Sedimentological study of the Jurassic and Cretaceous sequence in the Revinge-1 core, Scania

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Cover Picture: A fossil bony fish from the Revinge-1 drill core. Depth: 252 m. Photo: Casandra Hajny

Abstract

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Hajny, C., 2016: Sedimentological study of the Jurassic and Cretaceous sequence in the Revinge-1 core, Scania. *Dissertations in Geology at Lund University*, No. 465, 51 pp. 45 hp (45 ECTS credits).

Abstract: This thesis presents a study of the core from the Revinge-1 borehole from the Vomb Trough. The core displays strata from the Upper Jurassic to the Upper Cretaceous including strata covering the the J/K−boundary . Sedimentological, biostratigraphical and lithological studies (such as SEM-EDX) were performed as to get a multi-disciplinary characterization of the strata. The core have been divided in eight different units, A−H. The basal part of the core includes strata belonging to the Upper Jurassic Fyledal Clay overlain by the Upper Jurassic−Lower Cretaceous Vitabäck Clays of the Annero Formation followed by the Arnager Greensand and the Upper Cretaceous Vomb Formation. The Jurassic and Lower Cretaceous succession is overall dominated by fine-grained siliciclastic deposits such as clays/claystone, siltstone and fine-grained sandstone. The Upper Cretaceous is still siliciclastic but significantly calcareous and in parts characterized as an arenaceous limestone. The Arnager Greensand is a sandy unit rich in glauconite and numerous burrows and has likely been deposited in a shallow marine environment. Biostratigraphical data also suggests a Cenomanian age of the Arnager Greensand. Black and dark grey clays of the Vitabäck Clay does furthermore commonly include a rich and well-preserved fossil fauna of thin-shelled bivalves and bone fish fossils indicating a low energy-environment in a brackish-marine setting. The core furthermore displays an iron ooid-rich interval which is interpreted to be related to a volcanic influence during the Early Cretaceous, i.e. c. 145 Ma in Scania. Palynological data of the unit indicates a Volgian to mid Berriasian age. The basal Fyledal Clay is a yellowish grey clay rich in rootlets, pieces of coal and includes fossil imprints. It was likely deposited in a quiet water environment with lagoons and wet marshes.

Keywords: Jurassic, Cretaceous, Vomb Trough, Fyledalen, Vitabäck Clay, Fyledal Clay, Arnager Greensand, Molluscs, Bivalves, Palynology, Biostratigraphy, Volcanism, Pyrite, Iron ooids

Supervisor(s): Mikael Erlström & Leif Johansson

Subject: Bedrock Geology

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Svensk sammanfattning

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Hajny, C., 2016: Sedimentologisk studie av den jurassiska och kretaceiska sekvensen i Revinge-1, Skåne. *Examensarbeten i geologi vid Lunds universitet*, Nr. 465, 51 sid. 45 hp.

Sammanfattning: Denna uppsatsen presenterar en studie av Revinge-1 kärnan borrad i Vombtråget. Borrkärnan uppvisar en sedimentär berggrundssekvens från övre jura till övre krita inkluderande jura/krita-gränsen. Sedimentologiska, biostratigrafiska och litologiska studier (så som SEM-EDX) utfördes för att uppnå en multidisciplinär karaktärisering av sedimenten. Borrkärnan kunde delas upp i åtta olika enheter, A–H. Basen av kärnan innehåller sediment tillhörande Fyledalsleran från övre jura överlagrad den överjurassiska och underkretaceiska Vitabäcksleran från Anneroformationen som överlagras av Arnagergrönsand och Vombformationen från övre krita. Den jurassiska och kretaceiska lagerföljden är i allmänhet dominerad av finkorniga siliciklastiska avlagringar så som lersten, siltsten och sandsten. Sekvensen från övre krita är fortfarande siliciklastisk men i vissa delar mer karbonathaltig och sandig. Arnagergrönsanden, rik på glaukonit, innehåller även riktligt med grävspår och har troligen avlagrats i en grund marin miljö. Biostratigrafiska undersökningar tyder på en cenomansk ålder. Vitabäcksleran innehåller svart och grå lera och även ett intervall med välbevarade fossil så som benfiskar och tunnskaliga mollusker som tyder på en avlagringsmiljö med låg energi. Borrkärnan innehåller därpå även ett järnrikt intervall med ooider. Intervallet tros ha påverkats av vulkanism i Skåne under äldre krita, mer exakt för c. 145 Ma år sedan.. Avlagringsmiljön har troligen varit en strandnära miljö där en kemisk utfällning i ett Fe, Al och Si-berikat vatten. Reaktionen har skett på tillgängliga mineralkorn på sandbottnen och initierats av hydrotermala fluider, vulkanisk aska eller hastig vittring av vulkanisk sten. Palynologiska undersökningar tyder på en tidig kretaceisk ålder, c. 150–145 Ma. Fyledalsleran i botten karaktäriseras av gul-grå lera med rotbottnar, kolbitar och avtryck av musslor. Leran har troligen avlagrats i en stilla sumpmarksmiljö med strandsjöar.

Nyckelord: Jura, Krita, Vomb, Fyledalen, Vitabäck, Arnagergrönsand, Mollusker, Bivalver, Palynologi, Biostratigrafi, Vulkanism, Pyrit, Järnooider

Handledare: Mikael Erlström & Leif Johansson

Ämne: Bedrock Geology

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1 Introduction

The Jurassic–Cretaceous boundary strata are poorly constrained in Scania. This is partly because the sequence includes deposits formed in marginal marine to coastal and lacustrine setting with few stratigraphical markers. Biostratigraphical investigations have not been conclusive enough to enable precise definition of the boundary. This is largely caused by the lack of cores from the actual interval and that the interval subcrop younger strata at various depths. A sequence at Vitabäck and a core from Fårarp-1, in the Vomb Trough, are so far the best described Jurassic–Cretaceous boundary strata in Scania (Erlström et al. 1991; Lindström & Erlström 2011).

The 279.8 m deep core drilled at Revinge in 2012, includes a sequence of similar strata as the one in Fårarp-1. The most conspicuous and most interesting feature is that the core includes an interval with iron ooids and siderite, likely related to influences from volcanism, which would further verify the volcanic event at ca. 145 Ma (Bergelin et al. 2011). The core furthermore displays intervals with a rich fauna of macrofossils (molluscs and bony fishes), which together with the lithofacies give a unique possibility to describe and evaluate the depositional setting. The absence of good sections and borings representing the interval, makes the Revinge core an unique succession as to further assess the evolution of the Jurassic—Cretaceous boundary strata in Scania.

The Revinge-1 drilling is located in the northern part of the Vomb Trough, adjacent to the village of Revinge. This study includes, besides a review of previous performed studies on the Jurassic–Cretaceous boundary strata and a description of the geological setting, also sedimentological, lithological and palaeontological investigations. The study aims to give a sedimentological and petrological description of the core and to present an interpretation of the sedimentary succession in relation to known Jurassic–Cretaceous boundary strata in Scania, with preference to information from the Fårarp-1 and Vitabäck successions. Emphasis is also put on attempting to evaluate the composition and petrology of the iron-rich ooid interval in the lower part of the core.

2 Geological setting

The Jurassic–Cretaceous boundary strata are well defined in England, Germany and France. Here the boundary is evidenced by sediments verifying a climate change from semi-arid (Tithonian) to semi-humid climate conditions (Allen 1998), exhibited in the Cinder Beds in association with a maximum flooding surface (Schnyder et al. 2006).

The most fundamental change occurred during the Berriasian (Early Cretaceous) when weathering increased and winds switched from east-dominated during winter and west-dominated during summer, to predominantly westerlies (Allen 1998). This climatic shift took place during deposition of the *Heteroceras kochi* Boreal Ammonite Zone, at which time also a long-term sea-level fall has been registered (Sneider et al. 1995, Lindström & Erlström 2011). This evident in the Purbeckian type section at Durlston Bay (UK) where the lower Berriasian beds of limestone and mudstone contains numerous evaporitic beds (Riboulleau et al. 2007).

During the Tithonian–Berriasian, Scania, in the southernmost of Sweden, was situated on the margin of an epicontinental sea connected to the Tethys Ocean. Marine conditions dominated throughout this time and marginal marine deposits formed on the margin of the Fennoscandian Shield including Scania (Poulsen & Riding 2003).

The southwesten part of Sweden includes a complex block-faulted zone involving the Precambrian basement and Early Palaeozoic, Mesozoic and Palaeogene sediments, i.e. the Fennoscandian Border Zone (Norling & Bergström 1987). The zone covering most of the Kattegat, Scania and Bornholm constitutes the southwestern part of the weakened Fennoscandian Shield bordering younger geological provinces to the south.

During the Early Palaeozoic, Scania was situated on a shelf, facing the rising orogen of the Scandinavian and North Sea-Polish Caledonides (Norling & Bergström 1987). During Late Silurian times, Scania was tilted to the south, an event accompanied by faulting (Norling & Bergström 1987). Permo–Carboniferous wrench-faulting led to uplift of basement blocks and truncation of the Lower Palaeozoic series. The wrench deformations associated with the development of the Oslo Graben (Ziegler 1982) induced the intrusion of an extensive dolerite swarm in Scania and by the Early Permian Scania was covered by sheet flows and volcanic cones. During this period the well-known Permian peneplain was formed in Germany and in the North Sea. Data show that Scania was affected by tensional tectonics during the Triassic to the Cretaceous (Norling & Bergström 1987).

Palynological datings (Tralau 1973) and K–Ar radiometric datings of basalts (Klingspor 1976) indicate Aalenian–Bajocian ages of part of the volcanism. The K–Ar radiometric datings also indicate volcanic activity during Middle−Late Jurassic, Early Cretaceous and in the early Late Cretaceous (Klingspor

1973, Bergelin et al. 2011). Bergelin et al. (2011) has furthermore presented datings of Scanian basalts that give three episodes of volcanism, i.e. 178–191 Ma, 145 Ma and one at 110 Ma coinciding with the datings by Klingspor (1973).

This complex tectonic history affecting the bedrock province of Scania has resulted in a mosaic of Precambrian basement rocks and sedimentary strata. The stratigraphic representation of strata is heterogeneous in the strongly faulted bedrock terrain. Scania has endured several events, which have resulted in periods characterized either by extension, compression or wrench tectonics. The coupled deposition was besides regional sea-level changes strongly affected by fault movements, resulting in localized subsidence and uplift. This has consequently resulted in a varying representation of strata. The Tornquist Zone transecting the southwest margin of the Fennoscandian Shield and bordering the Danish Basins extends from the North Sea to the Black Sea with a length of more than 2000 km (Pharaoh 1999; Fig. 1 herein). The major branch and the most important structure is the Sorgenfrei-Tornquist Zone (STZ), which has been active since the Palaeozoic (Erlström et al. 1997; Smirnov & Pedersen 2009). The STZ experienced compression and wrench tectonics during the Late Cretaceous which resulted in a general uplift as well as localized subsidence and development of local half grabens such as the Vomb Trough in southeast Scania (Fig. 1).

Mesozoic basins and structures in adjacent areas to the Vomb Trough are the Kristianstad Basin in northeast Scania, the marginal parts of the Danish Basin to the southwest, the Fyledalen Fault Zone and the Romeleåsen Ridge crossing NW−SE of Scania, the Hanö Bay Basin to the east of Scania and the Christiansö Fault north of Bornholm.

The Kristianstad Basin formed during the Early Cretaceous in relation to movements in the Tornquist Zone. The Christiansö Fault forms the southern border of the Hanö Bay Basin, which constitutes the marine part of the Kristianstad Basin (Norling 1981; Erlström et al. 2004). The sediments studied in these areas rep-

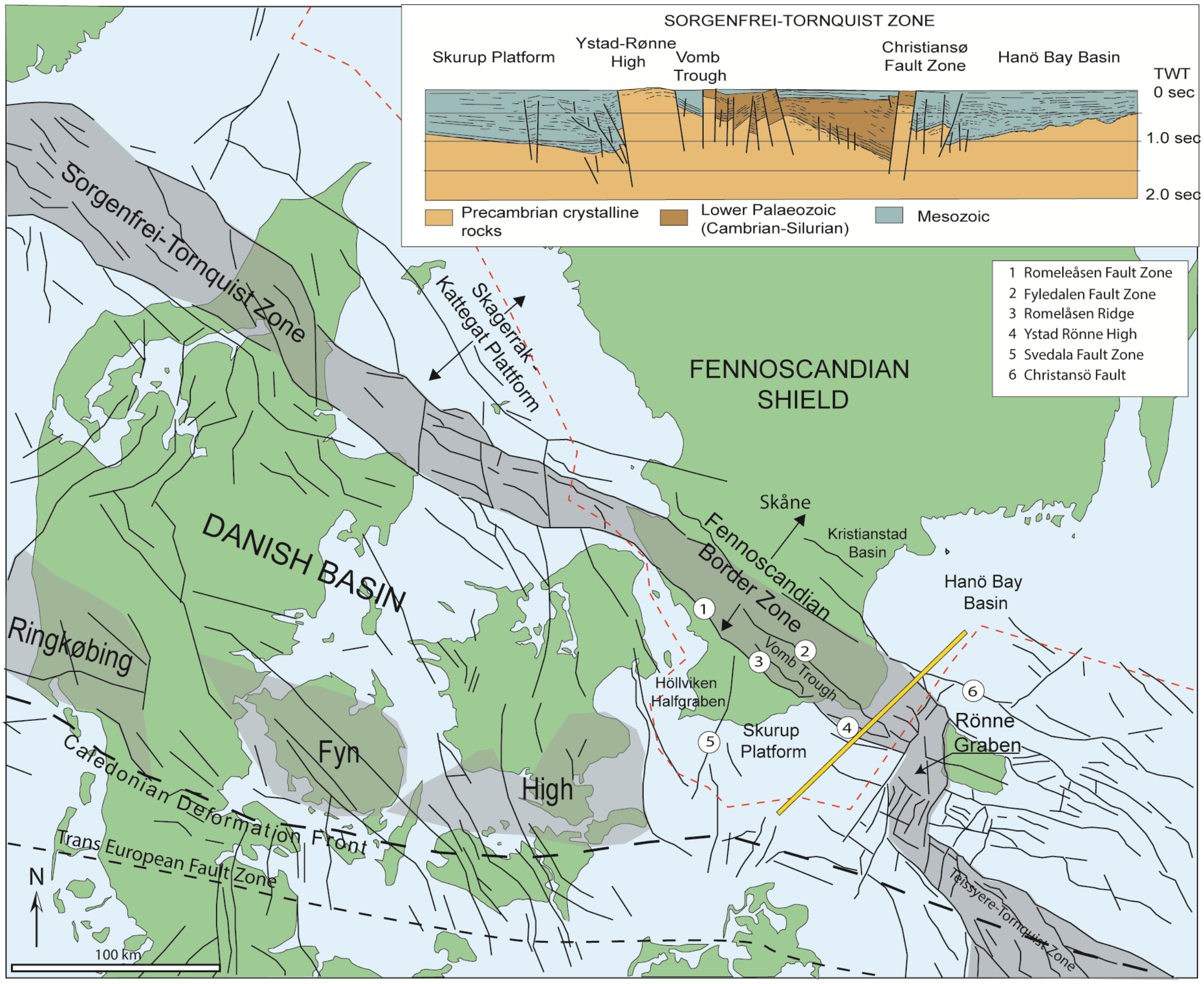

Fig. 1. Map showing the Fennoscandian Shield, the Danish Basin and the Sorgenfrei-Tornquist Zone. The location of the Vomb Trough and adjacent structures are also marked. Framed area is enlarged in Fig. 3. Modified from Erlström in Calner et al. (2013).

resent up to four transgressive sequences since the Early Cretaceous (Erlström et al. 2004).

Fyledalen is located on the northeastern margin of the Vomb Trough (Fig. 1) and exhibits similar strata to those in the Vomb Trough. The sediments are tilted or overturned due to faulting (Erlström et al. 1994). The Fyledalen Fault Zone displays strata from the upper Silurian to the Lower Cretaceous, including the upper Silurian Colonus Shale, the Lower Jurassic Röddinge Formation and the Mariedal Formation containing the Fuglunda and Glass Sand members from the Middle Jurassic. The Upper Jurassic and Lower Cretaceous are represented by the Annero Formation with the Fyledal Clay, Nytorp Sand and the Vitabäck Clays. The Vomb Formation representing Lower Cretaceous−Upper Cretaceous is stratified upon the Fyledalen Fault Zone in the southwest (Erlström et al. 2004) (Fig. 2).

The sedimentary succession on the Skurup Platform is very similar to that in the Vomb Trough, at least with respect to the pre-Cenomanian succession, i.e. up to the Arnager Greensand. Above this level the strata on the Skurup Platform is represented by the Turonian–Danian Höllviken Formation including the Arnager Limestone, Granvik, Lund, Kruseberg-, Hansa- and Kyrkheddinge members and finally the Köpenhamn and Limhamn members (Erlström et al. 2004).

The Mesozoic of Scania includes is incomplete and contains several gaps in the succession (Fig. 2). The deposits show, however, evidence of a wide range of depositional environments. The Lower and Middle Triassic are dominated by Carnian–Norian redbeds. In the Rhaetian there was a dramatic a change into more humid conditions which affected the overall characteristics of the deposits, which include coal beds and plant fossils. During Rhaetian to Hettangian times the depositional setting was dominated by deltaic environments interrupted by several marine transgressions and increased tectonic activity, particularly during the Early Jurassic (Norling & Bergström 1987; Erlström et al. 2004) . The presence of siderite iron ores associated to the Fyledal Fault system indicates hydrothermal processes during Early Jurassic faulting (Norling & Bergström 1987). Similar siderite deposits have also been found in the Late Triassic–Early Jurassic Höganäs Formation (Fig. 2) of the Helsingborg area (Ahlberg 1994), and now also in the Revinge-1 core.

During the Early Jurassic, the area of the present Fyledalen was dominated by near-shore environments and coastal lakes (Röddinge Formation) and deltaic environments (Mariedal Formation). The Röddinge Formation of Sinemurian to Aalenian age contains green, grey and red, weathered fine-grained sandstones (Erlström et al. 2004). The Mariedal Formation is divided into the Fuglunda Member and the Glass Sand. The Fuglunda Member is made up of cycles of grey-black, heterolithic, kaolinitic clay followed by fine-grained bioturbated sand (Erlström et al. 2004). On top is a siltstone containing roots and coal seams. These layers are typical for a deltaic setting. The same setting is also given for the succeeding Glass Sand (Erlström et al. 2004).

Limnic-deltaic to nearshore, coal bearing clays and sand accumulated in narrow troughs of Scania during the Middle Jurassic. These troughs extended from the Polish Trough to the North Sea Basin (Ziegler 1982). The Middle Jurassic in Scania was largely subject to non-marine conditions (Norling 1981), but later, during the Bathonian, the sea invaded parts of Scania. This marine interval was again replaced by brackish conditions during the Oxfordian until the Late Jurassic. The Nytorp Sand and Vitabäck Clays indicate rapid changes between brackish, limnic and marine conditions during this time interval (Norling 1981). Other parts of Scania were during this period subject to erosion.

At the end of the Middle Jurassic new marine transgressions affected Scania. In the Vomb Trough, the Late Jurassic sea transgressed over the Middle Jurassic Glass Sand.

The main Upper Jurassic lithostratigraphic units, for example the Fyledal Clay, the Nytorp Sand and the Vitabäck Clays are regionally distributed units recognized in the Vomb Trough and in parts of western Scania (Norling & Bergström 1987) (Fig. 2). In the Assmåsa-1 borehole, located in the Vomb Trough, the base of the Fyledal Clay is represented by sandy layers resting on the basement (Norling 1981). The Fyledal Clay reaches a thickness of 140 m in its type area at Eriksdal in the Vomb Trough (Christensen 1968).

The stratigraphy of the strata underlying the Upper Jurassic is variable in Scania. In the Ängelholm Trough, the Fyledal Clay rests on Middle Jurassic strata (Vilhelmsfält Formation) or on Pliensbachian rocks (Norling 1981), while in the Vomb Trough the Fyledal Clay succeeds Bathonian strata (Glass Sand;Tralau 1968; Norling 1981; Fig. 2 herein). At Eriksdal in Fyledalen, almost all units from the Jurassic are represented (Erlström et al. 2004), including the units mentioned above. The uppermost Jurassic (Annero Formation) indicate fluctuating depositional settings between lagoons, lakes and swamps (Fyledal Clay) to sandy beaches (Nytorp Sand) and back to lagoons, lakes and swamps (Vitabäck Clays) (Erlström et al. 2004). The Fyledal Clay is characterized by green, brown, red and sometimes black clay beds with inter

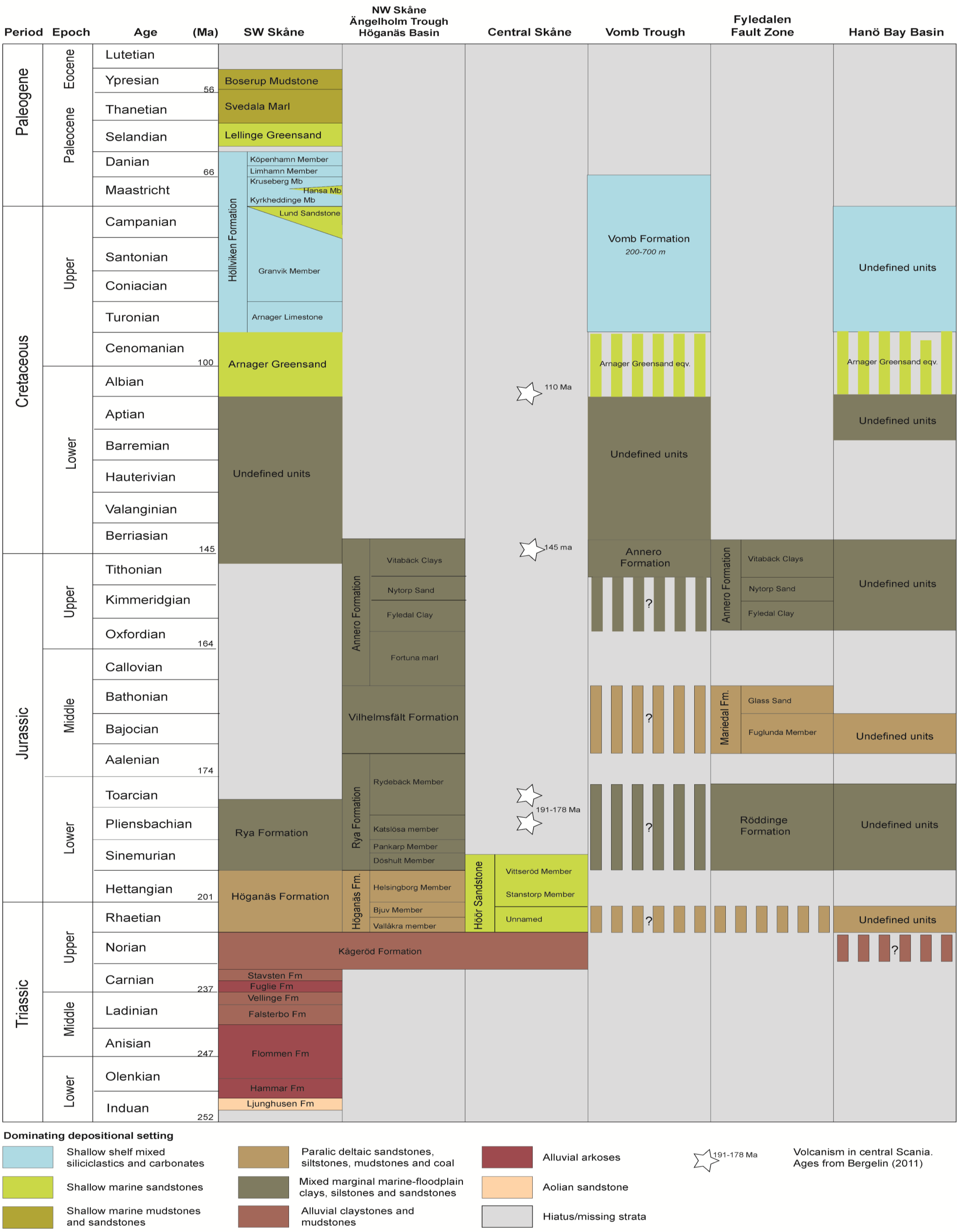

Fig. 2: Stratigraphic Chart showing the Mesozoic and Paleogene stratigraphy in Scania. Both defined and undefined units are shown. The Revinge-1 core covers the undefined parts from Upper Jurassic to Lower Cretaceous in the Vomb Trough as well as the Upper Cretaceous Vomb Formation. (Erlström in prep.).

beds of silty and sandy layers. In its type area, the Vomb Trough, the Fyledal Clay represents the Oxfordian−Kimmeridgian boundary and consists of greenish and brownish claystone with a varying content of silt (Norling 1981). Fossils such as coralline algae and ostracodes have been identified in Eriksdal (Erlström et al. 1991), indicating lacustrine-brackish environments. The Nytorp Sand is white, well-sorted and fine-grained with thin clay layers rich in organic material. The sand indicates environments close to the beach (Erlström et al. 1991).

During the brackish conditions in the Oxfordian (Upper Jurassic), clastic sediments were deposited in troughs trending NW−SE. The brackish sedimentation was reduced during the Kimmeridgian and hereafter the sediments show evidence of alternating brackish and limnic conditions with short-lived marine ingressions that prevailed into the Early Cretaceous.

During the transition from the Jurassic to the Cretaceous, the tectonic activity increased in Scania as well as in Central and Western Europe. The Vitabäck Clays are typical for the transition and comprise clays, limonitic claystone and layers of arenaceous marlstone succeeded by clayey, silty and sandy deposits.

The beds of the Jurassic−Cretaceous transition were mainly deposited during limnic and brackish conditions (Norling 1981). The actual boundary seems to fall within the Vitabäck Clays. A molluscan fauna from a sequence of dark grey, slaty clay overlying brown green claystone and arenaceous marlstone, is interpreted as evidence for a "Purbeckian" or Early Cretaceous age (Hägg 1940; Norling 1981). In addition Christensen (1968) and Ekström (1985) described an ostracode fauna from the Vitabäck Clays also showing evidence of a similar age.

Upper Lower Cretaceous to Cenomanian strata in Scania are represented by Aptian marine shales and Albian−Cenomanian marine glauconitic sandstones which were deposited during a calm period with deposition on a shallow shelf (Norling & Bergström 1987). Glauconitic sand beds in for example Höllviken-2 (Norling 1981), have thicknesses ranging from 30 to 50 m, and display Cenomanian−Albian, Aptian and Barremian ages.

The upper part of the sedimentary succession in the Vomb Trough consists of the 400–700 m thick Upper Cretaceous Vomb Formation. This relatively thick unit is composed of mixed siliciclastic deposits. The strata range in age from Coniacian to Maastrichtian (Chatziemannouil 1982) and include a variable mixture of quartz sand, carbonates and clay, and also a rich marine fossil fauna of bivalves, belemnites and microfossils. The formation constitutes the bedrock surface in most of the Vomb Trough and crops out at several places in the southeasternmost parts of the trough (Erlström & Guy Ohlson 1994).

2.1 The Vomb Trough

The Vomb Trough is a narrow half graben approximately 80 km in length and with a width ranging from 7 km in the northern part to 11 km in the southern part (Erlström et al. 1991). It is divided by the Herrestad High (Fig. 3). The trough, formed during the Late Cretaceous, is bordered by the Romeleåsen Ridge and the Fyledalen Fault Zone, and extends from the lake Vomb to Ystad and further out in the south Baltic Sea towards Bornholm (Fig. 3) (Erlström 2004; Lindström & Erlström 2011). Previous works made in the Vomb Trough and adjacent areas have described the sequences, biostratigraphy, petrography and sedimentary strata mostly representing the Jurassic but also Lower Cretaceous, e.g. Chatziemannouil (1982). Palaeoecological, petrographical and sedimentological studies covering the boundary interval have been made by Guy-Ohlson (1982), Erlström et al. (1984) and Erlström et al. (1991), and a specific study dealing with the Jurassic sequences is that of Guy-Ohlson & Norling (1994).

The Mesozoic succession in the Vomb Trough overlies a Precambrian crystalline basement (Fig. 4). There have so far not been any observations of Paleozoic or Triassic subcrops in the trough. Snaven-1 reaches all the way down to the Precambrian bedrock and include a of 755 m thick Jurassic–Cretaceous sequence (Fig. 3). The Precambrian basement is here overlain by the Fuglunda Member and Glass Sand from Middle Jurassic. The Fyledal Clay, Nytorp Sand and Vitabäck Clay from Upper Jurassic are also present in Snaven-1, together with a thin interval of Lower Cretaceous strata including the Arnager Greensand. The Assmåsa-1 boring penetrated similar strata, however with a slightly less total thickness of 528 m. The 117 m deep Fårarp-boring displays a 100-meter-thick unit of Lower

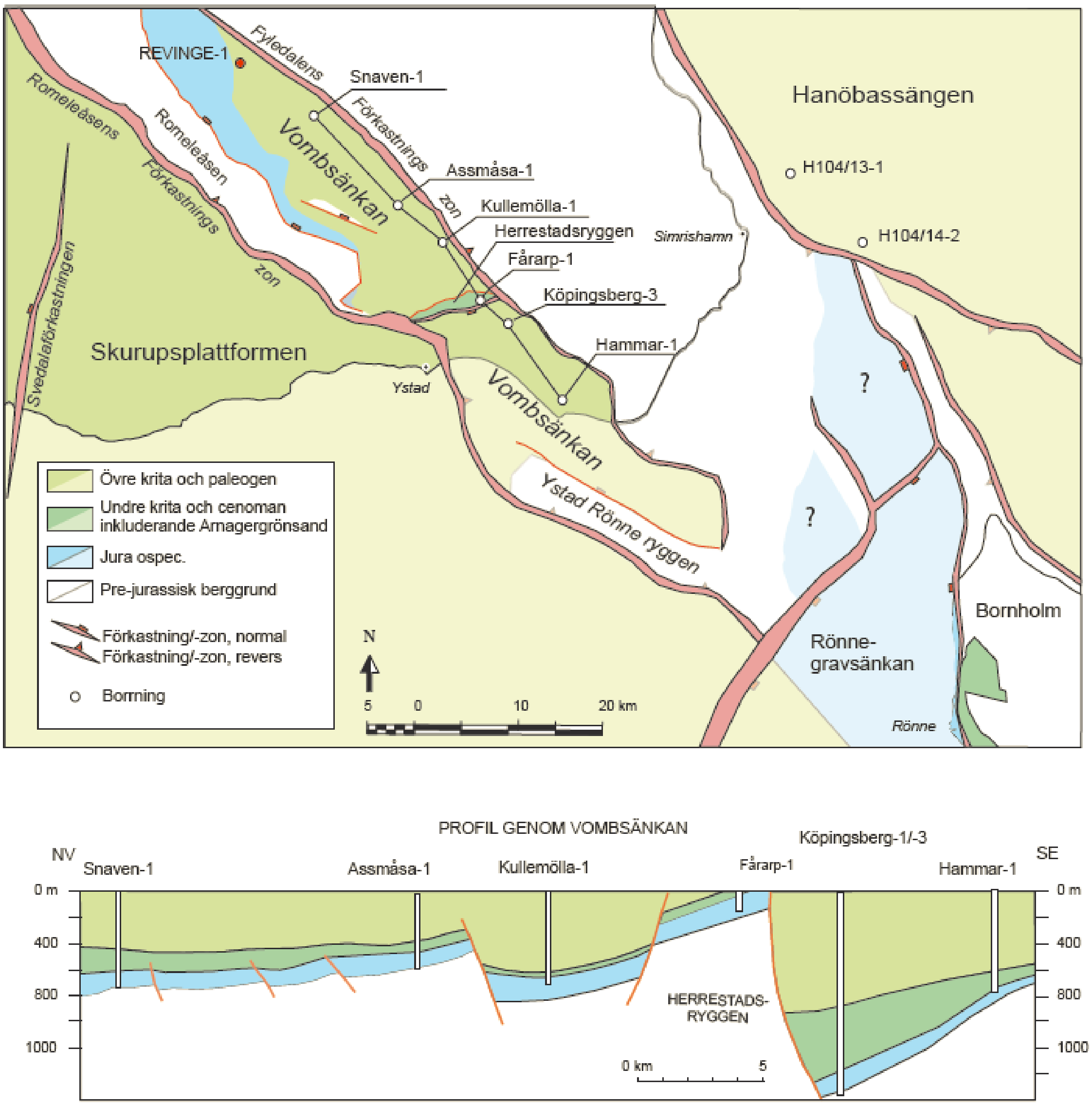

Fig. 3: Figure showing the location of the Vomb Trough and the adjacent Skurup Platform, Romeleåsen Ridge, Fyledalen Fault Zone, Herrestad Uplift and Hanö Bay Basin. The locations of the earlier drillings Snaven-1, Assmåsa-1, Kullemölla-1, Fårarp-1 and Köpingsberg-3 and Hammar-1 are also marked on the map. A profile with the drillings through the Vomb Trough is shown below and displays the complex and faulted geology of the Vomb Trough. Figure from Lindström & Erlström, 2011.

Cretaceous strata including the Arnager Greensand overlying Upper Jurassic strata, including the Vitabäck Clay and Fyledal Clay (Lindström & Erlström 2011). The aim of the Fårarp-1 boring, located on the Herrestad High, was to reach the basement. The Cretaceous–Jurassic layers are on the Herrestad High uplifted, which results in relatively shallower position in comparison to other parts of the Vomb Trough (Erlström et al. 2004). Unfortunately, the drilling had to be abandoned at 117 m depth due to stuck drill pipe in the Fyledal Clay. Seismic data indicate a basement level at c. 250 m.

Köpingsberg-3 (Fig. 3), an exploration well located in the southeast part of the onshore part of the Vomb Trough, includes an 1180 m thick sequence including the Vomb Formation, Lower Cretaceous undefined strata of the Vitabäck Clay and undefined Jurassic strata overlying the Precambrian basement.

All these wells display strata which include the Jurassic−Cretaceous boundary. However, most of the stratigraphical and sedimentological data are based on cuttings. Coring of this interesting interval had until now only been performed in Fårarp-1. The subsurface data set regarding this interval is, thus, poor and any new information from the Revinge-1 core is of great importance in understanding the depositional setting for these strata.

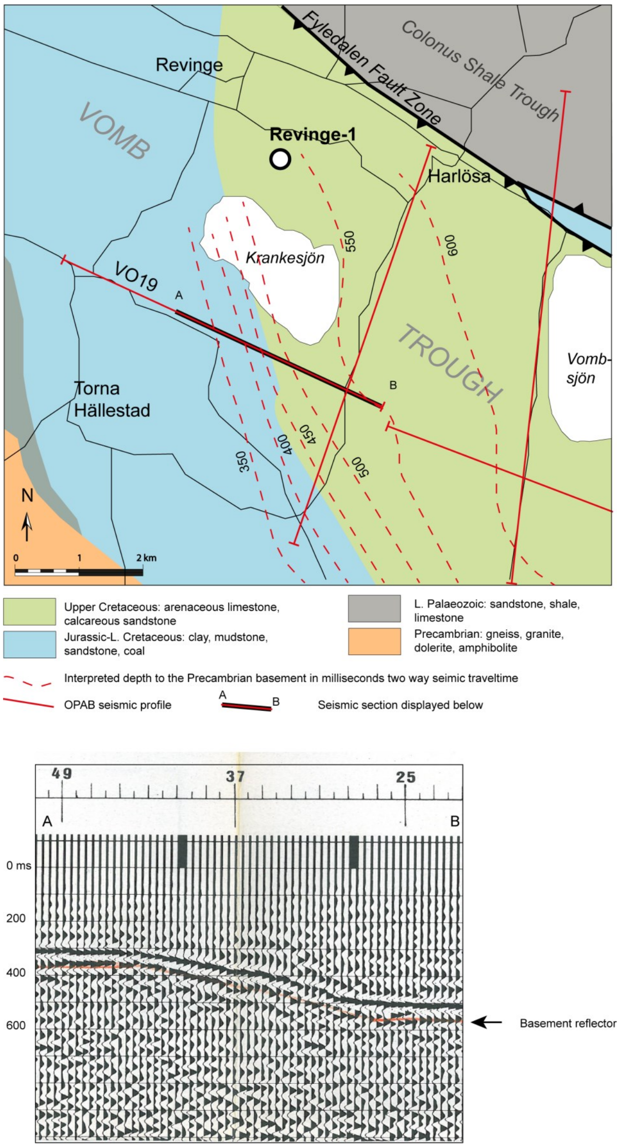

Fig. 4: Seismics of the location of the Revinge-1. The section A−B on the map is displayed in the figure below. The figure displays the Revinge-1 core and also how the core might contain Upper Cretaceous strata and dipping Jurassic strata. The bedrock map is modified from SGU Af 211.

2.2 The Revinge-1 locality

The boring was performed in the northwest part of the Vomb Trough close to the locality of Revinge. There are in the vicinity a few older seismic lines performed 1972 by OPAB. The resolution is relatively poor for the sedimentary bedrock, however, the basement level is seen as a strong reflector between 380 and 480 ms. Taken into consideration that the velocities in the overlying strata are relatively low, due to poorly consolidated strata, the depth range to the basement in the area lies between 300 and 400 metres. The boring is located, according to the bedrock map (Sivhed et al. 1999), in an area with Upper Cretaceous strata. To the south there is a Jurassic succession of strata dipping from Romeleåsen ridge towards the Fyledalen Fault Zone (cf. Fig 4). A seismic section displayed in Fig. 4A−B, reaches from the Jurassic−Lower Cretaceous strata to Upper Cretaceous strata. The seismic data indicate a fairly smooth and undisturbed succession of strata.

3 Materials and methods

3.1 The Revinge core

Revinge-1 was drilled in 2012 during May−June and October−November, using the National research rig funded by the Swedish Research Council and operated by Lund University, Department of Engineering Geology (Fig. 5). The Atlas Copco CT20C rig is capable of core drilling down to 2.500 m. The core drilling at Revinge was performed as a test well for the new drill rig. The drilling started at 85.8 m depth from the bottom of an older well. The Quaternary overburden is 50 m in the area. The core diameter is 45 mm and the core recovery was even through partly unconsolidated sedimentary strata as high as 95 %. The drilling aimed to a target depth of ca 350 m, i.e. the top of the crystalline basement. However, due to drill pipe failure the drilling had to be stopped at 279.8 m. The core was initially described and sampled concerning main lithological and sedimentological characteristics. A summary of samples for various analyses are presented in Table 1. The description included identification of rock type, colour, grain-size, bedding and structures (ripples, burrows etc.), and fossils. Intervals with a rich and well preserved fauna of mollusks and bony fish remains were especially investigated concerning the composition of the fossil fauna. The petrology of the sandstone intervals was investigated by use of polarizing microscopy and SEM-EDX studies of thin sections. The database for the work presented here also includes preliminary biostratigraphical results by Sofie Lindström (GEUS pers. comm.). A set of existing carbon isotope data from the lower part of the core was also included in the study.

The work has also included a study of a few seismic lines, performed by OPAB 1973, that give information on the subsurface structural framework of the sedimentary sequence.

3.2 Total organic carbon and C-isotopes

In total 41 samples taken from the lower part of the core have been analysed regarding total carbon content and C-isotopes. The samples were collected every 0.5 m by SGU and analyzed by ISO-Analytical ltd. The investigation was intended to cover the complete core but so far only the interval 235–277.5 m has been analysed. SGU provided the data for this study.

Prior to δ13C analysis the samples were ground

Fig. 5: Photograph showing the national Research Rig at the Revinge-1 drill site.

Table 1. Summary of performed analyses in Revinge-1.

Thin sections	C-isotope	SEM - EDX	Palynology/ biostrat.
185.75–185.80 m	Samples every 0.5 m from 277.5 m to 235 m	240.75–240.80 m	87.18 m
191.70–191.78 m		240.80–240.85 m	92.65 m
196.90–196.97 m			98.1 m
237.30–237.35 m			106.9 m
238.60–238.75 m			128.5 m
239.12–239.26 m			160.15 m
240.75–240.95 m (5 sections)			169.95 m
			226.0 m
			238.45 m
			245.45 m
			266.17 m
			269.32 m
			276.3 m
			277.05 m

into a fine powder and then acidified with 2M hydrochloric acid and left overnight to allow inorganic carbon to be liberated as CO_2. The samples were then neutralized by repetitively washing with distilled water and subsequently oven-dried at 60°C prior to δ 13C isotope analysis.

The technique used for analysis of the samples was Elemental Analyser-Isotope Ratio Mass Spectrometry (EA-IRMS).

3.3 Palynology

Fourteen samples have been prepared and a preliminary investigation and biostratigraphical assessment has been performed by Sofie Lindström (GEUS). The preliminary palynological analysis has shown that there is a well preserved and diverse palynological assemblage in most samples.

3.4 Thin sections

As most of the core is composed of very fine-grained siliciclastics only a few intervals were suitable for preparation of thin sections. In total five intervals with arenaceous clastic deposits were sampled. The thin sections were then investigated concerning texture and mineralogy of detrital, accessory grains and cements. A 20 cm thick interval with iron ooid-rich sandstone between 240.75 and 240.95 m was covered by five thin sections as to enable a more or less continuous microscopical study of this interval.

3.5 SEM-EDX

Based on the results of the microscopic investigation, two samples, 240.75–240.80 m and 240.80–240.85 m, from the interval with sideritic and Fe-ooid rich sandstone were chosen for detailed SEM-EDX investigations. The samples come from a section of the core which is clearly different from the rest of the core, and at a first sight these strata seems to be of volcanoclastic origin.

The thin sections from the two samples were carbon-coated, which improves image quality as it increases the conductivity on the sample surface and decreases electric charging effects (Goldstein et al. 1992). Secondary electron (SE) images and back-scattered electron (BSE) images were obtained using a scanning electron microscope (SEM); a Hitachi S-3400N, at the Department of Geology, Lund University. The process is principally that a beam of primary electrons is focused onto the sample surface. The high energy electrons excite the electrons in the sample, which are in turn emitted as secondary electrons that form the SE-images. A portion of the primary high energy electrons are scattered back from the sample surface. A detector collects the radiation signals emitted from the sample, which are projected onto a screen as BSE-images. The back-scattered electrons offer a way of compositional interpretation, as the number of back-scattered electrons increases with atomic number. Areas with higher average atomic number will therefore appear brighter on the image (Goldstein et al. 1992).

The thin sections were scanned at high resolution with a flatbed scanner. The scanned images were used as maps for orientation while investigating certain points in the thin sections.

Another technique was used in connection to the SEM to help identifying elements in the samples; Energy Dispersive X-ray Spectroscopy (EDX). EDX detects x-rays emitted from the sample during bombardment by an electron beam to characterize the elemental composition of the analysed material. When a sample is bombarded by the SEM's electron beam, electrons are ejects from the atoms comprising the sample. The resulting electron vacancies are filled by electrons from a higher state, and an x-ray is emitted to balance the energy difference. The energy of the x-ray is characteristic of the element from which it was emitted. A detector creates a charge pulse proportional of the energy of the x-ray. This pulse is analysed further and lastly sorted by voltage. This energy is sent to a computer and the spectrum of x-ray energy versus counts is evaluated to determine the elemental composition of the sampled area (Russ 1984; Goldstein et al. 2003).

4 Results

4.1 Core description

Below follows a comprehensive description of the lithological units identified in the core. The decription is based on a combination of visual observations and results from the performed analyses. Note that the interval from 191 to 77 m has not been analyzed as detailed as the interval from 279.8 to 191 m. Each identified unit is designated by a capital letter (A–F) which is used as reference in the coming text and interpretations (Figs 6, 7). Detailed logs can be found in the Appendix.

The units are described in ascending order from the base.

Unit A
278–268 m

Varicoloured claystone with thin layers of silt and scattered thin layers and nodules of light brown and dense siderite. The claystone has often a mottled texture and displays also in parts shiny and greasy surfaces. The unit contains scattered burrows and rootlets as well as dispersed pieces of coal (Fig. 8). The burrows are indistinct and a few centimeters in length. The pieces of coal are ca. 0.2 mm thick and approximately 1 cm in length. A few ripples, observed at 275 m depth have a height of ca. 2–3 cm. A few scattered imprints of bivalves have been found (Fig. 8).

Unit B
269–263 m

Interval dominated by dark grey and black claystone/mudstone with thin interbeds of calcareous light grey sand. Clay/sand relationship is approximately 80/20. The interval contains several shell-rich lamina and up to 4 cm thick coquina layers. The layering is commonly disturbed by bioturbation. A number of minor fining upwards cycles are common, beginning with coarse shell debris followed by successively finer sand grading into clay. The interval contains a rich fossil fauna of thin shelled molluscs, mainly bivalves (Fig. 9). The shells are often found enriched in coquina layers at 269, 268, 267, 266.7, 264.5 and 263.9 m (Figs 6–8).

263–261 m

The unit is composed of brown–dark grey homogeneous claystone and contains mm-thin and a few cm long undulating rootlets. There is also an irregular jagged bedding surface at 262 m which could indicate erosion. In addition, there are also, as in the underlying interval, a number of 2–4 cm thick coquina layers containing white thin bivalve shells and some gastropods.

261–258 m

This unis is composed of laminated claystone with a yellow, green brown and grey colour (the interval is similar to the interval between 278 and 268 m). The interval is rich in detrital fine coal fragments. It contains up to 4 cm thick scattered interbeds of fine sand and fine layers enriched in shell debris . There is also a possible paleosol horizon with mottled texture and with a darker brown colour (Fig. 9).

258–257 m

Interval dominated by claystone, dark brown, grey and black, alternating with beds of argillaceous very fine-grained sand. The interval contains a rich and relatively well preserved fauna of mollusks, primarily thin-shelled bivalves.

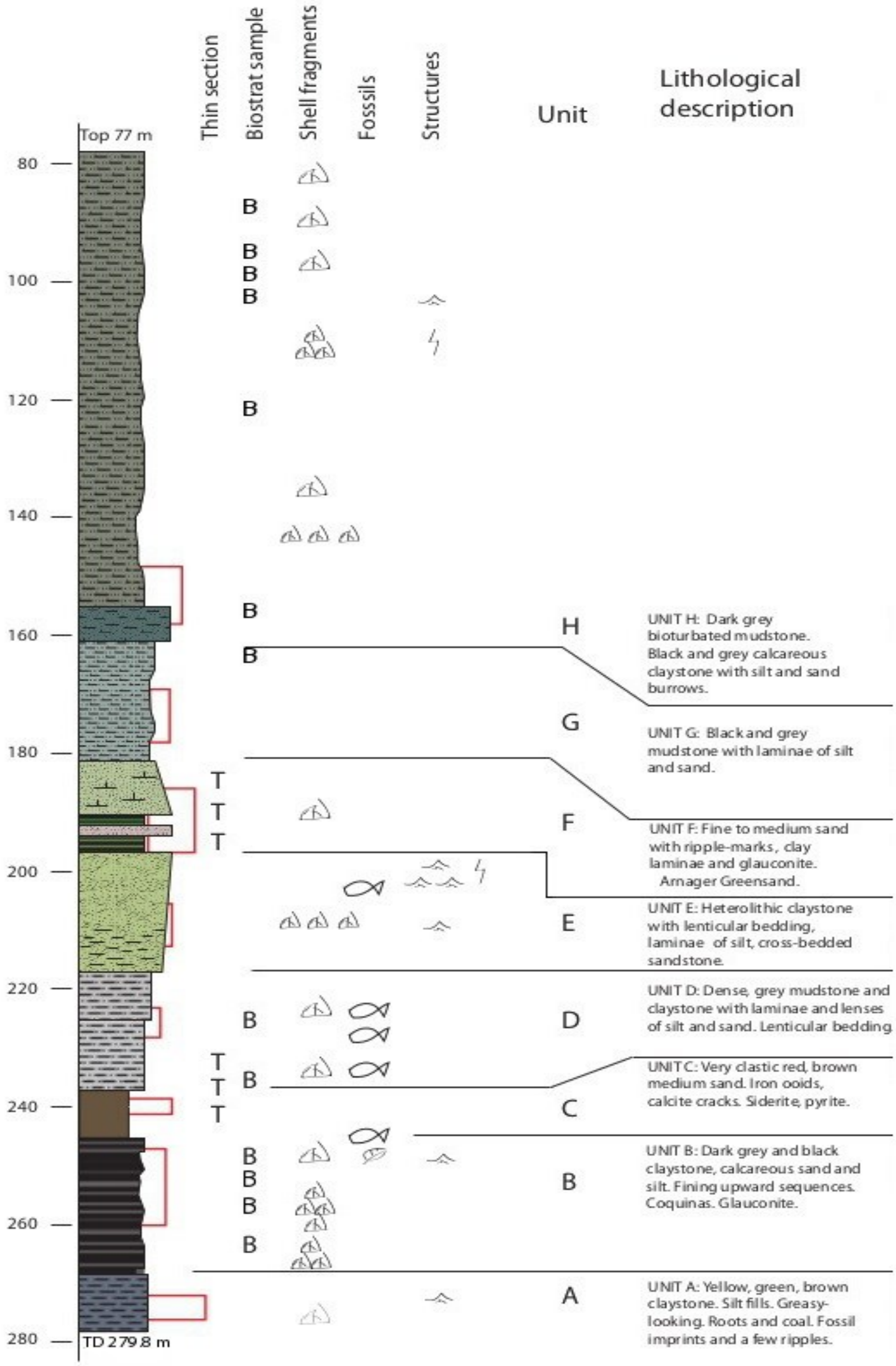

Fig. 6: Graphic log of the Revinge-1 succession. Red frames are photographed units (See Fig. 7). The log includes a lithological description and also fossils, ripples, faults, thin sections and samples for biostratigraphy. The letters mark the different units.

257–246 m

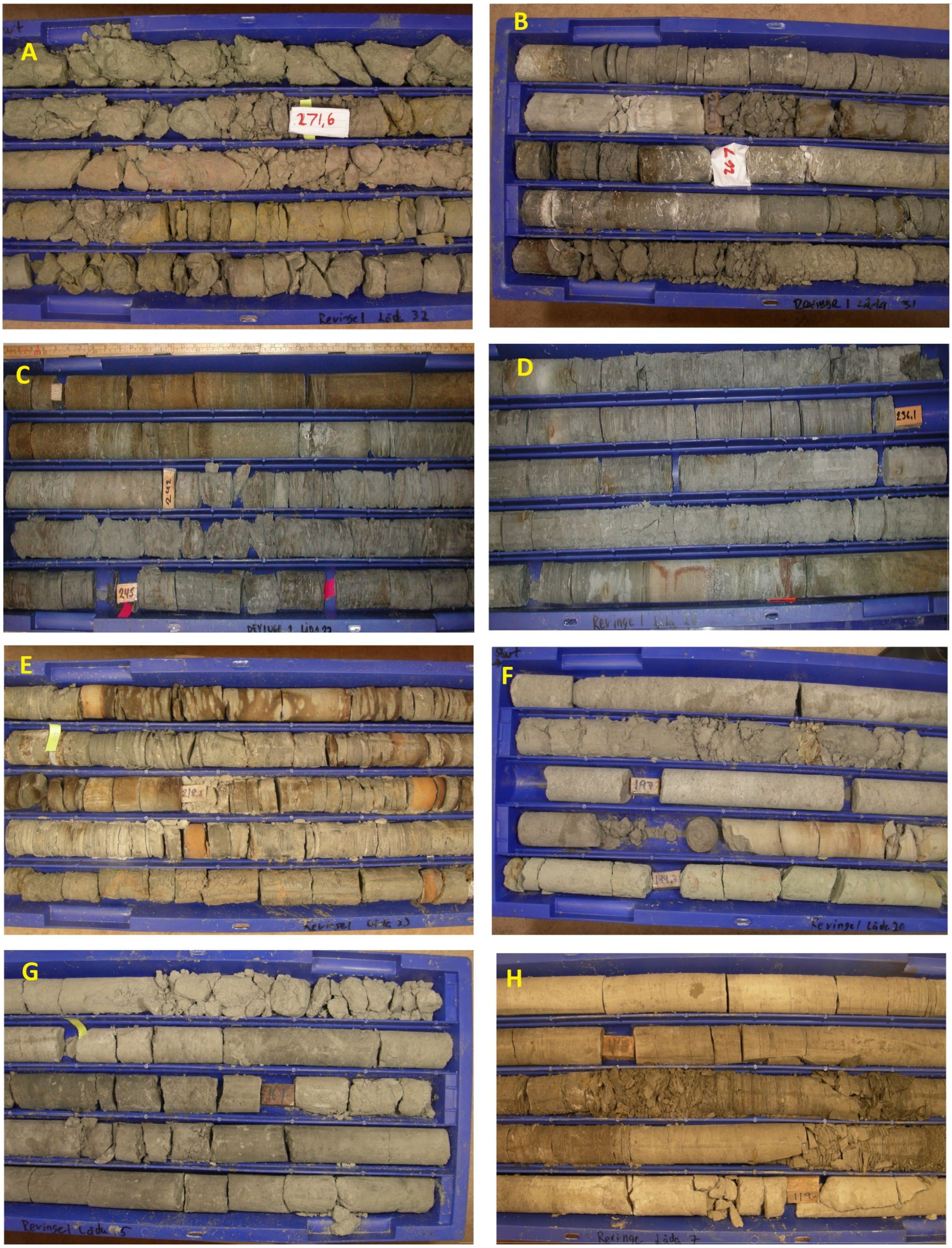

Fig. 7: Photographs of the units A-H from the Revinge-1.

Interval composed of argillaceous sandstone and arenaceous claystone. Varicoloured red, grey and dark green. Variably siderite cemented sandstone layers. Glauconitic or chamositic sand at 250 m. The texture is heterogeneous and mixed indicating significant bioturbation. A few cm-thick rippled layers are found as well as some scatted 1– 3 cm thick shell beds. Occasional fining upward cycles are observed. The interval contains as previous intervals a rich shelly fauna but also mm-large bony fish remains are commonly

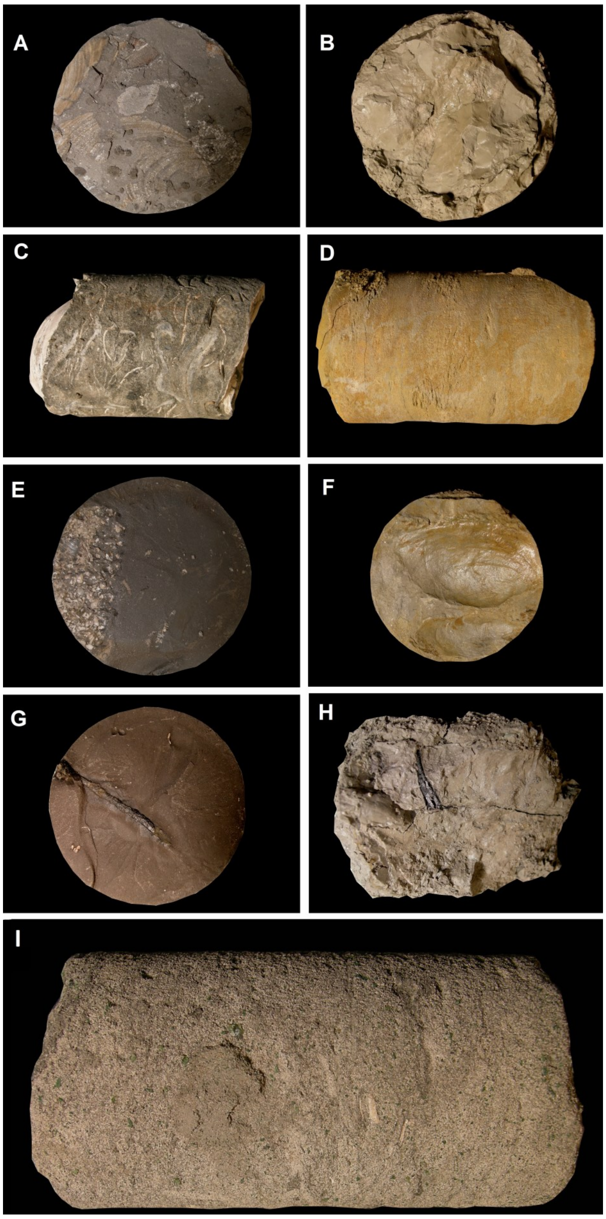

Fig. 8: Photographs of lithological characteristics from the different units in Revinge-1. The diameter of each sample is approximately 5 cm. A, B, D, F and H show the fossil imprints, coal parts and the yellow, grey and "greasy"-looking characteristics of unit A, interpreted as Fyledal Clay. The depth is ca 278-273 m. C show one sample of the fossils shells found in unit B, interpreted as Vitabäck Clay. E represents unit H, from a depth of 113 m, with small shells and black clay. G, 252 m depth, shows unidentified fossils and brown clay. I displays the sandy glauconite-rich interval, here at a depth of 197 m (Possibly interpreted as Arnager Greensand).

found. A plant fossil (cm-large leaf) is also found.

246–242 m

Dominated by lenticular bedded dark grey and brown claystone. Lenses of grey and brownish iron-rich fine-grained sandstone. Scattered <1 cm thick layers with shell fragments.

Unit C
242–239.9 m

Reddish brown medium-grained, iron-rich and calcareous sandstone (Fig. 7). This unit is prominent in the core with its distinct dense iron-rich lithology, which in parts resembles tuffaceous sediments of volcanoclastic origin or sediments strongly influenced by hydrothermal precipitations of iron. The overall texture is dominated by several generations of fissures, usually calcite-filled or with pyrite mineralizations. Intervals of 2—5 cm thick undulating dense microcrystalline dark grey claystone. The medium-grained sandstone contains high amount of mm-large iron ooids. No fossils have been found.

Unit D
239.9–234 m

Dominated by grey thinly laminated mudstone and clay interbedded by white medium-grained sand between 239.2 and 239.4 m. The interval is lenticular bedded at the top and also contains a fining upward sequence (Figs 6, 7). Scattered molluscs shell fragments and mm-large bony fish remains.

234–226 m

Dominated by brown and grey laminated claystone with <0.5 cm thick irregular layers and lenses of silt and fine-grained sand, approximately 0.5 cm thick. In parts with lenticular bedding. Scattered red-brown coloured slightly calcareous patches. No calcareous shells found. One brown shell imprint found. Bony fish remains as in previous interval.

226–219 m

Brownish grey thinly laminated claystone with up to 0.5 cm thick lenses of sand and silt. The claystone does occasionally have a heterolithic texture. The siderite-rich sand lenses have a mottled texture. Also a distinct compact and homogenous yellow/orange calcareous claystone layer at 223.9 m. Scattered shells and bony fish remains.

Unit E
219–206 m

Grey claystone/clay with silt and sand interbeds , up to a few centimeters thick (Figs 6, 7). Mottled brown by irregular iron precipitations. Frequently occurring shell fragments and recurring shell debris layers up to a few

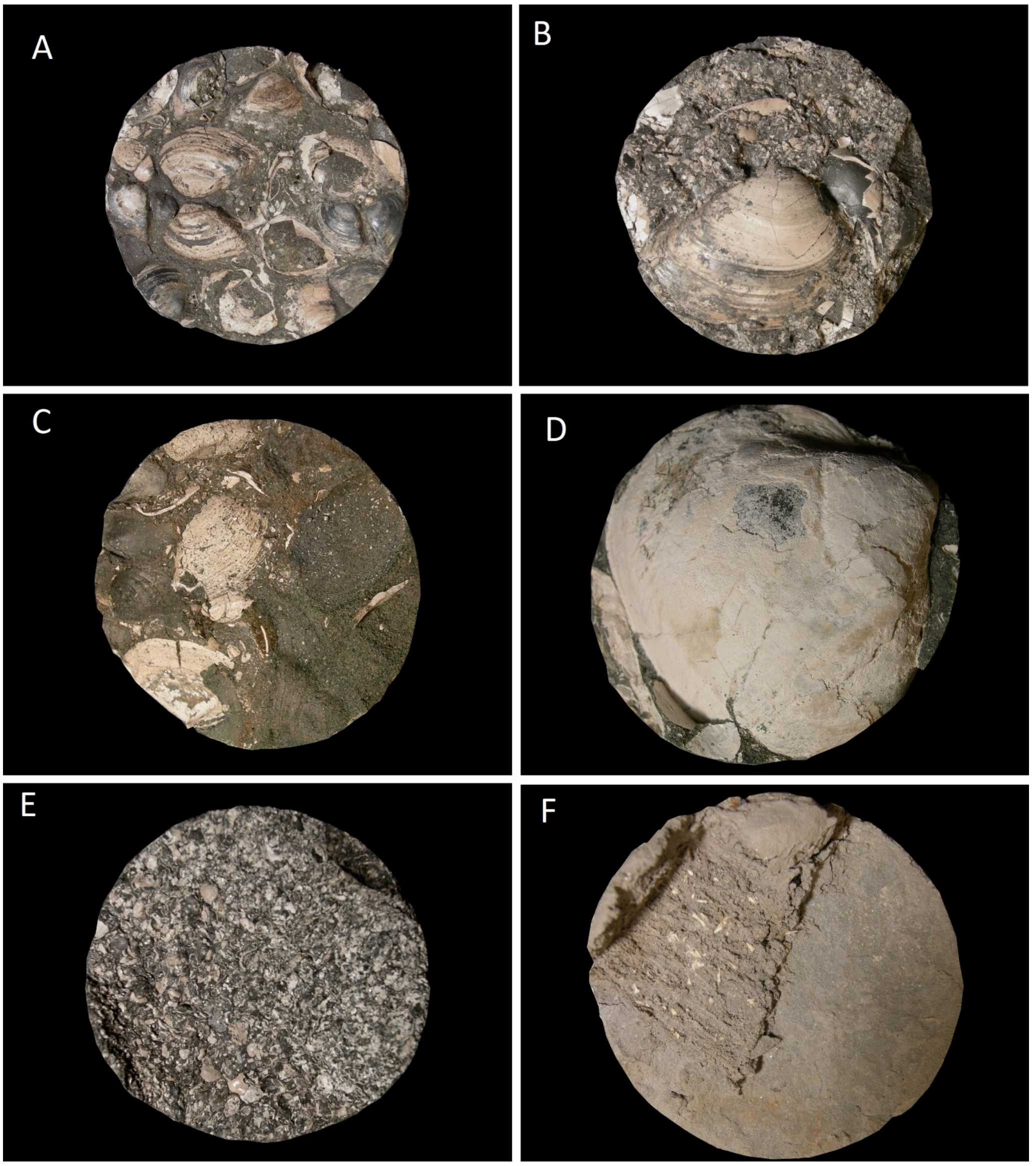

Fig. 9: Fossils from the interval interpreted as the Vitabäck Clays. A: 258.3 m B: 252.7 m C: 250.3 m D: 267 m E: 252.7 m F: 245 m. The samples are c. 4 cm wide.

centimeters in thickness. Numerous bivalve shells occur between 216 and 217.5 m, including two up to 3 cm thick shell beds. Scattered dark brown-grey precipitations, likely siderite. A few diffuse burrows are identified as well as a few ripples with a height up to 4 cm.

206–200 m

Mottled light grey, fine- and medium-grained argillaceous sands. Heterogeneous texture likely caused by intense burrowing. Interbeds of heterolithic claystone/siltstone. A few mm-large bony fish remains are found in the claystone.

Unit F
200–193 m

Mostly fine-grained, yellow–grey calcareous and argillaceous sandstone (Figs 6, 7). Basal part (200–198.5 m) including trough cross bedded sandstone. Upwards increasing amount of carbonate and glauconite. Mottled bioturbated texture. No macrofossils have been found.

193–171 m

Alternating beds of fine- and medium-grained calcareous sandstone and arenaceous limestone. The colour is grey with a green tint due to presence of glauconite. The texture is mottled due to intense bioturbation. Shell fragments are found at 191 m and 189 m.

Unit G
171–164 m

Black and grey claystone with thin silt and sand laminae (Figs 6, 7). The claystone contains vertical and horizontal undulating burrows up to 5 cm in length. No macrofossils have been found.

Unit H
164–137 m

Alternating fining upwards cycles including light grey calcareous sandstone and dark brown/grey claystone/mudstone with silt-filled burrows (Fig 6 & 7). High amounts of scattered shells and thin shelled molluscs as well as a 2–3 cm thick coquina layer occur 144 m depth.

137–118 m

Similar to previous interval, but with a higher content of silt and sand, at least 30%. The colour varies between grey and brown, and the lithology alternates between variably calcareous mudstone and fine sand. The sediments are characterized by undulating burrows, approximately 0.5 cm wide which give the sediments a mottled texture. Shells of molluscs and bivalves occur at 137 m.

118–99 m

This interval is dominated by alternating beds of grey and dark grey mudstone and claystone (Fig. 6). There are several fining upward sequences and the overall mottled texture is a mixture of clay and silt. At 99 m the sediment is dominated by dark claystone with a few silt-filled burrows, ca 0.5 cm wide. The sediments grade upwards into a grey, calcareous mudstone with some bioturbation, followed by a ca 2 cm thick layer of light grey silt with numerous shell fragments. A fault cuts through the core at 109.8 m. Pyrite nodules are found scattered in the interval. Several cm-large thin shelled bivalves occur at 113 m and 109 m depth.

99–77 m

This interval is dominated by grey variably calcareous mudstone, silty grey clay and dark grey clay. Scattered up to 0.3 cm thick silt laminae.

4.2 Microscopical investigations of thin sections

The following text describes the results from the microscopical investigations of the thin sections. Focus is mainly on the siderite sandstone interval between 242 and 239.9 m in order to investigate if this distinctive unit of iron-rich clastics displays any volcanic influences. Photographs illustrating core samples from the intervals are presented in figure 10.

Sample: 240.75 m

The thin section is dominated by dark green brown matrix with a few ca 0.4 mm large iron ooids. The matrix is penetrated by several, almost horizontal calcite-filled fissures. The up to 0.5 mm wide undulating fissures are composed of several generations. A second order of fissures has formed perpendicular to the first generation (Fig. 11). The matrix is dominated by green/brown clay mm-sized minerals. Towards the top of the thin section (Fig. 11) two veins filled with pyrite occur (Fig. 11). There are also a few scattered quartz grains, up to 0.7 mm in length. The iron ooids in this thin section are concentric and have an ellipsoid shape. Most of them contain some kind of detrital core material.

Sample: 240.80 m

This interval is similar to the previous one but contains higher amounts of iron ooids. At least 50% of the sample is composed of ooids. The matrix is still very fine-grained with a green and brown colour. The matrix is dominated by a mixture of clay minerals and siderite.
The sample displays up to 3-4 generations of calcite-filled fissures. The later ones are less undulating in comparison to the earlier ones. The mainly elliptical iron ooids are in general yellow or grey and have a few concentric visible layers and cores (Fig. 12). The central nucleus of the ooids seem to be composed of the same mineral as the matrix, i.e. clay minerals. The calcite fissures are both formed around as well as cutting through the iron ooids (Fig. 12).

Sample: 240.85 m

This is the third successive thin section from the same interval. This section displays the most varied textural features of the three (Fig. 13). The matrix varies between dark brown, fine-grained and a light grey granular matrix composed of minute 0.03 mm large particles. The sample is also rich in iron ooids, which make up at least 70% of the whole thin section. The 0.5 mm large iron ooids are dark brown to reddish brown and have a distinct concentric habit. The shape of the ooids varies between spherical and elliptical. In places the ooids are stretched, ca 1 mm large, flattened and elongated (Fig. 3). The center nucleus is occasion-

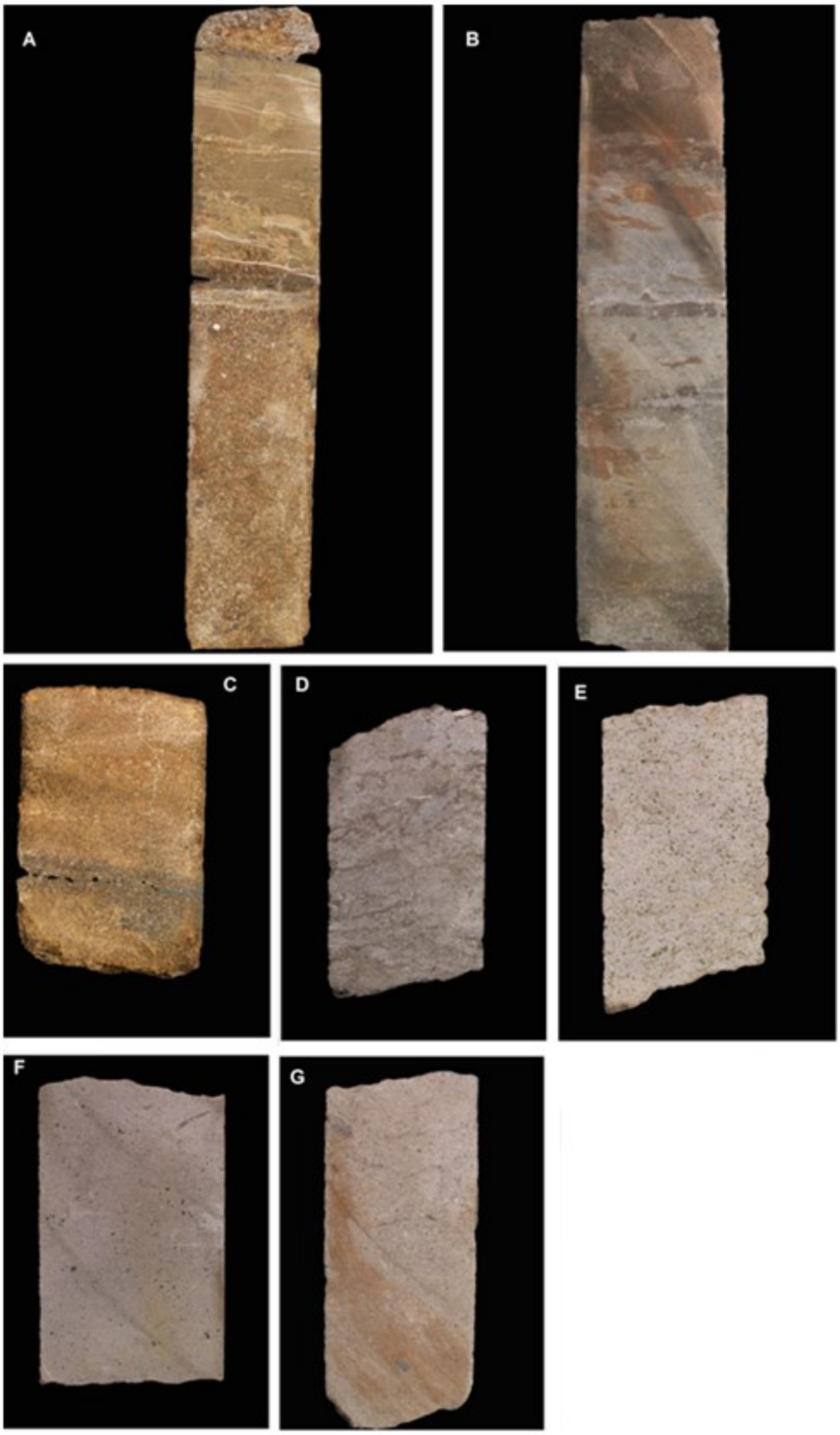

Fig. 10: Figure showing the samples from which the thin sections were made. A-C are the iron ooid-rich interval, here from 240.75 m, 238 m and 239.12 m of depth respectively. D-G are sandstone with different amount of glauconite and fossil parts, from 237.3 m, 196.9 m, 191.7 m and 185.75 m respectively.

ally composed of silt sized quartz grains. The remaining 25% of the thin section is composed of calcite-filled fissures, quartz grains and clay minerals. Another feature is a deformed calcite fracture, 1 mm thick,

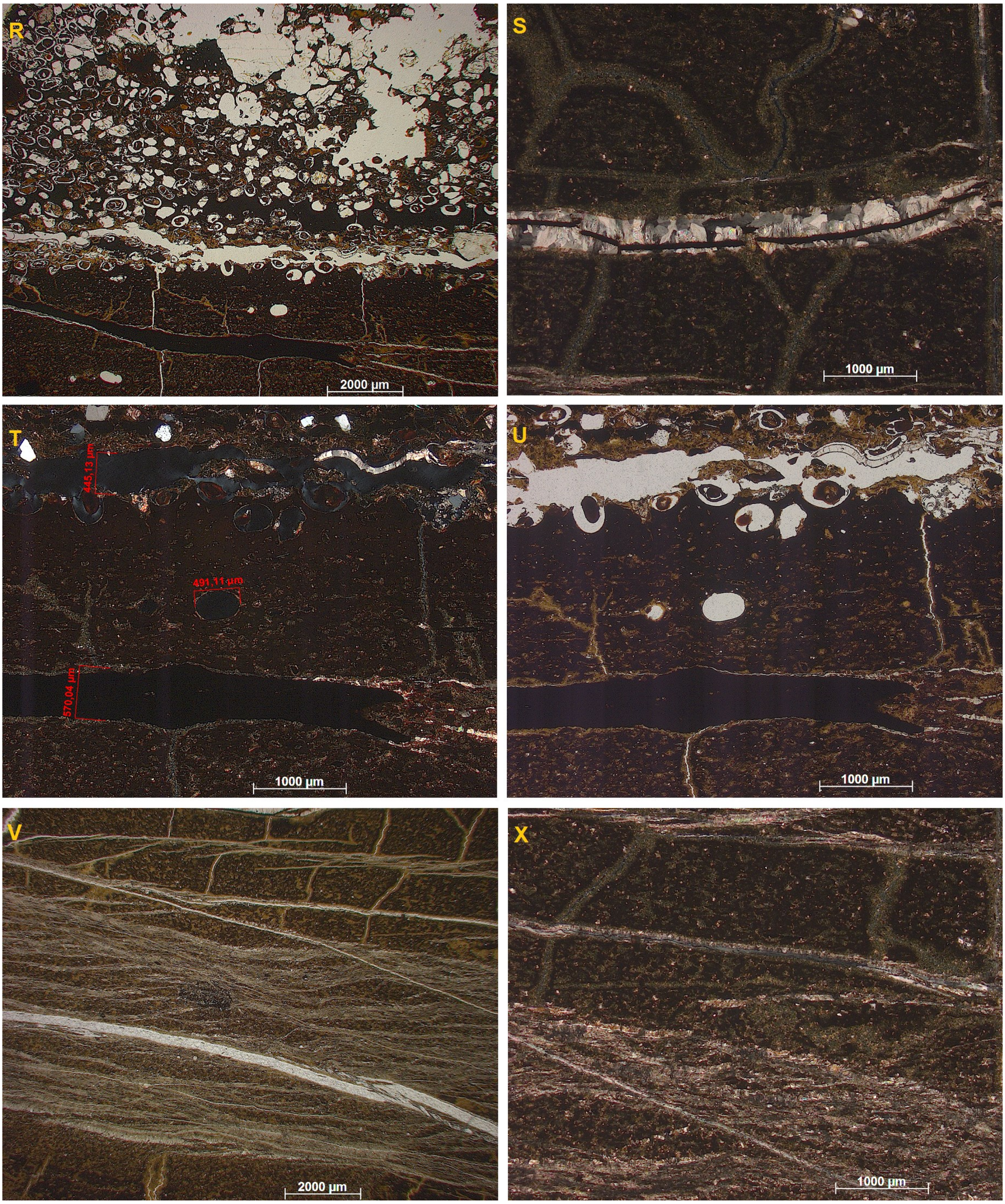

Fig. 11: This figure illustrates the start of the iron ooid-rich interval, from a depth of 240.75 m. The picture on top to the left shows the iron ooids. The other pictures show different veins and fissures covering most of the thin section.

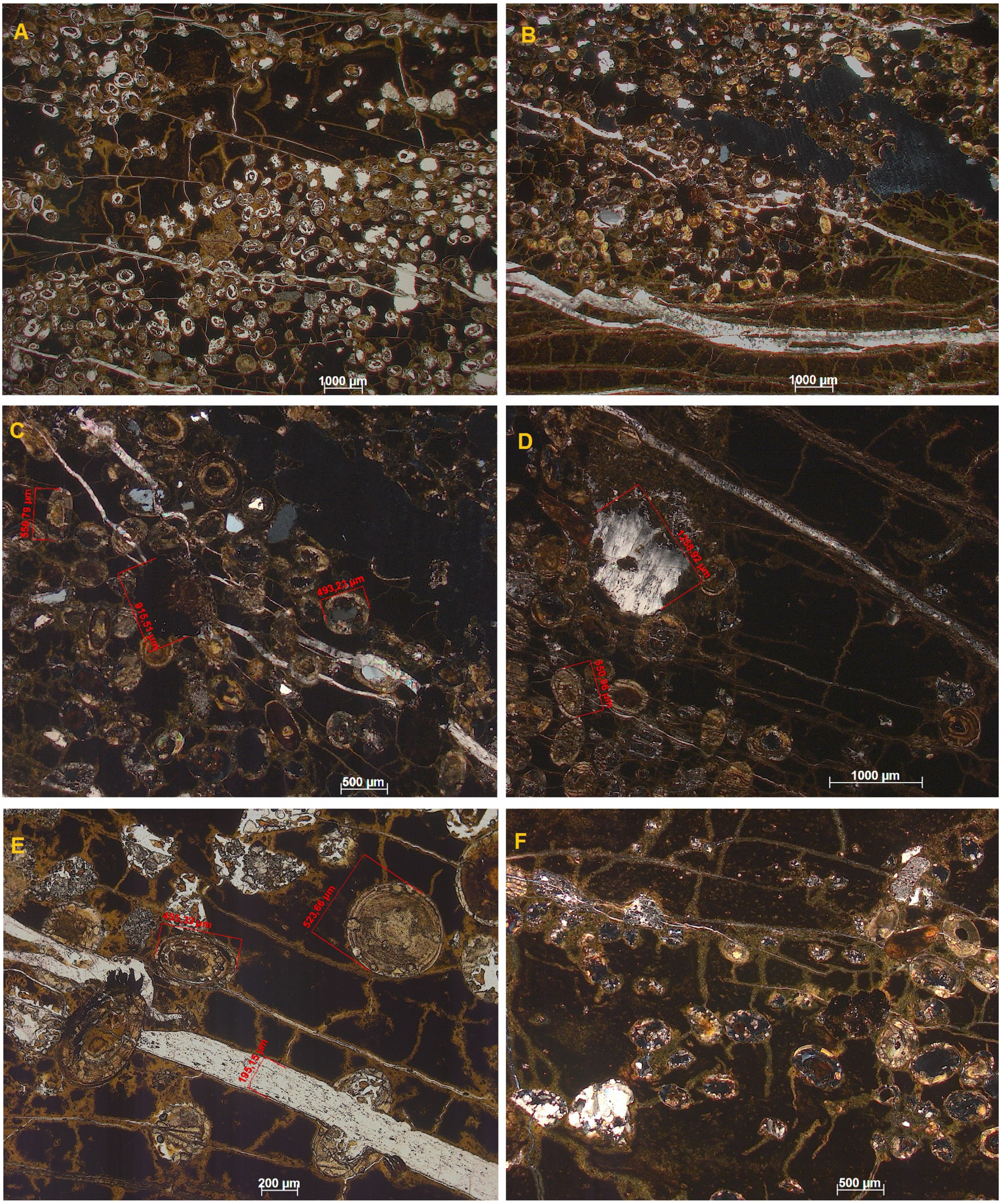

Fig. 12: The second thin section from the iron ooid-rich interval, 240.80 m. A fine-grained dark brown matrix, more iron ooids than previous thin section and fissures characterizes this thin section. Note the iron ooids, both spherical and elliptical in picture E. Also note the lack of visible layering in most ooids.

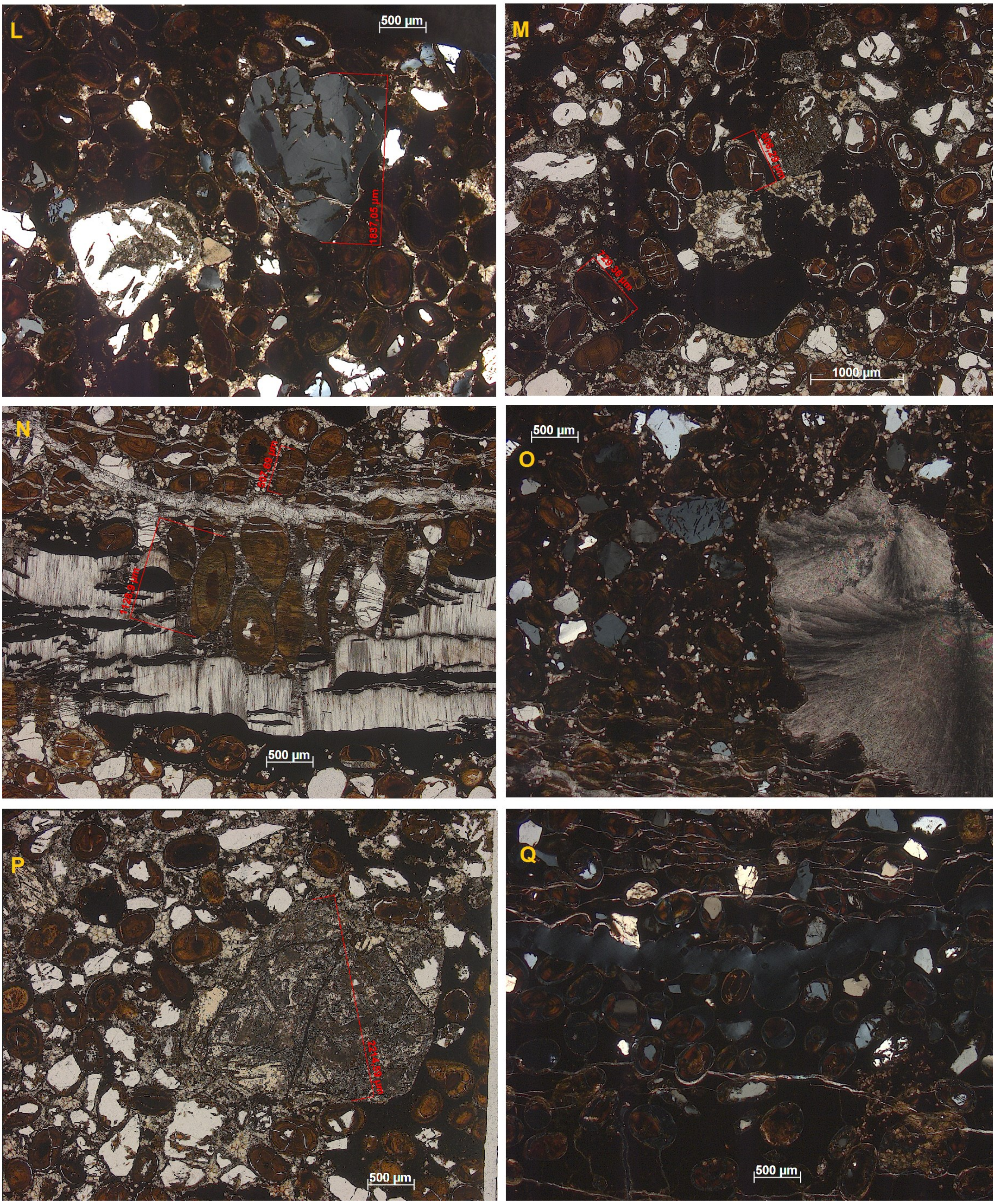

Fig. 13: The third thin sections from the ooid-rich interval, 240.85 m. The thin section show deformed crystals, fissures and ooids, as in the middle pictures. There are also deformed aggregates/crystals as in the picture in the bottom to the left.

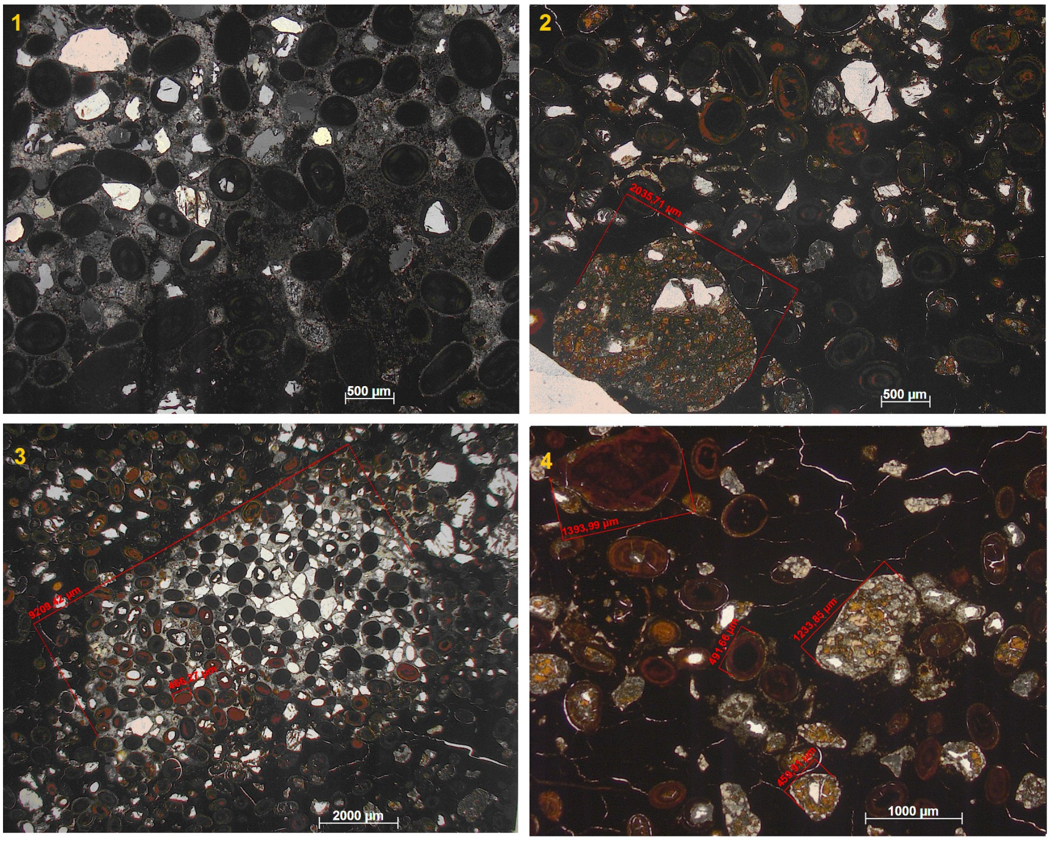

Fig. 14: The fourth thin section from the ooid-rich interval, 240.90 m. It has an high amount of iron ooids in a fine-grained matrix, brown and grey. Aggregates of a yellow and grey minerals in XPL.

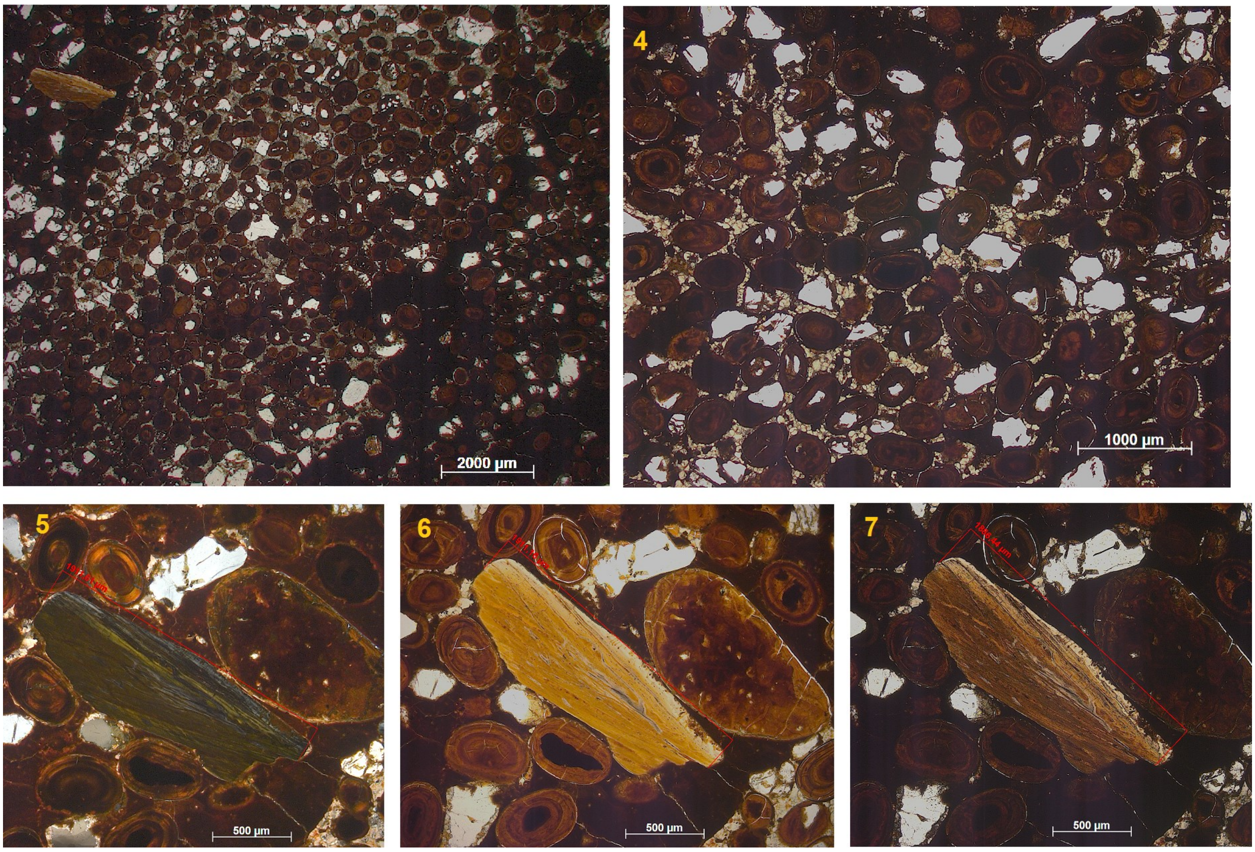

Fig. 15: The fifth thin section from the ooid-rich interval, 240.95 m. The thin section contains a very high amount of iron ooids with mostly elliptical shape and visible layering. A fine-grained brown matrix and mineral grains are present aswell. A large odd -looking grain ca 2 mm large, can be seen in the bottom pictures.

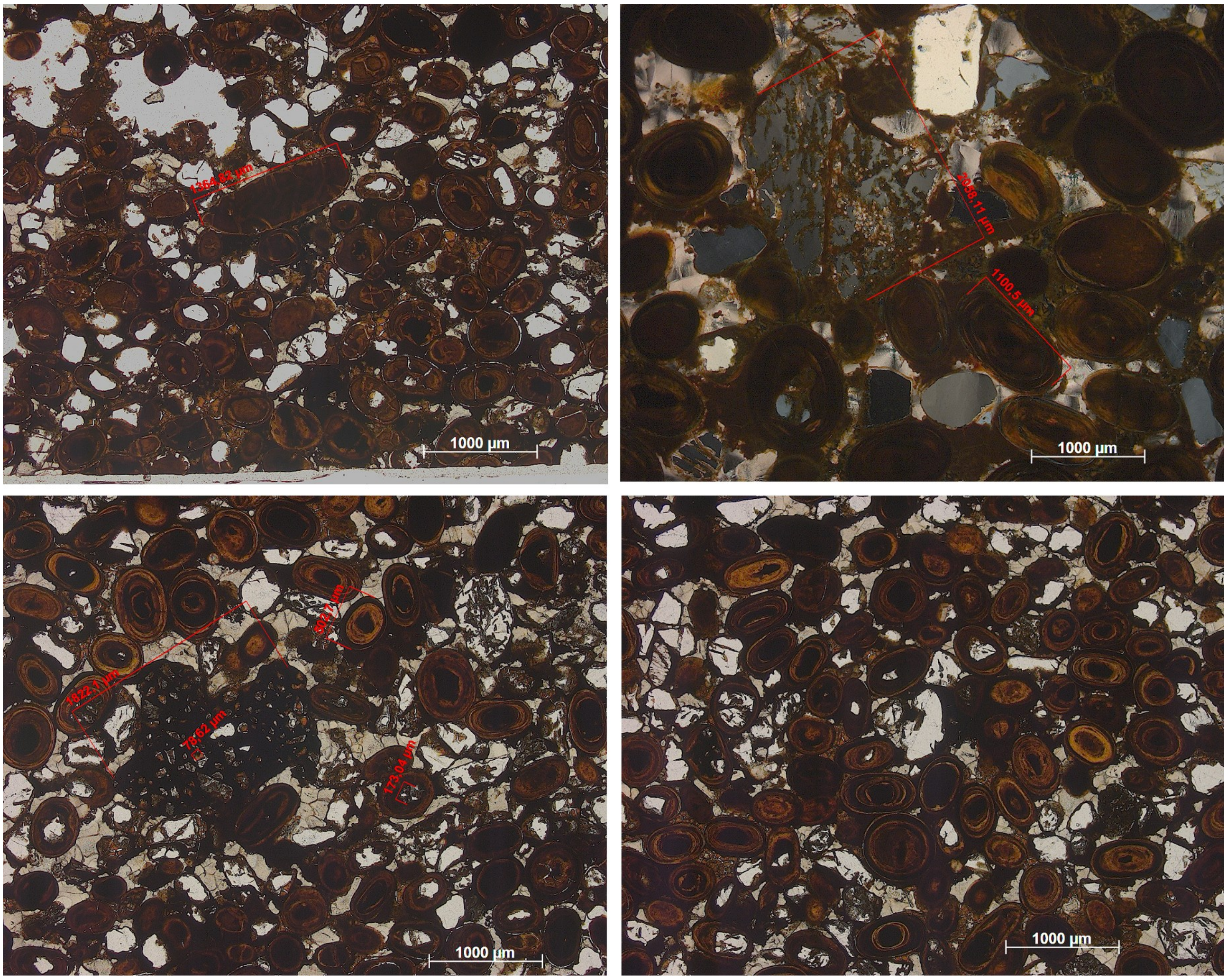

Fig. 16: This figure covers the two thin sections from the depth of 239.12 m. They are not differing that much from previous thin sections. They contain a high amount of ooids, grey mineral aggregates, and fine-grained light-coloured matrix.

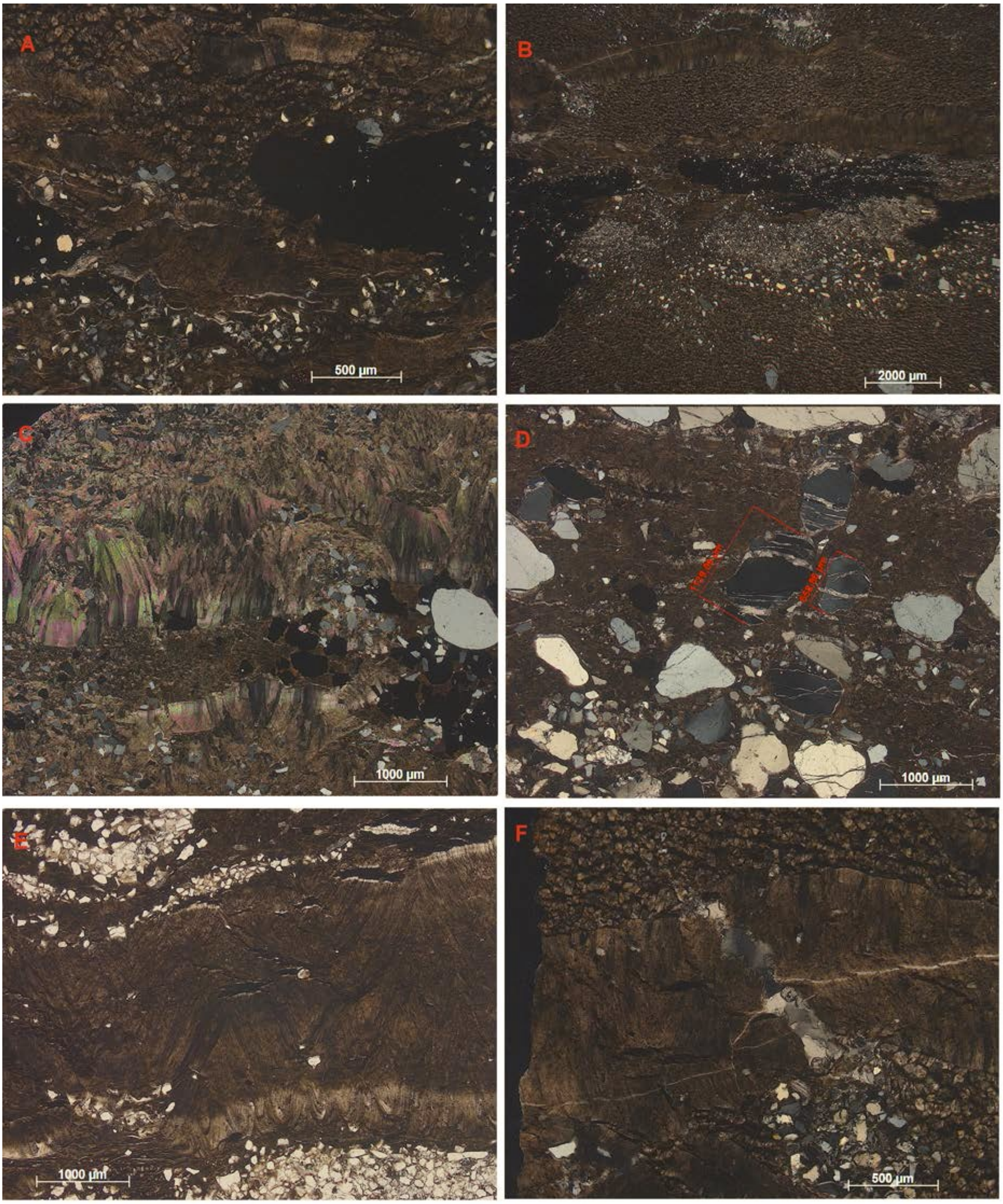

Fig. 17: This figure illustrates thin section from 238.60 m. Millimeter-large crystals of probably carbonate have grown outwards from a fine-grained matrix. None or very few iron ooids are found in this sample. There are plenty of mineral grains, interpreted as quartz and clay minerals. Also opaque phases are present.

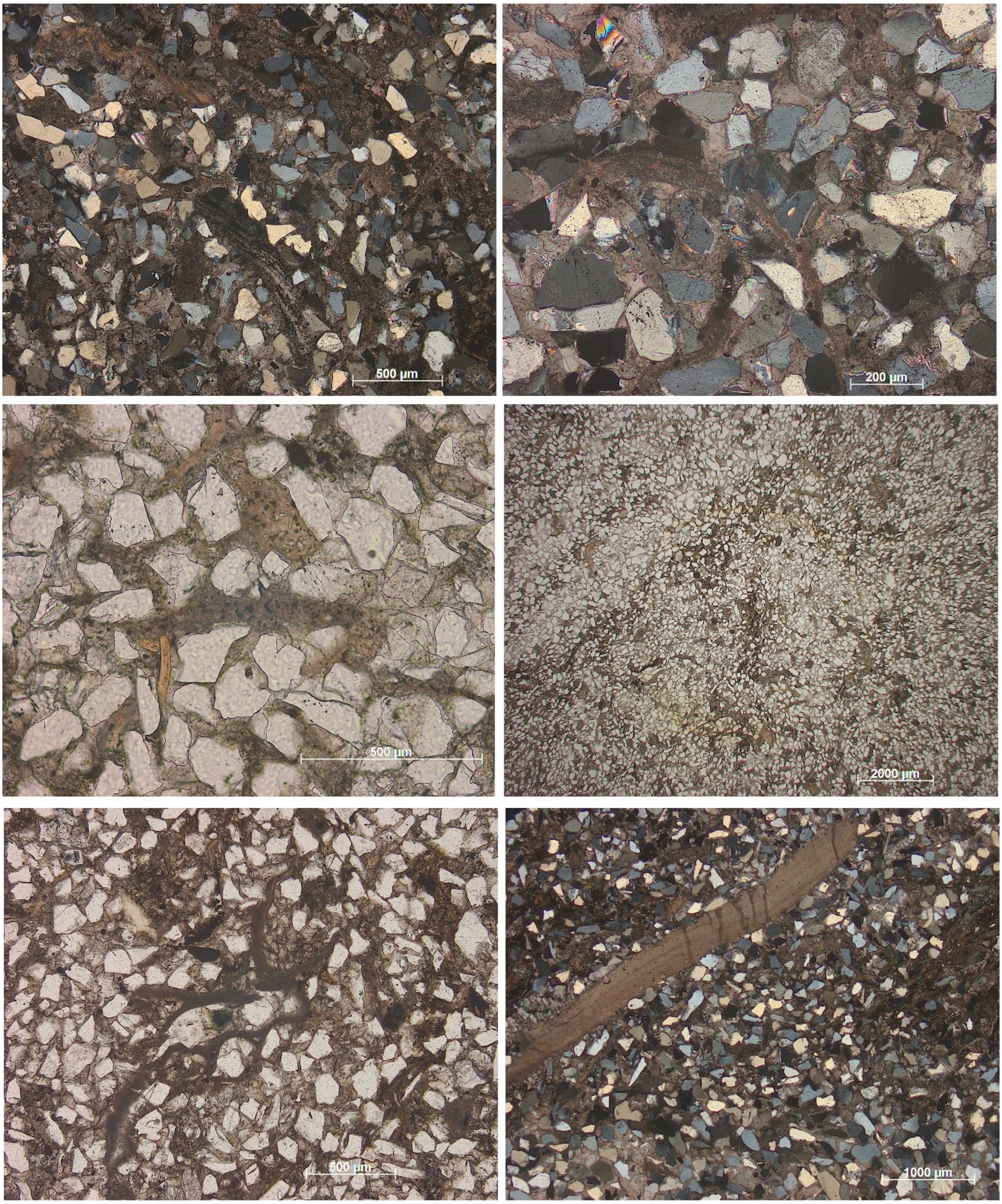

Fig. 18: This figure illustrates the thin section from a depth of 237.30 m. The thin sections has a high amount of grains, interpreted as clay minerals in a grey cemented matrix. Up to 4 mm long shells and few echinoderms can be found. Burrows can be seen in the left middle picture.

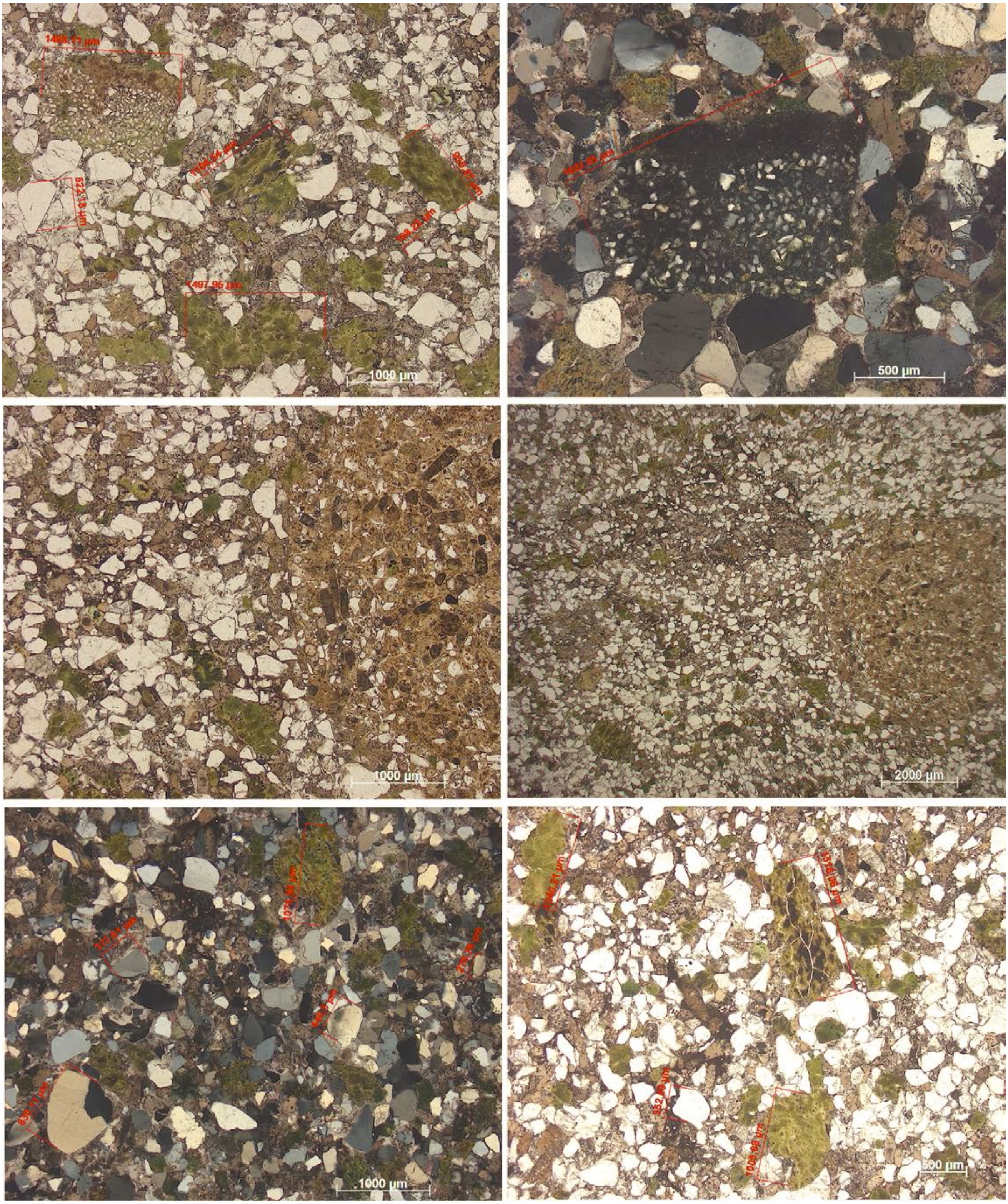

Fig. 19: This figure displays the thin section from a depth of 196.90 m. The thin sections still has an high amount of what is interpreted as clay minerals, but also echinoderms. Burrows and trails are visible. Glauconite is also present throughout the sample displaying a khaki green colour.

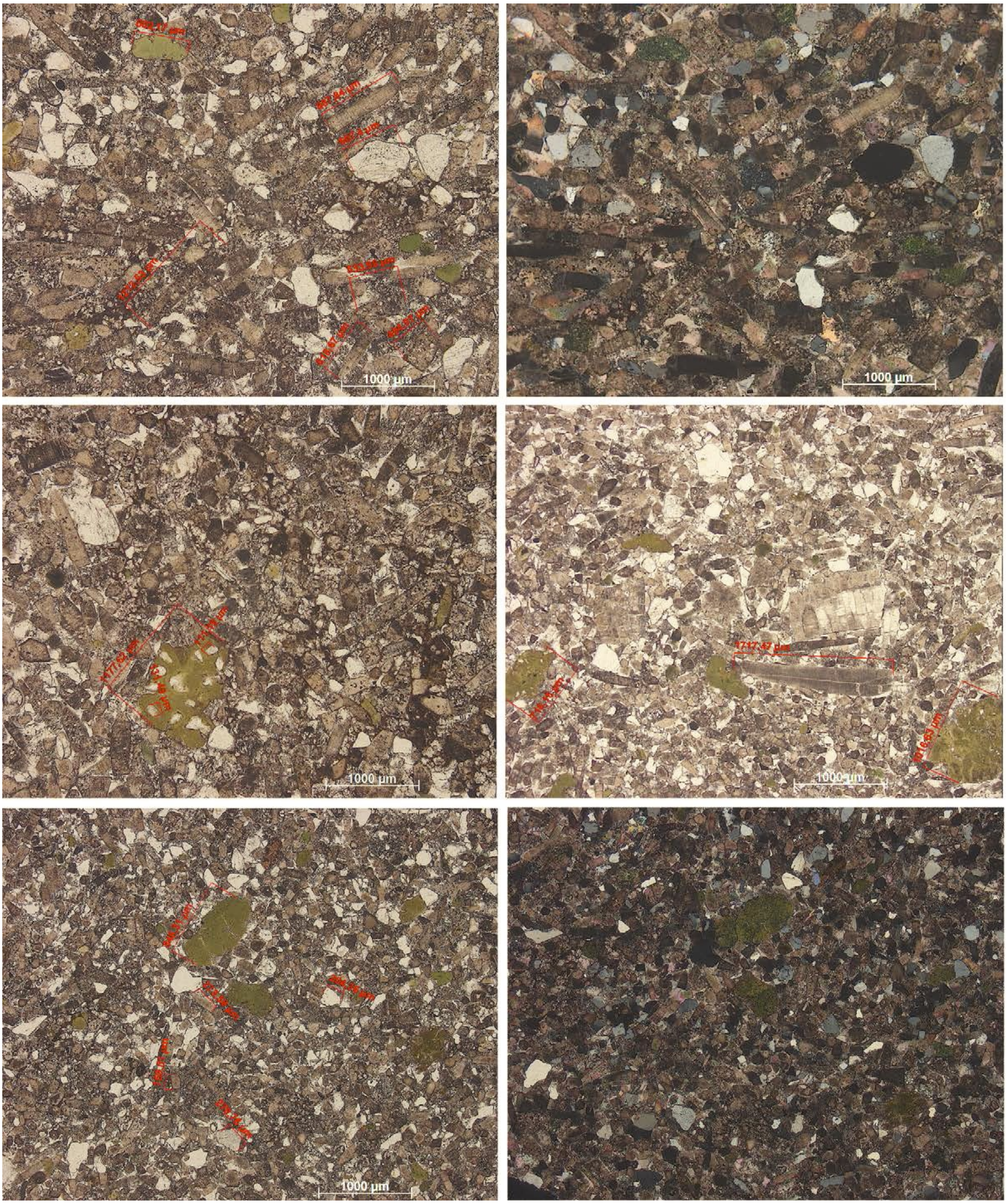

Fig. 20: Thin section from a depth of 191.70 m. The thin sections contains a very high amount of echinoderms, at least 70%. The grain size varies from 0.2 to 2 mm. Glauconite is also present with a green brown colour, and encloses occasionally mineral grains.

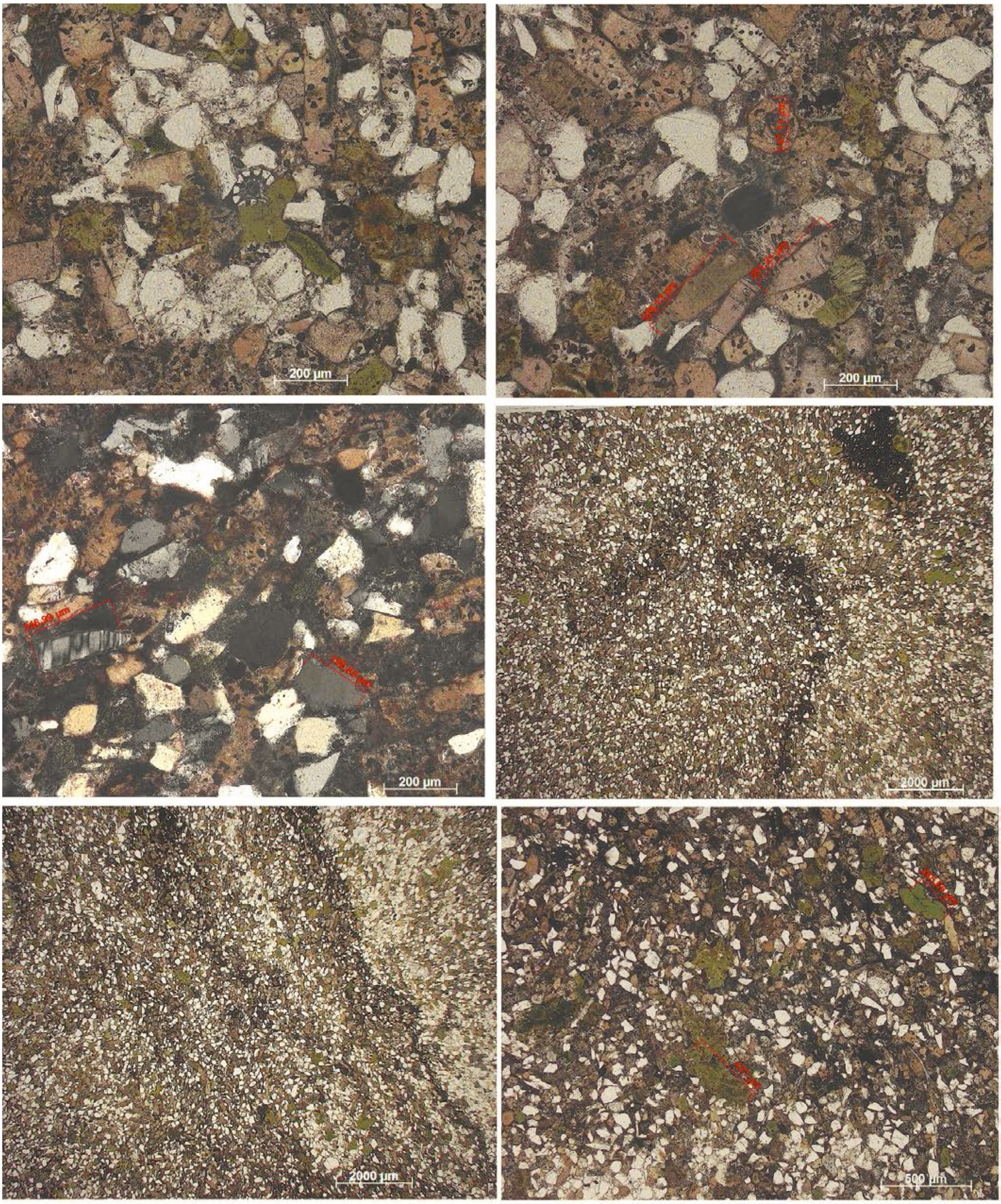

Fig. 21: Thin section from a depth of 185.75 m. The figure illustrates six different pictures taken, displaying burrows, clay minerals, echinoderms and green brown glauconite.

running straight through the middle of the thin section (Fig. 13). The fracture undulates around as well as crosses over the ooids. In the surroundings to a deformed fracture there are also patches of deformed fine-grained carbonate mineralizations , with sharp edges (Fig. 13). The fracture does also contain some pyrite mineralizations.

Sample: 240.90 m

This thin section has the same characteristics as the previous from the same interval, but it is much darker indicating a higher amount of iron. The rock is dominated by iron ooids, at least 80% of the thin section is composed of ooids (Fig. 14). The spherical-shaped iron ooids are dominating. These have well developed concentric layers and have a distinct core grain. The matrix in the sample is fine-grained and dark, consisting of iron-rich minerals (Fig. 14). Scattered up to 2 mm large quartz grains and clasts composed of aggregated fine-grained clastics are also found (Fig. 14). This thin section does not contain any calcite-filled fissures which are characteristic for the other samples from the same interval.

Sample: 240.95 m

This is the final thin section from the same lithology. It is also the one that contains the highest amount of iron ooids. An estimation is that at least 85% of the thin section is composed of ooids (Fig. 15). The thin section display two types of matrix; one dark brown, iron-rich and fine-grained and another light grey yellow and granular (Fig. 15). The grey yellow type forms a diagonal aggregate across the section from the top right to the bottom left, embedding the iron ooids. The grey yellow matrix also occurs as 1.4–2 mm large crusts and aggregates scattered in the thin section. The dark brown matrix contains several 0.01 mm wide irregular fissures. The on average 0.6 mm large iron ooids are concentric and display visible layers, varying in thickness and in different shades of brown (Fig. 15). In this thin section the same 2 mm large aggregates are present with a yellow brown mineral clustered into a bigger aggregate.

Sample: 239.26–239.12 m

The two thin sections covering the interval are both characterized by a high amount of iron ooids.
The iron ooids are dark brown or dark red and have a concentric structure with very tight lamination (Fig. 16). The length of the lamina of the ooids range from 0.2 to 0.6 mm (Fig. 16). The matrix varies from fine-grained dark brown to a lighter grey yellow matrix with undulating extinction in polarized light (XPL) (Fig. 16). Apart from iron ooids there are also aggregated clay minerals and quartz grains having sizes up to approximately 1 mm.

Sample: 238.60 m

The interval 238.60–238.75 m is represented by three thin sections. One of the characteristics in the first thin section is the occurrence up to 3 mm large carbonate crystals (Fig. 17) which have grown outwards from a granular brown matrix (Fig. 17). The matrix has a horizontal, undulated and layered texture (Fig. 17). The very fine-grained brownish grey matrix contains c. 0.2 mm large brown grains of clay minerals and quartz grains. This thin section also contains a few c. 0.2 mm wide quartz-filled veins or fissures. There is also an opaque mineral phase of pyrite in a 0.3 mm thick vein.

Sample: 238.65 m

At least 50% of the thin section is composed of calcite crystals. A granular brown matrix is also present. The sample is characterized by an undulating texture. It also contains the same brown clay minerals, an opaque phase of pyrite and a small amount of quartz (Fig. 17) In some parts of the sample the clay minerals form a horizontal flow-like texture, dividing the opaque phase, likely pyrite (Fig. 17). White mineral grains (In PPL) up to 1.5 mm large are forming ca 2 mm thick, undulating bands and irregular layers (Fig. 17).

Sample: 238.70 m

This sample is composed of at least 40% of a colourless mineral (grey brown in XPL), likely a clay aggregate, with a length up to 1.2 mm. Quartz make up at least 20% of the grains. The quartz grains are frequently up to 1 mm large. There are also scattered up to 3 mm large calcite crystals, in close relation to opaque parts of the section, likely composed of pyrite. Towards the top of the sample the calcite crystals look deformed (Fig. 17). The brown and slightly greenish matrix is fine-grained and has an undulating texture.

Sample: 237.30–237.35 m

The sample displays a mottled texture with a light grey blue colour (Fig. 18). It is furthermore dominated by medium-grained detrital angular quartz. The clasts are cemented by a very fine-grained carbonate. There are also several up to 4 mm large mollusc fragments (Fig. 18). Apart from these, there are a few brown echinoderm-like fragments in the thin section. The texture of the sediment seems to be bioturbated. Two detrital grains of glauconite are found, with a clear green colour and smooth edges.

Sample: 196.90–196.70 m

This thin section is characterized by a high amount of glauconite, at least 10%. It also contains more of what is likely echinoderms, than previous thin sections, ca. 20%, and the carbonate matrix makes up about 30% of the section (Fig. 19). There is also a large amount of a brown grey mineral, likely clay mineral, with a grain size up to 0.5 mm. The up to 1.5 mm large glauconite grains have an uneven, elliptical shape with smooth edges and is unevenly coloured, ranging from brown to lighter khaki green (Fig. 19).
There are also clasts in the section made up of a brown grey clay mineral but also some quartz. The grain size ranges from 0.2 to 0.8 mm. This thin section also show evidence of burrows. For example there is a large, ca 5 mm thick aggregate of echinoderms surrounded by burrows (Fig. 19).

Sample: 191.70–191.78 m

This thin carbonate-dominated sample contains the highest amount of echinoderm fragments and other calcareous fossils of uncertain affinity (Fig. 20). It contains less glauconite than the previous sample. The greenish glauconite grains are mostly moderately rounded (Fig. 20). One glauconite grain has 0.1 mm large mineral grains incorporated in it. Grey brown 0.5 mm large clay mineral aggregates make up c. 15% of the thin section
Up to 2 mm large elongated fossils are also present (Fig. 20).

Sample: 185.75–185.80 m

This thin section is characterized by numerous burrows. The content is ca 50/50 between clasts and echinoderms. The echinoderms are brown and mostly elongated (Fig. 21). The size ranges from 0.15 to 0.35 mm. There is also a high amount of moderately rounded glauconite grains, ca 10%. The glauconite grains have a green colour and are moderately rounded (Fig. 21). The detrital components consist of quartz but also clay minerals. The clay minerals are angular with a size up to 0.25 mm (Fig. 21).

4.3 Carbon isotopes and total carbon content

The results are somewhat difficult to interpret since the results vary greatly through the sampled interval. The most significant change occurs at the 270 m level where the curve drops to overall lower values on the $\delta^{13}C$ curve in the interval above (Fig. 22). This corresponds also to a shift in the depositional setting and perhaps also a hiatus between the Kimmeridgian Fyledal Clay and the Upper Jurassic to Early Cretaceous Annero Formation (read more in upcoming the chapters). The analysis of the total organic carbon content does also clearly visualize the change at 270 m depth from very low to variably high values.

4.4 Fossils

The macrofossils in the Revinge core are dominated by mollusc shell fragments and imprints of primarily bivalves and gastropods. The preservation is generally good, even if many of the species and genera are thin shelled. Beside these fossil groups there are frequent beds between 125 m and 265 m depth which contain numerous remains of bony fishes. These are characteristically composed of less than 0.1 mm large plates and teeth. Other fossil findings are a few gastropods, microfossils and palynomorphs (cf. Fig. 9).

In Revinge-1, the interval interpreted as the Vitabäck Clays, 269–246 m (Unit B), includes several layers containing well preserved molluscs. The following fossils have earlier been found in the Vitabäck Clays in Scania (Ekström 1985): *Myrene* cf. *angulata*, *Neomiodon* (Barremian), *Jurassicorbula sp.* (M. Jurassic), *Quenstedtia* sp. (Jurassic), *Isognomon* cf. *mytiloides*, *Lepidotus* sp. (fossil fish tooth, Early Cretaceous), *Integricardium* (Jurassic/Cretaceous) and *Ostrea*. Some species of gastropods were also found: *Hydrobia* cf. *acuminate*, *Cloughtonia* sp. (Jurassic) and *Valvata* cf. *helicelloides*.

The identified fauna from the Vitabäck Clays indicates brackish environments (Ekström 1981; Erlström et al. 1991).

The well-preserved shells of Revinge-1 are difficult to determine the species of because they almost exclusively consist of dorsal shells. Well preserved specimens were found at 275 m, 267 m, 258.3 m, 252 m and 250 m depth. The mollusc imprints at 275 m are up to 4 cm wide and inequilateral , with a small anterior part in relation to the posterior part, which is larger (Fig. 9). At 267 m a 6 cm large bivalve is found (Fig. 9). The valve is rounded and almost equilateral. The umbo is very straight. The valve might have an inconspicuous ridge. The overall poorly preservation of the shell makes it hard to identify. At 258 m smaller bivalves, approximately 1 cm large, were found. Most are white but some of them possess a darker blue-grey colour (Fig. 9). These bivalves have clear inequilateral valves with a very prominent ridge and several clear growth- and rest lines. They are ra-

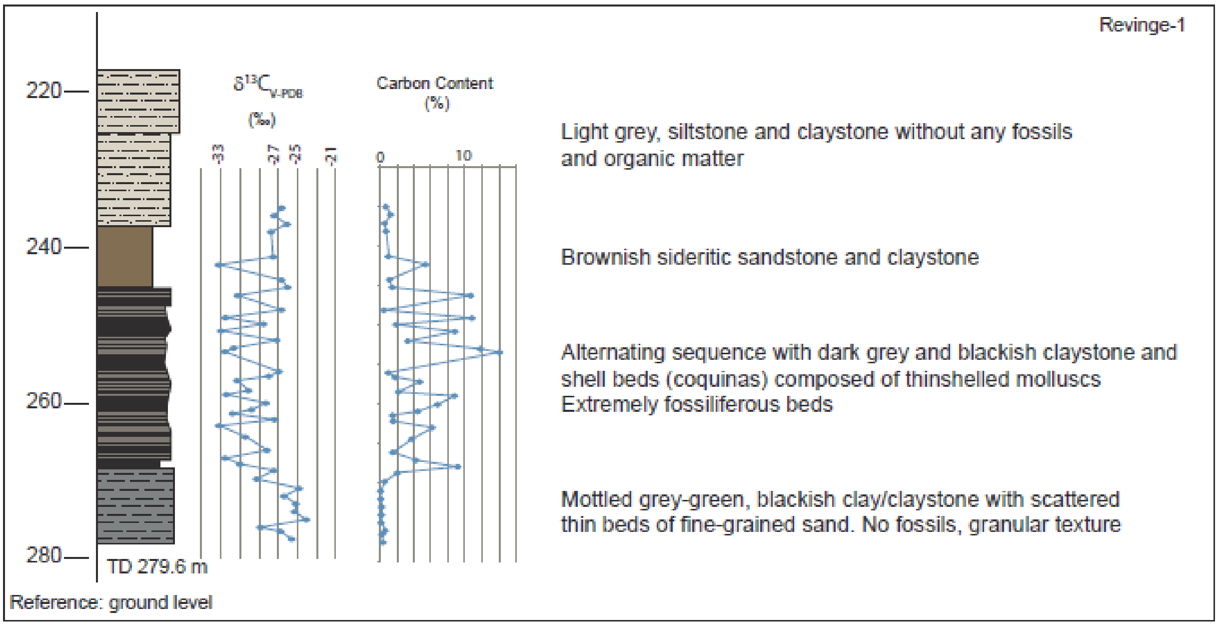

Fig. 22: This figure illustrates the carbon content change in the displayed interval. A change can be seen at ca. 270 m, with a prominent plateau.

ther similar to the bivalve family Neomiodontidae.

A finding was made at 252.7 m containing numerous molluscs in different shapes (Fig. 9). For instance, there are 3 cm large bivalves with a seemingly equilateral valve. There are also more poorly preserved bivalves with a size of approximately 1 cm present. One of the small bivalves possesses an inequilateral valve, unlike the other 1 cm large bivalves.

The shells at 250.3 m are hard to identify (Fig. 9). Their curved valves seem inequilateral and look elongated in a dorsal-ventral direction.
Worth to be mentioned is also the finding of a well-preserved 3 cm large gastropod at about the same depth. The gastropod has a 1.5 cm large body whorl and the tip of the shell, the apex, looks broken.

The sediments together with the fossil material provide evidence for an environment with low water energy. Findings made in this core are very similar to taxa mentioned by Ekström such as *Myrene* and *Neomiodon*, e.g. molluscs at 250.3, 252.7 and 258.3 m. The fauna can be correlated to similar faunas in Northwestern Europe of the same age (Berriasian) (Ekström, 1985). Some of the bivalves in Revinge-1 also look similar to bivalves found in the Jydegård Formation.

4.5 Biostratigraphy

The succession is predominantly siliciclastic, including the interval that covers the Cenomanian-Turonian, and as such provides for the first time non-carbonate core material from this time interval. Preliminary palynological analyses have shown that there are well preserved and diverse palynological assemblages throughout the core. The depositional environment is marine to marginal marine.

Preliminary palynological analysis of selected samples from the core provide evidence of well preserved and diverse dinoflagellate cyst assemblages (and spores and pollen) of Cenomanian age within the 128−170 m interval, while the top of the core (at 87 m) indicate Turonian age. At 226 m the palynofloral analysis indicate a Volgian to mid Berriasian age. Preliminary palynological data of the lowermost part of the succession also indicate a Volgian−mid Berriasian age (at 245 m) and possibly older Jurassic strata below. At 238.47 m, palynomorphs such as sphaeromorph clusters, *Cerebropollenites thiergartii*, *Botryococcus* and sapropel were identified.

The pollen *C. thiergartii* is an important marker for the Early Jurassic in continental successions (von Hillebrandt et al. 2007; Kuerschner et al. 2007; Bonis et al. 2009; Pienkowski et al. 2012). *C. thiergartii* usually occurs in close connection to the ammonite species *Psiloceras spelae*, which argued to represent the base of the Jurassic (Hillebrandt & Krystryn 2009).

Previous palynological work performed within a joint SGU/GEUS-financed geothermal project on old core material from deep drillings in the Höllviken Halfgraben and on the Skurup platform has confirmed the presence of a major unconformity between the Lower to Middle Jurassic and the Lower Cretaceous, and between the Rhaetian and the Lower Cretaceous, respectively.

4.6 SEM-EDX analyses

The purpose of the SEM-analyses was to investigate the brown iron ooid clastic unit (Unit C) covering the interval from 239.9 m to ~ 242 m. The aim was to investigate if there were characteristics related to a possible volcanic event.
Overviews of the investigated samples covering the interval are shown in Fig. 23 and Fig. 24.

The first sample (Sample 1) contained four different features: veins, matrix, grains and iron ooids (Fig. 23). There are numerous horizontal undulating veins and smaller vertical irregular vein transecting the sample. The very fine-grained matrix has a green brown colour. The observed iron ooids are poorly preserved) and do not show any clear lamination and are mostly with an elliptical shape (see figures from microscopical investigations).

The second sample (Sample 2) displays the same features as the previous sample, however the amount of iron ooids is much higher, at least 40% of the sample is composed of ooids (Fig. 24). There are also veins covering the entire thin sections, both horizontally but also vertically. Most are undulating or irregular. The matrix is fine-grained but does now possess a more brown colour. Iron ooids are both elliptical and spherical and well-preserved ones can be found with concentric layers.

A detailed study of the samples was made using SEM-EDX. The presented results come from selected grains or specific areas which display mineralogical or textural features of interest.

Thin section 240.75 m (1) : The first analysed part of the sample was a vein rich in iron and was found to be composed of pyrite (FeS_2) (Fig. 23). A white zone adjacent to the vein contains Ca, Fe and a smaller amount of Mg. This zone displays several generations of either white or grey backscatter fields (Fig. 25), indicating some kind of mineralogical heterogeneity in the materials. The light material is richer in iron, and interpreted as siderite ($FeCO_3$) while the grey material containing more Ca and Mg is interpreted as carbonate $(Ca,Mg)CO_3$.

The deposition of carbonate did most likely occur first, followed by a mineralization of siderite followed by pyrite crystallization in veins. Additional analyses were performed on a fine-grained, mottled and porous matrix (Fig. 25). The small crystals found were flaky and elongated, mostly randomly orientated. A preferred orientation was, however, observed for some of the crystals. The crystals contain Mg, Al, Si, K and Fe and are interpreted to represent some kind of clay mineral, likely hydromica or illite. Several crystals similar to this can be found in the sample.

Analysis of a dark grey fine-grained area occurring in the outer fringe of the thin section gives a clay mineral associated composition dominated by Fe, Al, Si, Mg and Ca. In this case likely some kind of chlorite or smectite due to the lack of potassium which is present in the hydromica-illite clays.

The last presented analysis from this sample is performed on an iron ooid. The nucleus of this ooid turned out to be the same kind of clay mineral as in the rest of the thin section. The material surrounding the nucleus was interpreted as siderite, containing Al, Si and some Fe and a minor amount of clay minerals.

Thin section 240.80 m (2) : This analysis focused on the iron ooids. The first analysed area included three iron ooids (Fig. 25). The dark grey centre of the first one is identified as calcite while the lighter grey surrounding areas are composed of iron rich carbonates, i.e. siderite. The second ooid is composed of very thin, concentric layers and more or less pure calcite, together with a few siderite crystals. The third ooid is largely hollow with siderite in the centre and an outer zone of calcite (Fig. 25). The second analysed area also contained iron ooids, however slightly different from most of the other iron ooids in the samples. These ooids contained minute needle-like crystals of pyrite within the calcite zones building up the ooid (Fig. 25). The first ooid examined had an oval shape and pyrite was present in contact with calcite. The nucleus of the ooid contained minerals interpreted to be quartz and siderite. The second analysed ooid with a similar shape contained a higher amount of siderite. The siderite seems to be migrating outwards and intruding the previously formed calcite layers. Another iron ooid examined had a core containing a light mineral, also interpreted as siderite. A thin layer of quartz occupied the outside of the core. The rest of the ooid consisted of a layer interpreted as calcite with needle-like pyrite (Fig. 25). The sample also contains an undulating minor calcite filled fracture passing around one ooid and through a siderite grain. The needle-like pyrite is also present within the calcite filled fracture. The last ooid examined in this thin section has a core made of what is interpreted as a clay mineral, surrounded by layers of calcite and siderite.

The occurrence of odd-looking needle-like pyrite is striking. This needle-like crystal shape of the pyrite is called acicular (Årebäck et al. 2008) or dendritic (Murowchick & Barnes 1987). It is very rare in nature, but is known to occur in Mexico, Haledon, New Jersey and Kentucky. The habit is thought to be produced under conditions of low supersaturation and

Fig. 23: Scanned copy of the first thin section from the iron ooid-rich interval at 240.75–240.95 m. It is dominated by the green brown fine-grained matrix, disrupted by calcite-filled fissures and veins. Iron ooids are found at the top and in the bottom right corner. The thin section is c. 2x3 cm large. Most of the analysed spots are located within the red circle.

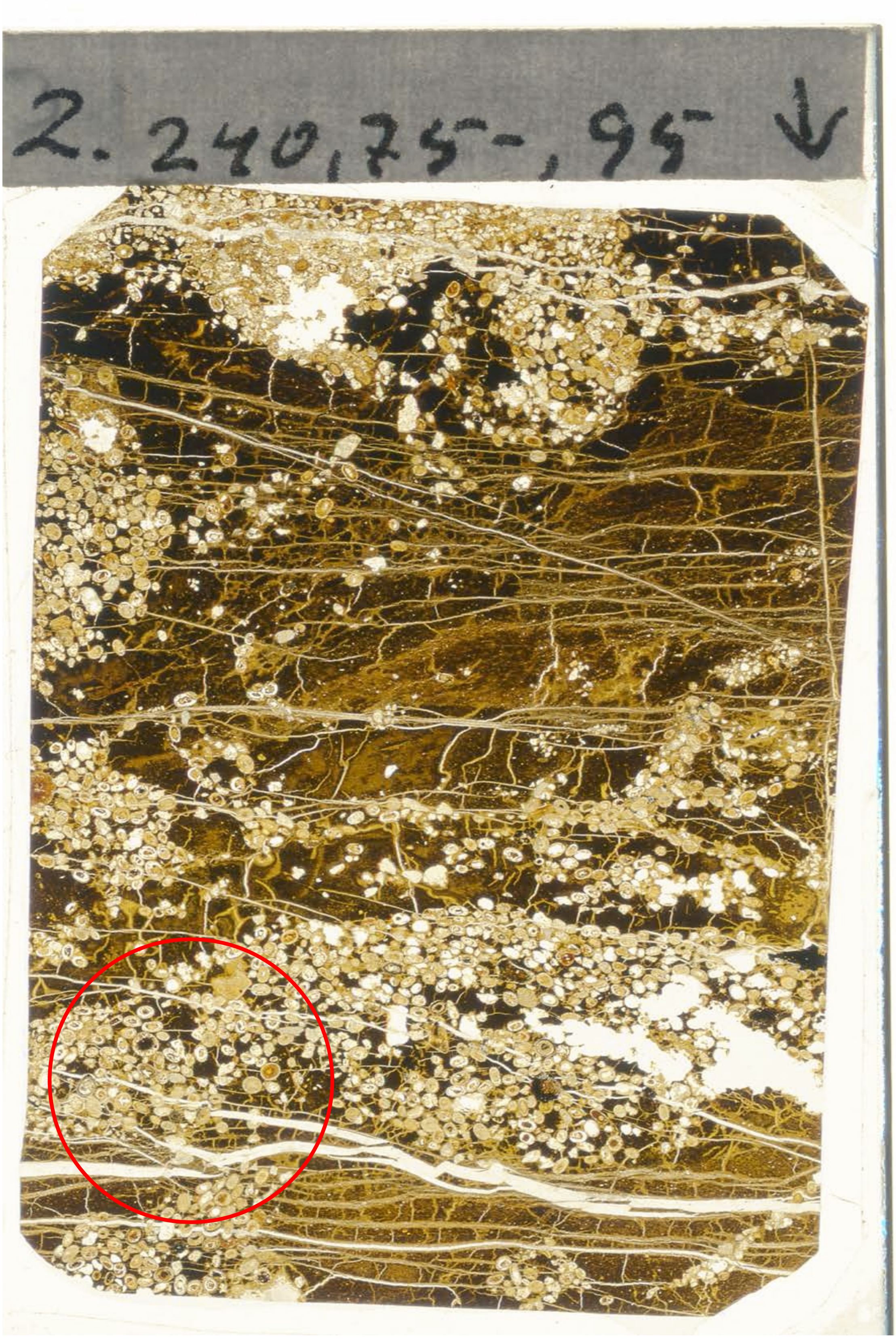

Fig. 24: Scanned copy of the second thin section from the iron ooid-rich interval at 240.75–240.95 m. This thin section possess a darker colour and more iron ooids than the previous one. Note the different generations of fissures. The thin sections measures c. 2x3 cm. The red circle marks the location of the analysed ooids.

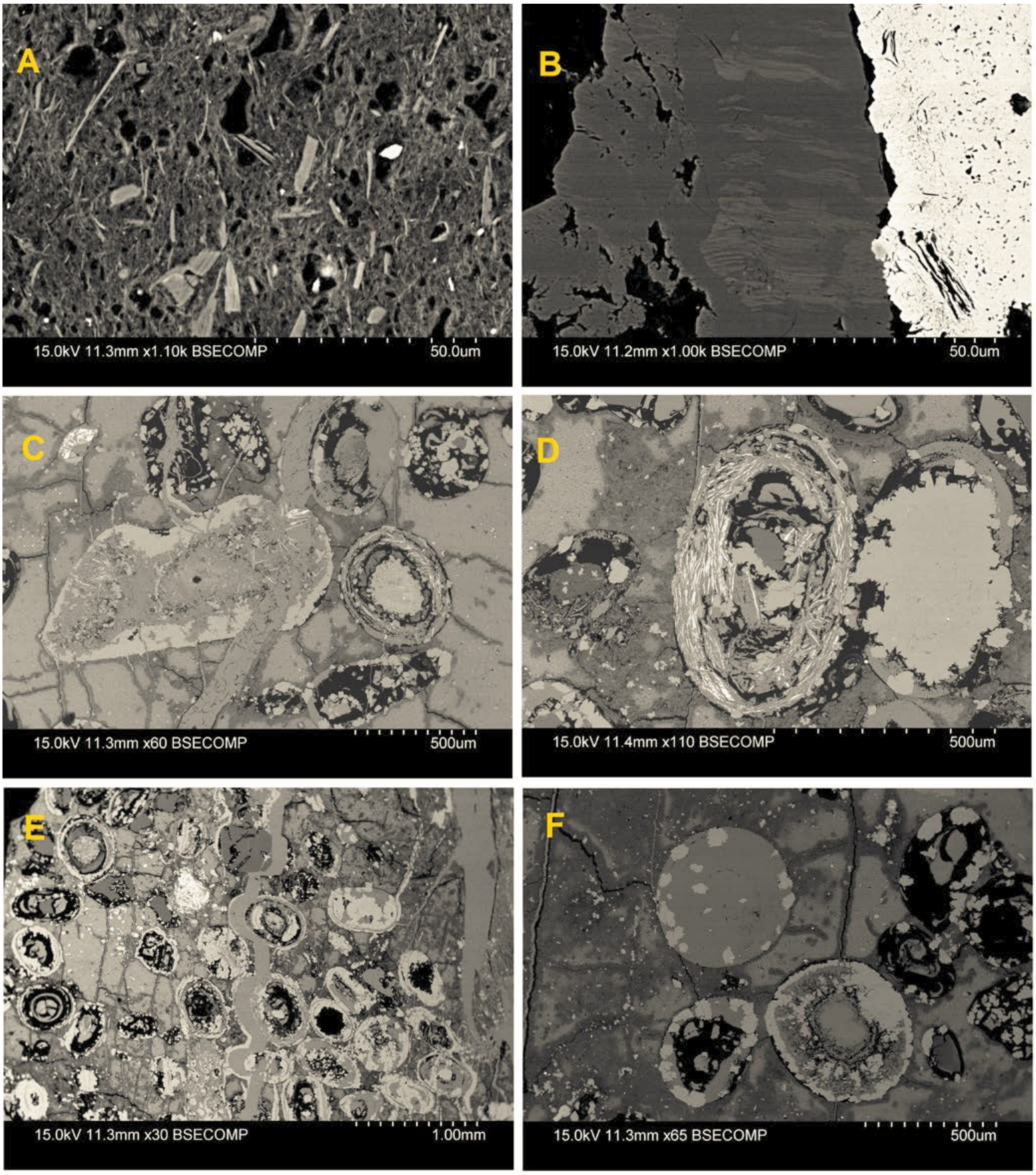

Fig. 25: BSE-images taken from the thin sections in Fig. 23-24. A: Porous fine-grained matrix with flaky clay mineral grains. B: Mottled texture in vein; carbonate and siderite (light grey). The white material next is an iron-rich vein, interpreted as pyrite. C: Calcite-filled fissure through a siderite grain and iron ooids, elliptical and spherical. D: Elliptical iron ooid, with needle-like pyrite incorporated in the carbonate layer. The core contains quartz and siderite. The ooid next to it contains siderite. E: Iron ooids and calcite-filled fissure, going around the iron ooids and more seldom, through them. F: Spherical ooids consisting of carbonate (dark grey) and siderite (light grey).

low to moderate temperatures (<250 °C) through a "screw-dislocation" (Murowchick & Barnes 1987), meaning that the mechanism can provide for a continiuous growth of the crystal. Pyrite dendrites have also been observed where fluids were stagnant in a submarine hydrothermal chimney at latitude 13°N on the East Pacific Rise (Murowchick & Barnes 1987).

The steep temperature gradients needed to produce this type of pyrite are not common in nature except in sea-floor geothermal systems, e.g. at the highest degrees of supersaturation (Murowchick & Barnes

1987). Under these settings, pyrite growth is very rapid as the hot water comes out of the crust and chills instantly against sea water (Murowchick & Barnes 1987). In Revinge-1, where no extreme environment, as mentioned above, is thought to have been present, the possibility of a volcanic impact cannot be neglected. The material in thin sections from 239–240 m has probably been affected by a transport of hydrothermal fluids rich in sulphides, iron, magnesium etc. in connection to a volcanic event, giving rise to the visible texture and content in these thin sections. This might have partly helped to produce the iron ooids and the needle-like pyrite.

5 Interpretation of the Revinge succession

See Appendix for more detailed logs.

5.1 Unit A: 278–268 m

Stratigraphic affinity: Fyledal Clay

The Fyledal Clay is dominated by the green, yellow and brown claystone. Norling (1981) described the findings of charophyte gyronites, megaspores and coal as an indicator of littoral and even limnic environments. These findings were made SE of Helsingborg (Rydebäck-Fortuna Boring No. 5) (Norling 1972) and at Eriksdal. Similar findings occur continuously in the Revinge core at depths below 267 m.

Norling (1981) mentions a foraminiferal fauna of arenaceous forms, represented by genera such as *Ammobaculites, Cornuspira, Reophax* and *Valvulina*. They reflect brackish conditions after comparison with present-day faunas (Gordon 1970). In the Revinge-1 core it is equal to a green, yellow, green and brown-black argillaceous claystone with some silt fills, lacking shelly fossils but containing fossil imprints and several roots and coal parts (Fig. 26).

Depositional setting: The Fyledal Clay was most likely deposited in an "undisturbed quiet water environment with lagoons, lakes and wet marshes" (Norling et al. 1993; Erlström et al. 1994, p. 37). The very fine-grained material such as clay and mud with rootlets and coal fragments are very good indicators of this depositional setting. The general absence of coarser detrital material indicates no supply and thereby no rivers, so this area likely represented a low, protected hinterland setting (Erlström et al. 1994). Findings of ostracodes, arenaceous and calcareous foraminifera, caliche nodules, gypsum and organic-rich beds in e.g. Eriksdal, support this depositional environment (Norling et al. 1993). Findings like these are present at the bottom of the Revinge-1 core, below 267 m. Shallow brackish lagoons were opened and closed, and carbonate verifies evaporation leading to saturation. The wet areas between lakes and lagoon consisted of swamps with deposition of clay and silt.

5.2 Unit B: 268–246 m

Stratigraphic affinity: Vitabäck Clays

This unit is characterized by a stacked sequence of fining upward cycles grading from fine-grained sand to silt and organic rich clays (Fig. 26). The interval is also very rich in fossils and shells and contains several coquina layers. The fossils are mostly very well preserved and dominated by thin-shelled molluscs (Fig. 9). The lowermost part of the unit is slightly sandier in comparison to the upper part. The fauna and sediments indicate a brackish-freshwater environment temporarily influenced by marine conditions (Fig. 26).

Vajda & Wigforss-Lange (2006) examined and identified terrestrial pollen and spores, algae (*Botryococcus*) and dinoflagellates from the Vitabäck Clays in Southern Sweden. A Berriasian age was obtained for these palynological data (Vajda & Wigforss-Lange 2006). The Jurassic—Cretaceous boundary should therefore be placed in the basal part of the Vitabäck Clays (Fig. 26) (Erlström et al. 1991; Vajda & Wigforss-Lange 2006).

In the Vomb Trough, Christensen (1968) mentions some 18 m thick sand that occurs between the Fyledal Clay and the Vitabäck Clays, possibly representing the Nytorp Sand. The Nytorp Sand is earlier described as a well-sorted fine- to medium-grained sand with shell debris, detrital coal and interbeds of clay (Erlström et al. 1991). Norling (1981) describes the Nytorp Sand as a light brown and whitish sand and silt with thin darker bituminous bands as well as bluish grey and dark grey argillaceous calcareous sand with coal fragments. The Kimmeridgian–Portlandian boundary may be within the Nytorp Sand in western and north-western Scania (Norling 1981). The Nytorp Sand is not verified in the Revinge-1 core. There is no potential sand candidate corresponding to the Nytorp Sand between the units A and B. The ostracode fauna of both the Fyledal Clay and the Vitabäck Clays indicate a Tithonian age (Christensen 1968).

Depositional setting: The clay is interpreted to be deposited in quiet water environments, such as lagoons (Erlström et al. 1994). This is also verified by the thin-shelled bivalves in the numerous shell beds. The lagoons were sometimes disturbed by increased supply of clastics from rivers or channels, indicated by the fine sand-layers. A closure of this lagoonal environment is indicated by the occurrence of dark, dense and

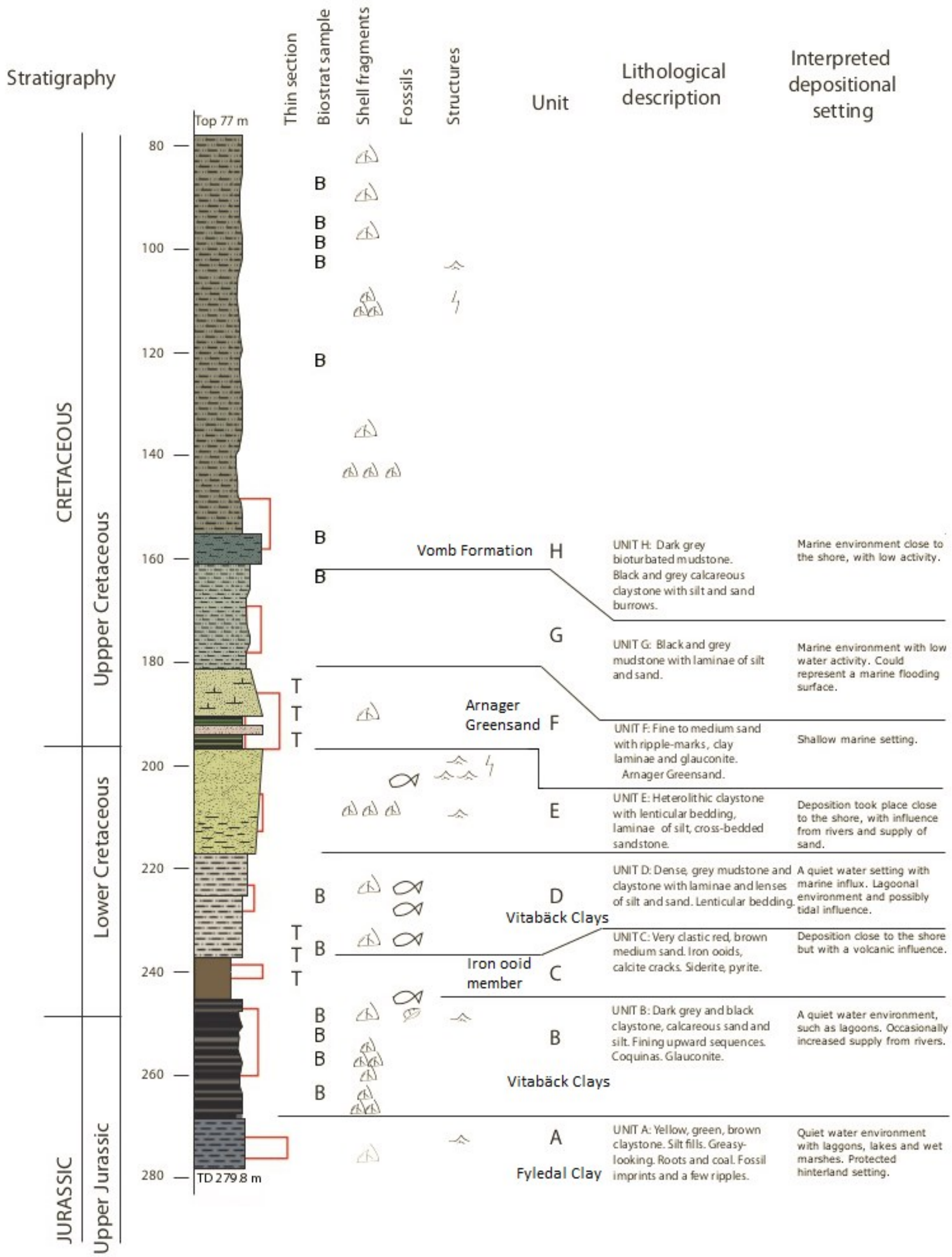

Fig. 26: Stratigraphic log illustrating defined units and their depositional environment, and the interpreted location of the J/K–boundary.

organic-rich claystone and a few layers of silt repre senting deposition in closed lagoonal and marsh settings (Fig. 26).

5.3 Unit C: 242–239.9 m

Stratigraphic affinity: Lower Cretaceous undefined iron ooid member

From the petrological analyses it has been determined that the clastic, red brown interval of Revinge-1 contain a series of iron rich layers of sandstone which in parts are extremely rich in Fe-ooids. The lithological characteristics make this interval distinctive in comparison to the Vitabäck Clays of the underlying unit B and overlying unit D. The mineralogy is dominated by siderite, calcite, quartz and clay minerals such as hydromica, illite, smectite and chlorite. Pyrite is also a common accessory mineral found both as pore and fracture filling precipitations and as needle-like (acicular) mineralizations in the ooids.

Results from investigations on an unconsolidated deposit of iron ooids at the volcanic island Mahengetang in Indonesia, have given a better understanding on origin of this type of acicular pyrite (Heikoop et al. 1996; Sturesson et al. 1999). The ooids were formed by chemical precipitation of cryptocrystalline iron oxyhydroxides on available grains on the seafloor, from seawater enriched with Fe, Al and Si. The enrichment is interpreted to be initiated by the presence of hydrothermal fluids, volcanic ash in shallows basins or rapid weathering of fresh volcanic rocks (Oftedahl 1958; Kimberley 1989; Sturesson 1992a, b, 1995; Sturesson et al. 1999).

Depositional setting: The Indonesian ooids are formed from iron and silica-rich fluids, while the Ordovician examples were probably formed from volcanic ashes (Sturesson et al. 1999). The ash fell into the sea and/or was transported from land into the sea and accumulated near the shore. The dissolution of the ash goes rapidly, and the enrichment of iron, aluminum and silica in the seawater occurred locally. The elliptical shape and concentric texture suggest a direct chemical precipitation of iron oxyhydroxide and silica rather than a mechanical accretion of these minerals from the seafloor (Heikoop et al. 1996). It is, thus, highly plausible that the iron-rich deposit enriched in iron ooids in the Revinge-1 core could have been generated in a similar environment, thus strongly related to volcanic activity in the adjacent area (Fig. 26). Several of the iron ooids found in the Revinge-1 show a very fine lamination and the SEM-EDX analyses show that most were made of siderite but dominated by a clay mineral, probably chamosite, that was rich in iron. The preliminary palynological data indicates a Volgian to mid Berriasian age (at 245 m). This provides further evidence that the possible volcanic event might be the actual event occuring at 145 Ma (Bergelin, 2011), close to the J/K−boundary.

5.4 Unit D: 239.9–219 m

Stratigraphic affinity: This interval is very similar to Unit B, thought to represent the Vitabäck Clays.

This clay-rich unit with varying amounts of fine sand and silt is occasionally mixed into lenticular bedded deposits (Fig. 26). There are also several fining upward sequences. It is mainly distinguished from Unit B by a relatively low abundance of fossils. There are still some scattered molluscs and also some bony fish remains, but remarkably lesser than in Unit B. This fact could be related to unfavorable or hostile environments for the shell-bearing fauna, coupled with a possible volcanic activity in the area, represented by unit C.

Depositional setting: Unit D sediments also show evidence of deposition in a quiet water setting, occasionally with a higher water activity, due to the fine sand and lenticular bedded deposits (Fig. 26). The lenticular bedded structures might be evidence for tidal deposits. Most likely this unit was also deposited in a lagoonal environment, with a few events and an increased supply of sand from rivers, as thought for Unit B. The sand is occasionally also very rich in iron, as can be seen from the mottled reddish colour.

5.5 Unit E: 219–200 m

Stratigraphic affinity: Lower Cretaceous undefined

This unit is characterized by higher proportion of sand in comparison to underlying intervals. The unit is also frequently heterolithic (Fig. 26). It is also characterized by the presence of ripple-lamination, cross-bedding, bioturbation and burrows.

Depositional setting: The relatively high amount of sand, ripples, heteroliths and burrows indicate a deposition closer to the shore, with some influence from rivers and supply of sand-sized material (Fig. 26). Still, fine-grained clastics dominate and indicate an overall relatively quiet setting. A rich infauna is indicated by heavily mottled and burrowed sequences.

5.6 Unit F: 200–171 m

Stratigraphic affinity: Arnager Greensand

In this unit, as in Unit D, sand continues to be the dominating detrital constituent. The sand has a greenish grey colour from the high amount of glauconite and also looks mottled brown from discolourations by iron-rich carbonates (Fig. 26).

This unit is interpreted to be of Cenomanian age. In the Assmåsa-1 core it is described as a light grey glauconitic sandstone overlying the Annero Formation (including the Vitabäck Clays) at a depth of 456 m (Chatziemannouil 1982). The Arnager Greensand occurs also in SW Scania, and in the Kristianstad and Hanö Bay basins. The only exposed parts of the Arnager Greensand can be found on the island of Bornholm, at its type location at Arnager on the south coast.

In SW Scania, the formation is thoroughly mapped out by seismics. The distinct seismic reflection due to the great difference in acoustic impedance between the sandstone and the overlying Arnager Limestone results in one of the strongest seismic reflection surfaces in the Mesozoic sequence of Scania.

In the Vomb Trough, the Arnager Greensand has been hard to define as similar sandstone intervals occur over a broader time span in comparison to the other areas. However, a sequence of Arnager Greensand, overlying the Vitabäck Clays in the Fårarp-1 core is dated to the Tithonian − Valanginian (Lindström & Erlström 2011).

The interval described as unit F in the Revinge core is composed of sediments very similar to the ones found in the other deep borings in the Vomb Trough (cf. Erlström et al. 2004). The conspicuous content of glauconite, carbonate cement, interbeds of arenaceous limestone and scattered fossils of possible echinoderm origin all point towards the Arnager Greensand.

Depositional setting: The Arnager Greensand has probably been deposited in a shallow marine setting (Fig. 26).

5.7 Unit G : 171–164m

Stratigraphic affinity: Lower Cretaceous–lower Upper Cretaceous undefined lithostratigraphic unit

This unit is mostly made up of black and grey claystone (Fig. 26). The sediments are also lacking fossils.

Depositional setting: This fining-upward sequence from previous sediments might indicate a transgression (Fig. 26). The black clay indicates marine settings and the interval could thus represent a marine flooding surface. The palynological data indicate a Cenomanian age for the interval 128−170 m.

5.8 Unit H: 164–77 m

Stratigraphic affinity: Upper Cretaceous Vomb Formation

This interval is dominated by variably argillaceous, arenaceous and calcareous deposits (Fig. 26). They are commonly mottled due to intense bioturbation. The interval is in parts also rich in shells. The characteristics are very similar to the ones described in Erlström et al. (1994) for the Upper Cretaceous Vomb Formation.

Depositional setting: Most likely deposited in a shallow marine environment (Fig. 26). The palynological data from 87 m indicate a Turonian age. Shells and intense bioturbation indicate an environment relatively close to the shoreline, not a deep sea.

5.9 Sequence stratigraphy – successions relationship

Starting from the bottom, Unit A (the Fyledal Clay), indicates an environment dominated by lakes and wet marshes. The climate was likely warm and humid with a rich vegetation occupying the land areas. The sediments contain a few molds of bivalves, where the carbonate shell has been dissolved by acidic water. The Fyledalen Clay is regarded as Oxfordian to Kimmeridgian in age, thus uppermost Jurassic. The boundary towards Unit B is seen as an erosional surface. As we move into unit B, the Vitabäck Clays, the sediments still contain a lot of clay and mud, but also a higher frequency of silty and sandy beds. The landscape is now interpreted as a lagoonal environment with occasionally increased supply of silt and sand from nearby rivers. Bivalves thrived in this environment and both marine and terrestrial influences characterize the sediments as indicated by the presence of rootlets, black clay and coquinas. These sediments are cut off abruptly by a unit dominated by red and brown Fe-rich coarser sands (Unit C). The boundary does at first sight look gradational, due to a dirty and alternating texture, but it is actually quite abrupt. Unit C is enriched in iron ooids, clay minerals and siderite . The cause of this is interpreted as related to volcanic activity in the vicinity to Revinge. There was likely a hydrothermal as well as a geochemical impact on the deposits formed, resulting in the rich iron ooid beds found in Revinge-1. This is interpreted to be the volcanic event at the Jurassic–Cretaceous transition (ca. 145 Ma; Bergelin et al. 2011). This event can be correlated with volcanic activity in the Central Graben (Bergelin et al. 2011). Two other volcanic events have been identified in the Mesozoic of Scania, i.e. a Jurassic event (Sinemurian to Toarcian; 178–191 Ma) and one in mid-Cretaceous (Albian; 110 Ma; Bergelin et al. 2011).

The volcanic event related to unit C most likely had a strongly influence on the environment and the organisms living in the area. Before deposition of unit C there was a rich fauna preserved in the deposits while in the overlying unit D, also with a quite abrupt boundary, the abundance of fossils is conspicuously low even though the sediments are similar. Some bony fishes and a few shells can, however, still be found in unit D. The lagoonal environment with influx from rivers does otherwise still seem to persist into the the Lower Cretaceous. Moving into unit E with a gradational contact, a large increase in grain size is the most obvious change. The sediments are now mostly dominated by cross-bedded sandstone. The area is probably close to the beach with a large influx of sand from rivers. In the next unit with a gradational contact, Unit F (Arnager Greensand), a large increase in glauconite, burrows etc. and some clay laminae indicate a more marine environment in which marine organisms and molluscs thrived. The following Unit G, with a gradational contact and Unit H, with a sharp contact also indicate a marine transgression. The sea level rise is indicated by bthe presence of black and grey claystone and mudstone with limited amounts of silt and sand. Black claystone is only deposited under very quiet conditions, as in an undisturbed sea with low water activity.

To summarize, the facies of Revinge-1 indicate a progressively increased influence of marine conditions. The Upper Jurassic is mainly marine (Batten & Koppelhus 1996) but up-section it was deposited during lagoonal or deltaic conditions, which persisted into the Lower Cretaceous. Towards the end of the Late Cretaceous, the marine influence increased. Vajda (2001) mentions an increase in marine palynomorphs in Höllviken during the Valanginian (Vajda 2001).

6 Discussion

The area dealt with in this paper spans a succession from the Late Jurassic to the Late Cretaceous. The succession show characteristics of a coastal plain to a shallow shelf environment. Relative sea-level changes played a significant role in controlling the facies distribution, as deposition mainly takes place in a coastal environment (Ahlberg et al. 2003).

Erlström et al. (1997) describes the structure and tectonic evolution of the basins in Scania, from the Triassic to the Cretaceous. During the Rhaetian−Jurassic block faulting resulted in lateral thickness variations and lithofacies differentiation. The deposits are mainly dominated by marine−lacustrine sediments such as clays, coal and sand. The deposits were thicker in pull-apart basins. The Cretaceous was initially characterized by fairly calm tectonic conditions followed by several transgressive pulses coupled to basin subsidence and uplift of the Sorgenfrei-Tornquist Zone (Erlström et al. 1997).

A distinct maximum flooding is recorded by an abundance of dinoflagellate cysts in the lowermost Berriasian and also by the presence of shell beds in the Fårarp-1 core (Lindström & Erlström 2011).

Strata from the Danish island of Bornholm, equivalent in age to the succession in Fårarp-1, and also Revinge-1 were deposited in a bay setting varying from fully terrestrial to marine (Lindgren et al. 2008; Lindström & Erlström 2011). The strata of the Fårarp-1 core, are very similar to the ones of the Rabekke Formation (Lindström & Erlström 2011) of the Lower Cretaceous Nyker Group on Bornholm (Piasecki 1984). The Jydegård Formation, from the same group, contains mass occurrences of the bivalve *Neomiodon angulata* coinciding with blooms of the dinoflagellate cyst *Sentusodinium pelionense*. This was interpreted as representing mass mortality of the bivalves from toxic algal blooms (Lindström & Erlström 2011). The Jydegård Formation is also in age corresponding to the German "Wealden", equivalent to the Upper Purbeck and also to the lower Ashdown Formation; the base of the Hasing Beds of the Wealden-type in Britain (Gravesen et al. 1984). Units A–D in Revinge-1 is contemporaneous to these formations as well and to the Fårarp-1 core and indicate a similar depositional environment and development. The bivalves from the Jydegård Formation is very similar to bivalves found in Revinge-1. A climatic change from the Jydegård Formation has yet not been reported due to lack of detailed studies of especially the terrestrial palynology.

In Revinge-1, the J/K–boundary is drawn at the interpreted volcanic event and iron ooid deposition (Unit C) at 145 Ma ago. Other parts of Western and Central Europe were also under the influence of an increased tectonic activity, as well as in Scania, where pre-existing faults were reactivated (Norling & Bergström 1987).

The J/K–boundary is currently placed at the base of *Berriasella jacobi* Tethyan Ammonite Zone, corresponding to somewhere within the lower part of the *Subcraspedites preplicomphalus* Boreal Ammonite Zone (Hunt 2004; Lindström & Erlström 2011). In Fårarp-1, the boundary is set in the lower part of the Vitabäck Clays at 106.78 m, corresponding to the volcanic event at ca 240 m depth in Revinge-1.

The Fårarp and Revinge investigations provide complimentary information on the boundary. The studies show how marginal deposits from the northeastern coast of the epicontinental sea that connected the Boreal and Tethys oceans reflect climatological and environmental changes across the J/K–boundary. As mentioned in the introduction, a change from semi-arid conditions during the Tithonian to a more humid climate during the Berriasian has been described and discovered through a change in pollen and spores (Allen 1998; Lindström & Erlström 2011). The climate change also involves a Berriasian marine flooding in the area where Revinge now is located; terminating the stagnant depositional environment during the Tithonian (Lindström & Erlström 2011).

The final conclusions to be drawn about Revinge-1 are:

- The core displays a succession of strata ranging from the Upper Jurassic Fyledal Clay to the Upper Cretaceous Vomb Formation.

- The core includes strata of the Annero Formation including the Jurassic-Cretaceous boundary.

- The molluscan fauna of the Vitabäck Clay Member of the Annero Formation is exceptionally well-preserved and mostly contain thin-shelled bivalves indicating low energy-environments in a brackish-marine setting.

- Silty clays in the Vitabäck Clays contain a fauna rich in mm-large bony fish remains.

- The sediments show evidence of a successive change in sea level into more marine conditions and a related climatic change when moving from the Jurassic into the Cretaceous.

- A rich interval of well-preserved and perfectly shaped iron ooids indicate a volcanic event and influences of hydrothermal fluids during deposition at the J/K–boundary, likely corresponding to a 145 Ma volcanic event in Scania.

Further research can be done and should focus on the theory about the volcanic event. Additional biostratigraphic analyses could help to constrain the J/K–boundary. Also further research should be done on the strangely shaped pyrite and if this actually can be scientifically proven to be related to volcanic events in any way. The well preserved mollusc shells and bony fish remains allow also for more detailed work regarding genus and species affinity as well as their stratigraphic and paleoecological importance.

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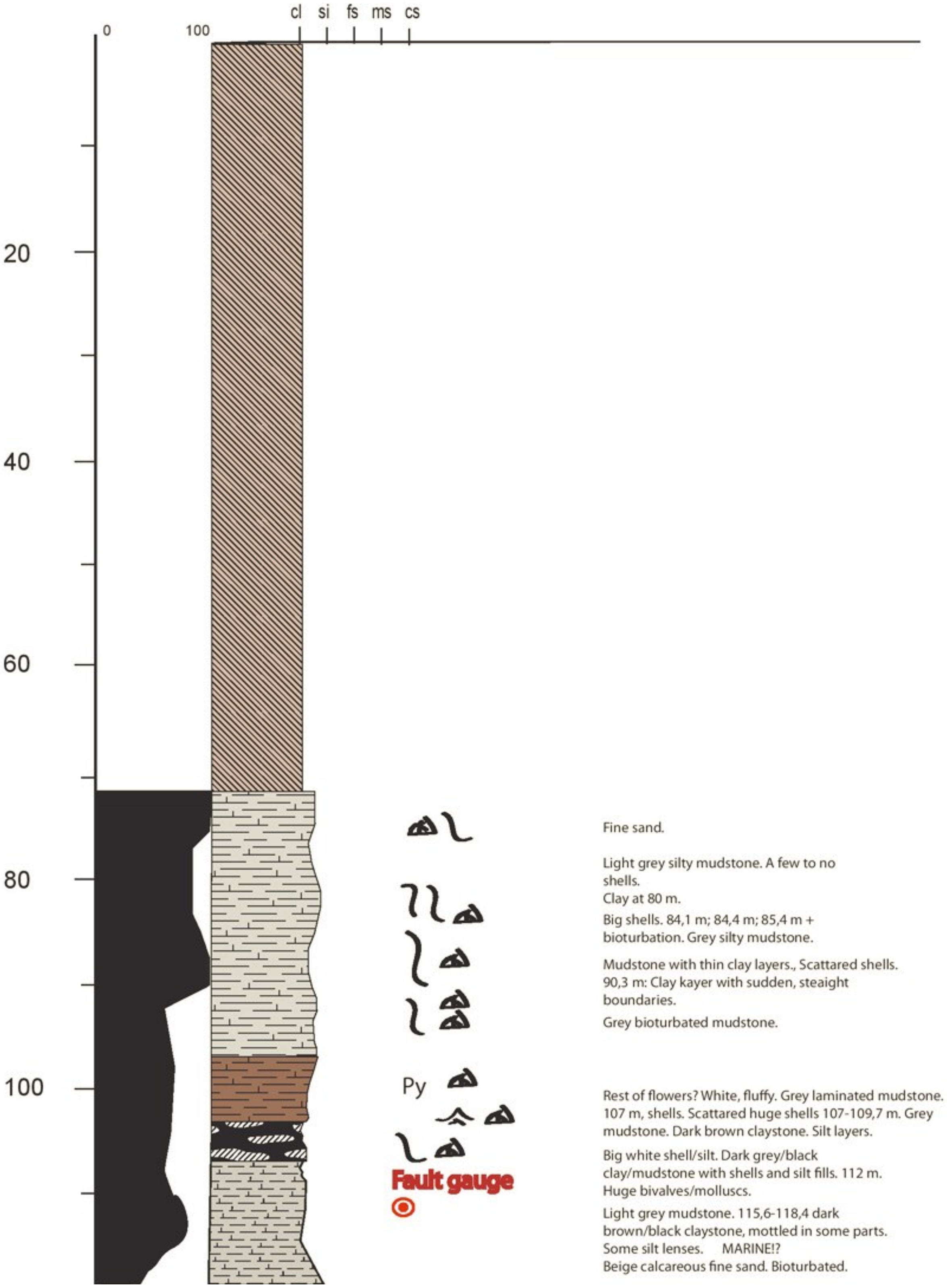
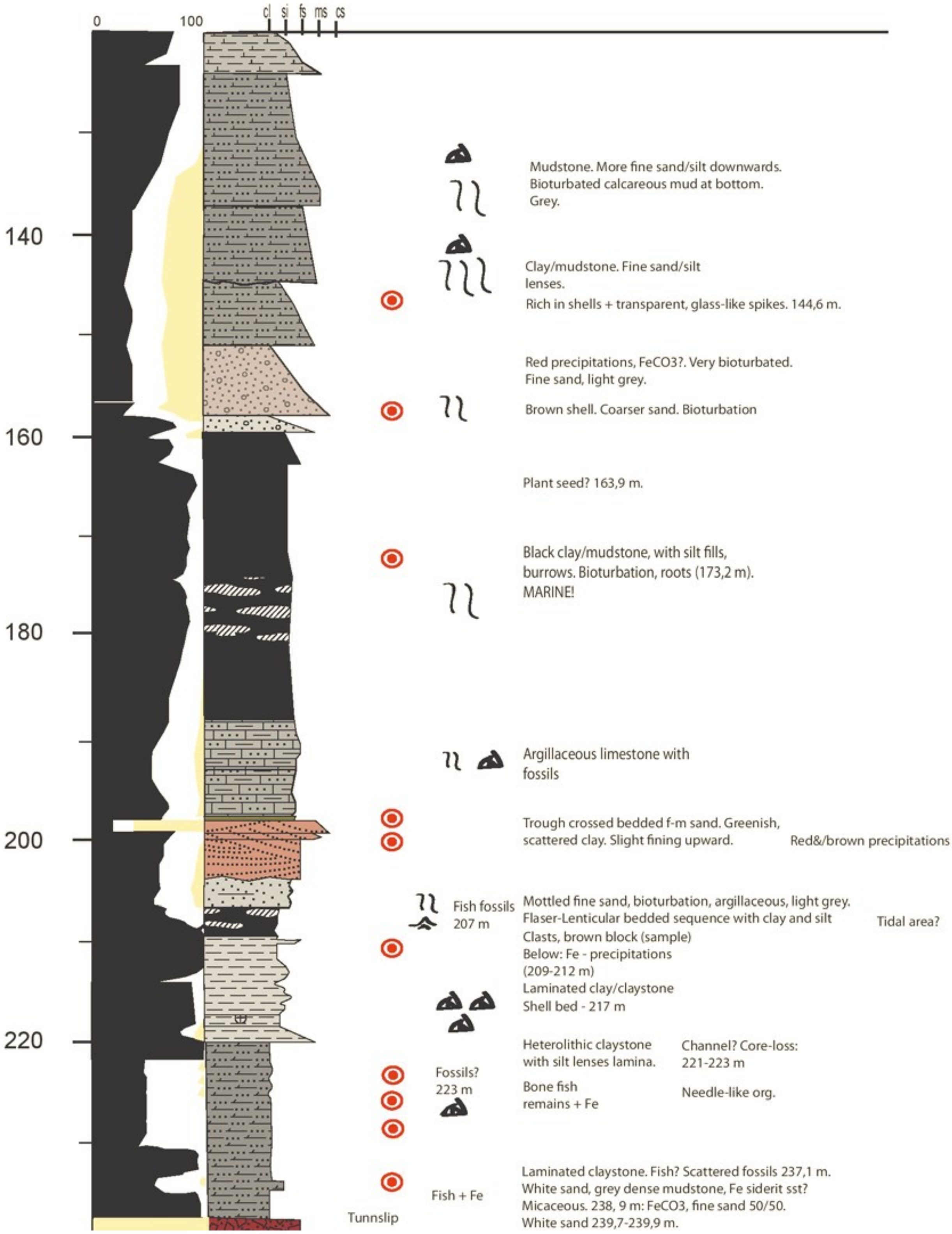
Appendix


cl si fs ms cs
0
100
20
40
60
80
100
Py
Fault gauge
Fine sand.
Light grey silty mudstone. A few to no shells.
Clay at 80 m.
Big shells. 84,1 m; 84,4 m; 85,4 m + bioturbation. Grey silty mudstone.
Mudstone with thin clay layers., Scattared shells. 90,3 m: Clay kayer with sudden, steaight boundaries.
Grey bioturbated mudstone.
Rest of flowers? White, fluffy. Grey laminated mudstone. 107 m, shells. Scattared huge shells 107-109,7 m. Grey mudstone. Dark brown claystone. Silt layers.
Big white shell/silt. Dark grey/black clay/mudstone with shells and silt fills. 112 m. Huge bivalves/molluscs.
Light grey mudstone. 115,6-118,4 dark brown/black claystone, mottled in some parts. Some silt lenses. MARINE!?
Beige calcareous fine sand. Bioturbated.


0
100
cl
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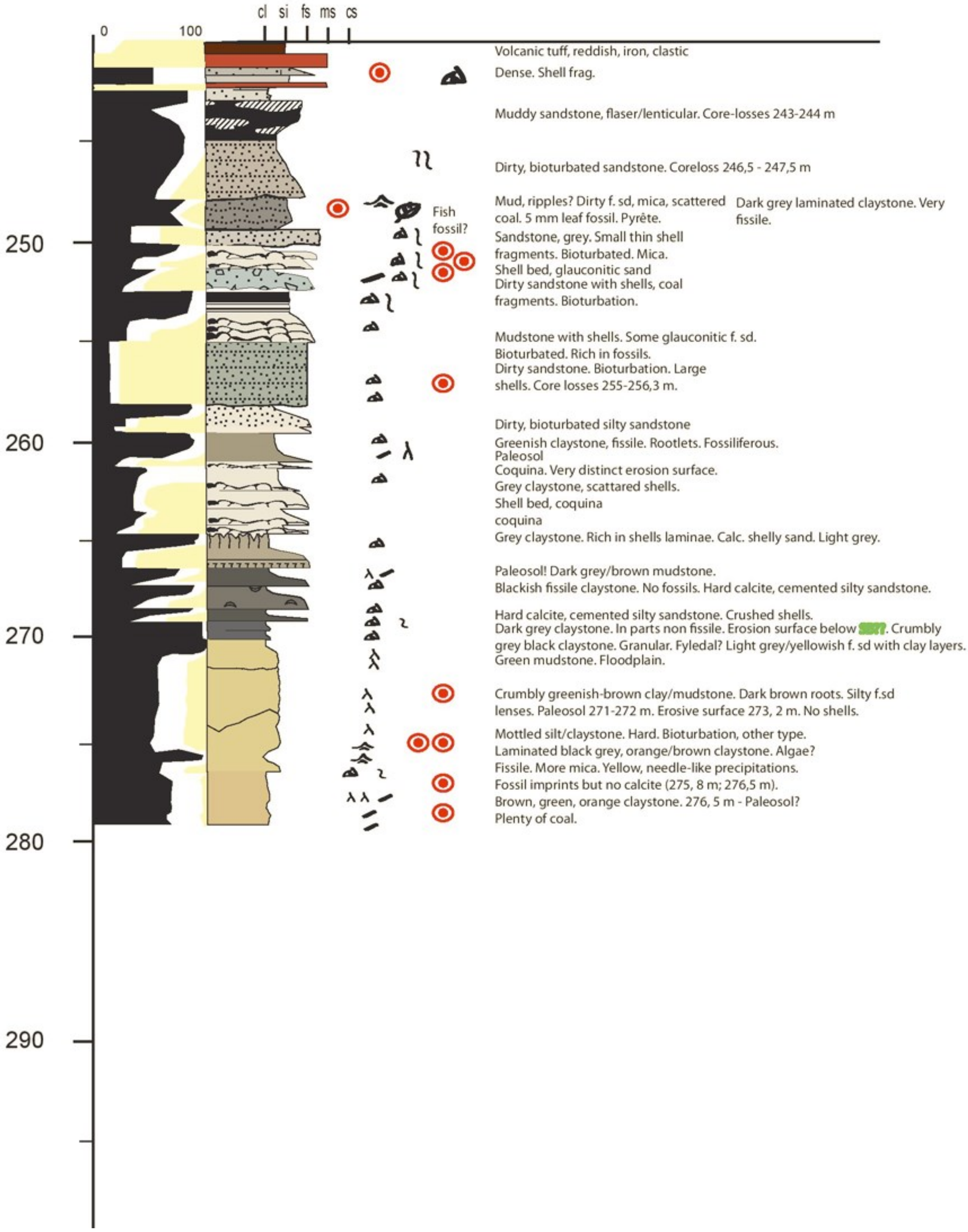
fs
ms
cs
140
160
180
200
220
Mudstone. More fine sand/silt downwards.
Bioturbated calcareous mud at bottom.
Grey.
Clay/mudstone. Fine sand/silt
lenses.
Rich in shells + transparent, glass-like spikes. 144,6 m.
Red precipitations, FeCO3?. Very bioturbated.
Fine sand, light grey.
Brown shell. Coarser sand. Bioturbation
Plant seed? 163,9 m.
Black clay/mudstone, with silt fills,
burrows. Bioturbation, roots (173,2 m).
MARINE!
Argillaceous limestone with
fossils
Trough crossed bedded f-m sand. Greenish,
scattered clay. Slight fining upward.
Red&/brown precipitations
Fish fossils
207 m
Mottled fine sand, bioturbation, argillaceous, light grey.
Flaser-Lenticular bedded sequence with clay and silt
Tidal area?
Clasts, brown block (sample)
Below: Fe - precipitations
(209-212 m)
Laminated clay/claystone
Shell bed - 217 m
Heterolithic claystone
with silt lenses lamina.
Channel? Core-loss:
221-223 m
Fossils?
223 m
Bone fish
remains + Fe
Needle-like org.
Laminated claystone. Fish? Scattered fossils 237,1 m.
White sand, grey dense mudstone, Fe siderit sst?
Micaceous. 238, 9 m: FeCO3, fine sand 50/50.
White sand 239,7-239,9 m.
Fish + Fe
Tunnslip



cl si fs ms cs
0
100
250
260
270
280
290
Volcanic tuff, reddish, iron, clastic
Dense. Shell frag.
Muddy sandstone, flaser/lenticular. Core-losses 243-244 m
Dirty, bioturbated sandstone. Coreloss 246,5 - 247,5 m
Fish fossil?
Mud, ripples? Dirty f. sd, mica, scattered coal. 5 mm leaf fossil. Pyrête.
Dark grey laminated claystone. Very fissile.
Sandstone, grey. Small thin shell fragments. Bioturbated. Mica.
Shell bed, glauconitic sand
Dirty sandstone with shells, coal fragments. Bioturbation.
Mudstone with shells. Some glauconitic f. sd.
Bioturbated. Rich in fossils.
Dirty sandstone. Bioturbation. Large shells. Core losses 255-256,3 m.
Dirty, bioturbated silty sandstone
Greenish claystone, fissile. Rootlets. Fossiliferous.
Paleosol
Coquina. Very distinct erosion surface.
Grey claystone, scattered shells.
Shell bed, coquina
coquina
Grey claystone. Rich in shells laminae. Calc. shelly sand. Light grey.
Paleosol! Dark grey/brown mudstone.
Blackish fissile claystone. No fossils. Hard calcite, cemented silty sandstone.
Hard calcite, cemented silty sandstone. Crushed shells.
Dark grey claystone. In parts non fissile. Erosion surface below. Crumbly grey black claystone. Granular. Fyledal? Light grey/yellowish f. sd with clay layers.
Green mudstone. Floodplain.
Crumbly greenish-brown clay/mudstone. Dark brown roots. Silty f.sd lenses. Paleosol 271-272 m. Erosive surface 273, 2 m. No shells.
Mottled silt/claystone. Hard. Bioturbation, other type.
Laminated black grey, orange/brown claystone. Algae?
Fissile. More mica. Yellow, needle-like precipitations.
Fossil imprints but no calcite (275, 8 m; 276,5 m).
Brown, green, orange claystone. 276, 5 m - Paleosol?
Plenty of coal.


5. 240,75-,95

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