Triassic reworked palynomorphs occur sporadically, although the amount of reworking increases around the T/J-transition, indicating increased weathering and erosion at this time.

The Lower to Middle Jurassic succession: The interval covering the Lower to lowermost Middle Jurassic (Hettangian to Aalenian) interval consists of a highly heterogeneous clastic succession with substantial lateral variation.

- The Hettangian to Lower Sinemurian part of the succession is dominated by sandstones in the southern part of the Höllviken Halfgraben, but more fine-grained intercalations become more common towards the north, on the Barsebäck Platform and on Sjælland.
- The Upper Sinemurian–Pliensbachian is relatively thin in the southern part of the Höllviken Halfgraben, but increase considerably in thickness north of the Barsebäck Platform.

- The Toarcian interval is thin and relatively poorly defined biostratigraphically in the southern part of the Höllviken Halfgraben, where it is dominated by sand. In FFC-1 only a ca 10 m thick shale/claystone unit probably represent Toarcian deposits. Further north, in Margreteholm-1/1A and Karlebo-1/1A the Toarcian consist of a thick and relatively uniform shale/claystone succession.
- Aalenian deposits have only been identified in Höllviken-2 and Karlebo-1/1A, and consist of thin sandstones overlain by Lower Cretaceous sand.
- The palynostratigraphic dating of the upper Sinemurian to Aalenian interval is complicated by relatively high amounts of reworked Rhaetian to Hettangian palynomorphs, as well as sporadic occurrences of Carboniferous elements. The reworking probably corresponds to a phase of tectonic uplift of the Skurup Platform and Romeleåsen Ridge which were then subjected to erosion during the Early Jurassic.

The Lower Cretaceous succession: The base of the Lower Cretaceous actually corresponds to the Mid-Jurassic Unconformity (MCU) of Nielsen (2003).

- The Lower Cretaceous sand-dominated interval which corresponds to the primary reservoir in FFC-1, has been identified all over the basin. It appears to be of Berriasian-Valanginian age, and varies in thickness between the wells. It appears to consist of several sand units intercalated with thin fine-grained sediments. Especially in the southern part of the Höllviken Halfgraben, this unit contains high levels of reworked Middle Jurassic palynomorphs, indicating that the deposition of the sand is related to a period of increased erosion and reworking in the area. To the east this unit probably corresponds to a sand-dominated interval in Svedala-1, Bh-94 and to the more heterogeneous Vitabäck Clay Member in Fårarp-1 on the Herrestad Uplift. The Lower Cretaceous of the Fårarp-1 core also contain common reworked palynomorphs of Carboniferous, Rhaetian, Lower and Middle Jurassic age.

- The interval corresponding to the Intermediate seal in FFC-1 (Fig. 9) consists predominantly of more fine-grained sediments with varying in thickness between 20-40 m. This interval contains few age diagnostic palynomorphs, but reworked Jurassic and Triassic palynomorphs are common. The uppermost part of this interval is in many of the wells represented by the “Aptian Shale” consisting of a marine shale/claystone rich in dinoflagellate cysts of Late Barremian to Early Aptian age. No Hauterivian deposits have been confirmed within this study and it is possible that they are missing in the area. To the west Valanginian deposits appear to be unconformably overlain by Albian–Cenomanian strata of the Arnager Greensand Formation in Bh-94 and Fårarp-1, similar to the succession on Bornholm further to the east.
- The Arnager Greensand, which in FFC-1 is defined as a secondary reservoir, is present all over the basin, but is thickest in the southernmost part of the Höllviken Halfgraben (Höllviken-2 and Kungstorp-1). It becomes thinner towards the north and west.

This study has resulted in an extensive database and increased knowledge of the subsurface geology of SW Scania and the Öresund area within the Upper Triassic to Lower Cretaceous interval.

Data reliability

The palynostratigraphic analysis and log-evaluation of the wells form the basis of the correlation in this study. As mentioned earlier, cuttings samples commonly contain variable amounts of caved material that can make true age correlations difficult. The sample resolution can also present certain problems with assessing the reliability of biostratigraphic events. In this study, correlations are further complicated by the presence of fairly large amounts of reworked material in the samples at different levels.

The highly heterogeneous clastic succession in the area has resulted in multiple oscillations in the geophysical logs and these can vary considerably between the different wells. This is especially true for the Lower Jurassic to lowermost Cretaceous succession, e.g. in Höllviken-2 and Kungstorp-1 the Hettangian to Sinemurian interval consists predominantly of sand-dominated sediments and the gamma-ray logs are very similar and correlation straight forward. In Håslöv-1, Eskilstorp-1 and FFC-1 the corresponding gamma-ray logs are much more variable. This type of variability in combination with low-resolution sampling or only cuttings material available for biostratigraphy makes correlations difficult and increases the uncertainty of the final model.

The palynostratigraphic analyses of Håslöv-1, Eskilstorp-1 and Köpingsberg-3 holds some degree of uncertainty regarding the age assignments of various intervals. In Håslöv-1 only a few specimens of typical Lower Cretaceous palynomorphs have been encountered in the upper three analysed samples. The majority of the palynomorphs in the assemblages are typical for Lower to Middle Jurassic strata. However, the presence of high amounts of reworked Jurassic material in Lower Cretaceous core samples from both Höllviken-2 and Svedala-1 suggest that this may also be the case for Håslöv-1. In Eskilstorp-1 a sampling gap between 1503 m to 1464 m probably covers the entire upper Lower Jurassic and hinders evaluation of whether Middle Jurassic strata are present in this well like in Höllviken-2. The cuttings samples from Köpingsberg-3 contain large amounts of caved Lower to Upper Cretaceous material, and the assemblages are only poorly to moderately preserved.

In this study, the core samples from Höllviken-2, Svedala-1 and Fårarp-1, along with sidewall core samples from FFC-1 provide the most reliable data, and enable more accurate interpretations of the cuttings material from the remaining wells to be made.

Concluding comments and future work

The performed investigation has resulted in a stratigraphic subsurface framework of the Lower Cretaceous, Jurassic and Upper Triassic (Rhaetian) interval in the Höllviken

Halfgraben and on the Barsebäck Platform. With the use of the established biostratigraphic zonation it is now possible to progress with the description of the depositional and structural evolution of the area. Already a master thesis study is launched at Lund University regarding an evaluation of the distribution, frequency and characteristics of the sandstone units within the Rhaetian, Hettangian, Sinemurian and Pliensbachian successions.

The results have also been incorporated in the evaluation and characterisation of the deep saline aquifers in SW Scania regarding CO_2 storage. This is an ongoing work within the Mustang project (EU FP7 programme) where the geological succession of the Lower Cretaceous–Upper Triassic aquifers in SW Scania constitute an example of a multilayered aquifer system for numerical modelling of injection and storage of CO_2. Without the biostratigraphical results in this study it would not have been possible to progress with the Mustang geological models for SW Scania.

The results have also in parts been incorporated in an ongoing research project concerning the evaluation of the geothermal potential in Denmark where the deep aquifers in the Öresund area constitute one of the target investigation areas. The project is funded by the Danish Council for Strategic Research and is a research collaboration project between GEUS, GFZ Potsdam, SGU and Århus University.

The study has in addition to the biostratigraphical correlation of the Höllviken Halfgraben and the Barsebäck Platform contributed with new information regarding the distribution and occurrence of deposits of different ages on the Skurup Platform and in the Vomb Trough. The obtained data has, in combination with the occurrences of high amount of reworked Lower Jurassic palynomorphs in the Höllviken Halfgraben, provided new evidence regarding the tectonic evolution of the individual rock blocks. Based on this our interpretation is that the rock block to the east of the Höllviken Halfgraben constituted a high area subject to erosion during much of the Jurassic period. However, there are still many questions regarding the tectonic evolution and relationship between the mentioned structure elements, which have to be investigated further in future studies. This is especially important for the understanding of the Lower Cretaceous sequence where there is a need of a better lithologic and litostratigraphic definition of the sequence in order to be able to interpret the tectonic events in the area during this period.

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Captions figures 14–31

Range and events charts for Fårarp-1 are displayed in Lindström and Erlström (2011) in the Appendix.

Fig. 14. Event chart for FFC-1 displaying chrono- and lithostratigraphic subdivision of the well, as well as important palynostratigraphic events, marine vs terrestrial elements, and amount of reworking.

Fig. 15. Event chart for Höllviken-2 displaying chrono- and lithostratigraphic subdivision of the well, as well as important palynostratigraphic events, marine vs terrestrial elements, and amount of reworking. Geophysical logs are from the closely located well Höllviksnäs-1. The logs have been shifted -6m to fit the lithological shifts in Höllviken-2.

Fig. 16. Event chart for Håslöv-1 displaying chrono- and lithostratigraphic subdivision of the well, as well as important palynostratigraphic events, marine vs terrestrial elements, and amount of reworking.

Fig. 17. Event chart for Eskilstorp-1 displaying chrono- and lithostratigraphic subdivision of the well, as well as important palynostratigraphic events, marine vs terrestrial elements, and amount of reworking.

Fig. 18. Event chart for Svedala-1 displaying chrono- and lithostratigraphic subdivision of the well, as well as important palynostratigraphic events, marine vs terrestrial elements, and amount of reworking. No geophysical logs are available for this well.

Fig. 19. Event chart for Margreteholm-1/1A displaying chrono- and lithostratigraphic subdivision of the well, as well as important palynostratigraphic events, marine vs terrestrial elements, and amount of reworking.

Fig. 20. Event chart for Karlebo-1/1A displaying chrono- and lithostratigraphic subdivision of the well, as well as important palynostratigraphic events, marine vs terrestrial elements, and amount of reworking.

Fig. 21. Event chart for Köpingsberg-3 displaying chrono- and lithostratigraphic subdivision of the well, as well as important palynostratigraphic events, marine vs terrestrial elements, and amount of reworking. No digital geophysical logs are available for this well.

Fig. 22. Range and events chart for Mossheddinge-1 displaying chronostratigraphic subdivision of the well, as well as important palynostratigraphic events and palynostratigraphic data. DC=Dinoflagellate cysts, AL=Algae, AC=Acritarchs *1=presence/absence, *2=reworked occurrences *3=caved occurrences *4=*in situ* occurrences *5=Algae, *Botryococcus* and *Pediastrum.*

Fig. 23. Range and events chart for BH94 displaying chronostratigraphic subdivision of the well, as well as important palynostratigraphic events and palynostratigraphic data.

SP=Spores and pollen, *1 presence/absence, *2=caved occurrences, DC=Dinoflagellate cysts, AC=Acritarchs, *3=stratigraphic range, *4=Algae, *Botryococcus* and *Pediastrum*.

Fig. 24. Range chart for FFC-1 displaying chrono- and lithostratigraphic subdivision of the well, and quantitative palynological data. SP=Spores and pollen, *1 % within discipline, *2=reworked occurrences, DC=Dinoflagellate cysts, AC=Acritarchs, *3=stratigraphic range, *4=Algae, *Botryococcus* and *Pediastrum,* Algae=, and ALIN=Algae other.

Fig. 25. Range chart for Höllviken-2/Höllviksnäs-1 displaying chrono- and lithostratigraphic subdivision of the well, and quantitative palynological data. Logs from Höllviksnäs-1 are shifted -6 metres. *1 % within discipline, *2=*in situ*, reworked occurrences, ? occurrences, *3= Algae, *Botryococcus* and *Pediastrum*, CT=Chitinozoa.

Fig. 26. Range chart for Håslöv-1 displaying chrono- and lithostratigraphic subdivision of the well, and quantitative palynological data. SP=Spores and pollen, DC=Dinoflagellate cysts, *1 % within discipline, *2=Algae, *Botryococcus* and *Pediastrum,* Algae=, and ALIN=Algae other.

Fig. 27. Range chart for Eskilstorp-1 displaying chrono- and lithostratigraphic subdivision of the well, and palynological data. SP=Spores and pollen, DC=Dinoflagellate cysts, *1=reworked occurrences, *2=stratigraphic range, *3= Algae, *Botryococcus* and *Pediastrum.*

Fig. 28. Range chart for Svedala-1 displaying chrono- and lithostratigraphic subdivision of the well, and quantitative palynological data. DC=Dinoflagellate cysts, AL=Algae, other, *1=Presence/absence, *2=Reworked occurrences, *3= Algae, *Botryococcus* and *Pediastrum.*

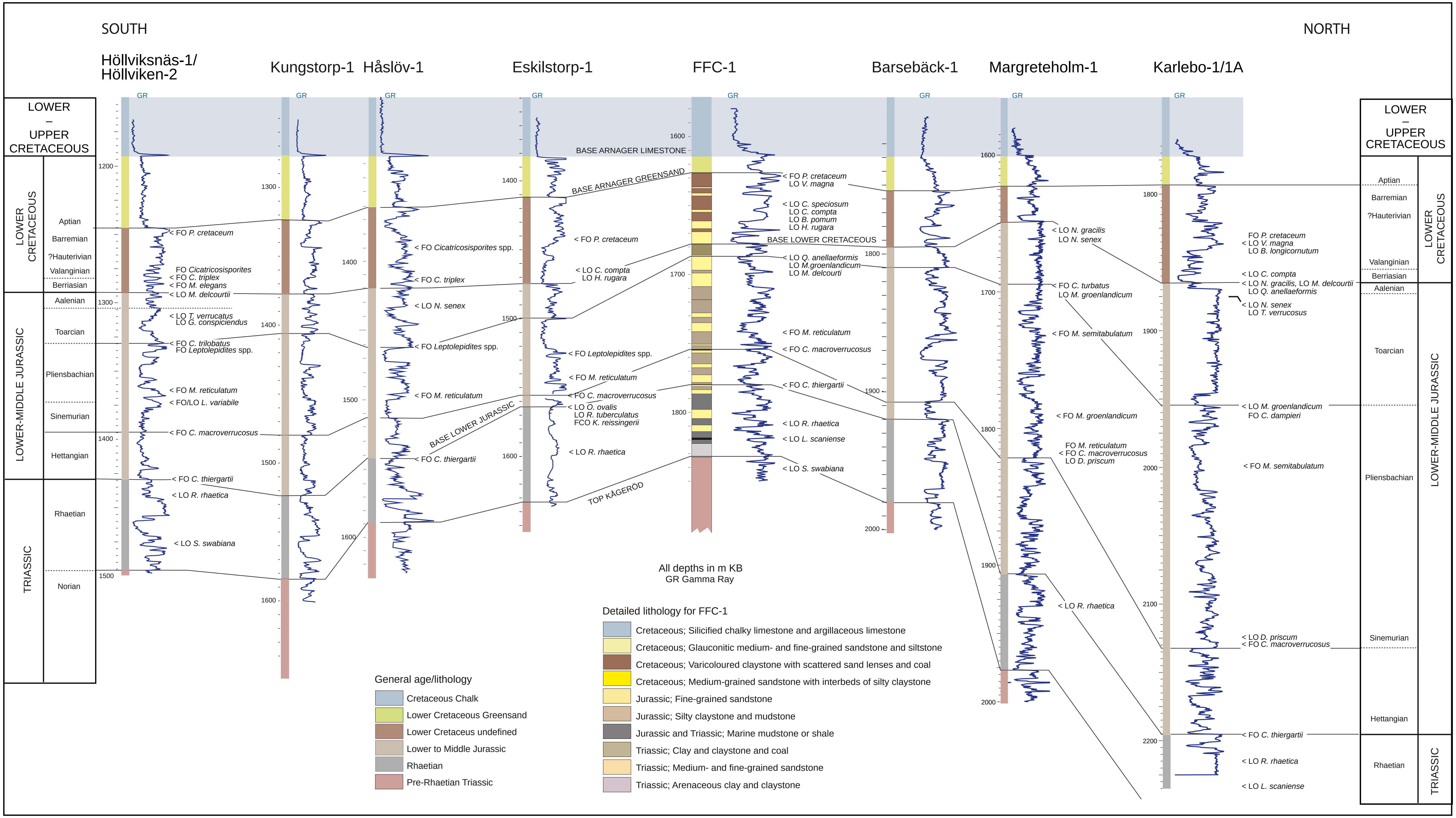
Fig. 29. Range chart for Margreteholm-1/1A displaying chrono- and lithostratigraphic subdivision of the well, and quantitative palynological data for all samples except 1615-1695m which have not been counted. SP=Spores and pollen, DC=Dinoflagellate cysts, AL=Algae, other, *1=% within discipline, *2=caved occurrences, *3=Algae, *Botryococcus* and *Pediastrum.*

Fig. 30. Range chart for Karlebo-1/1A displaying chrono- and lithostratigraphic subdivision of the well, and quantitative palynological data. DC=Dinoflagellate cysts, *1 % within discipline, *2=reworked occurrences, ALBO=Algae, *Botryococcus* and *Pediastrum,* AL=Algae, other.

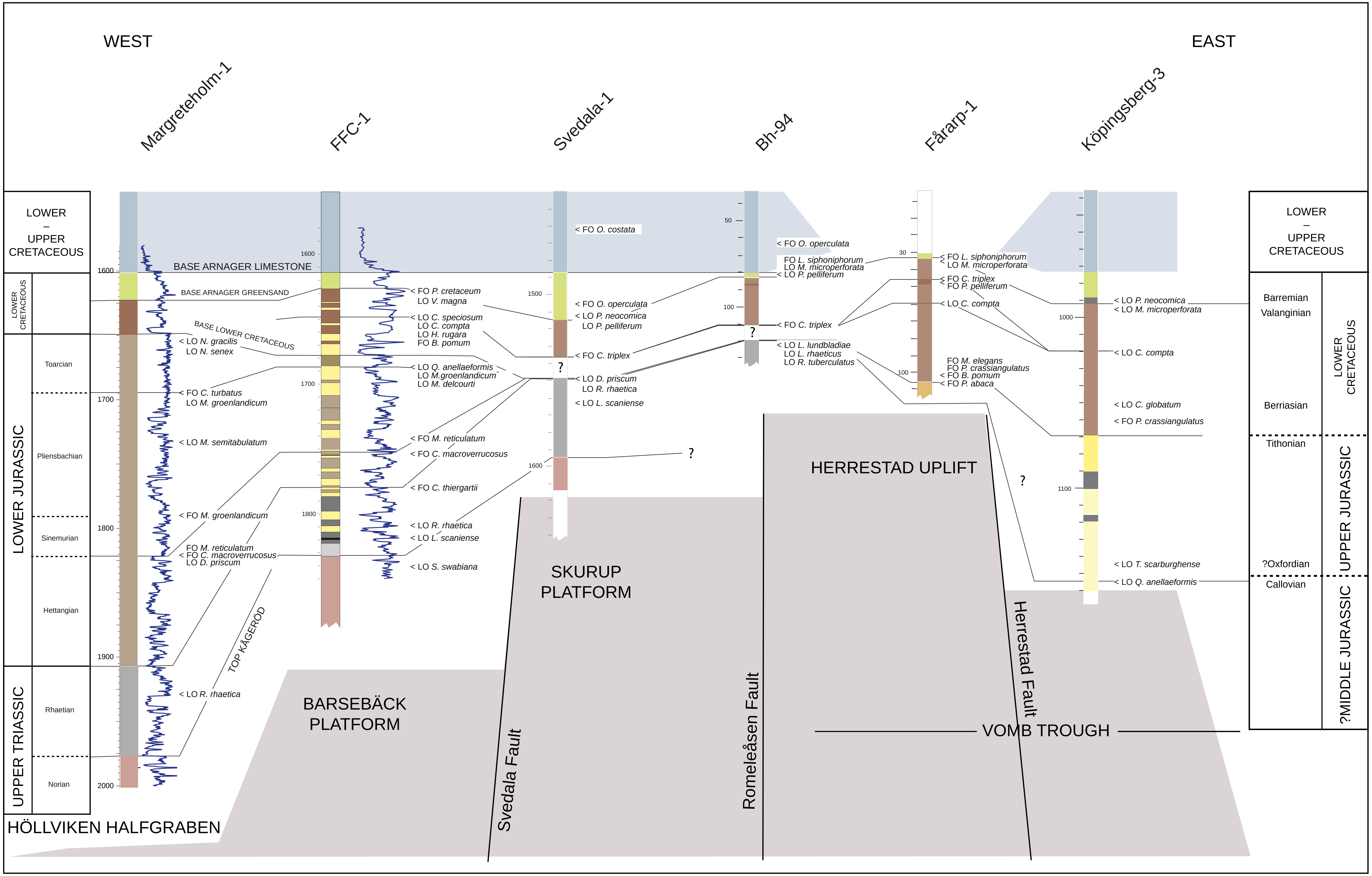
Fig. 31. Range chart for Köpingsberg-3 displaying chrono- and lithostratigraphic subdivision of the well, and palynological data. For this well only caving of late Early to Late Cretaceous dinoflagellate cysts have been marked on the chart, i.e. the column for Spores and pollen also contain elements that may be caved. SP=Spores and pollen, ALBO=Algae, *Botryococcus* and *Pediastrum,* AL=Algae, other, *1=Presence/absence, *2=caved occurrences.

Enclosures and Appendices

Fig. 11
Fig. 13
Figs. 14–31



SOUTH
NORTH
Höllviksnäs-1/ Höllviken-2
Kungstorp-1
Håslöv-1
Eskilstorp-1
FFC-1
Barsebäck-1
Margreteholm-1
Karlebo-1/1A
GR
LOWER – UPPER CRETACEOUS
LOWER CRETACEOUS
LOWER-MIDDLE JURASSIC
TRIASSIC
Aptian
Barremian
?Hauterivian
Valanginian
Berriasian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
BASE ARNAGER LIMESTONE
BASE ARNAGER GREENSAND
BASE LOWER CRETACEOUS
BASE LOWER JURASSIC
TOP KÅGERÖD
< FO P. cretaceum
FO Cicatricosisporites
< FO C. triplex
< FO M. elegans
< LO M. delcourtii
< LO T. verrucatus
LO G. conspiciendus
< FO C. trilobatus
FO Leptolepidites spp.
< FO M. reticulatum
< FO/LO L. variabile
< FO C. macroverrucosus
< FO C. thiergartii
< LO R. rhaetica
< LO S. swabiana
< FO Cicatricosisporites spp.
< LO N. senex
< FO Leptolepidites spp.
< LO C. compta
LO H. rugara
< LO O. ovalis
LO R. tuberculatus
FCO K. reissingerii
< LO V. magna
< LO C. speciosum
LO C. compta
LO B. pomum
LO H. rugara
< LO Q. anellaeformis
LO M.groenlandicum
LO M. delcourti
< LO L. scaniense
< LO N. gracilis
LO N. senex
< FO C. turbatus
LO M. groenlandicum
< FO M. semitabulatum
< FO M. groenlandicum
FO M. reticulatum
< FO C. macroverrucosus
LO D. priscum
< LO R. rhaetica
FO P. cretaceum
< LO V. magna
LO B. longicornutum
< LO C. compta
< LO N. gracilis, LO M. delcourtii
LO Q. anellaeformis
< LO N. senex
LO T. verrucosus
< LO M. groenlandicum
FO C. dampieri
< FO M. semitabulatum
< LO D. priscum
< FO C. macroverrucosus
< FO C. thiergartii
< LO R. rhaetica
< LO L. scaniense
All depths in m KB
GR Gamma Ray
General age/lithology
Cretaceous Chalk
Lower Cretaceous Greensand
Lower Cretaceous undefined
Lower to Middle Jurassic
Rhaetian
Pre-Rhaetian Triassic
Detailed lithology for FFC-1
Cretaceous; Silicified chalky limestone and argillaceous limestone
Cretaceous; Glauconitic medium- and fine-grained sandstone and siltstone
Cretaceous; Varicoloured claystone with scattered sand lenses and coal
Cretaceous; Medium-grained sandstone with interbeds of silty claystone
Jurassic; Fine-grained sandstone
Jurassic; Silty claystone and mudstone
Jurassic and Triassic; Marine mudstone or shale
Triassic; Clay and claystone and coal
Triassic; Medium- and fine-grained sandstone
Triassic; Arenaceous clay and claystone



WEST
EAST
Margreteholm-1
FFC-1
Svedala-1
Bh-94
Fårarp-1
Köpingsberg-3
LOWER – UPPER CRETACEOUS
LOWER CRETACEOUS
LOWER JURASSIC
UPPER TRIASSIC
Toarcian
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
1600
1700
1800
1900
2000
1500
50
100
30
1000
1100
BASE ARNAGER LIMESTONE
BASE ARNAGER GREENSAND
BASE LOWER CRETACEOUS
TOP KÅGERÖD
< LO N. gracilis
LO N. senex
< FO C. turbatus
LO M. groenlandicum
< LO M. semitabulatum
< FO M. groenlandicum
FO M. reticulatum
< FO C. macroverrucosus
LO D. priscum
< LO R. rhaetica
< FO P. cretaceum
LO V. magna
< LO C. speciosum
LO C. compta
LO H. rugara
FO B. pomum
< LO Q. anellaeformis
LO M.groenlandicum
LO M. delcourti
< FO M. reticulatum
< FO C. macroverrucosus
< FO C. thiergartii
< LO R. rhaetica
< LO L. scaniense
< LO S. swabiana
< FO O. costata
< FO O. operculata
< LO P. neocomica
LO P. pelliferum
< FO C. triplex
< LO D. priscum
LO R. rhaetica
< LO L. scaniense
< FO O. operculata
FO L. siphoniphorum
LO M. microperforata
< LO P. pelliferum
< FO C. triplex
< LO L. lundbladiae
LO L. rhaeticus
LO R. tuberculatus
< FO L. siphoniphorum
< LO M. microperforata
< FO C. triplex
< FO P. pelliferum
< LO C. compta
FO M. elegans
FO P. crassiangulatus
< FO B. pomum
< FO P. abaca
< LO P. neocomica
< LO M. microperforata
< LO C. compta
< LO C. globatum
< FO P. crassiangulatus
< LO T. scarburghense
< LO Q. anellaeformis
Barremian
Valanginian
Berriasian
Tithonian
?Oxfordian
Callovian
LOWER CRETACEOUS
UPPER JURASSIC
?MIDDLE JURASSIC
HÖLLVIKEN HALFGRABEN
BARSEBÄCK PLATFORM
SKURUP PLATFORM
HERRESTAD UPLIFT
VOMB TROUGH
Svedala Fault
Romeleåsen Fault
Herrestad Fault

Well Name : FFC-1

Interval : 1600m - 1850m

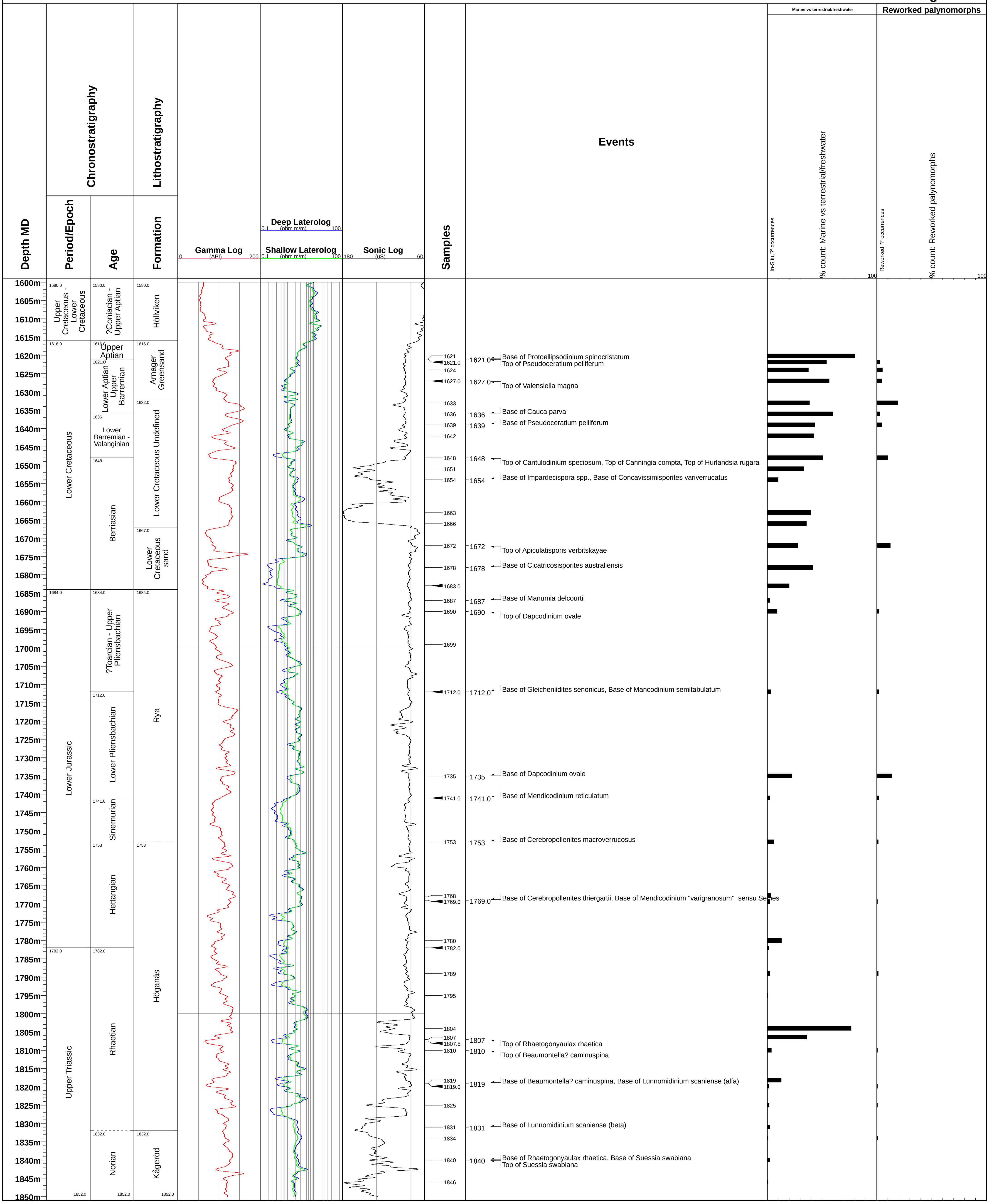
Scale : 1:750

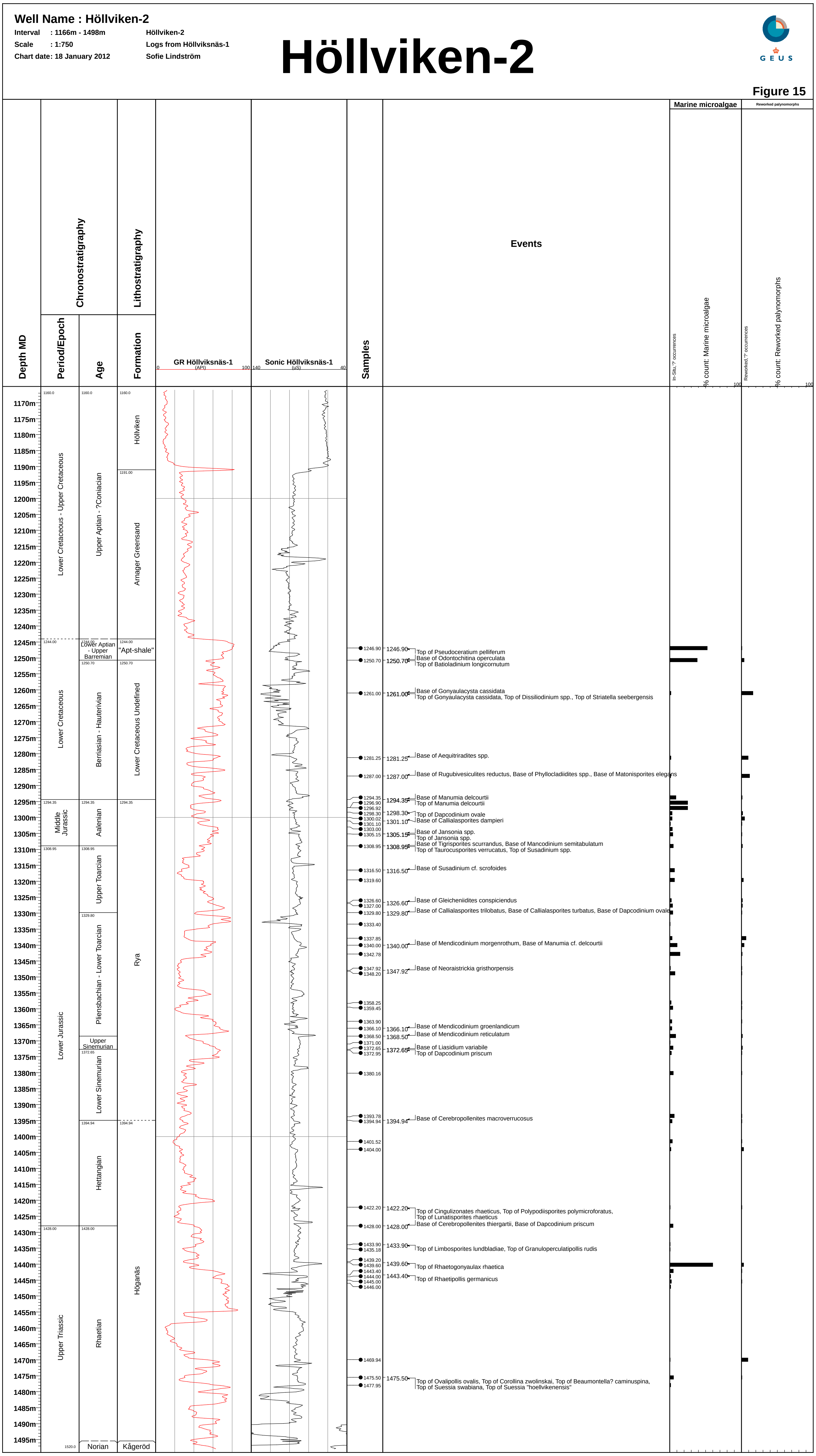
Chart date: 19 January 2012 **Sofie Lindström**

FFC-1

GEUS

Figure 14





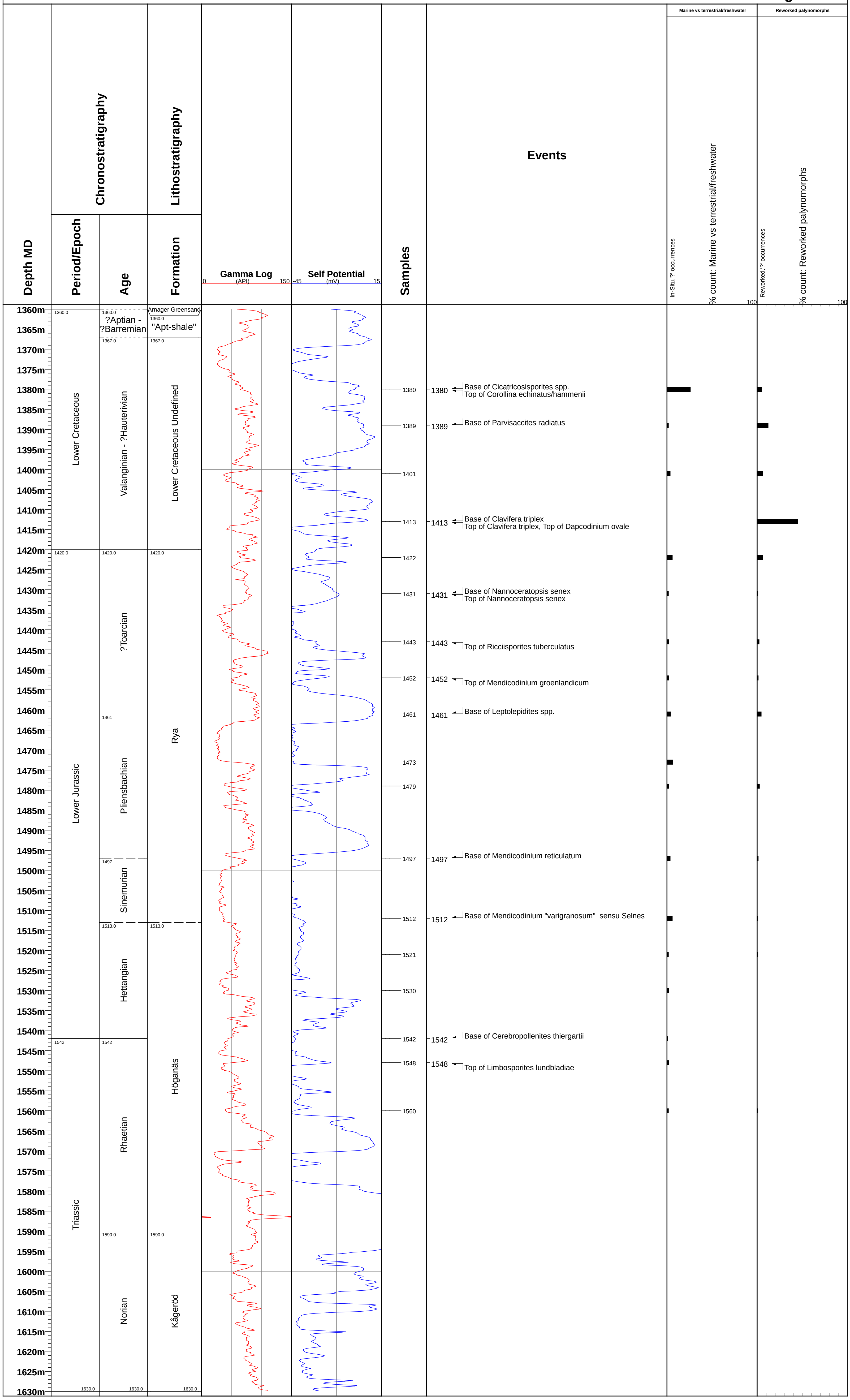
Well Name : Höllviken-2
Interval : 1166m - 1498m
Scale : 1:750
Chart date: 18 January 2012
Höllviken-2
Logs from Höllviksnäs-1
Sofie Lindström
Höllviken-2
GEUS
Figure 15
Marine microalgae
Reworked palynomorphs
Depth MD
Chronostratigraphy
Period/Epoch
Age
Lithostratigraphy
Formation
GR Höllviksnäs-1
(API)
Sonic Höllviksnäs-1
(uS)
Samples
Events
In-Situ,"?" occurrences
% count: Marine microalgae
Reworked,"?" occurrences
% count: Reworked palynomorphs
Lower Cretaceous - Upper Cretaceous
Upper Aptian - ?Coniacian
Höllviken
Arnager Greensand
Lower Aptian - Upper Barremian
"Apt-shale"
Lower Cretaceous
Berriasian - Hauterivian
Lower Cretaceous Undefined
Middle Jurassic
Aalenian
Rya
Lower Jurassic
Upper Toarcian
Pliensbachian - Lower Toarcian
Upper Sinemurian
Lower Sinemurian
Hettangian
Upper Triassic
Rhaetian
Höganäs
Norian
Kågeröd
1246.90 Top of Pseudoceratium pelliferum
1250.70 Base of Odontochitina operculata
Top of Batioladinium longicornutum
1261.00 Base of Gonyaulacysta cassidata
Top of Gonyaulacysta cassidata, Top of Dissiliodinium spp., Top of Striatella seebergensis
1281.25 Base of Aequitriradites spp.
1287.00 Base of Rugubivesiculites reductus, Base of Phyllocladiidites spp., Base of Matonisporites elegans
1294.35 Base of Manumia delcourtii
Top of Manumia delcourtii
1298.30 Top of Dapcodinium ovale
1301.10 Base of Callialasporites dampieri
1305.15 Base of Jansonia spp.
Top of Jansonia spp.
1308.95 Base of Tigrisporites scurrandus, Base of Mancodinium semitabulatum
Top of Taurocusporites verrucatus, Top of Susadinium spp.
1316.50 Base of Susadinium cf. scrofoides
1326.60 Base of Gleicheniidites conspiciendus
1329.80 Base of Callialasporites trilobatus, Base of Callialasporites turbatus, Base of Dapcodinium ovale
1340.00 Base of Mendicodinium morgenrothum, Base of Manumia cf. delcourtii
1347.92 Base of Neoraistrickia gristhorpensis
1366.10 Base of Mendicodinium groenlandicum
1368.50 Base of Mendicodinium reticulatum
1372.65 Base of Liasidium variabile
Top of Dapcodinium priscum
1394.94 Base of Cerebropollenites macroverrucosus
1422.20 Top of Cingulizonates rhaeticus, Top of Polypodiisporites polymicroforatus,
Top of Lunatisporites rhaeticus
1428.00 Base of Cerebropollenites thiergartii, Base of Dapcodinium priscum
1433.90 Top of Limbosporites lundbladiae, Top of Granuloperculatipollis rudis
1439.60 Top of Rhaetogonyaulax rhaetica
1443.40 Top of Rhaetipollis germanicus
1475.50 Top of Ovalipollis ovalis, Top of Corollina zwolinskai, Top of Beaumontella? caminuspina,
Top of Suessia swabiana, Top of Suessia "hoellvikenensis"

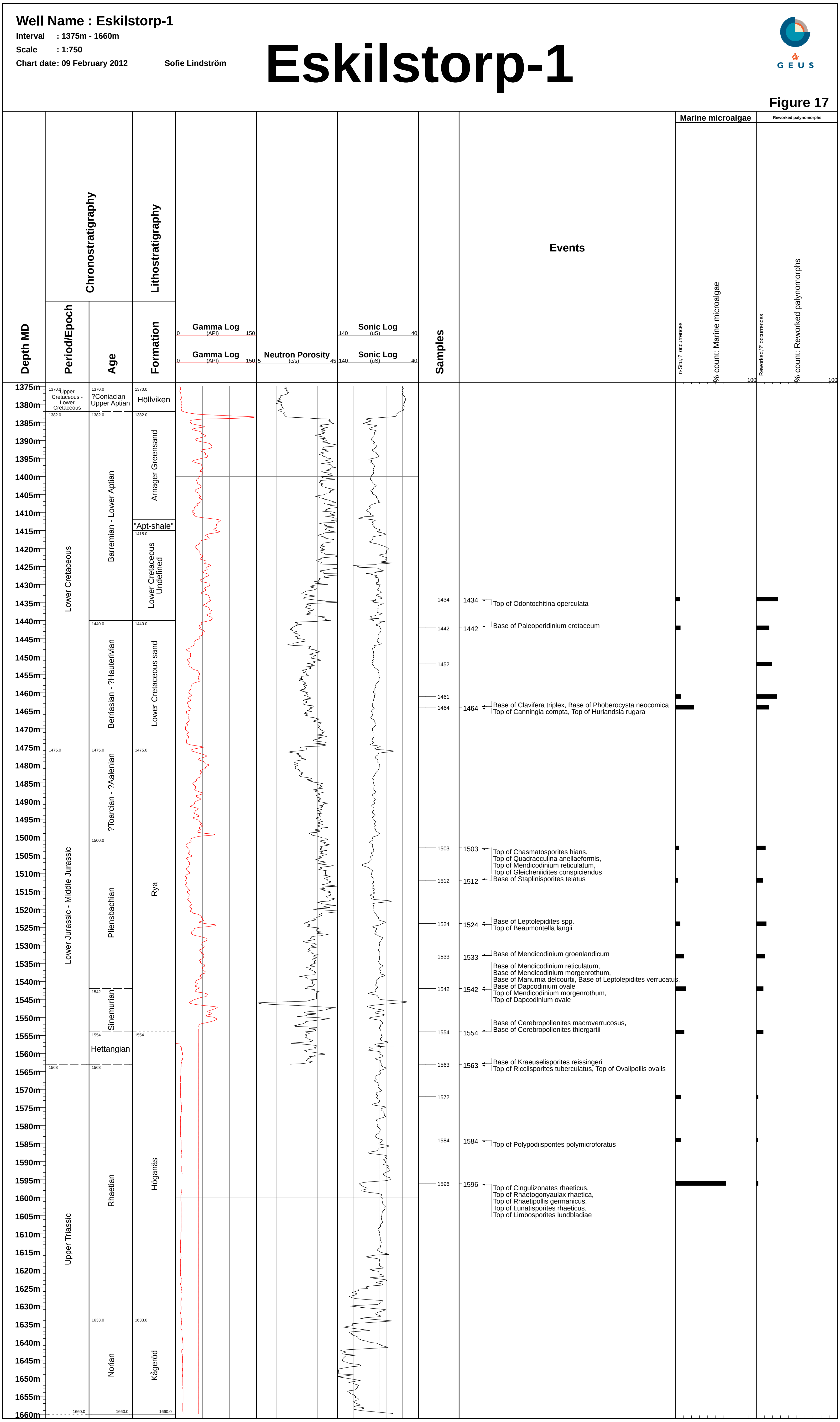
Well Name : Håslöv-1
Interval : 1360m - 1630m
Scale : 1:750
Chart date: 19 January 2012 **Sofie Lindström**

Håslöv-1

GEUS

Figure 16





Well Name : Eskilstorp-1
Interval : 1375m - 1660m
Scale : 1:750
Chart date: 09 February 2012
Sofie Lindström
Eskilstorp-1
GEUS
Figure 17
Depth MD
Chronostratigraphy
Period/Epoch
Age
Lithostratigraphy
Formation
Gamma Log (API) 0 150
Neutron Porosity (c/s) 5 45
Sonic Log (uS) 140 40
Samples
Events
Marine microalgae
Reworked palynomorphs
In-Situ,'?' occurrences
% count: Marine microalgae
Reworked,'?' occurrences
% count: Reworked palynomorphs
Upper Cretaceous - Lower Cretaceous
Lower Cretaceous
Lower Jurassic - Middle Jurassic
Upper Triassic
?Coniacian - Upper Aptian
Barremian - Lower Aptian
Berriasian - ?Hauterivian
?Toarcian - ?Aalenian
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
Höllviken
Arnager Greensand
"Apt-shale"
Lower Cretaceous Undefined
Lower Cretaceous sand
Rya
Höganäs
Kågeröd
1434 Top of Odontochitina operculata
1442 Base of Paleoperidinium cretaceum
1452
1461
1464 Base of Clavifera triplex, Base of Phoberocysta neocomica
Top of Canningia compta, Top of Hurlandsia rugara
1503 Top of Chasmatosporites hians,
Top of Quadraeculina anellaeformis,
Top of Mendicodinium reticulatum,
Top of Gleicheniidites conspiciendus
1512 Base of Staplinisporites telatus
1524 Base of Leptolepidites spp.
Top of Beaumontella langii
1533 Base of Mendicodinium groenlandicum
Base of Mendicodinium reticulatum,
Base of Mendicodinium morgenrothum,
Base of Manumia delcourtii, Base of Leptolepidites verrucatus,
1542 Base of Dapcodinium ovale
Top of Mendicodinium morgenrothum,
Top of Dapcodinium ovale
Base of Cerebropollenites macroverrucosus,
1554 Base of Cerebropollenites thiergartii
1563 Base of Kraeuselisporites reissingeri
Top of Ricciisporites tuberculatus, Top of Ovalipollis ovalis
1572
1584 Top of Polypodiisporites polymicroforatus
1596 Top of Cingulizonates rhaeticus,
Top of Rhaetogonyaulax rhaetica,
Top of Rhaetipollis germanicus,
Top of Lunatisporites rhaeticus,
Top of Limbosporites lundbladiae

Well Name : Svedala-1

Interval : 1439m - 1613m

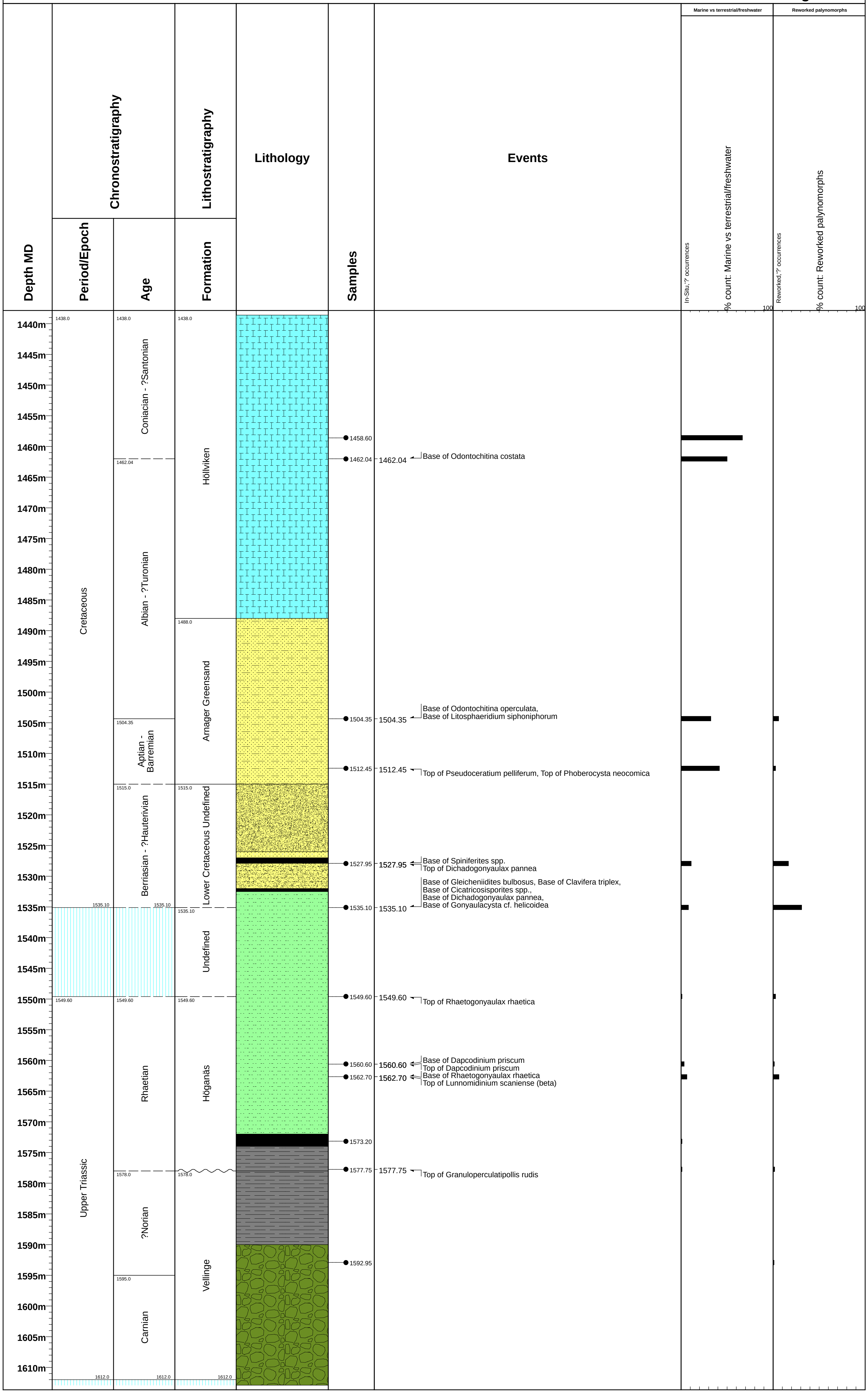
Scale : 1:500

Chart date: 18 January 2012 Sofie Lindström

Svedala-1

GEUS

Figure 18



Well Name : Margreteholm-1/1A

Interval : 1560m - 2100m

Scale : 1:1200

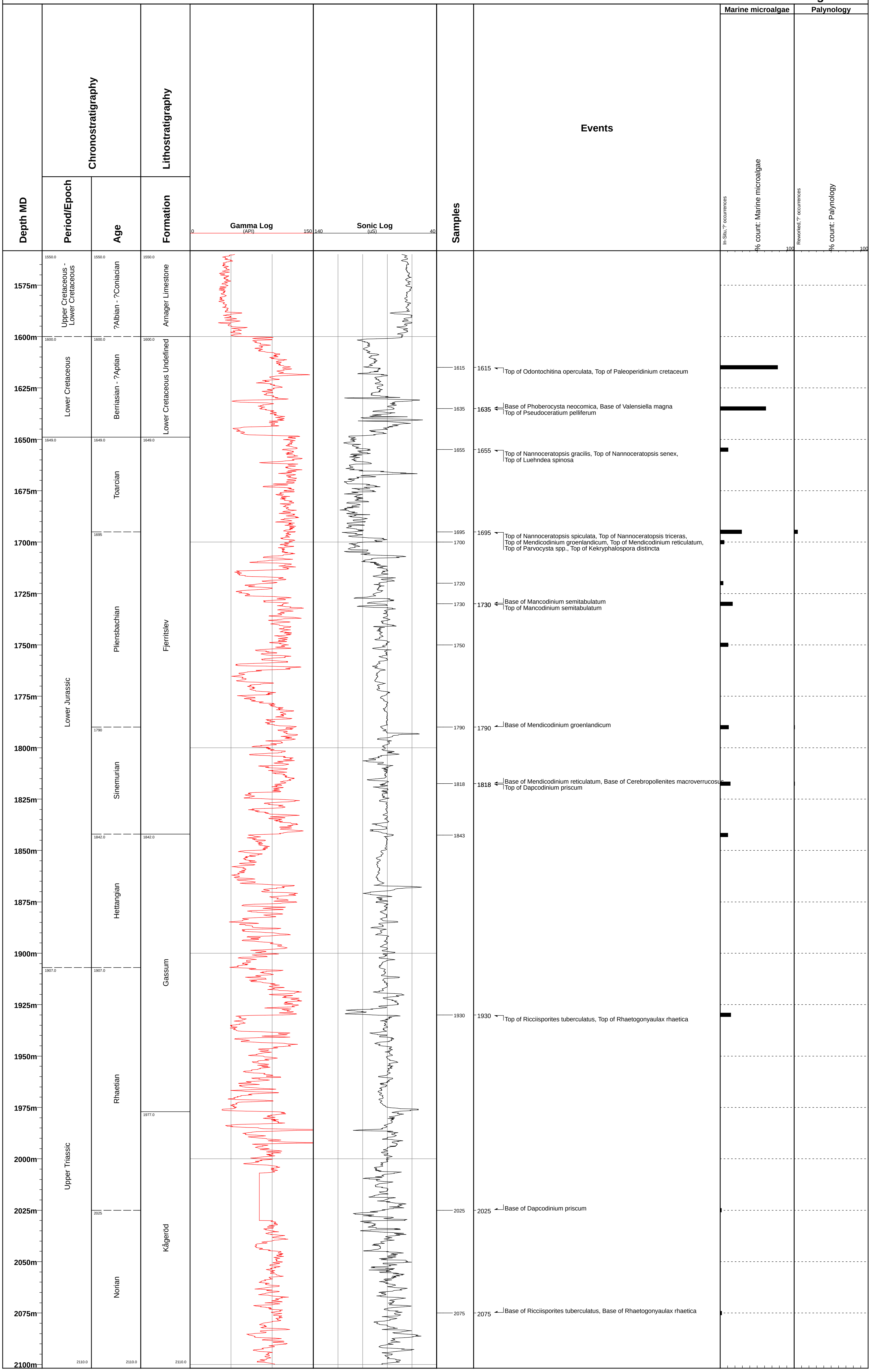
Chart date: 19 January 2012

Sofie Lindström

Margreteholm-1/1A

GEUS

Figure 19



Well Name : Karlebo-1/1A

Interval : 1834m - 2293m

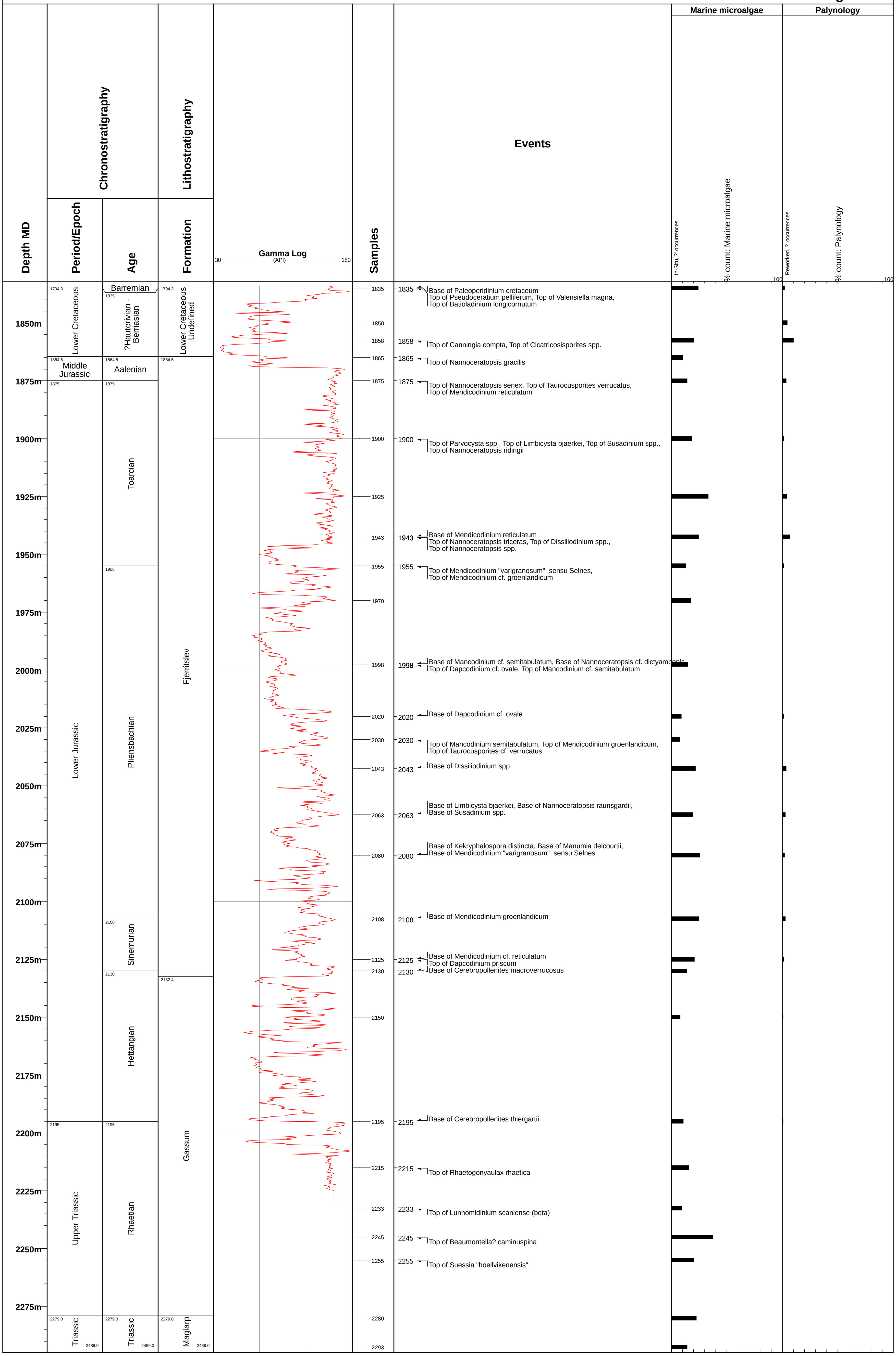
Scale : 1:1200

Chart date: 19 January 2012 Sofie Lindström

Karlebo-1/1A

GEUS

Figure 20



Well Name : Köpingsberg-3

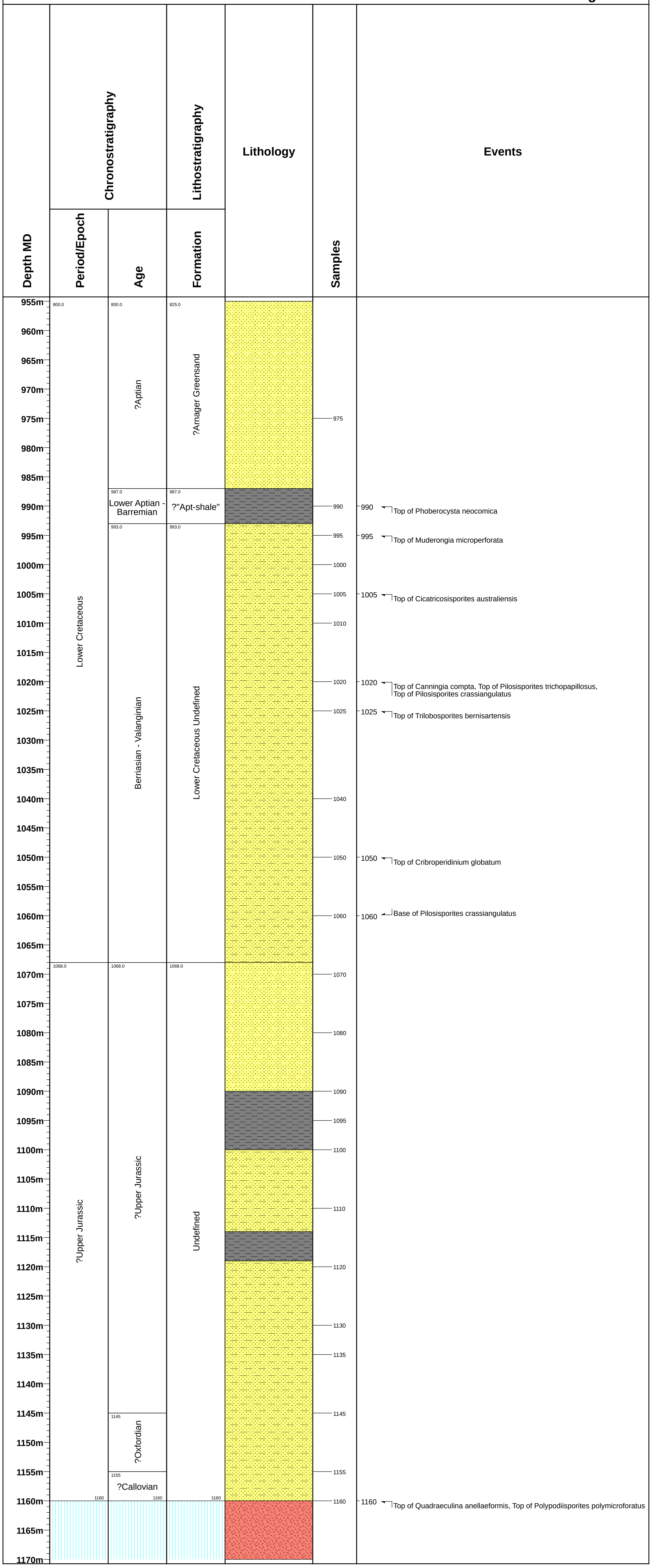
Interval : 955m - 1170m

Scale : 1:500

Chart date: 19 January 2012 Sofie Lindström

GEUS

Figure 21



Well Name : Mossheddinge-1

Interval : 1628m - 1815m

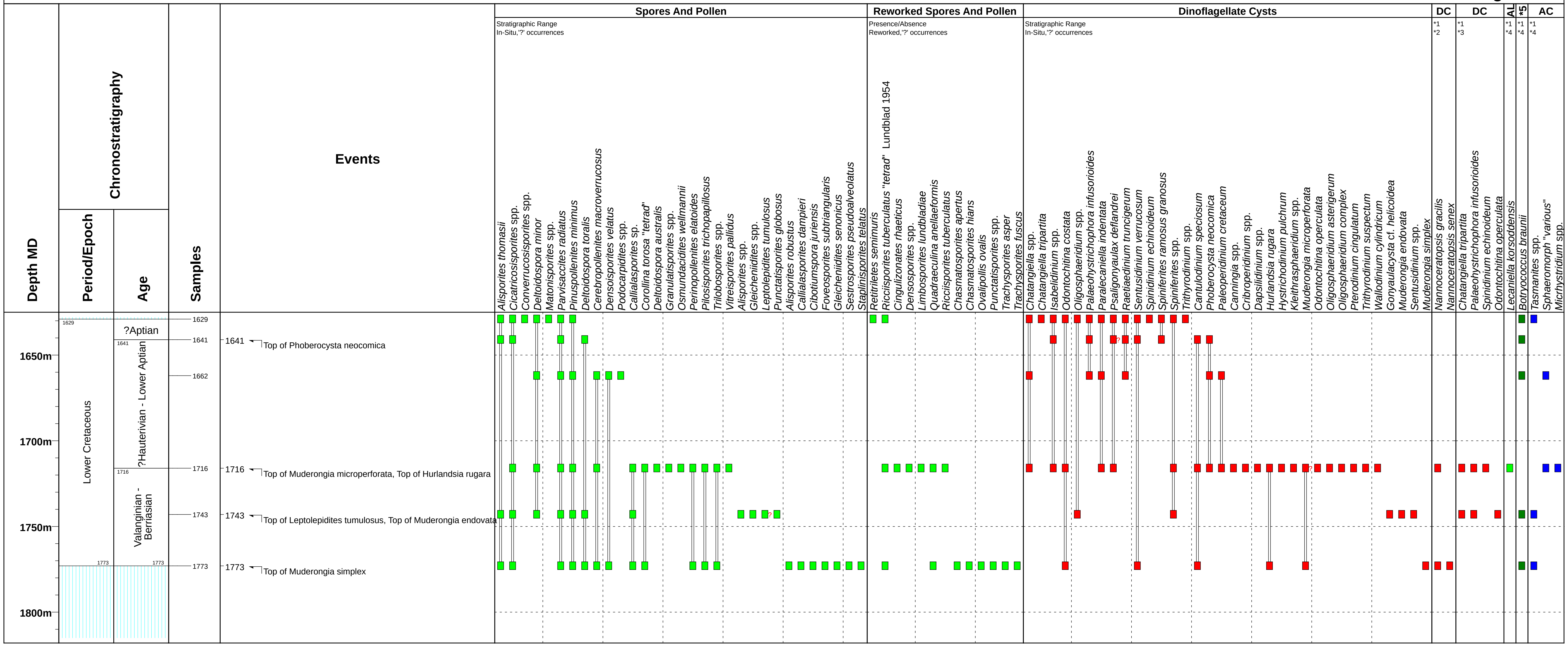
Scale : 1:2000

Chart date: 19 January 2012 **Sofie Lindström**

Mossheddinge-1

GEUS

Figure 22



Well Name : BH94

Interval : 54.00m - 128.00m

Scale : 1:500

Chart date: 19 January 2012 **Sofie Lindström**

BH94

G E U S

Figure 23